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V Subramony Memorial Lecture

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Background of
V Subramony Memorial Lecture

Hailing from a well-known family in Quilon, V Subramony had his early education in Quilon before joining Banaras Hindu University for the Graduate Course in Metallurgical Engineering. After graduation, he had his initial training in the USSR and had visited Steel Plants in Japan, West Germany and the USA.

He had a rich and varied career in steel. Joining the Bhilai Steel Plant in 1956, he rose steadily, occupying the posts of Superintendent (Blast Furnaces), Chief Superintendent (Iron Zone), Assistant General Superintendent (Technical Development) and Deputy General Superintendent (DGS). As DGS, he looked after the plant operations and was instrumental in bringing about a number of technological improvements that resulted in higher productivity. He was associated with the expansion of Bhilai Steel Plant to four million tons.

Shri Subramony joined SAIL Headquater as General Manager (Operations) in June 1978, and subsequently he took over as Director (Technical) in January 1981. On April 30, 1982, he assumed charge as Managing Director, Rourkela Steel Plant. He was also Director, MECON; Nagarjuna Steel Ltd, Hyderabad and Director, Fertilizer Association of India, New Delhi. He was conferred the 'Distinguished Alumni Award' by Banaras Hindu University on the November 15, 1983.

Shri Subramony introduced several new management techniques, which ultimately resulted in the Rourkela Steel Plant turning the corner. He won the hearts of everyone by his sense of values, enthusiasm and fairness. A high performer, he was the pride of many. A rising star was cut short cruelly by a quirk of fate on January 23, 1986.

In memory of his dedicated service, The Institution of Engineers (India) instituted an Annual Memorial Lecture in his name during the National Convention of Metallurgical and Materials Engineers.

V Subramony Memorial Lecture

presented during **National Conventions** of **Metallurgical & Materials Engineers**

Some Salient Features of Chinese Iron & Steel Industry

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Ex Chairman, SAIL

PRODUCTION OF CRUDB STBBL IN CHINA AND INDIA

Peoples Republic of China has emerged as the World's fourth largest producer of steel and has ambitious plans to produce around 100 m tons of raw steel towards the turn of the century. As can be seen from Table No.1, China produced 59.4 m.t. .of crude steel in 1988 out of a total world production of 780 m. t. The Indian production was only 13.94 m. tons in comparison.

TABLE - 1

PRODUCTION OF CRUDE STEEL 1988

Ranking		
	World	780 m.t.
1.	U.S.S.R.	163 m.t.
2.	Japan	106 m.t.
3.	U.S.A.	91 m.t.
4.	China	59.4 m.t.
5.	India	13.9 m.t.

The performance of China is all the more remarkable in view of the fact that both India and China started at almost the same level of production of Crude Steel in 1951 and until the year 1962 the production of two countries were comparable. As a matter of fact, the Indian production of Crude Steel was slightly higher than the Chinese production in the year 1951 6 1952. The Graph No.1 shows the Crude Steel production of China arid India between 1951 and 1988.

TABLE - 2

CRUDE STEEL PRODUCTION OF CHINA AND INDIA

m.ton.

Year	**1951**	**1955**	**1960**	**1962**	**1968**	**1976**	**1981**	**1988**
China	0.9	2.85	18.66	6.67	9.04	20.46	35.60	59.43
India	1.5	1.67	3.42	5.40	6.56	9.66	10.76	13.94

From the graph and Table - 2, it can be seen that the Chinese steel industry made a big spurt in production between 1955 and 1960 but could not maintain this tempo of production and came down from 18.66 m. t. to 6.7 m.t. in 1962 at which time India was producing 5.4 m. t. The big increase in production between 1955 to 1960 was due to construction of hundreds of mini-blast furnaces or so called backyard blast furnaces, but they were not such .a mitigated success as it was made out at that time. One of the top ranking Indian expert team which visited China at that time widely acclaimed Chinese experiment and recommended India to emulate their example. The development of Steel Industry .in China remained erratic upto 1968. However, the Chinese built a number of key and local medium and small steel plants between 1968 and 1974 and this resulted in a big increase in steel production but there was again a set back to production and it was only from the year 1977· onwards that the Chinese Steel Industry made a real break-through when the Crude Steel Production increased year to year continuously from 20.5 m. t. in 1976 to 59.4 m.t. in 1988, a three-fold increase. It is a very creditable achievement that in a matter of just 12 years the production increased three-fold in China. In the same period Indian Steel Production increased from 9.7 m. t. in 1976 to 13.9 m.t. in 1988.

The Chinese achievement is all the more significant since during this period they only constructed one new plant on greenfield site at Baoshan near Shanghai, with Japanese. collaboration. The construction of Baoshan Steel works was started in 1978 and is being constructed in three stages. Stage one is in operation and the plant is now producing

3.51 IV ton Crude Steel per year. Stage II will be completed in 1991 when the plant will have a capacity of 6.7 m. t. and stage III when completed will have ultimate capacity of 10 m. t. per annum.

It will thus be seen that the Chinese have increased their steel production from 20.5 m. t. in 1976 to 61.3 m. t. in 1989 by constructing only one new steel plant with a capacity of 3.5 m. t. only. Let us see as how the Chinese achieved this feat.

CHINESE STRATEGY TO DEVELOP STEEL INDUSTRY

The strategy adopted by Chinese was as follows

1. To modernise the existing steel plants by replacing O.H. with L.D., addition of sintering / pelletising capacity 30 as to use high amount of agglomerate in the burden (89%), to improve product quality and side by side to improve environmental conditions and improve efficiency.

2. To improve raw material quality by beneficiation and blending for uniform quality.

3. Most important step adopted was to give operational and management personnel of the steel plant, freedom to work and manage. The breakthrough came in the year 1976 when these reforms were introduced and year to year these have been strengthened. This is called Contracting Responsibility System.

Graph No. 2 brings out the steep increase in the Crude Steel Production from 1977 onwards. The same is true for pig iron production as shown in graph no. 3.

Before we deal with this phenomenal improvement affected by the Chinese Steel Industry between 1977 and 1989, let us have a look at the composition of the Chinese Iron and Steel Industry.

The Chinese Iron a Steel Industry consists of total 1342 large and small plants. divided in three categories namely :

1. Category I – Key Iron 6 Steel Enterprises

These comprise of 48 enterprises which include 12 integrated steel plants of 1 m.t. and above capacity and other large as well as small capacity but notionally important plants. They include Anshan Steel Works which produced 8.01 m.t., Baoshan Steel Works 3.51 m.t., Wuhan 4.05 m. t., Shoudu 3.57 m.t., Benxi 2.27 m.t. and Baotri 2.03 m. t. Crude Steel in 1988.

The Crude Steel Production in 1988 from the Key Iron and -steel Enterprises was 42.22 m. t. which according to capacity can further subdivided as under :

a) Integrated Steel Plant producing 36.28 m. t. or 61% of the total.

b) Smaller Steel works of capacity between 800000 to 3300 t/a with total production in 1988 of 5.94 m.t. or 10% of the total.

2. Category II

These are called Local-major medium and small Enterprises and consist of 80 enterprises of varying but small capacities. These enterprises in 1988 accounted for a production of 11.70 m.t. which was 19.7% of the total.

The average capacity of these undertakings was 260.000 r/a but the capacity varied between 864,000 t/a to 2000 t/a. These plants are locally controlled.

3. Category III

This consists of a large number of very small units which in 1988 accounted for a production of 5.5 m.t. or 9.3% of the total production.

Pig Iron Production

As in the case of raw steel, the pig Iron production also comes from key enterprises, Local-major, medium and small enterprises and very small enterprises. The production of pig iron in 1988 was distributed as follows:

Total pig iron production in 1988 was 57.04 m. t.

I. Key Enterprises having 69 blast furnaces with Average Furnace size of 834 m^3 produced 35.99 m. t. or 63% of the total.

II. Local major, medium 6 small enterprises consisting of 48 enterprises of which 42 enterprises produced on an average 300000 t/a and 6 units an average of 43217 t/a which together contributed 12.6 m. t. or 22% of the total.

III. Small blast furnaces totalling 1060 nos. with average production of 7972 t/a which together produced 8.44 m. t. or 14.8% of the total.

DECENTRALISBD PRODUCTION OF CHINHSE IRON 6 STEEL INDUSTRY

From the number of pig iron and steel making units and their locations, it can be seen that the Chinese Iron and Steel Industry is highly dispersed and while 62% of the total production of Crude Steel and Pig iron is from integrated steel plants or larger enterprises, the balance production of 38% comes from a very large number of smaller plants, small size Blast Furnaces, small steel making furnaces (L.D., O.H. Or EAF) and smaller rolling mills.

Location of Steel Industry

The steel industry is located more in Liaoning (Monchuria), Shanghai, Hebel, Sichuan, Beijing provinces which together account for 64% of the Crude Steel Production. However, there are other twelve provinces which each contribute 1 to 5 m.t. of steel annually. It would appear that locating a large number of small iron and steel producing units has helped in equitable development in different provinces in China. One advantage which China has is that its coking coal and iron ore are distributed very widely all over the country which advantage is not possessed by India.

Economics of smaller production units.

During a visit to China, it is difficult to obtain the figures for cost of production and the cost of various inputs. However, based on some earlier studies, the following conclusions have been drawn. :

Cost of production of pig iron in

Integrated steel plants	100 units
In Medium size plants	139 units
In small mini blast furnaces	220 units.

This would indicate that while installing mini-blast furnaces, one must take this important factor into account since cost of production can be as high as twice of integrated steel plants. Chinese have however, contented that the cost would be higher by only 20% in small blast furnaces and they take it that the capital cost for small steel plants is 70 - 80% of larger plants which is an important assumption.

Processwise Production of Steel

The total production of crude steel in 1988 was 59.4 m. t. which according to process was divided as follows :

L.D. or B.O.F.	34.24 m.t. or 57.6%
O.H. Furnaces	13.04 m.t. or 21.9%
Electric Furnaces	12.07 m.t. or 20.3%
Others	0.08 m.t. or 0.13%

The O.H. furnaces even now dominate the production in plants like Anshan Iron a Steel works which is the largest steel plant in China which in earlier years received Russian technical assistance and know-how. This plant was first started in 1916 and produced 8.01 m. t. in 1988 out of which 4.96 m. t. was produced by o. H. route, 3.0 m. t. by L. D. route and 48700 t by Electric Furnaces.

In the modernisation process the O.H. furnaces are being gradually replaced by L. D. converters as can be seen from Table No.3.

Continuous Casting

Another measure of modernisation of steel industry is continuous casting. In this respect, Chinese Steel Industry is comparatively behind as can be seen from Table - 4.

14.7 m. t. of the steel was cast through CCM which is very low compared to international standards, where Japan .Is leader with 93.1% and Western Europe at 82.6%. The Indian figure is estimated at 29.4% which will increase rapidly in the next 5 years.

TABLE - 3

PRODUCTION OF STEEL - PROCESSWISE

Year	By O.H. Process	By L.D. Process	By Elec. Furnaces
	%	%	%
1982	31.3	44.8	18.5
1983	29.8	46.5	20.3
1984	27.9	47.7	20.8
1985	26.3	49.3	21.5
1986	23.7	54.0	20.2
1987	22.7	54.8	20.4
1988	21.9	57.6	20.3

TABLE - 4

PRODUCTION OF CONTINUOUS CASTING

Year	% Continuous cast
1982	7.4
1983	8.9
1984	10.6
1985	13.9
1986	11.9
1987	12.8
1988	14.7

MODBRNISATION OF CHINESB STBBL PLANT

The main reason why Chinese have been able to achieve such rapid increase in production from 20.5 m. t. in 1976 to 61. 3 m. t. in 1989 is by making judicious investments in upgrading their technology, in revamping existing steel plants, in adding to capacity during modernisation, in diversifying to produce more sophisticated products in cutting down costs. in reducing environmental pollution and in improving the quality of inputs. Except Baoshan all their plants are old. Shoudu which is their Show-piece in profit' and productivity was first set-up in 1920. Anshan, their largest steel plant was set up in 1916, Benxi in 1905. Taiguan in 1939, Whuan in 1958 and Baotou in 1958. Thus Chinese have been successful in modernising these old plants, make them productive and profitable and increase their total steel production three-fold in just thirteen years which speaks highly of their ability and competence. In our country we have a comparable example in TISCO which was started in 1911-12 and is modernising, diversifytng and expanding in almost the same manner as Chinese have done it. Against this background, we have also the example of another steel plant which though started in 1939 is languishing for the last 20 years and there are plans to completely scrap it and build a new plant on the same site with very heavy investment.

CHINESE ANNUAL INVESTMENT IN STEEL INDUSTRY

During 1988, Chinese spent the following amounts in the construction and modernization of their steel industry.

Total investment during the year was U.S. S 3460 m. (1 US $ = 4.675 Yuan).This was divided (A) on capital construction US S 1500 m which was 43.4% of the total and (B) on technical up gradation US S 1960 m which was 56.6% of the total.

Capital Construction

As far as capital construction is concerned based on the category of the undertakings on Key Enterprises and Local medium a small plants they spent US S 1355 m or 90.3 of the total and on smaller undertakings US S 145 m or 9.7% of the total.

Technical Upgradation

The total amount spent on technical upgradation of 50 key Iron and Steel Enterprises was US S 1310 or 66.8% of the total. The break-up of this expenditure according to purpose was:

For expanding production	51.6%
For saving on energy	5.1%
For production diversification	10.0%
For improving quality	4.2%
To reduce pollution	3.3%
For non-productive purposes	11.4%
For other purposes	14.4%

Similarly the amount spent on 58 local-major medium and small enterprises was US S 375 m or 19.1% of the total. The break-up of this according to purpose was :

For expanding production	50.8%
For saving on energy	6.5%
For product diversification	10.9%
For improving quality	3.6%
For environment protection	4.4%
For non-productive purposes	10.4%
For other purposes	13.4%

The amount spent on other smaller undertaking was US S 275 or 14.5% of the total.

It would be seen that out of the total yearly 1nvestment as much as 56.6% was spent on technical upgradation above and only 43.4% on capital construction. Of the amount on capital construction, over 90% was spent on large and medium undertakings which went primarily for the construction of Baoshan Steel Plant and only 9.7% was spent on smaller plants.

As far as technical upgradation is concerned, 66.8% went to Key Iron a Steel Enterprise and 19.1 to local - major medium and small enterprises. Out of the expenditure on technical upgradation 51.6% was spent to increase capacity and rest on product diversification, saving on energy, improving quality, etc.

Investment done on Modernisation according to process

Between Key Iron a Steel Enterprises and Local - major, medium and small enterprises a total of US S 1007 m was spent on expanding production which process wise was spent as follows

Iron ore mining and ore dressing	8.6%
Agglomeration - sintering a pelletising	14.2%
Blast Furnaces	17.0%
Steel Making	15.8%
Continuous casting	11.7%
Rolling mills	32.7%

New Capacity created as a result of modernization

We have seen that the Chinese spent in 1988 over US S 2507 m on capital construction and expanding capacity during modernisation. As a result of this new capacity was created between years 1983 and 1988 i.e. in 6 years which process wise came to :

	m.t.
For sintering	5.31
For pelletising	0.36
For iron making	7.49
For steel making	10.38 (for LD process 7. 62 m)
For continuous casting	6.25
For blooming a slabbing mill	5.0
For other finishing mills	9.67

It is surprising that as late as in 1986 & 1987, Chinese have added to their primary mills rather than to continuous casting which capacity continues to be significantly low when compared to international standards. Going by the investment figures the Chinese have added to their capacity in an economic manner.

Quality of steel made

It is not possible to judge the quality of finished steel made in China and compare. it with international standards. However, the performance of China can be inferred from the quality of their crude steel produced by them for which figures are available. Out of total production of 59.42 m.t. of, crude steel in 1988, the qualitywise break-up was as follows :

	Production in m.t	% of the total
Rimming steel	15.47	26.0
Killed steel	27.28	45.9
Alloy steel	3.91	6.6
Low alloy steel	8.65	14.6
Others	4.11	6.9
Total	59.42	100.0

While the corresponding figures are not available for the Indian Steel Plants as a whole, the figures for some of the integrated steel plants can be taken as indicative which in 1988-89 were :

	Killed %	Rimining %	Semikilled %
Plant I	26.1	9.6	70.3
Plant II	Nil	6.7	92.4

It may be mentioned that killed quality is essential for products in higher quality and rimming steel is required for producing better quality flat products.

Product Mix

The year to year total finished steel production is given in graph 4. As in Crude Steel, the finished steel production has increased from 16.3 m.t. in 1977 to 46.9 m.t, in 1988, an increase of 288%. The break-up of this production in m.t. and as % is given in Table 5 where these are compared with figures for India Q Japan.

TABLE - 5

FINISHED STEEL PRODUCTS BREAK-UP FOR CHINA, INDIA & JAPAN IN 1988

	China m.t.	%	India m.t.	%	Japan %
Total	46.89	100	13.98	-	100.0
Bars & rods (including wire rod)	7.98	17.0	5.25	37.6	19.37
Structurals large med. small & quality structurals	19.94	42.5	1.675	12.0	12.95
Plate & sheet	11.17	23.8	1.305	9.3	9.72
H.R. coil & sheet	1.39	3.0	2.342	16.7	10.18
C.R. coil & sheet	-	-	1.521	10.9	13.48
GP/GC sheet	-	-	0.404	2.9	15.6
Tin plate	-	-	0.318	2.3	2.1
Electrical sheet	0.62	1.3	0.168	1.2	2.1
Pipes-seamless & welded	4.02	8.6	0.231	1.7	9.95
Railway materials	1.58	3.4	0.767	5.5	0.5
Others	0.20	0.43	Nil	Nil	Nil
Total flat & tubular products	17.20	36.7	6.29	45.0	63.13

N.B. The figures for C.R. coils & sheets, GP/GC sheets & tin plate for China are perhaps included in plate & sheet production.

From the Table it would be seen that the production of structurals, plates and pipes, both seamless and welded is high in China. The pipe production may be high due to its very large oil industry. However, the predominance in structurals to the extent of 42.5% of the total is rather surprising indicates lower sophistication. The figures for Japan in % are given for comparison where sophistication is of high degree.

The break-up of production in different sectors i.e. key enterprises, local-major medium and small sector and in other smaller enterprises is given in Table No.6. It may be seen that in local major medium and small plants as much as 1.9 m.t. plates, 0.6 m.t. of strip and 1.8 m.t. of pipes are produced. Their production is to an extent decentralised.

TABLE - 6

PRODUCTION OF DIFFERENT STEEL PRODUCTS BY VARIOUS SECTORS IN CHINA

m.tons.

	Total for industry	Total for Key Enterp Key total	Enterprises	Local major med. & small Enterprises	other smaller Enterprises
Railway materials	1.58		1.47	0.08	0.03
Large section. ord.	0.87		0.84	0.03	Nil
Medium sect. ord.	2.80		1.88	0.68	0.24
Small section ord.	11.18		4.47	4.25	2.46
Sections, special	5.09		4.12	0.60	0.37
Total section	19.94		11.31	5.56	3.07
Wire rod	7.98		3.94	2.86	1.08
Plates	11.16		9.27	1.59	0.30
Strip	1.39*		0.79	0.0	0.60
Pipe seamless	1.78		1.28	0.27	0.24
Pipe welded	2.24		0.96	0.30	0.98
Silicon sheets	0.62		0.30	0.32	-
Others	0.20		0.48	0.07	-
Total rolled prod.	46.89		29.80	11.04	6.05

*Includes cold rolled 0.64 m.t.

Energy Consumption

The total a different forms of energy consumption to produce 59.42 m. t. of Crude steel and 46.9 m. t. of finished steel in 1988 as well as consumption per tonne of crude steel were as follows:

	Total	Per ton of finished steel
Coking coal	51. 27 m.t.	1093 Kg
Boiler oil 24.20 m.t.	516 Kg	
Furnace oil	4.32 m.t.	92 Kg.
Natural gas	796 m Nm^3	154 Nm^3
Electricity	49.4766 Kwh	1055 kwh

In terms of specific energy consumption per tonne of crude steel the comparative figures for China, India and Japan are as follows :

		m. Kal/ton
China	Key Iron & Steel Enterprises	7.05
	For local major medium a small enterprise	7.9
India	Average of three integrated steel plants	9.76
Japan	Average for industry	4.44

One reason the figures for India are high is due to higher coke rate compared to China a Japan on account of high ash in coke. The Japanese are of course lowest in the world.

LEVEL OF TECHNICAL PERFORMANCE

Let us know examine the efficiency in operation' measured in terms of some of the techno-economic parameters for Chinese Iron a Steel Industry and see how they compare with some of the integrated steel plants of India.

(i) Iron Ore : Run-of mine % Fe 31.15

Iron ore concentrate % Fe 65.38

Tons of r.o.m. per ton of concentrate 2.64

(ii) Blast furnace :

	Key Iron a Steel Enterprise	Av. for all industry
Productivity tons/m³/24 hrs.	1.79	1.83
Coke rate kg./ton Pig Iron	507	557
Coal dust injection kg/ton Pig Iron	56.6	32
Fuel rate including coke & coal kg/ton	563.6	589
Blast temperature °C	988	
% Fe in burden	54.0	53.5
Down time %	-	2.37
% Agglomerate in burden (mainly sinter)	89.6	-
Labour productivity tons/worker/yr	1651	737

The above figures are for all the enterprises and represent industrywise average. However, the best figures were reported by Shoudu Iron a Steel Co. as given below :

B.F. productivity t/m^3/24 hrs.	2.225
Coke rate kg/t/P. I.	414
Coal dust injection kg/t/P. I.	130.9
Fuel rate kg/t/P. I.	554.9
Blast temperature degree C	1002
% Fe in burden	58.05

The Tangshan Furnaces have reported a productivity of 2.482 for older smaller blast furnaces but their new 1260 m^3 blast furnaces is running at a productivity of only 1.5 which they are hoping would go upto 2.0. It is therefore not advisable to quote the figures for the best performance of one or two Chinese plants out of context and take them as average for the Chinese steel industry. The Chinese steel industry also includes plants like Xiangtan Iron Ii Steel Co. which reported following figure for 1988:

Productivity t/m^3/24 hrs.	1.141
Coke rate kg/t	648
Coal dust injection kg/t	65.3
Fuel rate kg/t p. i.	713.3

There is however no doubt that taking the industry as a whole the Chinese have done well in their blast furnace operation and they are improving their performance year to year as can be seeri from graph No.4. While the productivity is going up the coke rate is going down. The amount of agglomerate (mainly sinter) used by the Chinese in 1988 was 89.62% which is very high.

The Chinese figures for 1988 are compared with Indian figures for the years 1985-86 upto 1988-89 in Table 7 and 8.

It would be seen that while year to year there has been an improvement in the figures for Indian steel plants, they are far below the Chinese figures. Among the Indian Steel Plants, best figures are those for TISCO primarily due to superior quality of raw materials. However, when comparing TISCO with China ~for the year 1988, the position has been summarised in Table 9.

TABLE - 7

SOME BLAST FURNACE FIGURES

Year	Country	Ash in coal %	Ash in coke %	Coke M10 %	Coal injection kg/t P.I.	Coke rate Kg/t P.I. P.I.	Agglomeration in charge
1985-86	India	18.67	24.44	12.32	Nil	785	45.9
1986-87	India	17.86	23.46	11.70	Nil	773	45.4
1987-88	India	17.49	23.20	11.49	Nil	760	46.5
1988-89	India	16.68	22.08	10.42	Nil	731	47.2
1988-89	TISCO	(15.78)	(20.12)	(8.5)	(Nil)	(716)	(34.5)
1988	China	10.63	13.81	7.7	56.6	507	89.62

TABLE - 8

BLAST FURNACE PRODUCTIVITY

Year	India		China		
	Average	TISCO	Productivity	Coke Ash%	Agglomerate%
1985	0.83	0.91	1.69	13.94	89.63
1986	0.84	1.01	1.74	13.76	89.84
1987	0.82	1.01	1.79	13.79	89.76
1988	0.91	1.11	1.79	13.81	89.62

N.B. For China the figures for coke ash and % agglomerate in the burden are given alongwith productivity. The TISCO figures have been reworked for comparison.

TABLE - 9

DATA ON B. FCE OPERATIONS - TISCO & CHINA

	Coke Ash %	Agglomeration %	B.F. Productivity t/m³24	% Fe ore fines	% Fe ore lump	% Fe in Sinter
TISCO	20.12	34.50	1.11	62.0	64.25	50.52
China	13.81	89.62	1.79	65.38	-	52.27

Thre is no reason that given equivalent raw materials 1. e. low ash coal, better sinter quality and. higher percentage of sinter in the burden, the TISCO figures would not come in the vicinity of the Chinese productivity and coke rate. As a matter of fact, tests done on an Indian Blast Furnace have shown that when coke ash went down from 26.5% to 620.0% the slag volume went down from 620 kg/t to 330 kg, the coke rate decreased from 860 kg. to 670 kg and the furnace productivity increased from 0.9 to 1.40 t/m^3/24 hrs.

In view of the fact that the price difference between imported coking coal as delivered at works and the indigenous coking coal as delivered has narrowed down considerably a rethinking is necessary on the mode of operation of our blast furnaces in future. While investment costs are running as high as 25000/ ton of steel capacity per annum, and even more it is better economics to use low ash imported coking coal for coke making, low ash non-coking coal for coal dust injection and to augment sintering capacity so as to use 80% sinter in burden. This should augment the productivity of our blast furnaces from a figure of 0.91 to 1.8. This would make a tremendous difference to the productivity, tonnage of production as well as cost of production of existing steel plants. This would mean almost doubling the output of hot metal from existing blast furnaces in the country. Of course the steel plants must pay for the import by exporting equivalent production of finished steel in value there should be no net foreign exchange outflow.

SINTER PLANT PRODUCTIVITY

The productivity of the sinter plants in China is also high when compared to the Indian sinter plants. The productivity of sinter plants is primarily a function of good maintenance, better coordination and higher availability of equipment. The figures for 1988 in t/m^2/hr are given below :

China	TISCO	Bokaro	Bhilai	Rourkela	Durgapur	Indian average
1.355	1.12	1.08	1.03	0.71	0.55	0.92

That there is a big scope to improve productivity of Indian sinter plants is obvious.

Some of the other figures for Chinese Sinter Plants are as follows

Sinter grade Fe	52.27%
Operating Rate	78.65%
Fuel consumption	63 kg/t
Labour productivity	2327 t/worker/year

LD Steel Melting Shop

There are two important measures to judge the performance of an L.D. shop, one by the lining life and another the total number of heats made from a converter during entire year. The figures for India and China are given in Table 9.

TABLE - 9

OPERATION : CHINA AND INDIA

Year	Lining Life		No. of heats made/vessel/yr.	
	China	*India	At Shoudu China	*India
1985	606	185	-	2321
1986	655	192	-	2643
1987	725	194	-	2830
1988	794	299	18333	3252

* Av. for Four Indian Steel Plants

Both with regard to lining life and production from each convertor, China has done remarkably well. Its average lining life is 2.7 times that of India and with regard to productivity at Shoudu which is the most productive L.D. shop in China they made as many as 18333 heats/converter/year which is 4.7 times more than 3882 heats/converter made at TISCO which is our best performance. Getting higher lining life and higher productivity depends on several key factors like lower silicon in hot metal, better quality of refractory, intensive and continuous blowing of LD vessel, quality of steel produced better coordination and high level of discipline and motivation in the workforce. It may be- mentioned that the international norm for the number of heats made per converter in a year is 10,000. In this respect, Chinese have done even better than international norms at Shoudu Iron 5 Steel Co.

Some of the other performance figures for Chinese LD shops are given in Table 10.

TABLE - 10

DATA ON LD PLANTS OF CHINA

	P.I.& scrap kg/t steel	of which scrap kg/t	ferro alloy kg/t	lining life No. of heats	av.heat time mts.	labour prod. t/worker/ yr.	killed steel %	quality steel %
Steel Industry	1135	104	13.7	374	34	530	45.9	21.2
Key Iron & Steel	1122	113	?	794	34	750	52.32	29.85

There is no doublt that Chinese have been able to run their L. D. plants moee intensively and with higher productivity. In Shoudu Iron 6 Steel Works with 3 - 40 ton convertors the plant was able to produce 2.2 m. t. of crude steel in 1988. As against this, in India with 3 - 50 ton and 2 - 60 ton converters we produced only 0.97 m ton in a year. the best we were able to do so for was around 1.2 m. t .

In Key Iron 6 Steel Enterprise, the Chinese had 59 L. D. Convertors with an average capacity of 52 t. and produced 24.72 m.t. in 1986. This works out to. 0.42 m.t. per converter per year. The Chinese use smaller converters and make intensive use. However, in their new plant at Baoshan, they have put up 300 t converters and at Shoudu they have recently put up two 210 t converters which they purchased second-hand from Belgium. While the Baoshan converter are running well, they are yet to achieve higher productivity from the new converters at Shoudu, the same plant where they are doing so well with 40 t converters.

Chinese have a total of 160 L.D. converters in the entire steel industry distributed as follows :

	No.	Av.size	Steel Prod. in m.t.	Production per converter/yr. ton.
Key Iron & Steel Steel Enterprise	59	52	24.72	419000
Other local major med. & small enterprises a small plants	101	11	9.52	94260
Total	160		34.24	214000

The production per ton capacity of converter, per annum would work out as follows :

		t/annum
China :	Key Iron & Steel Enterprise	8057
	Local Major, medium & small enterprises	8569
	Shoudu Iron & Steel Works	18333
India :	Average for all steel plants	2867

It would be seen that the Shoudu figures of production are far above the productivity prevailing even in Chinese Iron & Steel Industry and they do not represent average practice. What is surprising is that Local-Major. Medium and Small Steel Plants have productivity which is higher than larger Key Iron & Steel Enterprises.

In comparison the figures for India are very low which shows the possibility of big improvement in this area.

It would be seen from graph No. 5 that year to year China is improving with regard to lining life and labour productivity.

Techno-economic performance of other metallurgical equipments

1. Open Hearth Furnaces

While this route of steel making has been completely replaced in developed countries. it accounted for 13.04 m. t. crude steel production in China in 1988. Total number of O.H. furnaces in operation was 54 with average capacity of 220 t per furnace. Some of the important techno-economic indices and comparison with India are given in Table 11.

It would be seen that Chinese productivity in O.H. furnaces is substantially higher when compared to one of the Indian Plants.

Electric Furnaces

Total crude steel produced from electric furnaces in 1988 was 12.1 m.t. and Borne important indices of Key Iron 6 Steel Enterprises are given in Table 12.

In the Electric furnace operation there is nothing spectacular in China. The productivity, electricity 6 electrode consumption figures are just average and there are plants in India which are doing better than this. The figures for Japan with regard to electricity consumption are for superior as would be expected.

TABLE - 11

OPERATION OF O.H. FURNACES

	China	India (one plant)
Utilisation coefficient for Industry t/m²/24 hours	11.89	7.7 - 7 . 8
(Anshan)	15.86	
Pig Iron & Scrap consumption kg/t	1117	
Of this scrap consumption kg/t	269	
Heavy oil consumption kg/t	56.8	
Roof life in no. of heats	312	123
Average heat time hrs. & mts.	5 hrs. 57 mts.	9 hrs. 42 mts.
Cold repair ratio	3.27	25.0 - 28.3 (best 11.3)
Labour productivity t/worker/yr	591	

TABLE - 12

ELECTRIC FURNACES OF KEY IRON & STEEL ENTERPRISES

	Japan 1988
Total number of electric furnaces	207
Total production in m.t.	4.92
Average capacity per furnace	7 ton
Utilisation coefficient t/m²/24 hr	15.02
Scrap charge kg/t	878
Pig iron charge Kg/t	142
Electricity consumption KWH/t	594
Electrode consumption kg/t	6.5

COKB OVBNS

Coke in China is produced in three types of ovens, in modern by-product ovens, in simple ovens and in primitive oven. It would appear that primitive ovens correspond is bee-hive ovens and simple oven may be those without recovery of by-products. The productivity in 1988 was distributed as follows :

Total coke production	61.08 m.t.
Coke from modern by-product ovens (Metallurgical coke 39.32 m.t.)	45.34 m.t. (23.5% in plants outside steel plants).
Coke from simple oven	0.97 "
Coke from primitive ovens	14.77 "

Some other Chinese figures of coke ovens are given in Table 13.

TABLE - 13

COKE OVEN PLANTS IN CHINA

Total coke yield	77.0%
% Metallurgical coke	93.5%
Wet coal charged per ton of coke kg/t	1426
Coke ash %	13.81
Coke sulphur %	0.68
Coke strength : M10 %	8.03
Coke strength : M40 %	77.8

Apparently there is a lot of wasteful production of bee-hive coke in China which is as much as 25% of total coke production. The yield of metallurgical coke as % of total coke reported by Chinese is rather high. Apparently Chinese are taking + 15 mm as BF coke.

ROLLING MILLS

The dominent production of rolled production is in light and medium structurals plates and pipes as mentioned earlier. A number of Local Major medium and smaller works are also producing plates and pipes. The number of hot strip mills are few and the latest in operation is at Baoshan near Shanghai with Japanese collaboration.

The total rolled products and their product wise distribution has been given earlier.

One of the measures for the rolling mill performance is the yield of good product obtained from rolling. The yields obtained in China in 1988 for different products are given in Table 14.

TABLE - 14

YIELDS IN ROLLING MILLS, CHINA AND INDIA

	China	Figures for Indian integrated plants
Heavy rails	79.82	81.0
Light rails	83.80	-
Large structurals	85.52	92.8
Medium structurals	90.27	96.1
Light structurals	88.91	93.3
Wire rod	84.01	95.6
Heavy Plate	72.64	85.6
Light & Med. plates	82.07	85.2
Ingot to bloom	88.6	87.1
Ingot to sheets	86.25	80.5
Ingot to H.R. strip	86.46	81.0
Ingot to seamless pipe	73.24	-
Ingot to welded pipe	82.51	72.0

It would be seen that the figures for many products from Indian Integrated plants are quite comparable and in some respects better

CAPACITY UTILIZATION

From the figures reported the Chinese Steel Plants operate at very high capacity utilisation. The figures for L988 are given for important products in Table 15.

TABLE - 15

CAPACITY UTILISATION

	Capacity m.t.	Production m.t.	Capacity utilisation%
Pig Iron	57.0	57.04	100%
Crude steel	62.89	59.43	94.5%
Continuous casting	9.4	8.44	88.7%
Rolling mills	57.9	46.89	81.0%

MANPOWBR

Chinese steel plants carry a very large work force and their productivity in term of tons of raw steel/worker/year in lowest in the world.

For a production of 59.43 m. t. of raw steel and 46.83 m. t. of finished steel the total workforce was 3.044 m. in 1988. Its category wise division was as follows

Total Workforce	Workers	Technicians & Engineers	Managerial personnel	Supporting personnel	Apprentices	Others
3.044m	2.014m	144000	297000	419000	51000	119000

Based on permanent a temporary status the break-up was as follows

Total	Permanent	Contract workers	Temporary workers	Unplanned employees
3.044m	2.455 m	371000	38000	180000

The labour productivity in ton of crude oil/worker/year was:

Year	1985	1986	1987	1988
Whole Industry	16.56	18.07	20.22 19.94	19.94
Key Enterprise	23.66	27.77	28.18	27.80

Against this the productivity of Indian Steel Plants and Japan in 1988-89 was:

	Total manpower	Crude steel production	Productivity ton/worker/year
SAIL	235831	8.628 m	36.6
TISCO	41422	1.907	46.0
Japan	306000	105.68	345

When compared to Japan and other developed countries, both India and China suffer from low productivity but the position is comparatively worse in case of China.

However, in their newest steel plant at Baoshan the manpower is one third of the existing steel plants. For production of 3.51 m.t. in 1988 the workforce and productivity were:

Total workers	Production workers	Average age	Productivity t/worker/yr.
35000	25000	27 - 28	100.3

This is a threefold improvement. However, the Chinese contention is that their social conditions demand higher employment in their steel plants. Similar compulsions prevailed in India earlier but this is likely to change.

EARNINGS OF WORKERS

The earnings of the workers in China have been pegged low and correspondingly the prices of essential commodities like food, clothing, housing etc. have been kept low as well.

The average wages of all category of employees in the Iron 6 Steel Industry in 1988 was as follows (Taking 1 US $ = Y 4.675).

	All employees	Permanent workers	Contract workers	Temporary employees
US $/yr	460	500	278	304

Based on category and age of workers the wages were :

	Comparatively new worker	Older worker	Engineer & technician	GM/M.D. level
US $/yr.	150	528	564	1128

In addition to wages, a cost of living index is paid and bonus works out to one third of total take home pay. Other welfare benefits work out to US S 192 per worker per year which include free medical, housing, electricity and water together at 5% of the pay and pension until death at 75% of working income.

The employment cost in China works out to US $ 0.33 per hour and manhours required to ship one tonne of saleable steel 112. Corresponding figure of man-hour per tonne shippers for developed countries, was between 3.7 - 5.5. Similarly for China employment cost per tonne shipped was US $ 37. These figures bears no comparison to developed countries. Inspite of employing such a large labour force the employment cost per tonne shipped is low in China.

COST OF VARIOUS INPUTS AND COST OF PRODUCTION

It is difficult to get reliable data on costs in China. However, a western study done in 1985 has brought out some revealing facts. It is likely that while absolute figures would have changed in the last five years to an extent the relative picture is not likely to be different at present. The figures are given in Table 16.

The cost of various inputs are given in Table 17.

It would be seen that there are a lot of distortions while working out the cost of production and extreme caution is necessary while making a comparison of factors like cost of inputs, cost of production, profile from a particular plant etc. Moreover, after establishing a free market in China there is a wide variation between official price; spot price and free market price.

DEMAND FOR STEEL AND CONSUMPTION

The domestic production, imports and home consumption of steel in India and China during last five years are given in Table 18.

The per capita consumption in terms of crude steel as reported by IISI for the last 5 years are given in Table 19.

While the Chinese population is reported at 1130 million as against 860 million of India, which is in ratio of 1.31, the production of saleable steel in China is 3.7 times that of India and the consumption in terms of finished steel 4 times. The two countries started at almost identical base in 1953 and the steel production upto the year 1967 was not so far apart but thereafter the Chinese have made a tremendous headway and increased the crude steel production from 9 m. t. in 1968 to 61. 3 m. t. in 1989, an increase of 6.8 times, against India I s increase in 1868 from 6.6 m. t. to around 14.5 m. t. in 1989, an increase of only 2.2 times. This is true not only regarding steel but also about other economic parameters. Steel production in India can not increase alone without the overall advancement of the economy In other spheres as well.

TABLE - 16

PRICE OF INPUTS AND STEELS PRODUCTS

Item	Official price US $/t	Spot price US $/t	Free market price US $/t	Imported price
Coking coal freight	23 3	47-53	-	-
Iron Ore & freight	22 3.78			16-17 9-10
Coke	63			
Pig Iron	84	156		
Rebar	197-200	238	397	
Wire rod	200	238	500	
Merchant bar	156-188	206	344	
H.R.Sheet 6-8mm	281	337	562-843 (not available)	
C.R. Sheet	344	413	No free market	
Plate 6-20mm	250	300	None	
Welded pipe	438	-	-	
Steel scrap	81	168	-	141
Steam coal	16-19	-	38	
Electricity	0.038	(To domestic consumer 0.05)		
Fuel oil	63	(International price $ 180 p.t.)		

TABLE - 17

COST PER TONNE OF STEEL SHIPPED

	US $/t of steel shipped	% of pre tax cost
Iron Ore	47	18.1%
Coking coal	28	10.8%
Steel scrap	9	3.4%
Energy cost	44	17%
Labour cost	37	14.3%

TABLE - 18

STEEL DEMAND IN INDIA AND CHINA

m./tonnes

	INDIA				CHINA			
Year	Prodn.	Imports	Exports	Consum.	Prodn.	Import	Export	Consum.
1984	8.85	0.63	0.15	9.33	33.72	13.31	0.20	46.83
1985	10.20	1.06	0.02	11.24	36.92	19.63	0.18	56.37
1986	10.53	1.56	0.03	12.06	40.58	19.38	0.20	59.76
1987	10.92	1.54	0.04	12.42	43.86	12.27	0.28	55.85
1988	11.47	1.54	0.12	13.66	46.89	8.72	0.67	54.94

TABLE - 19

PER CAPITA CONSUMPTION OF STEEL

Crude steel kg/per person/year

Year	1984	1985	1986	1987	1988
China	58.1	68.3	69.8	65.8	64.6
India	16.6	19.2	19.6	19.7	20.5

During the years 1976-77, 1977-78 when the steel production in India was good, there was a glut in the market and there were not many takers for steel in India. SAIL had to export steel on a crash basis during those two years. The figures for these two years were :

Year	Production of saleable steel	Imports	Exports	Steel consumed
1976-77	7.62 m.t.	0.38 m.t.	1.4 m.t.	6.6 m.t.
1977-78	7.77 m.t.	0.50 m.t.	1.1 m.t.	7.17 m.t.

Our economy is not strong enough to consume large quantities of steel. There is no use comparing the production figures of China and Japan with India. Those economies are comparatively robust, they have less social tensions, governments and people in those countries are busy constructing and building their infrastructure. We have not yet found an environment for advancing and constructing our economy to get out of poverty syndrome and underdevelopment.

LESSONS FROM CHINHSE STEEL INDUSTRY

There are a few things which we can learn from Chinese development of Iron & Steel Industry.

1. Adequate attention on Raw Materials :

This point is known to us for several years but it is only during the recent years that real efforts are being made in this direction. Import of low ash coking coal and reducing ash in indigeneous washed Goal has brought down ash in coking coal from 20% to between 15.8 - 16.7%. This must be further brought down to below 15% by improving washery operations and blending with more low ash imported coal. For better coke quality we should practice vigorous blending and adopt either stamp-charging or briquet-blend carbonization practice. TISCOI S effort in this regard are noteworthy.

Washing of iron ore to keep .Fe content at 64% - 66% and to use sinter to the extent of 80% is another area which will improve the productivity of our Blast Furnaces. Equally important is to see that we practice efficient blending of raw materials so that there are no fluctuations in the feed to the blast furnaces. SAIL modernisation .and TISCO modernisation are aimed at in this direction. Chinese use an average of 89% sinter plus pellets in their blast furnaces and the fluctuations in raw materials are small. Japan used 84.2% sinter plus pellet in its blast furnaces in 1988.

2. Blast Furnace Technology

As for Blast furnace technology in China, we should study and adopt coal dust injection and conveyor charging practices which are robust in design and are working on furnaces of even smaller sizes. They are injecting upto 130 kg of coal dust in Shoudu blast furnace of 1327 m3 and with a national average of 56.6 kg of coal dust injection per ton of hot metal. We should consider importing low ash non-coking coal to make coal dust injection a real success in India. The pulvertsed coal injected in Japan, in 1988 was 27.7 kg/ton of Hot Metal.

There are other points on Blast furnace technology like high blast temp., cast-house slag granulation etc., varying stages of which are implementation in India in different steel plants and we have adequate know-how on these.

3. Sintering

On the sintering, the Chinese productivity is high and this is entirely due to better equipment availability, better equipment maintenance and rigorous discipline.

4. Steel Making in LD

In steel making by LD we have a lot to learn from China - on improved lining life, high equipment availability, perfect coordination in operation, good discipline in working and motivation of workforce. It is suggested that we train our L. D. operating crew s and managerial personnel at Shoudu Iron 6 Steel Works for short duration of say 3 months and invite from Shoudu one full crew to demonstrate operation on one converter in one of our plants and train our crews in operating at high temp of production.

With regard to lining life we should pool all our resources/know-how between TISCo and SAIL and develop the lining material between dolomite and seawater magnesite bricks such that by keeping the cost low we attain a lining life of 700 - 800 heats. This will also require a lot of improvement in blast furnace practice. Our present concept that between two converters one vessel is always to be kept idle or between three only two are to operate should be discarded. Chinese have shown that out of 30 days all three out of three converters can operate at high rate of production for atleast 24 days.

5. Managerial Autonomy

On managerial autonomy a lot has been debated and written in India but the fact still remains that the steel plant management do not feel free to take decisions affecting their plant performance and growth an in loss making unit the exchequer comes too rapidly to their rescue due to non-economic considerations. We should treat the problem as far as possible on economic considerations and take lessons from what China has been able to do in this regard in the last 15 years. If China could give autonomy to its steel plants inspite of their rigid ideological and centralised economy it should certainly, be possible for us to take a leaf out of Chinese experience. Our recent introduction of MOUs between individual PSUs and Government do not go far enough. It is only after Chinese introduced what they call the Contracting Responsibility System (CRS) which now covers 100 key and local major-medium and small Iron 6 Steel undertakings that China has tripled its steel production. It is a fundamental reform which has brought considerable stability to the enterprises.

Its principle states "firm chartering of the basic indices assuming the payment of tax to the State out of the profit of the undertaking and reservation of the balance profit in removing deficiencies of the plant and on the welfare of the workers. Without changing the ownership of the enterprise, the ownership and the management of the State-owned enterprises are appropriately separated. The management and the effective control of the enterprise are delivered progressively to the enterprises themselves, the management responsibility of the enterprises is strengthened so as to set up a management mechanism of self-stimulation and self-constraint for the purpose of unification of responsibility, power and profit within the undertaking. This is an approach for the independent management and self development of the enterprise. This approach mobilises the initiative and motivation of the senior ranks of the senior management, other managers and workers of the enterprises. On the foundation of the Contracting Responsibility System (CRS) the state has a stable income which grows every year and the enterprises can earn more and and reserve more for themselves, the managerial personnel and the workers can make more money and enlarge their income. This results in rapid advancement of the enterprise. The profit earned by the enterprise will fully be contributed to the State according to the Contracting proportion and the balance profit is largely shared based on a ratio of 6:2:2 i.e. 60% of the balance profit is used for the development fund of the enterprise. 20% is used for the collective welfare of the workforce and 20% given as reward to the managers and workers.

Through the contracting responsibility system, Shoudu Iron 6 Steel works alone has contributed in the last ten years 9 billion' Yuan or 1.925 billion US $ to the State and another 2.5 billion Yuan or US $ 535 million were contributed for the capital investment to enlarge production and modernise its facilities.

It may be mentioned that Shoudu is one of the best managed Steel works in China.

CONSTRUCTING RESPONSIBILITY SYSTEM

The Constructing Responsibility System not only enhances the economic efficiency of the enterprise but more importantly it strengthens the responsibility consciousness of individual workers as master of the enterprise, greatly improving the management effectiveness. Based on their performance the companies in China are graded as State First Class Enterprises. State Second Class Enterprises and the Chairman of the successful companies are acknowledged as outstanding managers of China.

It is suggested that we should make an in depth study of CRS of China and free our plants with regard to pricing. product mix. investment on modernization and enlargement of capacity and wages of managers and workers. Gradually the budgetory support to the enterprise should also stop and if the enterprise earns more, it could invest more and pay more to its employees. This would also mean allowing nonprofit making enterprises to privatise or close down.

6. Modernising existing steel plants

Another point which emerges from a study of the Chinese Iron 6 Steel Industry is that they are not discontinuing operation or closing down their old steel plants but going on modernising them and making them more productive and more efficient. This is a cost effective way. Some of their most productive plants were built in 1916 - 1920 and even earlier. In view of this, we must reconsider completely closing down some of our older integrated steel plants. It is very expensive to build a completely new steel plant in place of an older plant.

7. Medium capacity BF/BOF steel plants

Another area where Chinese have done well is in mastering the technology of producing steel through BFIBOF route in capacities as low as 100000 t/a which they call Local Major-Medium and Small Plants. In some of these plants small blast furnaces, small L.D. converters and small sinter plants are producing creditable results with high productivity. They have sinter plants of 24 m^2, 36 m^2 and 50 m^2 hearth area. Blast furnaces of 100 m^3, 300 m^3 and 500 m^3 and L.D. converters of 6t, 10 t, 15 t, 20 t and 25 t capacities. However, it should be noted that as per Chinese the cost of production from smaller .plant is higher by 23% (this can be still higher) and productivity is lower to the extent of 30%. However, in China the capital cost for smaller Blast furnaces per ton of production capacity is only 70-80% of large blast furnaces and of smaller LD converters 65-75% of large converters. It should be remembered that in China both the coking coal and iron ore are dispersed very widely throughout the country and for smaller local deposits of coking coal and iron are it is found economical to develop smaller plants rather than haul the raw materials to long distances and develop bigger capacity steel plants. Moreover, the type of investments needed to put up big integrated steel plant like the one at Baoshan is just not available. However, Chinese have not built any medium and small capacity steel plant in the last 10 years. They are only modernising the existing medium capacity plants.

Chinese experiment and experience is of interest to us in India in that we could think of B. F. IBOF based steel plants of 0.5 - 1.0 m. t. capacity based on imported coal in such locations where iron are is available, locally or can be hauled cheaply and where imported coal can be brought easily and economically. This will naturally favour such coastal locations from where iron are is already exported where imported coking coal can be readily brought by ship and used nearby. Certain infrastructural facilities at ports will need to be strengthened but that should not be difficult.

8. Imported Coal

It may be mentioned that India imported 4.3 m.t. of coking coal in 1988-89 between SAIL and TISCO and it has been worked out that for the existing steel plants of SAIL. TISCO and Visakhapatnam there is likely to be a Shortage of coking coal which yearwise would be :

Year	**1991-92**	**1992-93**	**1993-94**	**1994-95**
Shortage m.t.	5.37	6.14	5.04	5.19

In view of this, it is better to plan any new capacity for BFIBOF route based only, on 100% imported coal and for this purpose suitable coastal locations would mean less transportation cost for imported coal. With the use of, high

Globalisation and India

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SYNOPSIS

India is on the verge of completing half a century of its independence. Many mile stones have been crossed during these last 47 years. Industrial growth has accelerated manifold. We have shrugged off the vestiges of the British Raj and have stood up on our feet. But now for the past few years, we have busied ourselves into a different kind of activity. It is no more a question of standing up like a fledgling among towering giants, it is a question of being the first among equals. And this equalising ourselves to become a level player in the world market is what will be achieved through globalisation.

Globalisation means freedom to source our inputs from any legitimate market, freedom to market our outputs to any legitimate market. It means the recognition of a company as a player in the .world market .

India has long been considered a country with tremendous potential for economic growth. For years, it remained unexploited due to a strangulating web of regulations. Three years back, India has adopted liberalisation as its economic philosophy. Since then, metamorphosis has started to take place in the economic scenario of the country - changes which are affecting business, industry, our very psyche, our attitudes and our way of thinking.

Liberalisation means the removal of controls and protection of domestic industries. This opens up the free international trade on a global scale. The intern ationalisation of the market under the competitive environment is the integral part of the process of globalisation.

The liberalisation policy is both a challenge and an opportunity for the Indian industry to take up. The path defmitely is not bedecked with roses without its share of thorns. There are pit-falls - changes will be in such a root level that its fall-outs will also be felt far and wide. Indian industry has to gear up to meet the challenge, to be able to upgrade itself to global standards so as to be a key player to reckon with in the global market and we are sure, we will be able to conquer the Everest one more time.

LECTURE

I am thankful to The Institution of Engineers (India), IE(I), the first and foremost professional body of engineers in India for inviting me to deliver the Vth V. Subramony Memorial Lecture. For me personally it is of immense sentimental value since I and Subtamony worked and grew together in our worklife at Bhilai Steel Plant and Steel Authority of India fur more than quarter of a century. A perceptive metallurgist, a silent organiser and an able administrator, Mr V. Subramony was snatched away from us by the cruel hands of Destiny in a tragic fire accident in Vasant Intercontinental Hotel in Delhi in 1986. At the time of his death, Mr Subramony was just about 50 years old and it is a pity that we could not see the complete blossoming of his talents. Just a few days back, 9 years have elapsed after his death and please permit me to pay my best homage to the departed soul on my .behalf and on behalf of all of us present here.

The Institution of Engineers gave me a choice of the topic of my lecture theme today and I have chosen the subject "GLOBALISATION AND INDIA". The choice has been dictated by the compelling force of the inevitability of world history and of Indian economic scene in the twilight years of the 20th Century. During the first 94 years of the century that have passed the world has seen, apart from two World Wars, experimentation of various economic systems with telling results and a fantastic advance in science and technology. As a corollary, the political, economic and industrial structure of a number of countries have undergone profound changes. A time has come for India, when Indian industry is facing a challenge; a challenge of survival in the environment of accelerating industrial growth the world over. Gone are the days when a company could afford to operate in an isolated seller's market without catering to varying consumers' demands. The size of the market was small and the margin was acceptable. With ever increasing consumership, the size of the market is increasing and the customers are looking for varieties at reasonable prices. On the other hand, with the arrival of new producers, the consumers' expectations are growing, the market is rapidly changing in nature from being a seller's to a buyer's market where quality is the buzz-word. Consistency in quality in competitive environment demands continuous improvements. The Japanese call it Kaizen and today particularly in' Indian industrial context, it has acquired a comprehensive meaning.

The compulsion of course of history with the disappearance of centrally planned economies from the mid-eighties have brought in profound and far reaching changes the world over. In India, although the process got formally started in July 1991 with the first announcement of liberalisation of the economy by the Government, but the process of metamorphosis in the economic scenario commenced much earlier. The series of changes since then has not just affected business or industry but has brought in changes in our psyche, our attitude, and our way of thinking. The Government, which in the past took the role of the most resourceful and pervasive entrepreneur, have chosen to confine its activities within the limits of administration and regulations, leaving new initiative in the field of industry and business to private entrepreneurs. In the process, the door has been opened to Resident Indians, non-resident Indians and multi-nationals. The process following liberalisation has thus become globalisation.

It is to be expected that with the formation of World Trade Organisation, India will have to open its doors by reducing tariff and fiscal barriers to the trans-national companies for trade and investment in India. The Indian industry will have to, atleast in theory, follow the possibilities of operating trans-nationally. This opportunity will bring in some unknown dimension in operations of industry and trade and a way of changes at various levels within the country. As to the ultimate balance sheet which globalisation will bring in to the economy; while conceding that this will depend on the entrepreneurship, ingenuity and sheer tenacity of Indian managers and engineers, let us consider the experience of the countries which have brought in liberalisation in their economic policy in the recent past. Taiwan maintained GNP growth of more than 6% each year while Korean economy grew at about 5 %. In Latin America, Argentinan economy grew strongly. China, with the most imaginative liberalisation programme of all, have posted for last five years an impressive growth of 10% and above.

The internationalisation of the market under the competitive environment is the integral part of the process of globalisation. The tariff barrier over the years which created artificial protection for Indian industry are being systematically reduced. The Indian companies have become smarter, looking for fresh sources of improved technology and producing not just for Indian market but for market overseas. This also has brought in joint ventures. This has brought in merging with global giants, foreign tie-ups, establishment of branch offices or wholly owned subsidiary of trans-national companies.

Now what is Globalisation? In my understanding, globalisation means freedom to source our inputs from any legitimate source, along with freedom to market our outputs to any legitimate market. It means the recognisation of a company as a player in the world market. Through globalisation, therefore, not only technology transfer takes place but know-how in the areas like marketing, distribution and financing also acquire a different approach.

India has long been considered a country with tremendous potential for economic growth. For years, it remained unexploited due to a strangulating web of regulations. Since July 1991, however, the Government of India has earnestly undertaken pragmatic economic reforms to remove the shackles of controls that has stifled the Indian corporate initiative. A policy framework oriented towards imparting an export culture and making our economy open, efficient and competitive is being created. Major components of the reforms which can be considered as the footsteps for industrial development of a developing country and which have been adopted by the Government so far, are:

1. Dismantling of the licensing system.

2. Easy entry to foreign investment - both direct and portfolio

3. Liberalisation of Trade and Rupee convertibility on the current account.

4. Elimination of infrastructure bottle necks with entry of private sector.

5. Elimination of multiple clearances to provide transparent and simple procedural formalities through single window clearances.

This has been combined with the continuous efforts to make the banking and financial system efficient and competitive so that it supplements reforms in industry and trade. Much opportunities exist for joint ventures in the financial sector. A joint venture company ICICI Securities and Finance Company Ltd. (I-SEC) of the ICICI and J.P. Morgan arid Co. has been launched recently and more are on the way. Such financial tie-ups would lead to technological innovations, modem management methods and improved processing of operations.

The new import export policy has ironed out the lacunae in Indian foreign trade policies and procedures. Trade policy occupies a central place in India's economic restructuring. It is not merely a matter of exports and imports, but is essential for realising our true potential in the global market place.

Till two years back India put a ban on foreign companies to come and market their products. The Indian companies did not find any need to make their products of global quality standards and to adopt advanced technology to upgrade their products. This type of artificial protection not only inhibited Indian companies from becoming competitive with respect to foreign companies in term of quality and cost, but it also hindered the process of improved technology transfer. Now, this type of artificial protection has been substantially removed and the foreign companies have started to make their entry with new technology, new market policy. To compete with the foreign brands, Indian manufacturers are also getting a chance to make more intelligent products, to upgrade their products to global standard.

By simplifying the rules of investment by an Indian company either in overseas joint ventures or in wholly owned subsidiaries, more and more Indian companies are going for a joint venture in overseas. Joint ventures permit speedier market access than mere technology transfer. Essar Gujarat is setting up joint ventures in both Indonesia and Bangladesh which will buy hot rolled coils from its plant coming up at Hazira. This will then be converted to cold rolled coils. This offers a dual benefit; the joint venture will give a market for the production from Hazira, besides allowing value addition in the individual overseas markets themselves.

Under the winds of liberalisation, tie-ups and mergers between international giants and local companies has almost become the order of the day. Salora International has made a tie-up with Matsushita of Japan and Ericsson of Sweden to make its product competitive, quality and cost effective in global scale. Such type of tie-ups of local companies with internationally recognized companies not only help to improve their financial condition, it makes a way for new, advanced, upto- date technology to come.

With the liberalisation policies, Indian companies are concentrating on technology upgradation and quality and cost effectiveness to ensure that products are in line with the requirements of the export market. A Madras based company, Sundaram Fasteners is supplying radiator caps to General Motors, an automobile giant in USA. General Motors has also cleared in principle the Madras based Engine Valves Ltd (EVL), belonging to the Rane (Madras) group, for sourcing its requirement of engine valves. In fact, to meet GM's demand and to generally increase its export sales, EVL is setting up a new plant near Hyderabad.

Going global means looking at the world as a market not only for selling products, but also for sourcing inputs. Recently India has signed a contract with a Russian company, Mikoyan for transfer of technology for making vital spare parts used in the fighter aircraft MIG-21. India has also acquired the licence from the Russian company to upgrade all the equipment and to export it to a third country. Hindustan Aeronautics Limited has acquired this vital technology from Mikoyan. India has identified some items which they would like to source from western defence companies, such as the inertial navigation system (INS). India is intending to procure this from France while the radar warning receiver (RWR) may by obtained from Dassault Electronique, Germany. With this I upgradation programme India will be able to enter international defence markets.

Indian engineering companies have a major role to play in the aspect of development in the country. The technological competence in certain areas are comparable to international standards. This is amply demonstrated by the fact that more and more Indian companies are able to secure business intemationally.

It may be proper at this point to mention that globalisation is not an unmixed blessing and there are some significant fall outs of globalisation. Firstly, ownership pattern of the industries will undergo far reaching changes. Funds raised by Indian companies by way of GDRS or Euro Bonds or investment by Foreign Investment Institutions (FII) will bring in some salient changes in ownership. Globalisation has thus, while opening the floodgates for our Industry to the vast reservoir of international capital, brought in the possibility of changed pattern of the ownership with substantial change in trading and export. The trading will become international, giving possibilities of higher exports and therefore inducing global giants to investment in capacity augmentation in India. Thus, where technology is available, India Will hold out its advantages in terms of lower cost of production. This type of shifting of industries has been witnessed during past 50 years or so when American automobile industry initiative shifted to Japan, Japanese industry initiative shifted to Korea and now is in the process of being shifted to China and to Asia-Pacific countries. Similarly, we in India can avail of our advantage of lower cost of production in getting production facilities relocated from developed countries with technology available globally to our economic advantage.

Another hurdle of globalisation will be increased protectionism of developed countries although World Trade Organisation is keen to facilitate global trade. One has to reconcile with the fact that some of the developed countries have started protectionism barring developing countries to enter into' their market. Formation of NAFfA is one of such example. Whatever we may say in conferences and meetings, a borrower country will always remain at a disadvantage, vis-a-vis a lender country, until and unless the borrower can upgrade his position to that of a lender.

The third danger out of globalisation is disappearance of local technology inspite of intrinsic superiority by being steam rolled by the products of trans-national companies. The drugs and pharmaceutical and the cottage industries will be particularly vulnerable.

Keeping all these facts in mind, one has to concede that the winner of the globalisation process will be decided by the entrepreneurship, ingenuity and sheer tenacity of the players of the global market. This is a statement of fact which cannot be overlooked as no country can afford to remain isolated in the global scenario today.

Thus, globalisation brings to India an unprecedented opportunity along with stiff challenges. The days of protectionism are over, the day of innovation, the day of research and development and the day of winning in the competition have come in which the engineers, the men for application of science into technology, will have a decisive role. Research and development leading to improved products at lower cost will playa definite decisive role towards this.

It is gratifying to note that even within a very short time, Indian managers and engineers have made their mark in the global arena and have proved that their competence and dedication at the workplace is second to none in the world and this has to prevail to win over all the obstacles and challenges that globalisation would bring.

Key Role of Metallurgists, Material Scientists & Engineers in Managing Corrosion & Maintenance in Processing, Chemical, Oil, Petrochemical Industries

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In this increasingly technological global highly competitive scenario, the role of metallurgists, materials & corrosion scientists assume much greater Importance for any processing, chemical, petrochemical, fertilisers, oil industries for their survival and growth. Managing change with the changed scenario has become the main challenge for practising engineers as the choice is either to perform or parish. To compete globally, world class maintenance & engineering function/philosophy is essential A new era for metallurgical & engineering profession has been signalled for smooth, safe and economical operation of plants with much longer run lenghts by keeping the hardwares healthy & reusable so as to increase the 'on-stream' factor, while keeping the cost of maintenance and cost of production low. This also calls for sharpening technical & managerial skills.

It would be of fundamental importance that the voice of metallurgists & engineers becomes a driving force. The metallurgical profession must overcome decades of cultural complacency If It Is to regain lost status and attract high calibre talents. Professional bodies like IIE. & IIM., industry and Govt. must work together closely to change public perception of the profession and enable It effectively to take the Initiative on issues of national debate. We must find ways of pooling the efforts of the whole metallurgical and engineering community in order to create a more credible and productive dialogue with Government. The key issues affecting the metallurgical & engineering profession and the challenges that lie ahead must be adequately addressed. Mind you, India has best of brains & skilled manpower, and its capabilities adequately acknowledged & acclaimed. This is to be realised and fully exploited for our own country particularly when India today, is one of the largest markets for almost any product that you name and that almost all international players have set-up shops in India.

Matching with the changed competitive scenario, a fresh re-engineering exercise has been suggested, where redefining the roles, key tasks, re-orienting the work culture revamping the systems & procedures, remotivating people to raise their moral necessary to build a strong work force, redesigning the whole set-up, resetting new goals & targets, relooking & reshaping the whole approach, practices, & philosophies etc. have been called upon.

An attempt has been made to raise and discuss several relevant issues beginning with the design stage, selection of materials of construction, condition & health monitoring of hardwares, trending, good maintenance management & engineering practices, desired leadership & managerial skills, managing people the biggest asset, thrust areas, Down time trap Vs breakdown analysis concept, 'reliability approach' as against 'availability approach', major attention to minor details, quality consciousness, perfect understanding & coordination between materials scientist & engineers, between operations and maintenance groups, between technical and finance disciplines etc.

Ultimately it is the Leader, his leadership quality, style, and managerial excellence that matters, and it is the Leader who can make or break.

PREAMBLE:

Equipment & pipeline failure, fire, explosions, accidents, mishaps, leakages and disasters in chemical, processing, oil, refineries, petrochemical industries resulting into huge loss of properties and life of human beings are not uncommon, though by and large avoidable/preventable. Nearly 30% of major fires and explosions in process Industries are attributed to pipeline or piping related failures. A plant consists of capital Intensive hardwares, hundreds of them, pipelines thousands of kilometers of them and all kinds of fittings, mostly made of varieties of metals & alloys, and they are made to work continuously round the clock, throughout the year under very severe operating and design conditions of temperatures, pressures, flow, velocities, highly erosive and corrosive fluids and external corrosive atmospheres etc. These obviously result into gradual deterioration In their health and strength, and ultimate failures.

A major percentage (51%) of these failures of hard wares and pipelines, which jeopardize the safety of the plant and the people, is due to corrosion and material failures. The causes of corrosion are many, one of the most important being operational lapses, mal-operation apart from wrong MO.C., poor maintenance, absence of corrosion preventive measures, lack of awareness, factor of ignorance, lack of the right expertise and facilities, even poor house keeping, no inspection & corrosion monitoring practices etc. etc.

Corrosion has been a major source/reason for leakages, failures, losses, and such kind of serious damages, disasters and deaths. Corrosion, therefore, ought to be managed most essentially, most professionally and most sincerely. This discipline can no longer be ignored by any management and this branch of science & technology ought to be given top priority, top attention.

"Corrosion & Inspection" management in processing, chemical, petrochemical, oil and refineries, paper industries etc. thus assumes great importance and a prime requirement, which certainly calls for very high degree of professionalised, systematic, scientific approach and a very high standard of speclallsed knowledge and expertise to provide the necessary equipment caretaking technology and health monitoring programmes techniques for the hard wares.

"Corrosion & Inspection" management is one which is dedicated to improve the safety and economics of plant operation by keeping the plant equipment and pipelines In safe condition and always in good health. This is achieved by implementing and operating Corrosion monitoring & control programmes, good inspection practices, regular corrosion audits, investigating all kinds of corrosion related failures and by advising on the most economic means of prevention & mitigation.

THE BASIC PRINCIPLES GOVERNING SAFETY & RELIABILITY OF HARDWARES:

Let it be any industry, whether chemical, petrochemical, fertilizer, refineries, oil, pharmaceuticals, power, steel etc; however small or big, the performance and the survival of an equipment, and therefore the plant, and of course, the safety of the plant, and thus the safety of human beings, and obviously ultimately the profitability of a plant and the organization, depend on 'EQUIPMENT QUALITY & RELIABILITY & ON THE ENTIRE PLANT'S RELIABILITY. All the related parameters, and the activities, which go with it and which control & decide, as to how much reliable and safe the equipments are, the plant is, become of paramount importance, and these facts of life make it obligatory that quality cannot be compromised, at any cost, and further it can neither be underestimated nor ignored, nor neglected.

It is high time that we all understand and appreciate these fundamental principles governing quality, reliability, and plant safety that we honestly comply with their basic rules and it is necessary that we start believing and practicing the required professional code of conduct for achieving the most important objectives of plant's safety, plants, survival, and the organization's profitability. The professional monitoring in a plant, first calls for professional loyalty, definite professional codes and ethics, and loyalty to the organization, that a man is working for, if we really mean business for the organization and a safe plant Unless and until, we have such strong beliefs, with the full backing and support of the management concerned, we would, otherwise, simply make a mockery of the whole thing, and unless this profession has its required independence and no inference, whatsoever, this would not be able to function and perform, and the whole objectives would just be defeated, and this would remain a show piece only.

Managing 'Corrosion & Inspection' starts on the drawing board at the design stage but unfortunately always taken for granted, out of ignorance mainly. This is where the alloys the alloy combinations are selected, method of joining is chosen, heat treatment requirements and methods decided, crevices and dissimilar metals avoided or if not avoided, preventive measures then incorporated. Quality and reliability is ensures then incorporated. Quality and reliability is ensured from the initial stage of design, through the stage of raw material, fabrication, transportation, erection; installation, commissioning, and inservice/inoperation.

TIIE CARETAKING TECHNOLOGY:

The question before any management that I like to raise is "Can we afford to compromise equipment quality and reliability", which can otherwise create unsafe condition, and the plant's reliability and safety get totally jeopardized. There is mostly and generally a common tendency, prevailing everywhere, to compromise on quality and reliability predominantly on non technical reasons like ego, delay, urgency, production loss, cannot afford shutdown, ignorance, could not careless attitude towards these factors; absence of the right concept, interference, wrong reporting system of such important function, vested interest, negative approach, absence of encouragement and support from management, importance underestimated etc. It is a common knowledge that inspection practices, inspection rules and procedures, the ethics behind this are ignored and are widely regarded as a nuisance, troublesome chores to be avoided, if possible. Therefore, quality and safety merit only a casual approach, because the probability of accidents is assumed to be remote, and things are left to chances. But there has been many failures, accidents explosions, mishaps allover the world due to substandard material, bad quality components, defective items, unsafe equipment, unreliable plants, absence or quality consciousness, disregard to inspection rules and ethics, absence of good inspection practices etc. Even a minor defect, which if remains undetected, can result In a catastrophe. In modem high technology plants, where equipments are subjected to very severe process conditions, inspection, corrosion control, quality and reliability predictive maintenance equipment condition monitoring assume paramount importance, for achieving safety. Here, the caretaking technology during the operation of the plant, round the year, become the modem concept The plant equipment and pipelines also do get fatigueitired, after some period of hard and difficult working. Like human body which get often fatigued by overworking, overstraining, these equipment also need rest, relantion, periodic checks, and they also need to be looked after and adequately taken care of, In order to keep them fit, in good health, so that they can continue working, can continue to give trouble free and long service remain safe, and perform well. This is possible by the modem caretaking technology, the equipment condition monitoring programmes, extensive shutdown inspection, round the year 'on-stream' inspection, continuous corrosion monitoring system etc.

What is needed today is the 'Awareness', the correct understanding and knowledge and the skill to set up, develop, formulate the programme, and the best and most optimum uses, the right caretaking machinery's, and the adequate infrastructures to deliver the goods. Today the world is offering us most modem concept, latest philosophy, the techniques, the inspection method; instruments, tools and tackles, so much so that many of us are not even aware of, what we can talk about acquiring and using them.

There recent impact of world's worst man-made disaster, and the subsequent shock waves that this Bhopal tragedy has sent us and shook the world, that no one should even think of ignoring such vital field of inspection, and no one would at Tord to compromise at any stage with quality and reliability, and running the plant with unsafe equipment.

COMPLEX SITUATION & RESULTING PROBLEMS:

Petrochemical, Chemicals & Processing industries existing today allover the world consisting of many different types of plants each producing different petrochemical products, involve complex processes, complex metallurgy, very specilised weldings, critical and widely varying service conditions such as temperature as high as 1000·C and as low as -170°C and pressures as high as 3000 kg/cm^2. Some of these petrochemicals plants operating today namely DMf, Xylene; Polyethylene, Polypropylene, Rubber, PVC, Acrylic Fibre, Acrylonitrile, Ethylene, Glycol, Linear Alkyl Benzene, Naptha Crackers, Caprolactum, etc; involve long range of metallurgy starting from low carbon steel, low alloy and high alloys steels, various types of stainless steels, to special materials like aluminium, titanium, monel, hastelloy, HK-40, HP-40, Manurite, Inconel, Incoloy, Copper alloys etc. All these present varieties of problems and make the task or the Metallurgists or the corrosion engineer employed in such industries very dirncult and responsible, who have to play a vital role in meeting the challenge of combating all corrosion and metallurgical problems.

IMPORTANCE OF PLANT INSPECTION & FIELD MONITORING:

When chemical and petrochemical industries are built, many years under severe conditions. These equipments are required to be looked after properly so as to keep them in good health and to get trouble free service from them and at the same time to given them a longer life. This is not an easy task and one would then be expecting too much from them. All this can, however be made possible with the knowledge existing today on the philosophy of predictive maintenance, the nondestructive testing techniques in practice allover the world, a well planned and scheduled 'on-stream' as well as 'of T-stream' inspection programmes being adopted and the documented rich technical information and data bank system that is being followed. All this undoubtedly require the backings of experienced and knowledgeable technical personnel in the field, without which the whole system would fail.

Regular and routine 'on-stream' as well as 'of T-stream' inspection of the entire plant equipment is extremely important from predictive maintenance point of view. Various types of nondestructive testings and inspection techniques play a vital role in predicting and then preventing corrosion, and premature failures. Regular inspection of the plant can reveal faults, on-set of corrosion, damages, defects and the degree and nature of corrosion and metallurgical problems which can be highlighted, immediately attended, and timely rectified to prevent unexpected major failures. Such failures would otherwise cause extended shutdown with the subsequent loss of costly production. Modern sophisticated testing techniques available can establish cause of defects and corrosion, which are really helpful in preventing such failures. The cost of inspection and testing as compared to heavy production loss due to such unexpected premature failure, is negligible.

Regularly planned inspection and testing programmes are the basis of predictive maintenance. It is this, which make one be able to foresee and predict troubles, corrosion problems, defects, abnormalities, thus predicting the behaviour and life of the equipment. Accordingly, proper steps are taken to rectify them and also it enables to keep the replacements ready. It is the result of this advance forecasting that corrective actions are taken in time and suitable preventive measures are applied for avoiding major shutdowns. Use of reliable nondestructive testings as an integral part of corrosion control programmes can provide sizable savings as well as valuable information. The primary goal of both Inspection and corrosion control is to save money by predictive maintenance system and by preventing corrosion. Planned predictive inspection system should have well defined programmes, activities, objectives. The prime objectives of Inspection and testings should Include;

- Minimising corrosion.
- Identifying corrosion prone area and materials.
- Early detection or materials under attack and or symptoms leading to premature failures.
- Avoiding unnecessary inventories of metals and consumable electrodes:
- Predicting and thus obtaining maximum economic life of the equipment
- Preventing accidents due to material failures.
- Minimising unplanned shutdowns.

Ensuring quality of welding and equipment for safe operation of plant

All these can be achieved to a great extent by having a well planned programme of field inspection and testings supported by modem NDT techniques and an effective corrosion control system. A very important factor essential to achieve this goal is an effective inter-departmental communication and co-operation between inspection, maintenance, planning, production, workshop, and finally to the management.

'Visual inspection' and 'Instrumental inspection' both are equally important Regular inspection at scheduled frequencies greatly helps assessing the corrosion rate an essential parameter for predicting the life of the equipment, which provide advance warning when replacement parts are needed. Various actual service data obtained by these field testings and inspection on many materials of construction under plant conditions provide rich experience to guide new material selections for new process. Failure to check the initial corrosion rates in sensitive locations could result in a catastrophe. However, a good and experienced judgment is essential in interpreting these data.

Various DT and NDT inspection and corrosion instruments based on different principles and techniques are in use today all over the world.

The major inspection methods are vital predictive maintenance tools widely used allover the world which can really help the plant units keep running with minimum maintenance by timely detecting corrosion and likely failures. New developments are enhancing the role or NDT techniques in corrosion control programme of the future. The long range benefits of planned inspection and corrosion control programme can be substantial even though in Initial stages, It might seem uneconomical In some area. Once such system has become effective, it provides net savings many times its cost only through its continued use. Just one plant shutdown because of a corrosion failure can justity the cost of such programme.

The many instances, examples and case histories allover the world, and in India, of accidents, mishaps, explosions, disasters, serious failures, huge losses of money and profits, many of them having been due to metallurgical reasons, corrosion failures, lack of true inspection, by the general tendency of compromising with quality, and hence sacrificing reliability and therefore safety, prevalence of state of ignorance or negligence in this direction, for having disregard for such vital discipline, absence of the right concept, or mishandling and politicizing the concept of quality and reliability, apart from the hard facts that money of the order of millions and billions are going down the drain by corrosion problems and metallurgical reasons, and inspection failures, including the most recent world's worst disaster at Bhopal all of them only remind all of us, that quality, reliability, and plant safety can no more be neglected, underestimated, devalued, disregarded, compromised or sacrificed. The science and technology and discipline of "Corrosion & Inspection" can no more continue to be given the status of second class citizenship in an industry, how big or how small it may be, and it also hardly cost to an industry. There has been a wrong notion or belief that only giant industries can afford to establish such facilities. It is not really true, and the truth is that ultimately the benefits derived out of it, and the wonderful results that can be accomplished by such practices, are always very valuable not only in terms of financial savings and benefits, but in terms of equipment reliability, plant safety and therefore everybody's safety .

GOOD ENGINEERING PRACTICES & MAINTENANCE PIDLOSOPHY :

★ Secret of good maintenance is perfection & attention to details.
★ If you attend to minor details, major breakdowns never arise.
★ If you have to sweat during preventive maintenance, you do 'not have to bleed during breakdowns.
★ Aim for zero downtime & minimum breakdowns.
★ Let us also not talk only about downtime but also about breakdown & breakdown analysis. This would otherwise like doctor treating sickness without talking about the decease.
★ Availability & reliability of equipments are the important goals to be achieved in any manufacturing/producing organization.
★ Availability of a plant Is the percentage of the time plant Is not down for maintenance but available for productive use, whereas reliability Is average continuous running time of the plant between two failures.
★ Reliability is the road to reduce downtime & improve reliability.
★ Reduce downtime is not the measure of performance of a maintenance Engineers/Manager performance has to be measured by number of failures, number of faults on the running equipment
★ It is the breakdown analysis & breakdown control that will reduce downtime not the downtime analysis.
★ A minor fault, if ignored, can be a potential breakdown.
★ Any addl. manpower, extra standby capacities, enhanced budget cannot compensate or provide against poor maintenance practices.
★ A total harmony between maintenance/engineering & production, the two vital pillars is a must for any organization to remain healthy & prosperous.
★ Stock-out of spares in the midst of high stock levels is an unfortunate reality. Even when shelves of engineering stores are overflowing the engineers do not get desired spares in time & they continue raising emergency indents.
★ Any Inventory control, without initial inventory planning, without predictability on consumption pattern, will be a futile exercise. But the problem is not too difficult to resolve.

THE MISSING LINKS TO GOOD MAINTENANCE MANAGEMENT :

★ Lack of good maintenance management & a bad maintenance culture not only result into lower productivity level but also at times become the, cause of catastrophic failures, accidents.
★ Labour trouble, bureaucratic red tapeism, political bungling, bad operation are responsible for 60% of shut down time in industry whereas poor or insufficient maintenance accounts for remaining 40%.
★ The major reason for the chaotic state of maintenance in our country is not the lack of maintenance knowledge or awareness or preparedness but the low priority accorded to the maintenance function, low position, the low profile, low importance, lower hierarchy, lower freedom, lower power, lower status and the 2nd or 3rd class citizenship given to them as compared to those in production, R&D, Marketing, Personnel, Administration, F&A etc.
★ Undoubtedly, the important factor has been the failure to ensure that the contributions as well as the quality of maintenance management in the country are of the highest possible standard.
★ In our country, also the status & rewards of the maintenance function is less than any other function and it does not have the ranking that its importance (that exists in reality) deserves.
★ Engineering managerial profession is looked upon as merely a service function, sidelined, underestimated and it is not even remembered when all is fine & when records of achievements are broken. When plants do not operate, or maloperated, when things do not work, system fails, hardwares buggered-up, crisis situation arises, all blames passed on to engineering & maintenance and then this function becomes most important.
★ It is very common to find a Director Production, Personnel, R&D, Marketing, Finance, Projects, Operations, Technical, Commercial but perhaps never Maintenance or Engineering.
★ What we lack in our country is not the technical manpower, talent or knowledge of maintenance engineering but the consciousness of its importance, its value, its right status.
★ We have though the necessary know how, the right calibre of men educated in maintenance discipline, these men lack the motivation to give their best.
★ We at times take world tours to find the best technology, the best equipment possible and put it in the hands of the lowest paid unqualified, demotivated persons to do the job and then we wonder why the equipment does not perform.
★ The organization which creates assets have good intentions of maintaining them and no firm can survive with low utilization of its valuable assets. But a typical scenario is one where maintenance dept. is always considered a mere necessity.

★ Maintenance should not always be considered as cost centers. For similar skill & work requirement, outside agencies may charge the moon.
★ It is possible that maintenance may have to work in hard environmental conditions or at odd times but this is necessary to achieve corporate objectives.

TOTAL PRODUCTIVE MAINTENANCE

AT NO COST

- IMPROVE CLEANLINESS & HOUSE KEEPING
- MONITOR LUBRICATION
- CARRY OUT ROUTINE INSPECTION RELIGIOUSLY AND ELIMINATE MINOR PINPRICKS PROMPTLY
- OBSERVE STANDARD MAINTENANCE PRACTICES
- AVOID DEVIATIONS IN PROCESS PARAMETERS

AT LOW COST

- IMPLEMENT PREVENTIVE MAINTENANCE
- IMPROVE QUALITY OF SPARES
- CARRY OUT PREDICTIVE MAINTENANCE REGULARLY

AT HIGH COST (UNDESIRABLE) - TO BE AVOIDED

- KEEP LARGE STOCK OF INSURANCE SPARES
- HAVE STAND-BY EQUIPMENTS
- MODIFY EQUIPMENTS TO PREVENT FAILURES
- REPLACEEQUTPMENTS

MAINTENANCE MANAGEMENT & DOWN TIME TRAP :

Believe it or not, it has generally been experienced that down time has been on increase when it is actually being controlled and the maintenance expenditure has been rising inspite of tight maintenance budgetary control. How come. Yes, it is possible if emphasis is only to control downtime directly and no attempt is made to control downtime indirectly i.e. by controlling number of breakdowns. One has to understand and appreciate the difference between these two approaches, the first one being 'Availability' approach (not helpful), the other one being 'Reliability' approach (the real solution). In 'Availability' approach, the concern is always and only for downtime whereas in 'Reliability' approach, the concern is for breakdown, which should be the real concern of not only maintenance engineers but also production engineers as well as top management Avoiding planned maintenance jobs/planned shutdown, considered absolutely necessary, give immediate and short term gains but very costly long term losses. Direct concern for downtime does not help and in fact it leads to more breakdowns and higher downtime. Hardly 8-100/0 organizations follow 'Reliability approach' giving main emphasis on controlling breakdowns where downtime has been found to be negligible. Majority of the companies mistakably believe and adopt 'Availability approach' giving blind emphasis on reducing downtime directly which results into higher & higher downtime, because by doing so the job quality is sacrificed and people do not attend to minor jobs, actual faults in the machine with the result that more frequent breakdowns occur. Maintenance Engineers performance should be measured by number of breakdowns they prevent Concern should always be shown for number of breakdowns and not for downtime:

Availability of the plant/machine is the percentage of the time, plant/machine is not down for maintenance but available for productive use, whereas Reliability is the average continuous running time of the plant/machine between two failures. Reliability is the royal road to reduce downtime and improve availability. Improve reliability by reducing number of breakdowns and you achieve both reliability and availability.

When top executive is concerned only for the downtime and not for breakdown, the shutdown plans and schedules lose their importance. Whenever production targets is missed and production manager decides not to release the equipments for maintenance, the maintenance manager also by and large happily agree with him. This is a dangerous approach for short term gain. By postponing planned shutdown, he can bring about reduction in downtime without any efforts on his part but at a very high cost, and the company has to pay heavily soon. The other scenario is that though the equipments are released as per shutdown schedules, even then all jobs scheduled are not completed and only most essential, priority jobs, unavoidable ones are attended because the production manager and more so the top management are impatient to get the equipment/plant back to restart the production in order to meet the production target or sales turnover, and at times maintenance manager is also too happy to oblige as he is concerned for his confidential report and at the same time for reducing downtime and improve availability of the equipment, which can be achieved easily by postponing/ignoring less priority jobs keeping aside minor faults, non-priority maintenance jobs etc. Such unattended faults later on turn themselves into major crises and emergencies ultimately resulting into very high downtime.

Some top executives are so much concerned about short term production gains that they bother little when shutdown plans are postponed or when several jobs remain unattended during planned shutdowns. The situation then soon goes out of hands and the frequency of breakdowns rises to such a level that one totally loses control on downtime, and when this happens it becomes a God-sent situation for both production & maintenance managers, as both of them then get a handy execuse for not fulfilling the targets. The production Managers blame the maintenance manager for breakdown and the maintenance manager blames the production manager for not releasing the equipments for preventive and shut down jobs. Once the top executive falls into this trap, he hardly knows the way out; and often he himself starts finding execuses for mounting breakdowns such as poor or faulty design of equipment, spurious spare parts, incompetent engineers, manpower labour problems etc. Eventually, they turn brand new equipments into a piece of junk and push the company further and further into the downtime trap.

THE CORRECT THINGS TO DO WOULD BE ;

*Insist on records to be kept about number & frequency of breakdowns of each equipment.

*Allot targets to the engineers in terms of Reliability of equipments, thus keeping whole maintenance dept. on its feet all the time.

*Put engineers under pressure to analyze all breakdowns for root cause and then root out the causes of repetitive failures.

*Give major attention to minor details. Attend all the required preventive & predictive maintenance jobs, and do not go on postponing planned shutdowns.

*Remember any haste in maintenance is waste in production. But the boss says "why should you take 30 hours, you must do it in 18 hours, A dilemma".

* Adopt 'Reliability approach' rather than 'Availability approach', thereby reduce number of breakdown rather than reduce downtime alone.

Another paradox is the present traditional way of reporting the downtime hours/analysis and the figures/reasons given to the management, very convenient to the production managers, which is but far from the truth, and where the actual facts reasons of downtime remain buried under the ground. This is because the practice of doing breakdown analysis is either not followed or grossly discouraged/disliked, not welcome by the production people. In the present system of reporting downtime analysis, the column for downtime due to process/operation failures is absent and no one likes to talk about it, and the entire downtime hours is booked against power failure, mechanical failure, equipment failures, corrosion failure etc. but no one tries to go further as to mechanical failures but why ? equipment failures why? corrosion failures but why?

The result is that a sizable number of downtime hours out of these which are actually due to process problems, mal-operation but they are credited to the account of maintenance & engineering people.

Breakdown Analysis, therefore, needs to be made mandatory by a management directive which can not be edited by the production chief and such reports with the root cause of each breakdown go to the top management. This method alone can establish accountability and reduce breakdowns and thereby downtime, and will also remove any fear from the minds of maintenance m agers of getting poor confidential report from their production chiefs/bosses.

A boss must not be happy and must not compliment a maintenance manager if he completes the job in 7 hours by sacrificing the quality instead of originally planned 15 hours. He does it to please the boss because the boss has said so and also to claim that he could reduce the downtime. This proves to be fatal. He then develops tendencies to neglect quality of work he does and he overlooks minor details. It does not matter to him even if the same equipment breakdown again within a fortnight or a month or two. Each breakdown becomes an opportunity for him to show his ingenuity and skill to repair the equipments in the shortest possible time by using fault practices and get appreciation/rewards. Plant management must therefore be asked to reduce number of breakdowns rather than reduce downtime alone.

Maintenance means keeping equipments healthy without any faults and snags. Maintenance Manager is a doctor of his plant equipment in which he has to attack the source of decease where the Production Manager also plays a key role. Maintenance Manager keeps his equipments healthy all the time by routine checkups and inspection. 'Feel', 'listen', and inspect are the key words for him which he has to do day-in and day-out. Secret of good maintenance is perfection and attention to details. If you attend to minor details, major breakdowns never occur if you sweat doing preventive maintenance, you do not have to bleed during breakdowns. Unfortunate part is that no one records equipments breakdowns in history cards, no one analyses the causes behind them, no one keeps past data of failures while ordering spares. He is them like a doctor who tries to treat sickness without knowing the disease.

One must invest in preventive downtime. The real investment in maintenance should not be "to provide" against emergencies but "to prevent" emergencies from occurring. Lack of cleanliness costs millions of rupees because all kinds of waste, dust, powder, abrasives, dirt, rejects, fibres etc. get entangled into bearings, gear boxes, motors, conveyors, agitators, filters nozzles, machines etc. causing jamming, blockages, overloading, over heating, faster wear & tear all ultimately bring finest machinery to halt Plants have to be kept clean. Top management Directors should not make their maintenance Engineers 'cost conscious' but instead only 'quality-conscious'. Quality consciousness leads to cost consciousness automatically. A quality-conscious engineer is an asset to his company, whereas a cost-conscious engineer is a liability. Cost prevention must precede cost control by preventing breakdown cost A cost conscious engineer will use second quality spares, substandard material, and will insists on replacing spare only after its physical failure. As a result cost conscious engineer destabilizes the entire production process, as his cost-consciouness leads to more breakdowns and increase in all other costs.

For a competent maintenance manager, p.m. costs must be 80% of total maintenance costs. Such a manager is not controlled by breakdowns but he is controlling breakdowns, and preventing them. Maintenance manager must not, however, be complacent after improving ratio of p.m cost to total cost to 80%. He must keep striving to improve it till breakdown cost is eliminated totally. Thereafter, he can try to reduce preventive maintenance cost by eliminating over maintenance than needed.

IN AN ENVIRONMENT OF GLOBAL THREATS

MAINTENANCE & ENGINEERING FUNCTIONS

- ★ Engineering has to take fresh challenges & excel & succeed, through engineering competence.
- ★ Calls for more & more quality, safety, & cost consciousness.
- ★ Production & engineering have to work hand in hand as a cohesive team & work in harmony.
- ★ Engineering function -big role to play for the challenging mission of raising the profile of engineering.
- ★ Need to appear much less bureaucratic and more result oriented.
- ★ Decision making process to be made fast,
- ★ The new Identity of engineering should be forward looking, more professional & efficient, counter any perception that engineering is dull and not so helpful as it ought to be.
- ★ Communicating with improved communication skills to perform with transparency. Creating a structure for free flow of Information.
- ★ Lead by condemning action - not people, and projecting a culture of excellence through people.
- ★ Professional approach with no compromise on quality & safety.
- ★ Correct deployment of people to the best effect by putting the right man for the right job.
- ★ Frequent analysis of short comings in team design and accordingly bringing changes is absolutely necessary for good performance and also for resolving conflicts.
- ★ Endeavour to be seen as maintaining a good standard of competence within the engineering profession, second to none among all professions, and drive towards sustainable performance.
- ★ The mission ought to be is to right the wrongs of the past and prepare to face the challenges ahead.
- ★ Build confidence through improved self awareness, self development, self discipline & self motivation.
- ★ Only then we can survive, perform and compete globally when only one kind of manager will exist and that is a 'Global Manager', who will make things happen rather than just waiting & watching, and for whom achieving is not just enough but he thrives for the best

CHALLENGES AHEAD METALLURGISTS, MATERIAL SCIENTISTS & ENGINEERS

- ★ Those days are gone when you could relax & take things easy.
- ★ A new era of global competitiveness.
- ★ Either compete or perish.
- ★ Increasingly global & highly competitive scenario.

- ★ P.S.U^{S} have also to compete with private sectors & globally.
- ★ Role of metallurgists, engineers & managers assumes much greater importance.
- ★ Managing change with the changed scenario, the main challenge for practicing engineers.
- ★ To compete globally, a world class maintenance & engineering function is essential.
- ★ More economical operation with much longer run lengths by keeping hardwares healthy & reliable.
- ★ Cost of maintenance & cost of production have to be kept low in order to be competitive.
- ★ Sharpening technical & managerial skills necessary.
- ★ Voice of metallurgists & engineers must become a driving force and be in the forefront.
- ★ Professional bodies like I.I.E., I.I.M., I.I.CREME etc., Industry & govt. must work closely to change the public perception of the profession, for image building and take up Issues of national importance necessary to compete globally .
- ★ For example, the P.S.U^{S} particularly the 9 jewels are now being given lot more autonomy & freedom that are required to perform & compete.
- ★ The key issues affecting the metallurgical & engineering professions, the operating engineers must be adequately addressed & necessary change brought in.
- ★ Productivity of India Is the lowest In the whole world. Drastic changes in various statutory rules & acts, trade unions industrial relations act etc. called for, if we have to compete. Hiring & Dring systems need to be introduced.
- ★ Corrosion control, corrosion monitoring, equipment health monitoring hazop & hazards analysis etc. need to be made mandatory by law.
- ★ Maintenance philosophy of reliability approach needs to be adopted rather than availability approach.
- ★ Down time analysis practice is to be replaced with breakdown analysis practice.
- ★ Good engineering & maintenance practices need to be written down & followed.
- ★ Re-engineering exercises, redefining roles & objectives, re-orienting the work culture, redesigning & rebuilding the team, resetting new goals & targets, reshaping the whole approach/outlook etc. are the priorities to prepare ourselves.
- ★ Last but not the least, motivating & managing people, who are the biggest asset with desired leadership & managerial skills will remain the top priority.

CONCLUSIVE REMARKS:

This paper, a somewhat departure from normal conventional type of technical paper, assumes significance in the global competitive scenario, where the key word is 'Rising to the challenges' if we have to compete and survive. What is essentially required is total re-engineering exercise, re-orientation of work culture as we know the productivity of our country is unfortunately lowest in the whole world a major shift in our approach, in our attitude, full awareness, preparedness and readiness to accept the challenges and win over. Charismatic leadership, a total productive maintenance culture, cost consciousness, far less bureaucratic way of working, doing away with our hyprocracies, and eliminating the common culture of passing the buck etc. are the essential needs of this moment The metallurgists, material scientists, engineers are required to give a fresh relook and bring a major swing in their whole approach matching with the current environment of competitiveness.

In an environment of global threats, the maintenance & engineering functions have to take fresh challenges and excel through engineering competence and by raising the profile of engineering, and achieve economy through better engineering. Decision making process will have to be made fast by communicating with transparency and by creating a structure for free now of information. Leadership style will be to lead by condemning action, not people and projecting a culture of excellence thro' people, the biggest asset Managing change with the changed scenario shall be the main challenge for practicing metallurgists & engineers by building world class maintenance & engineering function.

Both technical and managerial skills will have to be sharpened. The voice of metallurgists & engineers must become a driving force and be in the forefront with a clear message that engineering means professionalism with quality as the top most priority. A new era for metallurgical & engineering professions has been signaled and these need to be given an altogether new identity to take the new challenges. There is a new mandate for metallurgists, engineers and engineering Younger generations will have to be adequately motivated. It should be the mission to right the wrongs of the past and prepare to face the new challenges ahead. Engineers speaking with one voice and working together will have a significant impact in making the desired swing. Working together works.

The Steel-Sun: Rise So Far and Beyond

Dr T K Roy

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The Sun was apparently set and the world, barring a few, was mourning the death of the widest and largest linkage provider to the economy. But the Golliath survived and rejuvenated with unprecedented resilience and strength. The world for the first time witnessed the crossing of billion ton mark a few years after the new millennium.

The moot agony of both producers and consumers is whether the Sun will continue to rise well beyond the horizon or will hide again like in winter at North Pole. Steel growth is always subjected to cyclic fluctuation and consequently the crest and trough appear over the years. Whether the span will be short or reasonably long-an intriguing apprehension to overcome with advanced planning, formulation of appropriate strategies, precision surgery of unnecessary frills and embracing the philosophy of growing along with other worthy fellow companions.

The march beyond the billion-ton line calls for definitive assurance in sustainable supply of materials, energy, utilities services etc besides efficient and knowledgeable technical personnel and elite managers to ensure the best performance of plant and equipment. The growing need of infrastructure will be a formidable barrier to overcome. On the top of it, the financial commitment is bound to be an agonizing head ache, if not well planed and properly structured to match time frame.

Challenges for the Steel Industry in the Next Decade

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V SUBRAMONY MEMORIAL LECTURE 2007

The steel industry in India is poised for exponential growth. Today the country's recorded steel production is around 40 million tonnes. By 2020 this figure is variously predicted to be anywhere between 80 and 200 million tonnes. Demand projections appear to support this growth rate. Even at 200 million tonnes, the per capita consumption of steel in India will be around 180 kg/person annum. This figure is just over today's world average of around 150 kg/person/annum, but is far below the consumption statistics of the leading countries, including China (anywhere above 300 kg/person/annum). This indicates that, as India grows further towards becoming a first world economy, steel production and demand will continue to grow beyond 200 million tonnes.

Such growth is necessary and can be sustained by demand. However, there are other challenges that need to be addressed in order for India to emerge as one of the leading steel manufacturers in the world. The first challenge is that of energy. Today India, overall, is an energy deficient nation and the cost of power is high by international standards. Additionally, the Indian steel industries today consume more specific energy (per unit tonne of steel) than the best in the world. For example, energy consumption by Indian steel plants varies around 6.20 :0 6.80 GCal/tcs; whereas, the world benchmark is 4.70 GCal/tcs. In order to sustain high growth rates, the Indian steel industry has to work along two directions in the area of energy. The first direction is to reduce energy consumption in the current processes by being more energy efficient. The second is to develop new technology and processes that require less energy. There is a third avenue to look for new, economical sources of energy.

The second challenge facing the steel industry is environment. Steel industry, by nature, is a significant producer of NOx, SOx and COx gases along with particulate merter. The pressure of environmental norms has forced new, cleaner technologies to be developed, such as the non-recovery coke ovens. The emissions remain high in India. For example, CO_2 emission by Indian steel companies is around 2.20 kg/tcs against a world benchmark of 1.2 kg tcs in a European company. However, most of the environmental measures are prohibitively expensive. Thus the challenge for the Indian industry and academia is to develop economic, indigenous technologies for reducing emissions of obnoxious gases and particulate matter.

The third challenge facing the steel industry is the availability of raw materials. Raw materials security, either through ownership of mines (preferable) or through long term contracts and partnerships, is going to be a key factor for sustainability. While the quality of raw materials can significantly vary between different mines, a company's iron making route can have only a few alternatives. The challenge of the future will be to develop the capability to match raw material source with the iron making process. Additionally, this will necessitate development of beneficiation technology to maximize mine life and suit the iron making route. India has the advantage of having rich iron ore deposits. However, Indian ore has high alumina, which reduces blast furnace productivity. In order to maximise the life of these mines and to maximise blast furnace productivity, beneficiation technology needs to be developed that would give low alumina and high yield in product iron ore. Similarly, Indian metallurgical coal has high ash (around 30%). For a long time we were living with 17 to 18% ash in washed coal. Today, with enhanced efficiency of washing, product coal can be obtained with 13 to 14% ash, without much decrease in yield. However, even this level of ash is much higher than what is available world-wide. The challenge, therefore, is to develop technology for obtaining significantly lower ash (say, less than 8%) without reducing yield. Another direction is to develop ways of using non-coking coal to make coke.

The fourth challenge is the availability of human resource. China, as nation, made plans to generate relevant human resource well in advance of its growth in this sector. For example, China set up five big institutions of research and development related to iron and steel. More than 6000 people work in these five institutions. The total national budget on iron and steel research is close to 800 million US $, which is close to what the rest of the world spends in this area (about 1000 million US $). India requires to gear-up on the human resource front through visionary, networked programmes that will attract people who like technical challenges and develop them as experts. People drive and sustain growth. Our country needs to develop such people.

These are exciting times for our country when we are seeing the nation perhaps at the tipping point. We are definitely in one of the most happening countries in the world today. However, in order to sustain the euphoria and optimism, it is necessary that the engineers, strategists and leaders seriously think about addressing the challenges that face us today.

We all miss the vision, energy and enthusiasm of Mr V Subramony today. Through his enormous experience and technical brilliance he could have guided us in the right direction. I am sure he is looking down from his heavenly abode and blessing us. May his soul rest in peace.

Bridging the Production Technology Gap for SM Applications

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It is an honour to be invited to address the scientists and engineers of this landmark convention on smart materials, their sciences and their applications and a privilege to accept it. I dare to do this with the humility I would need considering my limits of knowledge and skills in the vital area of understanding of materials and shaping them to various applications & commercialization. In this arduous journey, my own possible role/ viewpoint can at best be that of a Production / Industrial Engineers, one link in a chain of heads and hands starting from dreamer, scientist, technologist, technicians, Procurement Managers, Resource Persons, Share Holders. Of course you need managers, directors etc to coordinate and I am reminded of the sutra given by the doyen of all engineers Bharat Ratna Visweswariya that a good Engineer is always a good manager.

Having said thus, I must thank IE and IPE for this opportunity to share my viewpoint here in a session designed to commemorate Shri V. Subramony who is acknowledged as a great engineer and who eminently fits into the definition given by another great engineer Sir MY. To the comity of the engineers at large and to IE and IPE members he is one of the luminary models to emulate. Let us pay a renewed tribute to his memory for all the Steely contributions he made for making and shaping of Steel in India, in a pioneering effort, as engineer, technology transfer Manager and technocrat.

In focusing the role of the Procution Engineer in his productionising the Smart Material Application developed by the scientist into Batch or Mass

Production, it is necessary to understand the complexities of processes of Alloy Design and manufacture of Raw Stock, Laboratory scale application development process and identify the key process control parameters which are to be built into scaled up production plant, tooling and quality control which is broadly understood by the term Production Technology.

The complex processes in mass production demands higher level of accuracies in melting, forging and machining and corresponding Plant and Machinery are to be specified and realized Further the processes are to be tooled up proven and attached with necessary controls. I would like to take one application to bring the importance of mass Production Technology.

Research in India pioneered by BARC, ISRO and others have now produced viable Product Design Rules and Laboratory Scale Products in the area of Cryo Fittings for coupling similar or dissimilar pipes. These fittings are light, and are designed for use with Aluminum, Titanium, Stainless Steel and non Metallic tubing. Broadly, a nickel titanium alloy with any of Fe/Mo/Cr/V /Cu is compounded based on thermodynamic data and descriptions of their individual lattice structure based on iterative determination of Phase diagrams, Transformation / Curie Temperatures followed by computational modeling of mechanical behavior under Stress/ Strain Conditions. Of course the alloy design and Shape design rules are unique to each assembly couple. In each case, the work for the Metallurgical Scientist involves

-Characterization & design of alloy …….. Computational CAE
-Develop Shape Design …….. Computational Structural metallurgy
-Develop Melting, Forming Machining Process Lab Scale plants
-Develop Quality Control Procedures …….. (Metallurgical/Physical)

At the end of the day, we have a prototype fitting, with its pre designed micron level, high finish sleeve fitting which needs to be cooled to a pre-determined temperature to be simply inserted over the pipe couple and allowed to shrink and produce a durable joint of predetermined radial force (vibration and leak proof). The need to have swaged fittings, flanges, welding, brazing are all totally avoided.

SMA Springs avoid the need for costly and complicated hydraulic or electro mechanical actuating mechanisms for spools but get actuated by small controlled, increases in temperature or pressure of fluid.

While the R&D laboratory/ pilot methods of handling the design and processes is served by the availability of high caliber scientists, the methodizing the mass production without losing control of the quality presents a challenge to the manufacturing engineer. The methods, tooling and plant are to match to a host of parameters:

• Sourcing of extremely pure Raw Metals, their inward Inspection (Atomic Percentages)
• Creation of High Class Melting/Refining Facility and Establishing High Batch Processing Procedures with instrumented Stage Inspection
• Creation of Precision Forging / Roling and Machining Facilities (Diamond and CBN cutting, Grinding Lapping) Controlled Energy Forging and their mass production Methods and tooling
• Creation of a Works Test Lab with highest of Optical and Electron Micrography, Spectrometry and Differential scanning Calorimetry for control of Transformation Temperature
• Develop Tooling and Automation where needed

All these amount to the need for establishing what may be called as Part Technology for mass production. I might mention a few technologies where similar gap exists between Knowledge as systemized of processes and its industrialization such as High Speed machining of Metals. In the case of Aluminium Alloys, the Bench mark of Material removal Rates of 3500 cc/min has been achieved elsewhere but, it is as low as around 200 to 300 cc/min in complicated part geometries. The gap is in manufacturing engineering ability to analytically determine the required max power/ High Speed/Feed/ Cutter Material and geometry for each cutting Path with apt clamping to optimize the same for nil vibration and chatter which is Metal Cutting technology. Methoding Rules are to be establised by R&D. The same is applicable to High pressure Forming

I may recall the oft repeated yet unaddressed view of authorities and media as to the inability in the country to bring to viable commercialization a host of technologies generated by this country's advanced R&D institutions. This gap is in my opinion due to want of Production Engineering Skills or related organizations who can productionise the products to a mass production standard. They would need to establish the Mass Production Process, Define Plant, Tool Up and Instrument or Automate the Operations and then carry out a TOT to the Industry.

It may be argued that this activity should fall in the risk & responsibility of the large industries which may find the product viable for marketing. However the advanced nature of the process and the complex controls and knowledge to be built into mass production is such that the gestation period for realization as well as its low volume till they can acquire a sizable market share may not attract investment in skills and time. If we focus on SMEs, as production centres, for say SMA products, then there is need for the R&D Organisations to enlarge their good work into Production Engineering and provide the TOT on a mass production basis at a cost.

In this, the Russian Model of establishing all Factors of Production to match with Series or mass production and then introduce the threshold technology into factories is worth considering for implementation. The practice to some extent already exists in the Project Reports made for the benefit of SME Entrepreneur by the GOI Since R&D in Advanced Material Sciences and their applications lies by and large in the Government Sector it may be for the Government to bridge this Gap. The prospects of making the atoms of the crystal lattice of metals and other materials to dance to the tune or pressure and temperature music of the material scientist are mind bogging. Product realization would not only need to R&D ability of the scientist but also that of process engineer. Manufacturing Technologies in the area of MicrolNano Machining / Forming, among others, would need to be evolved and mastered. I have read somewere that an effort to design a Micro valve to be fitted to the eye cavity which would relieve ocular pressure in case of Glaucoma patients and release the fluid through the tear passages is being contemplated This would obviously need smart materials. The production of Stents would also need mass methods of fabrication in Nano/Micro dimension. The ideas are plenty & opportunities are phenomenal.

I would like to conclude by referring to the views of Prof CNR Rao reported in the media during the vision lecture he gave in the Bangalore Nano. He recommended that scientist professors should be allowed to set up companies (industries). It was important for the nation to produce nano materials and industrialize its applications. The challenges he said would be not so much for production of materials but to assemble and integrate them into the devices. This is Engineering. The interim model I propose would be that the R&D units encourage the industry with mass production TOT and have an advanced SM Laboratory located at the factory where the scientists can continue their R&D while assisting mass Production.

While thanking the IE and IPE for their kindness in inviting me to share my views for the kind audience, I wish the convention a path breaking success in its declared Objectives.

May New SMAs and Nano Materials be designed and applied to devices.

Delivered during the Twenty-second National Convention of Metallurgical & Materials Engineers on 'Advanced Materials : Characterisation and Processing' organized by Andhra Pradesh State Centre, January 23-24, 2009

Development and Characterisation of a Frontline Ni-Base Cast Superalloy for Aerospace Gas Turbines

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1. Introduction:

Materials development for gas turbine engines has been largely driven by military requirements, since their introduction to the propulsion of high performance aircrafts. Steady increase in demand for higher engine thrust, thrust to weight ratio and fuel efficiency have pushed engine operating temperatures and stresses progressively higher. Desired levels of engine performance and life can be expected, if the components have a good combination of high temperature strength, resistance to creep, oxidation, hot corrosion, fatigue & thermal cycling. Ni-base superalloy with its FCC (y) matrix and ordered FCC (yl) coherent precipitates has proved to be the right candidate to meet all the challenging demands.

Increased operating temperature requirements resulted in the use of Al plus Ti strengthened alloys with increasing additions of refractory metals such as W, Ta, Re, Ru & Hf etc., to name a few. This however, made the alloys difficult to hot work. The introduction of vacuum induction melting and vacuum induction casting in the early 1950's provided further opportunities to exploit the full potential of gl strengthening. To start with several polycrystalline cast superalloys were developed by the1970's, but the attention was placed more on process development with specific interest towards directionally solidified technology. For further improvement in creep properties, scientists eliminated the grain boundaries (which provides the weak link in the structure by encouraging diffusion processes) and introduced single crystal superalloys in the gas turbines as blades and vanes. Over the years introduction of improved materials has resulted in increase in the Turbine Entry Temperature (TET) by about 500°C. The present paper highlights some of the indigenous efforts that have been made in the last few years towards development of a frontline cast superalloy for aerospace gas turbines.

2. Evolution of cast superalloys

Cast superalloys can be grouped into

i) Conventionally cast (CC)
ii) Directionally Solidified (DS)
iii) Single Crystal (SC)

Conventionally cast superalloys developed in the initial stages utilized strengthening by $g^{I} – g^{II}$ by utilizing Al along with Ti or Nb as alloying elements. However, some of the alloys were prone to embrittlement after prolonged high temperature exposure due to precipitation of deleterious phases like s, m, d laves etc. as shown in figure l. Gradually the concept of phase computation technique (Phacomp) for calculating average electron vacancy number (Nv) was introduced, which could predict the formation of topologically close packed (TCP) phases. This led to the concept of tailoring the composition of cast superalloys, which resulted in introduction of several cast superalloys like IN 731, IN 738 & MarM 200 etc.

Experience accumulated through number of running engines revealed that creep failures in gas turbine aerofoils were occurring along the transverse grain boundaries through nucleation and growth of cavities, grain boundary sliding and interconnection of existing shrinkage pores. Elimination of transverse grain boundary through directionally solidified was a further step made to enhance the temperature withstanding capabilities of the aerofoils. By growing the crystals along [100] direction, which also coincides with the blade axis, the creep resistance as well as the thermal fatigue life could be enhanced by several orders. Performance of directionally solidified blades was further improved by introduction of complex cooling techniques through fine channels in the aerofoils. The cast superalloys were alloyed with Hfto facilitate casting of aerofoils in thin sections without encountering the problem of grain boundary cracking. Canon Muskegon developed the alloy CM247LC, which was essentially a derivative of MarM247 by tailoring the levels of C, Zr, Ti, W & Cr.

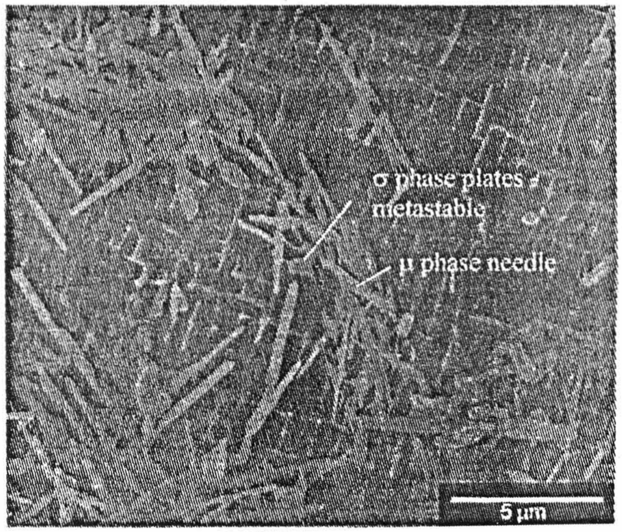

Fig 1. Morphology of TCP phases in cast superalloy

As a logical extension to elimination of grain boundary, single crystal superalloys were developed by providing a grain restrictor in the mold cavity, which would allow only one grain to grow during solidification. Absence of grain boundaries no longer required additions of grain boundary strengtheners like C, B & Zr. By striping these elements the alloy incipient melting point could be raised well above the glsolvus to achieve effective solutionizing of glleading to superior creep properties in these alloys. With this concept several alloys such as CMSX-2, Rene 6, PWA1426 etc., were developed and commercially introduced.

3. Metallurgy of CM 247

The alloy CM247LC was developed by Cannon-Muskegon from the base MarM247 composition. Carbon was reduced by one half to improve carbide microstructure, and enhance the stability and ductility of the alloy. The Zr and Ti contents were reduced and tailored to improve DS grain boundary cracking resistance without sacrificing strength. In addition the Wand Mo levels are also reduced to minimize formation of deleterious M6C carbide platelets and m phase. The alloy chemistry has been balanced to provide excellent DS castability and realize the required strength potential. The overall composition has been tailored by controlling Nv3B (PHACOMP) to less than 2.15 to ensure microstructural stability during high temperature exposure. After solution treatment and aging the alloy has approximately 75 % γ^{I}, whose typical structure is shown in the figure 2.

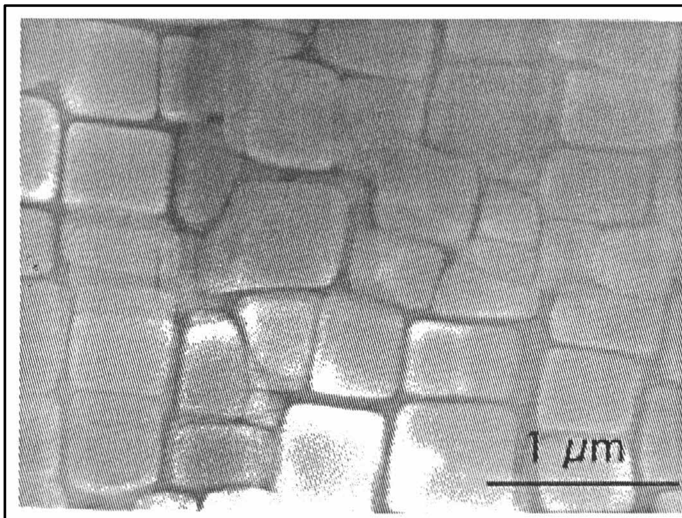

Fig 2. Morphology of γ^{I} in cast superalloy

4. Indigenous development of Supercast 247 LC

Midhani embarked upon the ambitious task of indigenizing the frontline cast superalloy equivalent to CM247 for development of turbine blades and vanes for the kaveri engine programme. The technical challenges ahead of taking up commercial scale development are summarized below

a) Controlling of main alloying elements within very narrow limits.

b) Controlling the levels of 31 elements categorized as trace elements & tramp impurities within specified levels.

c) Controlling gas levels of 0 & N less than 10 PPM.

d) Development and characterization of suitable analytical standard to facilitate online chemical analysis during melting.

Indigenization Methodology:

(A) Selection and characterization of raw materials

The first and foremost step towards indigenization of Supercast 247 was to identify suitable and reliable sources of raw materials with very low levels of trace impurities. Subsequently a mass balance analysis was carried out to determine the total quantum of trace impurity contribution from an the principal alloying elements to ensure that the net impurity level in the final product was maintained within the specified limits. The data with respect to trace impurities in individual alloying elements was generated by analyzing each alloying element separately in a glow discharge mass spectrometer (GD-MASS). Considering that very low levels of gas are to be achieved in the final product, the gas levels in raw materials (especially the ones, which are added after refining of the liquid metal) should be desirably at a very low level. With this objective, electron beam melted and refined Ta, Hf & Ti as well as very low gas content high purity Al were chosen as raw materials.

(B) Development and characterization of analytical standard

One of the biggest roadblocks towards the indigenization programme was the absence of relevant analytical standard, which could be used to control the chemistry within the specified narrow limits. Efforts to develop a standard by drawing a sample from imported bar stock and comparing the analysis with the test certificate of suppliers failed because of heavy segregation of alloying elements in the as cast bar stocks. In order to avoid the segregation problem it was decided to draw a sample from the liquid melt of the alloy using a chill cast mold having a small cross section. The chemical analysis of this sample was characterized through a round robin test in 5 different laboratories. Analysis of main alloying elements was carried out using ICP-OES in all the laboratories. Subsequently, a statistical analysis of raw data was done to predict the best possible analysis of the sample.

(C) Chemistry optimization

One of the important steps before taking developmental melts was optimization of chemistry of the alloy so as to achieve the desired mechanical properties in the product. The chemistry of the alloy needs to be tailored to satisfy the desired electron vacancy number (Nv3B ~ 2.15), to ensure that deleterious phases are not formed during high temperature exposure in service. PHACOMP control puts further restriction on the acceptable chemical composition range of main alloying elements. The aimed composition was decided after carrying out the PHACOMP analysis using the following formula.

$$Nv3B = \sum_{i=1}^{n} \left(X_{ir}^{*}\right)\left(Nv\right)_{I} \qquad (1)$$

Where, X_{ir}^{*} residual atomic fraction of each element;

Nv the electron vacancy number of respective element.

5. Furnace for Manufacture of Supercast 247LC Melts

A specially designed 600 Kg vacuum induction melting furnace from CONSARC Engineering Inc, UK with several advanced features was used for melting of the alloy. The furnace is equipped with vapour booster and diffusion pumps to achieve ultimate vacuum of 1 micron during melting. Several advanced features such as oxygen activity measurement facility and a mass spectrometer for analysis of residual gases in the melt chamber are incorporated with the furnace to ensure manufacture of very high quality alloys consistently. The melting furnace is specially lined with MgO- $A1_2O_3$ monolithic spinel refractory lining to ensure inertness and avoid reaction with reactive elements like Hf and Ti during melting. The casting of the liquid metal is done through a specially designed high alumina launder come tundish having dams and weirs and fitted with zirconia filters to ensure casting of metal free from slag inclusions.

(A) Trial melts and their characterization

Subsequent to optimization of chemistry trial melts were taken in 600 Kg VIM furnace and cast into f 75mm bar stocks. Online chemistry adjustment, was done using optical emission spectrometer, which was earlier calibrated with help of the secondary analytical standard developed through round robin analysis. Table 1 gives the chemical composition of one of the trial melts. The cast sticks were conditioned by machining and subsequently cut into small pieces for further remelting. Directionally solidified and equiaxed test coupons were produced by remelting cast sticks in a zirconia crucible, using vacuum investment casting facility available at DMRL. The test coupons were subsequently heat-treated (solution treatment and aging) at DMRL in specially designed vacuum heat treatment furnace. The heat treated samples were radiographed and taken up for preparation of test samples for mechanical property evaluation. Table 2, 3 & 4 gives the tensile and stress rupture properties of equiaxed and directionally solidified test coupons. As can be seen the properties of directionally solidified products are much superior to equiaxed cast products.

Table 1. Typical composition of Supercast 247 LC

Elements	C	Cr	Mo	Co	Ti	Al	Hf	W	Ta	B	Zr	Ni
Wt (%)	0.071	8.1	0.45	9.1	0.65	5.45	1.4	9.35	3.15	0.011	0.008	Bal

Nv3B of S ıpercast 247LC = 2.12

Table 2. Mechanical Properties of directionally solidified test bars

Temp °C	0.2% PS (MPa)	UTS (MPa)	%El	%RA
RT	955	1150	13	20
870	1000	1060	15	25
1000	520	650	25	35

Table 3. Mechanical Properties of equiaxed test bars

Temp °C	0.2% PS (MPa)	UTS (MPa)	%El	%RA
RT	800	930	10	15
760	790	900	11	15
870	620	720	5	6

Table 4 Stress Rupture of Equiaxed and DS test bars

Temp °C	Stress(MPa)	Life (hrs)	Remarks
760	585	200	Equiaxed
760	690	220	DS
980	220	70	DS
1040	140	65	DS

6. Conclusions and Future Course of Action

Mechanical property characterization of trial melts indicates that the indigenization programme is in the right track. Efforts are on to type approve the alloy to prove its airworthiness.

Indian Steel Industry — Past, Present and Way forward

Dr T Venugopalan

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Introduction

Ladies and Gentlemen

Good morning to all of you. At the outset, I would like to express my gratitude to the Organizers for the invitation extended to me to present Mr. Subramony memorial lecture today. As it was mentioned in my introduction, I worked in Rourkela Steel Plant from 1974 to 1984. During the last two years of my service in Rourkela, I worked as Deputy Manager in Plant Control of Production Planning & control Department, whose main role was to brief MD and GM (W) round the clock about the important happenings of the Steel Plant. I had several opportunities to interact with him during this period.

Mr. Subramony had a rich and glorious career in steel. He joined Bhilai Steel plant in 1956 and rose steadily to occupy positions such as Superintendent (BF), CS (Iron zone), AGM (Technical Development) and DGS (Plant Operations). He further held positions in SAIL Head Quarters such as GM (operations) and Director (Technical), before he took over the position of MD in RSP on 30th April 1982. He was also Director in other companies such as MECON, NSL and Fertiliser Association of India. He was conferred the Distinguished Alumni Award by BHU on 15th November 1983.

Mr. Subramony introduced several management initiatives, which resulted in the improvement of performance of Rourkela Steel Plant. During his tenure as MD, he was known for his sense of values, enthusiasm and fairness. Unfortunately a rising star was put out cruelly by the quirk of fate on 23" January 1986.

I am aware that many stalwarts of metallurgy have delivered Mr. Subramony memorial lecture in the past from this podium. When I got the invitation to deliver the lecture, I was indeed humbled by it. I considered the invitation to be a great honour and hence I readily agreed to do it in spite of knowing the difficulties in preparing the lecture material.

The title of my lecture today is 'Indian Steel Industry — Past, Present and Way forward'.

Status prior to 1980s

As we look at the evolution of ironmaking technology before 1980s, Blast Furnaces (BFs) were the only commercially successful technology. Despite its dominance, there was limited automation in BF technology. This technology involved a lot of manual operation and the productivity was low because of smaller size furnaces. Absence of raw material beneficiation and higher slag volume were responsible for lower production efficiencies. The quality of hot metal produced by these smaller BFs was also inconsistent.

The steelmaking technology before 1980s was mostly dictated by the Open Hearth Process. This was an energy intensive process where tap to tap time was as high as eight hours. The productivity suffered as a result and the steel quality, with specific mention of surface quality, was inconsistent. Secondary steel making technologies were non-existent which is why the steel cleanliness was an issue. Excessive central segregation was also present in the steel produced by this process.

The casting technology has seen a sea change in the past few decades. Prior to 1980s, ingot casting was the primary casting route. This not only resulted in poor yield, production costs were also higher because of additional processing steps of heating the ingots before subsequent rolling. Bulk of the steel production was in rimming and semi-killed grades. The chemistry tolerances were not very tight and the surface quality was inconsistent. The internal cleanliness of ingot cast steel was also not adequate for critical end applications.

Rolling technology mostly consisted of single stand reversing mills. Once again, the level of automation was low in this mostly batch process. The productivity was limited and the product was inconsistent with respect to flatness and gauge tolerances.

When talking about steel quality, the steel supplies were based on national standards, which by definition were lenient. The steel producers basically lacked the knowledge about customer process. There was no end product guarantee and the product services were limited to complaint resolution.

Development in the last three decades

Raw Materials

Looking at the ironmaking and steelmaking process in its entirety, a lot has changed since the 1980s. Iron ore, which is mostly hematite or magnetite, is undoubtedly the most important raw material in the iron making process. In yester years, the steel plants were mostly using lump ore which generated a lot of fines during the mining process. These fines were not utilized properly. Additionally, preference for iron-rich ore lump led to a lot of unutilized high grade iron ore which had fine size. Need for improvement forced the industry to move for the grinding of iron ore for better liberation of the iron content. Over a period of time, many companies have adopted suitable beneficiation process to extract usable material. Sintering and pelletizing processes are used for better utilization of ore fines. Alternate methods of iron making also have been developed for the use of fine and low-grade iron ores. Improvements in mining techniques also have enabled reduction in the fine generation. All these activities have been the appropriate steps to achieve increase in mine life as well as reduction in the mine waste. The need for land to dump process waste is also significantly reduced.

Another important raw material in the iron making process is coal which is used for production of coke and also as a fuel. Inferior and lower-grade coal can be used in the coke making process through Stamp Charge batteries. Coal washing techniques for lumps and fines are deployed to reduce the ash content of the coal for coke making. New processes are under development to improve the coal quality without loss of yield. Inorganic leaching process of middling coal is being developed for the recovery of higher coal values. Another major advancement of current times is the advent of non-recovery coke ovens to replace the ageing coke oven batteries.

Ironmaking Technology

The iron making technology has seen has seen a significant Change since 1980s. The size of operating blast furnaces has increased and there are furnaces which have a working volume of over 5000 m^3. Significant changes include high top pressure and high percentage of agglomerated burden. High blast temperature (1200°C) coupled with oxygen enrichment and humidity control along with injection of pulverized coal and other fuels has been instrumental in reducing the coke rates to about 250 - 275 kg/tonne of hot metal (THM). A campaign life of beyond 15 years is a common phenomenon now. The slag volume has also reduced to about 250 kg/THM. More agglomerated burden, such as pellets and sinter, improved the burden permeability. Another major change has been the use of advanced mathematical models for the burden and heat calculations.

Taphole clay improvements have lead to improved taphole life. The current day BFs have also resorted to multiple tap holes for faster tapping as well as for preventing excessive wear of the tap holes. Improvement in ironmaking processes and recycling of waste materials resulted in reduction of consumption of iron ore per ton of hot metal. The high levels of automation, process measurements and efficient process models have helped in the increase of the productivity level approaching 3 tonnes/m^3 per day. Use of copper staves in the stack, an efficient stove design, and bell-less charging are few of the changes the BF technology has seen in the recent years.

Despite these advances, a number of challenges still exist. High 'P' and high Alumina in the iron ore decrease the process yield as well as efficiency. Non availability of hard lump ore and limited resources of good quality coking coal (with low ash) are problems which are growing with each passing year. High capital costs involved in setting up a blast furnace as well as environmental concerns are other deterrents.

On account of the spiraling prices of raw materials (especially coal/coke, to make the BF iron making cost competitive, there is increasing need to carry out research on the following-

• Achieve Benchmark norms in consumption of vital raw material inputs

• Harness the thermal and kinetic energy of the entire system

• Increase the BF campaign life

• Produce good quality coke from cheaper coal blend

• Produce sinter/pellets from cheaper iron bearing materials

• Reduce slag generation

Alternate Ironmaking Technology

Advances made in the field of alternative iron making processes must be mentioned at this juncture. Numerous drivers have contributed to a sustained activity in this area. These factors included depleting sources of metallurgical coke as well as inefficient use of steel plant wastes, to reduce the consumption of iron-bearing materials. The increased production costs involved in the sintering, pelletizing and raw material beneficiation process as well as high capital costs of the conventional ironmaking process provide financial reasons for exploring alternate iron making technologies.

The alternative iron making technology can be categorized into two types namely Smelting and Solid state reduction processes. Iron ore is reduced to metallic iron using reductant such as coal or reformed gases (mixture of CO and H_2). The product thus formed is called as DRI (Directly Reduced Iron) or Sponge iron. The DRI or sponge iron is used in steelmaking furnaces as a scrap or hot metal substitute or sometimes charged into a blast furnace to improve the production rate. Fig. 1 and Fig. 2 provide a schematic of different alternative ironmaking technologies.

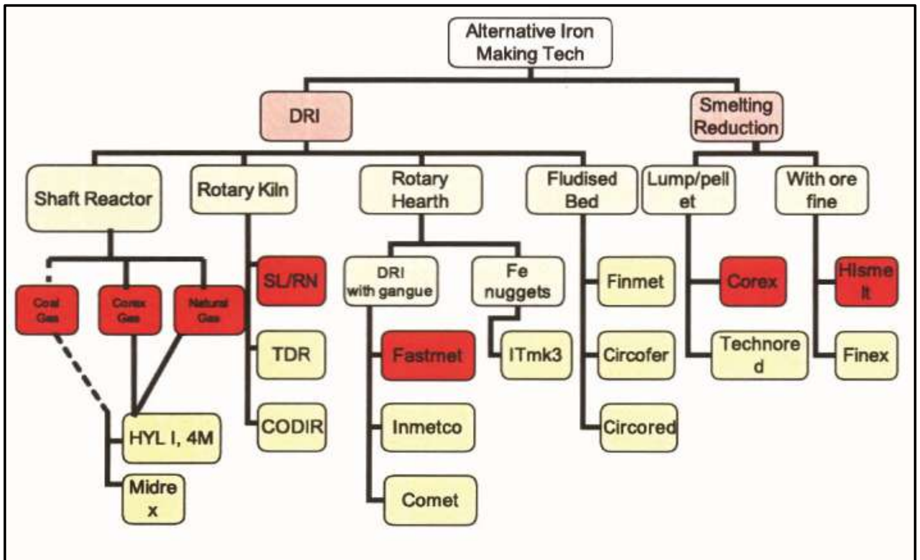

Fig. 1: A schematic of alternative iron making technology

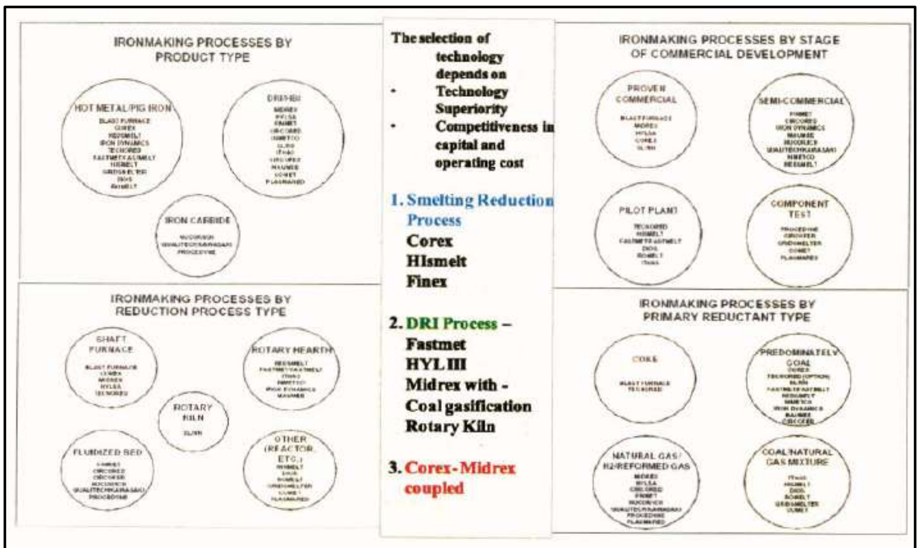

Fig. 2: Alternative ironmaking technologies

Smelting Reduction (SR) Process

This is an alternative ironmaking process which is completely independent of coke and coal is used as a reductant. A salient feature of this process is that it required at least two separate reactors, one for pre-reduction and the other for melting. The SR process has three discrete steps - preheating, indirect reduction by CO gas and final reduction by carbon. This process has higher productivity as compared to other alternative Iron making processes, because of higher mass transfer rates and better kinetics due to increased operating temperatures. The off-gas has higher thermal and chemical energy due to high temperatures and presence of CO both of these can be used for further reduction. Fig. 3 provides the status of the different types of SR processes, which are believed to have been developed in the last few decades.

Processes	Capacity, tpa	Remarks
Vertical Shaft		
MBF	30,000-1,125,000	Covers very wide range
Corex	300,000-900,000	5 operating plants. First and leading SR process. Very high volumes of off-gas; some coke often used. Coal properties cannot be varied over a very wide range.
Finex	1,200,000-1,500,000	Process development complete. Very promising for relatively large scale production.
Tecnored	150,000	Process still under development. It is amenable to modular concept for increase in capacity
Bath Smelting Processes		
HIsmelt	600,000-1,200,000	Process almost ready for commercial exploitation.
Ausmelt	Upto 2,500,000	Process not proven so far.
Romelt	200,000-1,000,000	Russian process with tremendous potential, but no plants have been installed despite efforts, including in India and Japan.
Rotary Hearth Furnace (RHF)		
ITmk3	500,000	Commercial plant commissioned in early 2010. Slag separation from DRI by partial melting is a novel feature of this process.
4. RHF Combined with Melting / Smelting		
Inmetco	60,000	Suitable for zinc-bearing iron ores.
FastMelt	150,000-1,000,000	2 operating plants mainly for smelting solid wastes from ISPs.

Fig. 3: Different types of smelting reduction (SR) processes

Of the gas based reduction process, HYL-3 and Midrex are popular. Gas based DRI is a highly suitable raw material in the Electric Arc Furnaces (EAF) and JSW (ISPAT) and ESSAR adopted MIDREX process for DRI production. The process ensures high level of metallization. The carbon in DRI also reduces the electric power consumption in the EAF. Since NG availability is limited to few states and locations, these processes are not finding wide acceptability in India, despite the fact that they offer better quality and productivity. MIDREX and HYL have come out with another process for the generation of synthesis gas from the gasification of coal, which is used for the production of Gas based DR!. Since coal is available across the country and coal gasification is a proven process, production of DRI by shaft kiln process is likely to grow in a big way.

Rotary kiln process has also stabilized in India. However, DRI produced by Rotary kiln process has lower metallization and the carbon content is lower, hence, the power requirements for melting are higher. As a summary, the selection of the DRI process depends on the availability of the reductant, i.e., gas or coal. India is a leading producer of DRI in the world.

Other processes which have become popular are COREX, Fast Melt, HISMELT, and Fine Smelt. These processes use steel plant wastes or inferior raw materials for the production of liquid iron. A significant advantage of these processes is that the capital cost is low due to the absence of agglomeration of iron ore and the requirement of coke oven batteries.

Increase in operational flexibility in terms of raw materials and minimum capacity for efficient operation are other advantages of alternative ironmaking processes. These processes are ecofriendly since gas based fuels are cleaner and more efficient. However, DRI process contains gangue which gives rise to higher slag volume during steelmaking. Additionally, residual FeO in DRI requires carbon and results in higher power and refractory consumption.

Steelmaking Technology

Basic Oxygen Furnace (BOF) and Electric Arc Furnace (EAF) are two major processes of steelmaking (Fig. 4). The requirements for very low levels of P, S, N and H have become even more stringent. Close chemistry control and high level of internal cleanliness have been possible due to secondary steelmaking processes such as Ladle Metallurgy Furnace (LMF) and Degassers (RH, Tank).

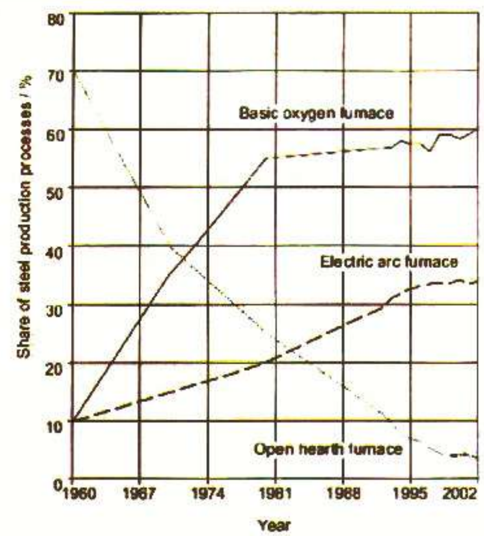

Fig. 4: Technological evolution of Steelmaking processes

Electric Arc Furnace Process

The EAF process uses scrap as its predominant iron-bearing raw material and is therefore more prevalent in USA where scrap availability is not a problem. DRI is another iron bearing material which is used when the scrap is not available. Hot DRI charging facility is used in these furnaces to reduce the power consumption. Modern EAFs are equipped with features such as high transformer capacity, oxygen lances for decarburization, and oxy-fuel burners for heating. Coal injection system has also been used by many EAFs for foamy slag practice. Bottom purge holes, water cooled boxes above the slag line, and water cooled roof are also common features in today's EAFs. Eccentric Bottom Tap (EBT) hole, and charge hoppers with vibrators are also used to improve the productivity and ferroalloy yield. Both DC and AC furnaces are available.

The capital cost for an EAF process is lower as compared to the BOF steelmaking process. EAF also provides flexibility in terms of operation and use. A new process, known as 'CONARC' has been developed by SMS-DEMAG. This process uses hot metal, scrap and DRI in different proportions as per their availability.

Basic Oxygen Furnace Process

BOF is a very widely prevalent process which uses hot metal, scrap and fluxes for steel production. Oxygen is blown through a multi-hole top lance to carry out the refining operation. This process does not require an external source of heat as it utilizes the heat generated by the exothermic reactions which take place during the oxidation of carbon and other elements in hot metal.

Modern converters have tuyeres in the bottom of the vessel through which argon or nitrogen gas is purged. Bottom purging leads to homogenization of bath chemistry as well as temperature and it helps in achieving equilibrium between the slag and metal reactions. This combined blowing operation results in lower FeO level in the slag for a given bath carbon and also enhances phosphorus removal. Fig. 5 provides a graphical comparison of the slag Fe and carbon content of steel at tap for different steelmaking furnaces.

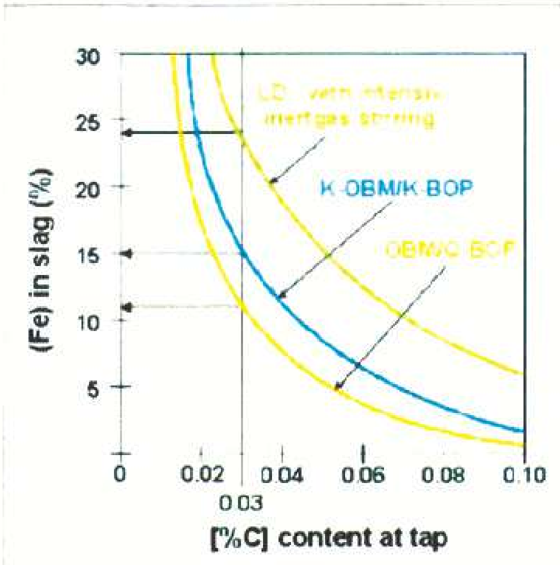

Fig. 5: Comparison of Fe in slag and C content at tap for different steelmaking processes

Numerous advances and instrumentations have improved the productivity of the BOF process. Use of multi-hole lances in collaboration with mathematical models for controlling the blow profile has helped optimization of the blowing process. Stack temperature measurements, installation of sub-lance and development of SMART lance have also helped the operators in efficient control of end-of-blow conditions to achieve higher alloy recovery, reduction in corrective blows, higher metallic yield, improved productivity and better quality. Besides, suitable flux addition practices have been instrumental in good S, P, and Mn control. Use of carbon bonded magnesia bricks and slag splash /slag engineering (MgO enrichment) have led to substantial increase in refractory lining life. Over 5000 heats are consistently achieved by BOF steel producers. However, there are steel units within India and outside, which have achieved vessel life beyond 10000 heats Use of slag arresters and slag prevention devices have reduced slag carryover from the steelmaking vessel into the ladle at tap. Auto alloy additions and bottom purging of steel ladle are some of the other developments in the steelmaking process.

Secondary Steelmaking Process

With such a wide variety of products, product quality improvement and productivity became essential for the companies to survive. It has forced the steel industries to quickly adapt to different technologies. The industries are looking to reliably fulfil these challenging expectations - perhaps in the area of ULC steels, where today a carbon content of less than 20 ppm is often expected. This necessitates advanced process models for the production of steel grades for high-end product segment. Ladle furnace and RH degasser meet all these requirements. The majority use of the Secondary Steelmaking technology such as Ladle furnace and RH degasser is to produce ultra-low carbon (ULC) steel, cold rolled sheet steel, EDD, Peritectic grade steel etc.

Ladle furnace has freed up the steelmaking vessel by restricting its role to dephosphorization and decarburization. At the LF, the steel can be reheated and larger alloy additions can be made. Temperature and composition homogenization can be achieved by inert gas stirring. It also provides thermodynamically conducive conditions for steel desulfurization. Besides, inclusion flotation can be facilitated by ensuring a gentle rinse before the ladle leaves the LF.

A vacuum degasser is another helpful aid available to a steelmaker in the secondary steelmaking area. Achieving ultra-low carbon levels, hydrogen and nitrogen removal and steel desulfurization are few of the process steps which can be done at the degasser. Besides, temperature control by oxygen blowing (RH-OB) and alloy addition can also be done here.

Continuous Casting Process

Ingot casting was the prominent casting technology until it was replaced by continuous casting. With several improvements, continuous casting process has higher productivity, and better yield and quality. Slide gate system and shrouding of liquid steel have been efficient in preventing the reoxidation of liquid steel. Slag detectors on the other hand have helped in preventing entry of slag into the tundish. Tundish metallurgy such as plasma heating, turbo stopper, tundish fluxes, and development of good tundish refractories for longer casting times have also been helpful. Besides, water modelling studies for better inclusion separation and prevention of vortex formation in the ladle and tundish have been instrumental in maintaining a clean steel practice.

In the mould, development of grade specific mould powder, mould and strand stirrers and EMBR (Electro Magnetic Braking) system have helped in high speed casting of steel. Liquid core reduction and dynamic soft reduction have helped in taking care of internal soundness issues. Similarly, development of air-mist cooling and mathematical modelling of strand cooling has been some of the improvements in the casting technology.

The new age of continuous casting includes the development of thin slab casting and strip casting both of which reduce the overall CAPEX of steel production. Likewise, near-net shape casting has been another improvement area for the long products.

A summary of technological evolution in the iron and steel production is given in Fig. 6.

Technology	Past 1990	1990 – 2000	2000 - 2010	>2010
Primary Steelmaking	Open Hearth	BOF converter EAF	Combined blowing with zero-slag	Direct steelmaking: IRSID, AISI
Secondary Steelmaking	Stirring systems Tank Degassers	Ladle Furnace RH, VOD	Ladle Furnace and injection RH-OB	CAS – OB
Casting	Ingot Casting	Slab Casting (210 – 250 mm)	Thin Slab Casting (50 – 70 mm)	Strip Casting (1 – 2 mm)

Fig.6: Summary of technological evolution in the iron and steelmaking production

Hot Rolling Technology

After casting of liquid steel into slabs, billets or blooms, the next processing step is their hot rolling into sheets, rods, bars and other desirable products. A number of advances have taken place in the hot rolling technology in the past few decades. Development of high capacity reheating furnaces has increased the productivity of the rolling mills. Use of reheating models, employment of walking-beam concept for uniform heating, atmospheric control (% oxygen) during heating and use of multi-fuel burners have been some of the salient developments in the slab reheating technology. The development of tunnel furnace technology, in case of thin slab casting, has been another major step in saving of energy during reheating.

High performance descalers (with water pressure: 200 - 450 bar) have been developed and are used for efficient furnace scale removal prior to rolling. Vertical edgers and short stroke hydraulic cylinders are also being used for better width control of the finished product. Another improvement has been the development of HSS roll and roll bite lubrication for improved productivity and quality performance of finishing stand in the hot strip mill. Introduction of heat shield, edge heating by induction heaters prior to finish rolling, semi continuous rolling, and use of coil box are few of the developments to improve the productivity, reduce the cost and improve the quality of the finished product.

As far as finishing mills are concerned, a number of improvements have taken place over the years. Continuously variable crown, roll bending and roll shifting, and mill lubrication to reduce the rolling load are some of the features of hot rolling. HSS rolls have been used for longer campaign life. Understand cooling, completely automated rolling with second level automation system and sophisticated measuring house for width, thickness and flatness control are being used now. Significant amount of work has been done in developing efficient Run-out table (ROT) cooling models for achieving the desired mechanical properties in the steel strips. While robust coilers have been used for winding high strength steels, ferritic rolling strategy has been developed to roll thin and soft grade steels. Surface Inspection System (SIS) is used in hot strip mills to aid the inspection and quality certification process.

Compact Strip Process (CSP) mills have been developed to roll wider and thinner gauge of steels. As thin as 0.80 mm strips has been rolled in such mills. CSP mills are considered superior in rolling of High Strength Low Alloy (HSLA) steel grades.

Cold Rolling Technology

Subsequent to hot rolling, the steel strips are further rolled to achieve thinner sheets. Development of 6-Hi mills for rolling coils which achieve heavy reduction per pass has been crucial for excellent shape control with specific focus on thickness and flatness control. Another important development has been the advent of PLTCM (Pickling line and tandem cold rolling mill). The PLTCM line converts hot rolled coil to cold roll continuously within very short period of time. High productivity and good quality are achieved in these mills. The modern mills have auto shape and hydraulically controlled AGC (auto gauge control). PLTCM also has universal crown (UG)to achieve good flatness. Work rolls and the intermediate rolls are bent to obtain the desired roll gap profile. Pickling facility is equipped with tension leveler to loosen the scale and improve the strip shape prior to pickling. Hot hydrochloric (HCI) acid is used to obtain complete removal of surface scale of hot rolled coil prior to cold rolling. Some of the modern pickling lines use Turbo pickling to hasten the scale removal.

Modern pickling units are equipped with ARP (acid regeneration plant) to regenerate the acid thereby reducing pollution. Single stand reversing mills are available for the production level of 2,00,000 TPA. Typical capacity of PLTCM is about 1.25 to 2.0 MTPA. The concept of twin stand mill has got developed to meet the intermediate production capacity around 0.4 - 0.8 MTPA. The rolling mills use rolling oils (stable/meta stable/unstable) of different quality depending on the mill design and product mix. Electrolytic cleaning line removes the rolling oil, which is present on the cold rolled surface. The facility helps to achieve clean and bright surface after cold rolling. The cold rolled product after annealing should be clean if the phosphatability and paintability at the customer place are to be ensured.

The cold rolled sheets are annealed for relieving stress generated during cold working as well as for microstructure development. There are two types of annealing — Batch annealing and Continuous annealing. Batch annealing is chosen when the volume involved is small (fragmented orders). During annealing, a protective gas such as HNX (4-6% hydrogen with balance nitrogen) or 100% hydrogen is circulated between the coils and the protective cover to facilitate annealing. Pure hydrogen is preferred in modern annealing furnaces because of superior heat transfer, higher annealing base productivity and good cold rolled (CR) surface quality.

High strength Steels can be produced by only Continuous annealing line (CAL). This process generally has a capacity of 0.50 - 1.0 MTPA. Due to higher productivity requirements, many integrated steel plants prefer continuous annealing. The mechanical properties and surface quality of CR coils are good and consistent. If the CRM complex has PLTCM and CAL, the hot rolled coil is converted into CR in less than one hour.

Galvanizing is a process by which the steel is coated by passing it through a molten zinc bath. The coating thickness is controlled by wiping with air or nitrogen, when the strip comes out of the zinc bath. Zinc Coating on steel prevents the corrosion of iron by sacrificial protection (Cathodic Protection). Coated steel was introduced as a replacement of cold rolled steel in early 70's. In the cold countries, salt is sprayed to avoid the snow on the road. At the end of the winter season, while the snow starts melting, salt rich water causes heavy corrosion of the underbody of the automobile. Because of this reason, automakers of the west could not provide any guarantee for the car body against perforation corrosion. Due to increase in the use of galvanized steels during the production of car, problem of corrosion has been successfully addressed. In the past, auto companies were mostly using electro galvanized steels on welding considerations. Due to the advent of high capacity welding transformers and consequent development of welding process for sheets with thicker zinc coatings, hot dipped GI and GA steels have become popular. Use of steels with thicker coatings have enabled the automakers provide longer guarantees against perforation corrosion.

Zn-0.2% Al coating is the most popular one both in construction and auto segment. In the last two decades, galvalume which has Zn-53.5% Al-1.5% Si has done well as the coating for construction. Recent research indicates that Zn-Mg coating is superior to all the existing Zn coating systems in terms of corrosion resistance.

Steel Quality

As the steelmaking process has evolved, so have the customer needs and demands. The steel industry has geared to address these requirements. The steel is supplied with a product guarantee. Product services are essential to understand the stated and unstated requirements of the customer. As the quality requirements are becoming increasingly stringent, continuous improvement in quality and new product development (NPD) are also vital. Research and Development has answered by developing high strength steel for high-end applications such as automotive, oil & gas and other specialty grades. In the downstream operations, new forming techniques such as roll forming, stretch bending and hydro forming have been developed. As part of product solution, suitable joining, pretreatment and painting processes have also been developed. Fig.7 provides an example of how steel from different grades and dimensions has been integrated to cater to specific customer needs.

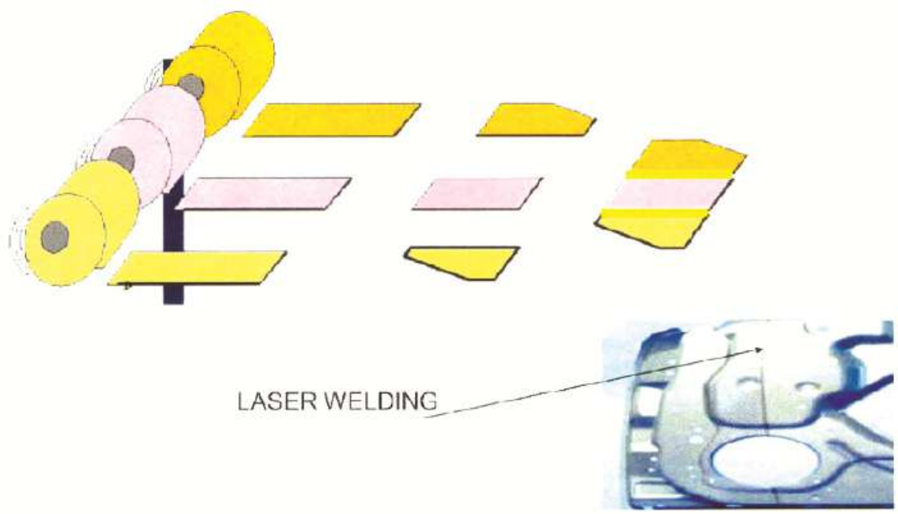

Fig. 7: Integration of steels of different grades and different dimensions

Rising income and emerging middle class have fuelled the buying capacity of people world over. Improvement in auto financing and decline in automotive taxation has also helped in people moving towards having their own vehicle. Improvement in road and infrastructure seems to be a major driver for the rise in the production of automobiles.

Bar and rod mills

In both LCWR (low carbon wire rod) and HCWR (high carbon wire rod), the customers need major improvement in drawability to achieve higher drawing speeds. This requires wire rods with improvements in microstructure and cleanliness. Controls on dimensional tolerances (+ / - 0.1 0 mm on diameter) and ovality (0.12 mm max) need focus. Product stringency with respect to surface quality and central looseness is continually on the rise. Dimensional tolerances and ovality greatly improve with the Installation of RSM (reducing Size Mill) and improved quality rolls. Due to stricter environmental norms, the acid pickling will be replaced by mechanical descaling. This will necessitate setting of rolling parameters to achieve loose flaky scales after rolling.

At the wire rod mill, the length of the Stelmor conveyor places limitation on the consistency of property that can be achieved both in low carbon and high carbon steel. Some of the developments in the cooling area are

- Direct inline patenting
- Mist cooling
- Retarded cooling
- 'Hybrid cooling' system to achieve rebars with YS >700 MPa (Developed by NSC)

A technology for endless casting and rolling (similar to thin slab rolling) has been developed for the production long products. The casting technology for the conventional billet production is also undergoing a massive change. Processes are developed to improve the casting speed (for 130 mm billets) beyond 7 m / min. This will allow the steel producers to achieve high productivity, quality and efficiency. High cast speed helps in production of billets with extremely high residual thermal load which improves the hot charging efficiency.

High Speed finishing rolling and delivery system has been developed for the production of rebars. The main advantage that is claimed is achieving high productivity even in case of small size rebars (6 mm).

Rail mill

Universal rolling of rails

In conventional rolling due to smaller reduction ratio and heterogeneous rolling, crack formation is encountered. Universal rolling of rails results in improved surface quality, full section forging by direct pressure, lower roll consumption, and improved mill productivity. Dimension tolerances are also improved using universal rolling.

Emerging Environment related Technologies

ULCOS

ULCOS stands for Ultra-Low Carbon dioxide (CO_2) Steelmaking. The ULCOS effort started in 2004 and is a consortium of 48 European companies and organisations from 15 European countries that have launched a cooperative research and development initiative to enable drastic reduction in carbon dioxide (CO_2) emission during steel production. The consortium consists of all major EU steel companies, energy and engineering partners, research institutes and universities and is supported by the European Commission. The aim of the ULCOS programme is to reduce the carbon dioxide (CO_2) emissions of today's best routes by at least 50% by 2050.

The programme in the first stage examined amongst others the (i) development of new carbon based smelting reduction concepts making use of shaft furnace (ii) natural gas based prereduction reactors, (iii) hydrogen based reduction using hydrogen from CO_2 lean technologies, (iv) direct production of steel by electrolysis, (v) use of biomass, which circulates carbon rapidly in the atmosphere and (vi) CO_2 capture and storage. Of all the technologies studied by ULCOS, the Top Gas Recycling (TGR) coupled with carbon capture and storage (CCS) is the most immediately promising route. ULCOS is presently moving into the final stage of the scale-up of the TGR-BF technology to commercial size. This second step demonstration initiative is called ULCOS-II. The next phase of the project will include capturing part of CO_2 and scaling up to the average size of EU blast furnace.

Way forward

In FY 12, the Steel Production is expected to be around 70 million tons and with the growth happening as per the forecast, by 2020, the Indian Steel production would reach around 140 million tons. Higher volume of steel provides 'critical mass' to pursue more serious research now than in the past. India is emerging as a major player in steel market. In a competitive global economy, Technology Providers have stated perceiving India as a potential threat and there is reluctance for providing assistance as they did in 90's and beginning of this century. Therefore there is an imperative need for the Indian Steel Industry to develop the new products / processes /technology to maintain the growth momentum. The country is poised for the high quality research in Iron and Steel areas due to the following reasons

• Availability of high quality technical education
• Good, talented and young manpower
• Value for education in the society
• About one hundred years experience in Iron and Steel Production

All the above positives are to be channelized into Innovation and Break through Research. While necessity is a mother of inventions, the other major driver for research is 'Institutional and National' pride, which acts a differentiator. India has adequate raw material resources for the production of Iron and Steel and a comfortable market opportunity. What is needed is an inherent urge to 'achieve' and add values for indigenous raw materials through innovation and technology.

I would like to conclude this lecture with a suggestion that establishment of good Design and Manufacturing facilities and high quality R&D centres is crucial for growth and sustenance of steel industry. I would like to thank the Organizers once again for this great opportunity given to me to present this lecture.

Sustainability of Materials – Thermodynamic, Kinetic and Environmental Dimensions

Dr S Srikanth

Director
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It is my pleasure and privilege to deliver the V Subramony Memorial lecture at the 26 National Convention of Metallurgical and Materials Engineers.

The term sustainability has become a keyword in the context of resource conservation, social existence, economic prosperity, political policy making, industrial growth and climate change and no subject has been as extensively debated as sustainability in recent times. However, as in the story of the blind men and an elephant, sustainability is interpreted differently by different people. Nevertheless today, there are universally accepted definitions for "Sustainability", the most common being that of the World Commission on Environment & Development which defines sustainability as;

"forms of progress that meet the needs of the present without compromising the ability of future generations to meet their needs"

Although this definition is broad, simple and elegant, it lacks details and could be open to misinterpretation. I found a more lucid definition of sustainability in a review paper published by Patzek and Pimentel (2005) given below:

"A cyclic process is sustainable if and only if it is capable of being sustained, i.e., maintained without interruption, weakening or loss of quality "forever" and the environment the process feeds and to which it expels its waste is also sustained forever"

The essence of this definition lies in the three phrases cyclic, forever and environment. Although sustainability can be evaluated for the full life cycle of the process, practical considerations would warrant that the analysis is carried out within a finite & defined time period & only changes to the immediate environment is considered.

Although sustainability can be applied to any resource, process, practice or even emotions such as food, water, land, natural resources, energy, environment, society, happiness etc., I would in this talk only address as to what sustainability means for materials especially in the context of Mining, Mineral Processing and Metallurgy.

The whole life cycle of a material more specifically metal (after the formation of the universe through cosmological processes) would comprise of ore formation through geological processes, mining, mineral beneficiation, metal extraction or production, manufacturing, use and end of use which could be recycling or burial back to earth to form the mineral. Extrapolating the definition of Patzek and Pimentel (2005) to this context would imply that: "The cycle of ore formation, mining, mineral processing, metal extraction, manufacturing, use and end of life stages are maintained without interruption, weakening or loss of quality "forever" and no net environmental change is brought about by this cycle over a period of time".

This definition essentially has four dimensions to it: spatial, thermodynamic, kinetic & environment. I will consider each one of these in the course of my talk. In addition, there are social and economic dimensions to sustainability: "Social sustainability is about equity within and between generations and within and between ethnic and social groups. It is inclusive of people's mental and physical well-being and the cohesion of their communities based on a fair distribution of natural resources" (www.seniorsecondary.tki.org.nz). "Economic sustainability means using resources to provide necessary and desirable products and services for the present generation without compromising the ability of future generations to do the same" (www.seniorsecondary.tki.org.nz). I will not be addressing the social and economic aspects of sustainability.

Thermodynamic & Spatial Dimension

From a thermodynamic viewpoint, material sustainability involves three fundamental questions:

Is sustainability a state of equilibrium?

Is there a mass & energy conservation to the material life cycle?

Is this process reversible or irreversible?

The spatial aspect is concerned with the geographical boundary of the system over which these conservation laws apply if they apply.

To answer the 1st question of attainment of thermodynamic equilibrium, one has to consider whether the material cycle goes to completion during the time period of analysis of sustainability. Thermodynamically, an equilibrium state is the lowest energy state and is independent of time i.e., a state of balance where the rates of forward and reverse reactions are equal. In the present context, equilibrium will be achieved if the cycle goes to completion with respect to all the natural resources used during the life cycle and the rate of natural resource consumption equals the rate of replenishment (in the same state as it was consumed) through natural processes. For example, if we are considering the life cycle of steel, the natural resources utilized in the life cycle are a variety of ores (iron/manganese/nickel/molybdenum ores, limestone etc.), coal, fossil energy and water and for sustainability, all these resources consumed have to be replenished to the same state and extent to which they were consumed. Hereon, any reference to a full cycle refers to all stages starting from the mining and exploitation of the various resources to its complete replenishment in the same form (i.e., cradle-to-cradle life-cycle). Obviously, depending upon the natural resource being considered, the time to attain this state of equilibrium can vary from a few days (evaporation and precipitation in the water cycle) to millions of years for minerals (~360 million years for the formation of anthracite coal). On the contrary, human beings have existed for maybe five hundred thousand years (however, life on earth has existed for close to 4 billion years). Therefore, in a practical sense, the analysis of sustainability is for a finite time period much less than that required for attaining complete equilibrium. Or in other words, sustainability in the real sense is a state of equilibrium that is possibly not achievable in the time scale of human civilization.

The 2nd question is addressed by the law of mass conservation for closed systems and 1st law of thermodynamics which states that the energy of an isolated system is conserved i.e., for the life cycle of the process and over the geographical area over which the system is defined, one can formulate elemental mass balance equations for all elements participating in the process and also energy conservation laws. Nevertheless, although elemental mass balance equations apply, there would be a change in the nature of species formed and the distribution of each element in the various states, namely solid, liquid and gas. For example, if any form of elemental carbon is used as a reductant in a metal extraction process, a variety of carbonaceous species such as carbon in solution, carbides, oxides and various organics may form in the process and these are redistributed in the solid, liquid and gaseous states. Similarly, although the total energy is conserved over the life cycle of the process, only some part of the energy may be converted to useful work and the rest may be irreversibly lost as heat which in thermodynamics is classified as the entropic component. It is appropriate to mention here that no geological system within the domain of the earth can be considered to be an isolated system because sun is a continuous source of energy. Other sources of renewable energy not included in the energy conservation law include hydro, wind, tide etc. This renewable energy influx is neglected in the energy balance. The spatial domain of the system defined for the analysis of sustainability must be such that within this geographical area, the mass and energy (barring the renewable energy input being received continuously which is assumed to be in steady state) must be conserved. This would bring us to the 3rd question of whether the material cyclic process is reversible or irreversible. Any of the process that brings about a permanent change to the immediate environment is irreversible. The permanent change could be to the land, water table or the atmosphere. Obviously, during the time scale of analysis, all the stages of the material life-cycle that bring about a permanent change to the environment do not go to completion. To answer the above question of irreversibility, we have to resort to the 2nd law of thermodynamics which implies that for any irreversible cyclic process, there will be a net increase in entropy that manifests itself as heat loss during the process. In other words, this means that all processes associated with the life-cycle of a metal continuously leads to heat loss to the environment or an overall global warming. More specifically, if we take the example of the Carbon-cycle for an industrial process, the complete cycle comprises of mining of carbon, its combustion to produce energy, the disposal of CO_2 into the atmosphere, its uptake by the plants for photosynthesis and its conversion to glucose, the dying of the plant and its fossilisation in the earth to reform coal. The atmospheric CO_2 balance is also controlled by geological exchange processes between ocean and atmosphere. This total cycle is irreversible in the sense that the net entropy of this cycle is positive or in other words a finite amount of heat is lost to the environment in this cyclic process. Similar arguments can be advanced for all the other material resources cycle. It is also appropriate to mention here that for the analysis of sustainability, the complete cycle of all resources utilized in the material life-cycle have to be considered together and not each one in isolation.

Although thermodynamics define the boundaries for sustainability, it does not account for the timescale of processes wherein they become sustainable nor does it address the temporal and spatial variations. We have already seen that the time scale to complete the full cycle of consumption to replenishment is far greater than the time scale to be adopted for the analysis of sustainability. From a practical viewpoint, several types of analysis exist such as cradle-to-cradle analysis, cradle-to-gate analysis, cradle-to-grave analysis, life-cycle-inventory analysis and full-life-cycle-impact analysis depending on the various stages of the cycle considered for sustainability analysis. To account for timescale of processes, we have to invoke kinetics.

The Kinetic Dimension to Sustainability

For a kinetic analysis of sustainability, one has to look into the mechanisms and rates of occurrence of the various stages that make up the full cycle (from mining/drawing of all raw materials to their complete replenishment in the same form after the end of use stage). The rate of the slowest of the stages would be the rate determining step in the achievement of equilibrium. If the full cycle is considered, it is obvious that all stages starting from mining or tapping of the natural resources until the material utilization stage has much lower timescales compared to the final stages of replenishment of the natural resources that are in geological timescales. Whereas the mining, processing, production and manufacturing stages are in the timescale of days, the use-stage can be of the order of years and the replenishment stage can vary from months to billions of years depending upon the natural resource being replenished and the replenishment processes. Since we are mainly concerned with the sustainability of quality of life for the human civilization for a finite number of generations which in terms of time scale can extend to may be one or two million years, it makes little sense to include the geological processes in the analysis. Since the rates of replenishment of the natural resources are several orders of magnitude slower than the rest of the stages in a material life cycle, sustainability will depend on the rates of consumption of the natural resources and the extent and rates of change brought about to the environment by the other stages of the life cycle. In chemical kinetics, rates of processes are determined by the concentration, frequency of collisions (or interactions between the elements of the process) and the activation energy of the various stages of the process. These in turn depend upon the mechanism of the process. In the present context of mining, mineral processing and metallurgy, concentration is defined by the availability, grade and spatial distribution of the natural resources. The frequency factor can be defined to be the frequency of the requirement of the relevant material by the society and the activation energy relates to the energy and environment penalty imposed by the process. The lesser the availability of the resource, the lesser the demands of the society (or lower the rate of consumption) and the lesser the energy consumed and changes brought about to the environment, the slower will be the process and more sustainable will be the material cycle. The rate of materials consumption is dictated by the resource availability and its spatial distribution and the material needs of the society whereas the extent and rate of change of the environment depends on the nature of technologies adopted in the mining, mineral processing, production, manufacturing and use stages. None of our material resources are infinite and therefore material sustainability cannot be achieved for an infinite time. Green et al (2012) have underlined the noun “sustainability” to be the asymptotically approachable, but ultimately unachievable result of continual sustainable development.

We have already seen that in the timescale of analysis of sustainability, the material life-cycle is always away from equilibrium. It would be interesting to see if one can apply the Le Chatlier's principle to this situation. In chemistry, Le Chatelier's principle is used to predict the effect of change in conditions on a chemical equilibrium. It can be summarized as: “If a chemical system at equilibrium experiences a change in condition (with respect to say concentration, temperature, volume, or partial pressure), then the equilibrium shifts to counteract the imposed change and a new equilibrium is established. In the present context, the material cycle is displaced from equilibrium with respect to the replenishment of the natural resources and the changes brought about to the environment. Application of Le Chatlier's principle to this situation implies that a new equilibrium would be established to counter these changes. The new equilibrium with respect to replenishment can result from attainment of steady state with respect to recycling or a balance between consumption and conservation and that to the environment can come from climate changes or geological readjustments.

The Environmental Dimension to Sustainability

We have already mentioned that although ideal sustainability in a real sense should be a state of thermodynamic equilibrium, it can be never practically attained within the timescales of human civilization. Therefore, practically a material cycle would be sustainable if it does not significantly deviate from equilibrium conditions i.e., the rate of consumption of the natural resources is very close to the rate of replenishment and the changes to the environment brought about by the life cycle of the material is minimum. This brings us to the question of identifying and quantifying the changes being brought about to the environment by the material life cycle. The possible changes that can be brought about by human processes on the environment and its social impact reproduced from the paper of Apelian (2012) is depicted below in Fig. 1.

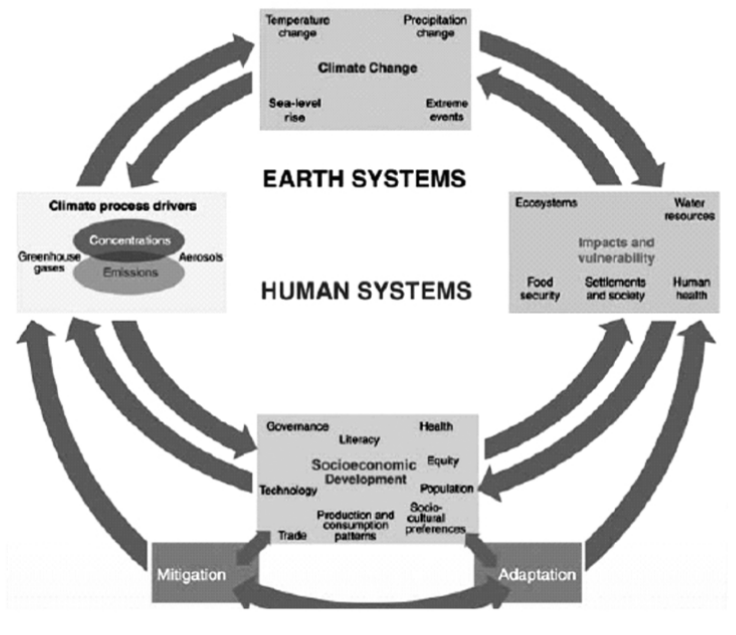

***Fig. 1** Cycle of Effect of the effect of human processes on the environment, climate and socio-economic development (Reproduced from Apelian, MRS Bullettin, 37, 2012, p.319)*

The environment dimension to sustainability is closely linked to the energy consumed as well as the health angle. Each stage of the material cycle namely mining and transportation, mineral processing, metal extraction, manufacturing, use and end-of-use stage has energy, environment and health implications. The environmental effects of mining include (Hudson et al 1999):

- Generation of large amount of wastes such as overburden, barren rocks, tailings, dump/heap leach and mine water.
- Physical disturbance of landscapes as a result of mine workings, waste rock and tailings disposal and facility development.
- Increase in the acidity of soils; such soils can be toxic to vegetation and a source of metals released to the environment.
- Degrade surface and groundwater quality as a result of the oxidation and dissolution of metal-bearing minerals, acid mine drainage
- Alteration of water table
- Loss of biodiversity
- Emission of greenhouse gases because of the energy spent in mining operations.

The metal extraction and manufacturing stages are both energy intensive and involves discharge of solid (slag, gypsum, effluent treatment plant cake, smelter dust, ESP dust etc.), liquid (organic effluent streams, contaminated water streams, bleed solutions etc.) and gaseous effluents (suspended particles, CO, CO_2, SOx, NOx, toxic metal vapors etc.) to the earth and atmosphere. Consumption of fossil energy results in greenhouse gas emissions. The use stage depending on the nature of use (industry, transportation, construction etc.) has significant energy and environment implications. The end-of-use stage i.e., products disposed to environment after the end-of-use stage as well as the various effluents disposed to the atmosphere take geological timescales to transform to their natural equilibrium states and therefore in the timescale of analysis, it should be considered that the changes brought about to the environment by all the stages of the life cycle are permanent in nature. In addition, since all these cycles are irreversible, the net entropy of the universe increases with every cycle. The energy and greenhouse-gas (GHG) intensities (CO_2 equivalent) of materials through the life cycle of the material are key parameters to measure materials sustainability. This in turn depends on the nature of ores, the geographic location, mining, production and manufacturing process and the end-use. This may also vary from place to place. As an example, the energy and GHG intensities for the life cycle of materials derived through internationally benchmarked mining, production and manufacturing processes and used in automobiles taken from Keoleian and Sullivan (2012) are given in Table 1.

***Table 1**: Life-cycle energy consumption and greenhouse gas emission intensity of various materials for automobiles (Reproduced from Keoleian and Sullivan, MRS Bulletin, 37, 2012, p 368)*

Material	Total life-cycle energy consumption (MJ/kg)	Greenhouse Gas Emission (kg of CO_2e/kg)
Steel		
Primary[@]	27	3.6
Secondary[@]	19	1.2
Cast Iron	33	0.5
Aluminum		
Primary (Ingot)	149	10
Secondary (Ingot)	13	0.9
Lead		
Primary	29	0.9
Secondary	5	0.5
Nickel		
Primary	148	12
Secondary	37	2.9
Copper		
Primary	111	8.5
Secondary		
Plastics		
Polypropylene	49	3.7
Polyester	87	6.9
High density polypropylene	53	4.1
Glass FRP	85	4.8
Carbon FRP	160	9.7
Glass	20	1.6
Fiber Glass	21	1.5
Rubber	44	3.2
Zinc	121	8.8
Magnesium	372	29
Platinum	199	16
Zirconium	226	16
Rare Earths	336	27
Manganese	121	8.8

[@]-primary processes refer to extraction from ores and secondary processes employ scrap

For conventional vehicles, the operation segment of the use stage accounts for about 85% of the total life-cycle energy consumption and greenhouse-gas emissions and the mining, production and manufacturing stages only 15% (Keoleian and Sullivan 2012). Similar life-cycle energy and greenhouse gas estimates can be made for other end applications such as for power plants, petrochemical industries, construction, metallurgical industries and so on. The spatial variation of life cycle energy and environmental impact can be gauged from the fact that aluminum produced in Asia has significantly higher greenhouse-gas emissions (21.9 kg of CO_2 e/kg of Al) than that produced in North America (10.7 kg of CO_2 e/kg) or Latin America (7.1 kg of CO_2 e/kg) because electricity in Asia is predominantly generated by coal, whereas it includes hydroelectricity in Latin America (Keoleian and Sullivan 2012). Recycled metals are generally recovered in the reduced state and therefore extraction processes for secondary materials are less energy-consuming than from virgin ores.

More than half of global energy consumption is by industry and transportation (~27.5% each). The other half is by services, residential consumers, and infrastructure (Lubomirsky and Cahen 2012). The energy used by industry is mostly for materials processing. The major industrial consumers of energy and consequent GHG emission in increasing order are: Construction, Power Generation, Cement Manufacturing, Oil and Gas extraction, Iron and Steel Mills, Petroleum Refineries, Truck transportation, Fertilizer Manufacturing, Lime and Gypsum Manufacturing, Pipeline Transportation, Waste Management and Remediation and Coal and Minerals Mining.

Thermodynamics vs Kinetics vs Environment

From the arguments and statements put forth, it is clear that sustainability of materials in real terms is a balance between the necessity of a thermodynamic equilibrium between exploitation and replenishment of natural resources vs the kinetic restraint in achieving these balance vs the permanent change brought about to the environment by the nonattainment of equilibrium. Since the rate of replenishment of the resources is much slower compared to the rate of exploitation, the critical factor that determines material sustainability with respect to materials availability is the abundance of natural resources and the rate of its exploitation by mankind. The abundance of elements in the universe are governed by the cosmological processes that went into the formation of the earth. The relative abundance of the elements in the universe is reproduced in Fig. 2 from a paper by Birat (2004).

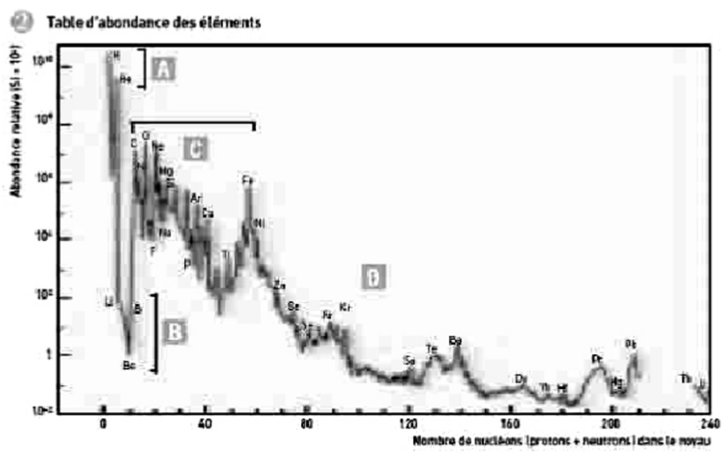

Fig. 2: Abundance of various elements in the universe (Reproduced from J P Birat, La Revue de Metallurgie, 2004, p.939)

However, the materials of the universe are presently not exploitable and only the materials in the earth's crust can be exploited by the human civilization. The major elements in the earth's crust are depicted in Fig.3 (Birat 2004):

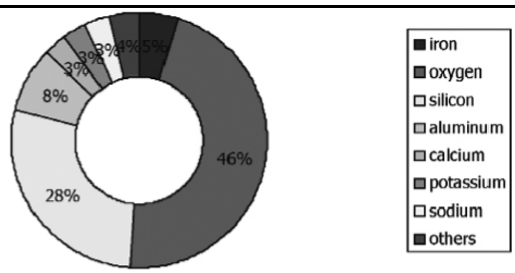

Fig. 3: Distribution of major elements in the earths crust (Reproduced from J P Birat, La Revue de Metallurgie, 2004, p.939)

The relative consumption pattern of the various metals in the past century as given by Graedel and Erdmann (2012) is also reproduced in Fig. 4.

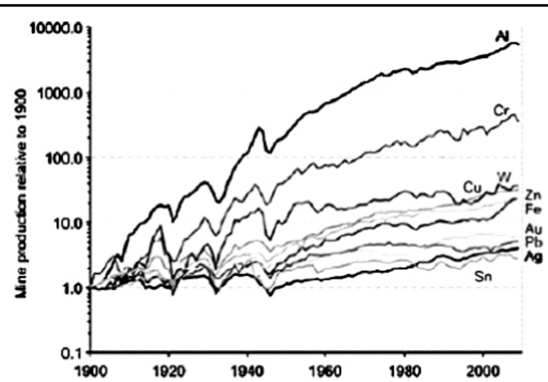

Fig 4: Relative rates of global use of materials in the 20th century. (Reproduced from Graedel and Erdmann MRS BULLETIN VOLUME 37 APRIL 2012, p. 326)

It is seen that in the past century, the relative rates of global use of materials has increased exponentially raising questions on the material sustainability for future generations. The corresponding increase in the global carbon emissions have also proportionally increased as shown in Fig. 5.

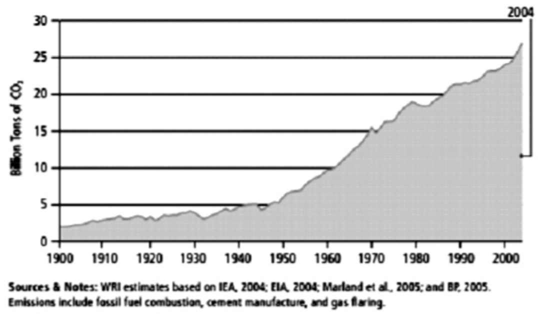

Fig. 5: Global CO2 emission over the last century (Reproduced from "Navigating the Numbers – Greenhouse Gas Data and International Climate Policy, ", K A Baumert, T Herzog and J Pershing, World Resources Institute, 2005)

Although only a part of this CO_2 emission is attributable to the material life-cycle, these data nevertheless indicate the trends. Transportation accounts for 13.5% of CO_2 emission, electricity and heat 24.6%, other fuels combustion 9%, industry and industrial processes 14.3%, land use change 18.2%, agriculture 13.5%, waste 3.6% and fugitive emissions 3.9% (Baumert et al 2005).

Life Cycle Assessment

Life Cycle Assessment (LCA) is a tool which is being increasingly used to evaluate sustainability i.e. material inventory, energy balance, the environmental footprint, health implications and the overall socioeconomic impact over the whole life cycle (mining, production, manufacturing, use, disposal and recycling of all products and byproducts, including the materials from which they are made) of the material or process being analyzed. An LCA comprises of four phases " – the establishment of the goals and scope of the assessment, the drawing up of materials inventory and energy balance for each stage of the life-cycle, evaluation of emissions/effluents for each stage of the product life cycle, an assessment of the impact on the environment, and the identification of actions for improvement" (IISI-UNEP 2002). The life-cycle assessment techniques are in the stages of infancy as a scientific discipline. The results are clearly sensitive to the exact assumptions made and since the natural resource and its occurrence as well as the practices/processes differ for the same end-use and further since environmental priorities and issues also differ in different societies, the analysis is both place and time specific. To a limited extent, LCA studies also evaluate how chemical toxicity, arising from material production, use, and disposal, affects human and environmental health. The mechanisms and adverse impacts of toxic effects vary widely at different points within material life cycles (Ogunseitan and Schoenung 2012). An international materials life cycle initiative was established by the United Nations Environment Programme (UNEP) and the Society for Environmental Toxicology and Chemistry (SETAC) in 2000. The scope of this initiative is given in Fig. 6.

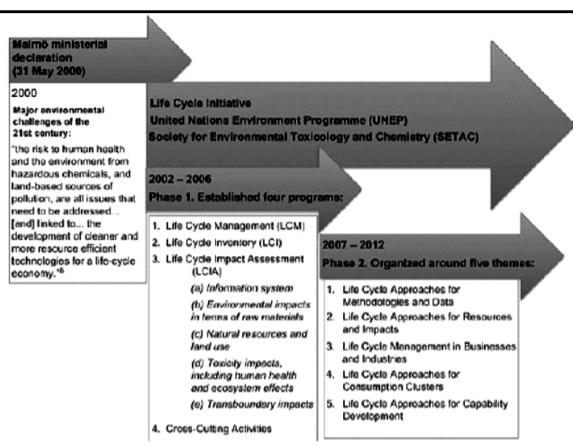

Fig. 6: Scope of the materials life cycle initiative of UNEP and SETAC ((Reproduced from Ogunseitan and Schoening, MRS Bulletin, 37, 2012, p. 357)

An example of the life cycle of aluminum reproduced from the paper of Green et al (2012) is given in Fig. 7.

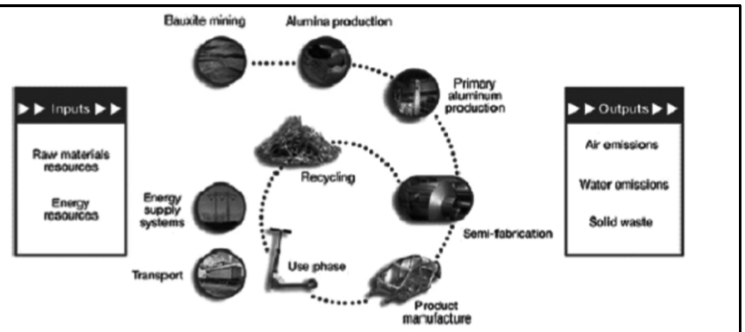

Fig. 7: Life cycle assessment flowchart for aluminum products (Reproduced from Green *et al*, MRS Bulletin, 37, 2012, p.306)

Because the material life cycle has so many stages and each stage has several degrees of variable and is dependent on location, time, nature of mining, production and manufacturing process, nature of use and nature of end-of-use disposal, carrying out a realistic life cycle assessment for the whole cycle from cradle-to-cradle becomes virtually impossible. However, a limited analysis of energy and greenhouse gas emission can be carried out within the premises of a set of assumptions or can even be carried out for each stage of the life cycle.

Today, several softwares and programs such as SIMA Pro, GREET (Greenhouse Gases, Regulated Emissions and Energy Use in Transportation Model), TRACI (Tool for the Reduction and Assessment of Chemical and other Environmental Impacts), BEES (Building for Environmental & Economic Sustainability developed by NIST, US), GEMIS (Global Emission Model for Integrated Systems), GaBi, USETox etc. are available for Life Cycle Assessment of materials and processes in various applications.

Examples of Common Misperceptions

Myth of Hydrogen Economy

There has been an increasing talk about the use of hydrogen as a clean and green energy carrier both as a storage medium and also as a fuel for automobiles and the use of hydrogen will eliminate the greenhouse emission of CO_2 presently generated by fossil-fuel based power plants and automobiles running on gasoline and natural gas. However, hydrogen does not occur in elemental form in the earth's atmosphere. They occur in association with carbon in the various fossil fuels (as hydrocarbons) or as water. Therefore to produce hydrogen, one has to either reform the hydrocarbon species occurring in nature or dissociate water into gaseous hydrogen and oxygen. Subsequently, the hydrogen produced has to be stored, transported, discharged, used for an end application and the oxidized hydrogen is discharged into the atmosphere as water vapor which precipitates as rain and gets back to the soil. The various hydrogen pathways that are possible are given in Fig. 8.

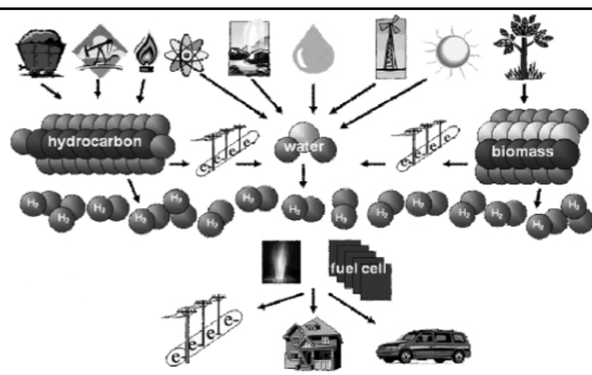

Fig. ***8:*** *Various hydrogen pathways possible from hydrogen production to use*

The calorific value of hydrogen is 10.8 MJ/m^3 or 142 MJ/kg in terms of higher heating value (HHV). The approximate specific energy requirement for production of hydrogen by various means are provided hereafter:

Hydrogen production by steam reforming = 7.2 MJ/m^3 of H_2

Hydrogen production by partial oxidation = 9 MJ/m^3 of H_2

Hydrogen generation through coal gasification = 14.4 MJ/m^3 of H_2

Hydrogen generation through biomass gasification = 12.0 MJ/m^3 of H_2

Hydrogen generation through biomass pyrolysis = 12.0 MJ/m^3 of H_2

Hydrogen through electrolysis = 14.4 MJ/m^3 of H_2

Hydrogen through solar energy = 50 MJ/m^3 of H_2

In addition, the energy consumed for the clean-up of hydrogen (removal of CO and S) and carbon sequestration will range between 5-30% of HHV of hydrogen (i.e., 0.54-3.24 MJ/m^3 of H_2) depending on the carbon content. Hydrogen is then either compressed in gaseous form or liquefied. Other forms of molecular and atomic storage have low volumetric or gravimetric densities for actual applications. The energy of compression varies from 5% of HHV of H_2 to 15% of HHV of H_2 depending on the pressures to which it is compressed and upon whether it is compressed isothermally or adiabatically (Bossel et al 2005). The liquefaction energy can vary from 200 MJ/kg (105% of HHV of H_2 for a 1kg/h plant) to 50 MJ/kg (30% of HHV for a 10000 kg/h plant) depending on the scale of the liquefaction plant (Bossel et al 2005). The transport of hydrogen can be through road or pipeline. The typical transportation energy by truck varies between 5% of the HHV of hydrogen (for 100 km) to 30% of HHV of H_2 transported (for 500 km)) (Bossel et al 2005). For delivery through pipelines, similar energies are consumed. The hydrogen transfer and release also consumes some part of the energy. If this hydrogen is then converted to electricity or for transportation using a fuel cell with 50% efficiency, then the complete hydrogen cycle is seen to consume much more fossil energy than the net energy generated. Therefore, employing a hydrogen economy will presently consume more fossil fuel and generate more greenhouse gases until renewable energy becomes an efficient option, the talk of a hydrogen economy is a myth.

Crystalline Silicon Solar Cells

It is also widely perceived that solar cells will soon pave the way for fullscale solar energy. The crystalline silicon used in the solar cells are at least 6-nine pure. Silicon is extracted from quartz available in nature in an electric arc furnace which is highly energy intensive (~15,000 kwh/ton). This silicon which is about 98% pure is subsequently purified in several stages through vapor-formation and decomposition such as of silane, silicon tetrachloride etc. These stages are again energy intensive. The process of manufacture of the solar panels consumes energy. If the energetic viability of crystalline-silicon solar cells is considered, the energy payback time, which is the time required for the cells to produce the amount of energy needed to make them, is still several years. The extent of degradation of solar cell performance because of dust, harsh weather and photo-corrosion during the period of use will therefore determine whether at all crystalline silicon solar cells will become practically viable at the present efficiency levels in the near future.

On the contrary, if technologies would ensure safety and sustainable nuclear waste disposal technologies are developed, nuclear energy would be a sustainable option in the timeframe of analysis. According to the Nuclear Energy Institute, nuclear plants are the lowest-cost producer of base load electricity. The average production cost of 2.03 cents per kilowatt-hour which includes the costs of operating and maintaining the plant, purchasing fuel and paying for the management of used fuel (CCA Report 2010).

Aluminum and Magnesium to replace Steel in Automobiles

Another common misperception is that the light-weighting of automobiles by replacing the steel parts with lighter materials such as aluminum, magnesium and plastics will result in significantly lower life-cycle energy and greenhouse gas emissions. Despite the fact that for conventional vehicles, the operation segment of the use stage accounts for about 85% of the total life-cycle energy consumption and greenhouse-gas emissions and the mining, production and manufacturing stages only 15% (Keoleian and Sullivan 2012), it is seen from Table 1 that aluminum in automobiles uses six times and magnesium thirteen times the energy that of steel over its lifetime. However, if Al and Mg from secondary processing is considered, there is a significant benefit in the use of Al and Mg over the life-cycle of an automobile.

Strategies for Materials Sustainability

Sustainability for a finite time period of human civilization can be achieved through several strategies around material conservation, adoption of energy efficient technologies, energy saving practices, use of renewable energy, spatial and temporal prioritization of activities, recycling, rejuvenation and re-use, efficient utilization of by-products and wastes including complete waste heat recovery and so on.

Material Conservation

Some of the material conservation strategies that can be adopted are:

- Regulation of demand in such a way that the natural resources exploited by each generation is minimum to ensure they would be available for future generations.
- Diligence in the selection and use of materials. Choice of raw materials in their natural state rather than in value added states. For example, it would be more sustainable to meet the thermal energy requirement of any process directly through fossil fuels rather than use electricity for heating.
- Minimize the use of higher orders of energy to conserve fossil fuel. Electricity derived from fossil fuel can be considered to be the 1st derivative of fossil energy and the energy efficiency of conversion (from mine to grid) is less than 25%. Electromagnetic radiations (microwave, X-ray etc.), ultrasonics, vacuum etc. can be considered to be the 2^{nd} derivative of fossil energy. Every stage of energy conversion is associated with an efficiency of conversion wherein significant energy is lost as heat.
- Substituting materials with lower environmental impacts. One example is increasing the direct use of blast furnace slag in the construction industry to reduce the consumption of the high energy cement.

Breakthrough Technology Interventions

Sustainability over a long period of time covering future generations over a foreseeable future (maybe the next few million years) can be brought about only through scientific intervention of disruptive technologies. The driving force for future technologies will be natural resources conservation, high energy efficiencies and minimum environmental footprint.

One of the classic examples of continuous technological interventions in iron-making has been the steady decrease in coke rates. The decrease in coke rates since 1750 when coke was first used in Blast furnace till 2000 and the timeline of technological interventions which brought this about is shown in Fig. 9.

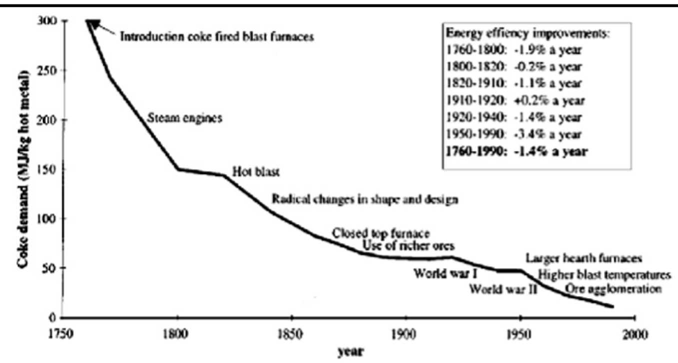

Fig. 9: *Decrease in coke rate in the blast furnace over time and the technological interventions that were responsible* (Reproduced from DeBeer, Worrel & Blok, *Annu. Rev. Energy Environ. 1998. 23:123–205)*

Similar technology breakthroughs have been achieved in almost every industry over time. In the context of metallurgy, mention can be made of the development of continuous casting of slabs to thin slab casting to direct thin strip casting of sheets of thickness 1.5 mm resulting in an exponential decrease of energy consumption in sheet metal forming. Another example that can be cited is copper metallurgy where the earlier flow sheet of roasting-smelting-converting of chalcopyrite concentrate in three separate furnaces has been replaced by a single reactor resulting in substantial decrease in energy consumption.

Recycling

One of the most effective measures towards materials sustainability is recycling of the material at the end-of-life. The large difference in the specific energy consumption between the primary and secondary (recycled) materials shown in Table 1 (Keoleian and Sullivan 2012) illustrates the energetic benefits of recycling. These are particularly significant for materials such as aluminum, magnesium nickel, and lead. Since many of the recycled metals are recovered in a reduced or partially reduced state, extraction from these secondary resources are generally less energy-intensive than those for virgin materials. It is reported (Lubomirsky and Cahen 2012) that six metals—copper, gold, lead, platinum, palladium, and rhodium—are used predominantly in elemental form, thereby enabling recovery in that form. Most of the other elements such as chromium, manganese, molybdenum, vanadium, gadolinium, and tellurium are used as alloys. Among the major metals, the current rates of recycling are: lead>90%; iron-55–65%; aluminum-40–50%; tin>50%; magnesium >40%; and copper >25% (Lubomirsky and Cahen 2012). In the construction industry, close to 10% of the materials used are recycled today (Graedel and Erdmann 2012, Vliet et al 2012). The recycling percentages for these metals may be expected to increase in the future.

Although recycling is a useful option towards material and energy sustainability, many items that are energy-intensive to make and/or use such as fertilizer and cement cannot be recycled (Heard et al 2012). Taken together, these materials comprise about 4–5% of global energy consumption and about 20–25% of global industrial energy consumption (Lubomirsky and Cahen 2012). For many others such as antimony and zirconium, the dominant use is dissipative and so little or no recycling is possible (Graedel and Erdmann 2012). For some of the metals such as gallium, yttrium etc. these are employed mostly in complex assemblages from which recovery in elemental form is technologically very challenging and expensive (Graedel and Erdmann 2012). It is also possible that recycling of some items might consume more energy than their production from the primary ores or by-products in current extraction processes.

Life Extension, Rejuvenation and Refurbishment

Another strategy that can be adopted towards material sustainability is the life extension of engineering components through rejuvenation and refurbishment techniques. The mechanical, physical, chemical, thermal and engineering properties of materials degrade with time while in service. This is mainly due to the degradation of microstructure of the material. The property and microstructural degradation of the components in service can be detected and remaining life estimated through a variety of non-intrusive techniques such as radiography, ultrasonic measurements, magnetic measurements, strain measurements, thermography etc. Subsequently in several cases it is possible to extend the life of the component by restoring or partially restoring the original microstructure and properties. A classic example in this regard is the rejuvenation and life extension of creep damaged gas turbine blades which are made of expensive Ni-base alloys. Here, the process of rejuvenation is carried out by heat treatment and hotisostatic pressing to restore the original microstructure. Refurbishment of several power plant components can be carried out through simple heat treatment. It has been reported (CCA Report 2010) that Caterrpillar's Remanufacturing & Sustainable Solutions Division returns end-of life components to same-as-new condition while reducing waste and minimizing the need for raw materials to produce new parts.

Efficient Utilization of By Products and Wastes — Waste Streams as a Raw Material Source

Many of the wastes generated in industrial processes can find useful applications elsewhere. For example, the waste streams of fly ash from coal combustion for power generation and slag from iron blast furnaces have been used to replace a portion of the cement binder in concrete. Red mud and slag from other metallurgical industries have been converted to pavement tiles by an energy efficient process of geopolymerization. According to the National Petrochemical and Refiners Association, the use of plastic building and construction materials saved 140 million MWh of energy use over alternative construction materials in one year (CCA Report 2010). During the mining of coal, methane escapes to atmosphere. Methods have been devised in recent times to exploit the coal-bed methane. Efficient use of combined heat and power from the power plants is another measure towards sustainability.

Energy Conservation Methods in Domestic Use

There is an increasing awareness in society on the use of more energy efficient appliances. Consequently more and more of the domestic households use Energy Star® certified appliances. There has also been an increasing consciousness towards reducing fuel consumption. It has been reported (CCA Report 2010) that since 2004, American Trucking Associations partners have reduced fuel consumption by 1.5 billion gallons and reduced CO2 emissions by 16.2 million tons – the equivalent of taking 2.88 million cars off the road.

Prioritization

More than half of all industrial energy is reported to go to very few materials, namely, steel (~6%), cement (~ 3%), ammonia by the Haber–Bosch process (1–2%), aluminum by the Hall–Héroult process (~1.8%) and plastics (2–4%) (Lubomirsky and Cahen 2012). It is therefore necessary to prioritize energy-efficient technology development of these materials, promote maximum recycling of these materials and minimize the use of these materials by finding alternatives which impose a lesser energy and environment penalty.

Similarly from a material conservation point of view, the application of materials has to be prioritized such that the demand in terms of the requirement for the various applications must be proportional to its abundance in the earth's crust. This is normally the case because the market price of a material is almost proportional to its availability as shown in Fig. 10.

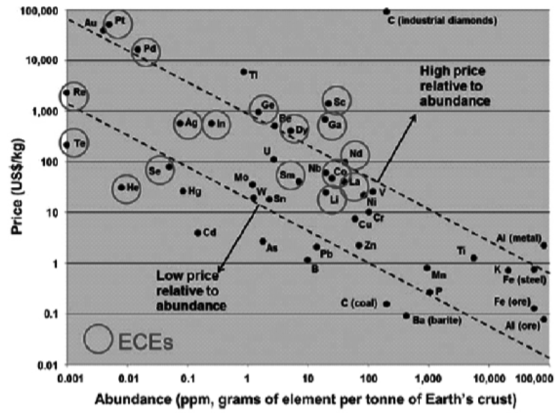

Fig. 10: *Relationship between market price and its abundance in earth's crust*
(Reproduced from Hurd *et al*; MRS Bulletin, 37(2012), p. 407)

Other strategies that can be explored towards greater sustainability are:

- Minimizing Wastage through legislation
- Use of renewable resources of energy wherever and whenever possible
- Install complete Waste Heat Recovery Systems in all industries
- Maintain domestic discipline in consumption
- Choosing the most energy efficient method for a particular application (especially transportation, light weighting etc.)
- Teaching Sustainable Development

Indices for Sustainability and Object Function

One of the best indices quantifying sustainability is the Kaya Identity (Yamaji et al 1991, Raupach et al 2007) discussed in detail in the paper of Green et al (2012). The Kaya identity is based on carbon-di-oxide emissions. The Kaya identity is given by the equation:

$$F = P\left(\frac{G}{P}\right)\left(\frac{E}{G}\right)\left(\frac{F}{E}\right)$$

Where F is the global emission, P the global population, G the sum of global gross domestic products and E is the global energy usage. Green et al (2012) suggest that (G/P) which is the per capita global GDP is a measure of "economic development or standard of living", (E/G) which is energy intensity of the GDP is a measure of "energy and resource efficiency" and (F/E) the carbon intensity of the global energy is a measure of "sophistication of energy production". Green et al have inferred the Kaya analysis to indicate that, to sustainably develop energy resources (i.e., lower CO_2 emissions), one can minimize P (which is a socio-political issue outside the realms of science and technology) or reduce G/P (this means a reversal of economic growth which is contrary to sustainability). Therefore, they imply that the only paths forward are to reduce (E/G) through demand reduction or to reduce (F/E) through energy supply substitution.

The sustainability object function can also be defined as a function of several variables as shown below:

Sustainability = f (resource abundance, rate of resource consumption, resource utilization efficiency, energy utilization efficiency, environmental impact, impact on health, innovation, value addition, human resource capitalization)

For sustainability, the object function defined above can be optimized (minimized or maximized depending on the variable) with respect to the above variables under the constraints of limited natural resources availability. Parameters such as innovation and creativity and human resource capitalization are non-conservative parameters which can optimize the sustainability function disruptively.

Materials Sustainability of India

We will first compile information on the mineral resources of India, the production and demand, the current and the projected future growth rates and in this context, analyze sustainability.

India has abundant resources of iron ore, manganese ores, bauxite, dolomite, gypsum, limestone, mica, chromite, ilmenite, zircon, graphite and atomic minerals such as monazite. India currently produces 87 minerals including 4 fuel minerals, 10 metallic minerals, 47 non-metallic minerals, 3 atomic minerals and 23 minor minerals (Ernst & Young 2011). The mining and metallurgical industry in India contributes to more than 2.3% of the country's GDP amounting to INR 2006 billion in 2010-11 (Ernst & Young 2011). India's metals and minerals industry is expected to reach USD30 billion and is expected to account for 2.5% of India's GDP. The reserve to production (R/P) and Proven Reserves to Estimated Resources (R/R) ratio for some of the metals and minerals, taken from an Ernst & Young report on sustainability (2011) is given in Table 2.

Table 2: *Reserves to Production (R/P) and Proven Reserves to Resources ratio for some of the minerals in India (From Ernst & Young Report 2011)*

Mineral/Metal	Reserves	Reserve/Production	Proven Reserve/Resources
Iron ore	4960 million tonnes	23.3	0.2
Coal	113408 million tonnes 286 billion tonnes*	211.2	0.4
Bauxite	539 million tonnes	40.2	0.16
Gold	66920 kgs	30.2	0.14
Diamond	605577 carats	8.5	0.13
Silver	2283 tonnes	24.0	0.22
Zinc & Lead	6766,000 tonnes	8.5	0.22
Copper	1644,000 tonnes	2.3	0.14

● As per Energy Statistics 2012 Report, Govt of India, www.mospi.gov.in

India is currently the 5th largest producer of crude steel at 70 million tones per annum and is expected to become the 2nd largest producer by 2015-16 at a growth rate of 6-9% (Hem Securities 2011). Presently, the per capita consumption of steel in India is 45 kgs against a world average of 198 kgs. India is the largest producer of sponge iron and is expected to produce about 38 million tonnes by 2013 at a growth rate in excess of 10% (Hem Securities 2011). Although India has 7.5% of the world's bauxite reserves, only 3% of the world's Al production is from India. However, the Indian manufacturers are the lowest cost producers of aluminum because of captive power generation, labor advantage and raw material. The per capita consumption of aluminum in India is very low at <1 kg as against nearly 25 to 30 kgs in the US and Europe and 3 kgs in China. The Al sector is presently growing at 7.8% in India and this is expected to go up to 9% (Hem Securities 2011). The current copper cathode manufacturing capacity in India is about one million tones and is expected to grow at 7- 10% (Hem Securities 2011).

The Indian oil & gas industry constitutes around 15% of India's GDP. The estimated reserves of crude oil and natural gas in India as on March 2011 was reported to be 757 million tonnes (MT) and 1241 billion cubic meters (BCM), respectively (Energy Statistics 2012). In the year 2010-11, the production of Petroleum Products in the country was 190.36 MTs and of Natural Gas was 51.25 BCM (Energy Statistics 2012). The reported consumption of crude oil was 206.15 MTs during 2010-11 with a cumulated accumulated growth rate (CAGR) of 6% over four decades (Energy Statistics 2012). The estimated consumption of natural gas was 51.3 BCM in 2010-11, with CAGR of 11.25% over four decades. The widening of the demand-supply gap has increased the dependency on imports. Presently, almost 75% of India's crude oil requirements are met from imports.

The energy statistics of the government projects that the potential for generation of renewable energy from various sources- wind, solar, biomass, small hydro and cogeneration bagasse in India is high. The total potential for renewable power generation in the country in 2011 was estimated at 89760 MW. This includes an estimated wind power potential of 49132 MW (55%), SHP (small-hydro power) potential of 15,385 MW (17%), Biomass power potential of 17,538 MW(20%) and 5000 MW (6%) from bagasse-based cogeneration in sugar mills (Energy Statistics 2012). The total installed capacity for electricity generation in India is 206,526 MW with a CAGR of 6.2% over the last four decades since 1971. The highest growth rate (7.1%) was for thermal power (7.1%) followed by Nuclear (6.1%) and Hydro (4.4%) (Energy Statistics 2012). At the end of March 2011, thermal power plants accounted for an overwhelming 64% of the total installed capacity in the country, with an installed capacity of 131.2

thousand MW. Hydro power plants come next with an installed capacity of 37.6 thousand MW, accounting for 18.2% of the total installed capacity (Energy Statistics 2012). The share of Nuclear energy was only 2.31% (4.78 MW). The total installed capacity of grid interactive renewable power is 19971 MW showing a growth rate of 18.75% over four decades.

Total Electricity generation in the country, from utilities and non-utilities taken together, during 2010-11 was 9,59,070 GWh. Out of this 7,04,323 GWh was generated from thermal and 1,14,257 GWh was from hydro and 26,266 GWh was generated from nuclear sources (Energy Statistics 2012). Total output from non-utilities was 1,14,224 GWh. The estimated electricity consumption increase was 6,94,392 GWh during 2010-11, showing a CAGR of 6.98%. The increase in electricity consumption is 13.34% from 2009-10 (6,12,645 GWh). Of the total electricity sales in 2010-11, industry sector accounted for the largest share (38.6%), followed by domestic (23.8%), agriculture (19.6%) and commercial sector (9.89%) (Energy Statistics 2012).

There is a growing realization worldwide that energy materials which include a variety of rare metals and rare earth metals are critical for a country's sustainability. The American Physical Society and the Materials Research Society, US constituted an Energy Critical Elements Panel who identified 29 elements under this list. The US Department of Energy identified another 14 elements as critical for energy security. These materials were chosen based on supply risk factors, market size, supply diversity, and market complexities caused by coproduction and geopolitical risks. These are highlighted in the periodic table given in Fig. 11 (Hurd et al 2012). The European Union has also identified a list of critical raw materials that include antimony, beryllium, cobalt, fluorspar, gallium, germanium, graphite, indium, magnesium, niobium, Pt-group metals, Rare Earth metals, tantalum and tungsten (Reuter and van Schaik 2012).

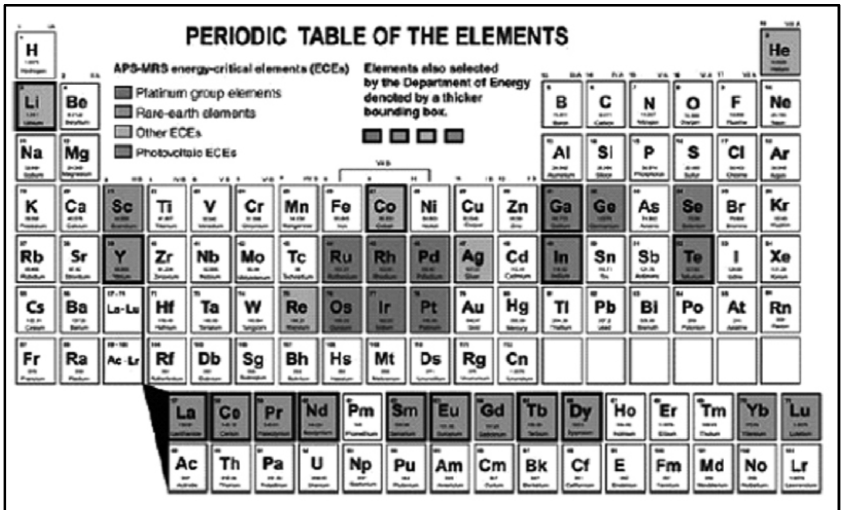

Fig. 11: Energy Critical Elements identified by American Physical Society, Materials Research Society and US Department of Energy (Reproduced from Hurd *et al*, MRS Bulletin, 37, 2012, p. 405)

In India also, a committee was constituted to provide a status report and roadmap for the country with respect to these energy critical elements and the committee has submitted its final report with recommendations. It appears that India's position with most of the critical elements in this list is not sustainable for long.

Strategy towards Materials Sustainability for India

Each country's strategy towards sustainability will be dictated by a variety of factors including its reserves or abundance of natural resources, the supply-demand scenario within the country, the international market, the present per capita income and GDP, per capita consumption vis-à-vis world average, the GDP growth targets, industrial policies, environmental regulations in place, international commitments, geopolitics and so on. The supply-demand scenario has a strong relationship with abundance, markets, and geopolitics.

It is seen that although the reserve-to-production ratio of many metals is low in comparison to some other mining countries, the natural resources even with respect to some of the abundantly available minerals such as iron ores, manganese ores, bauxite etc. are finite and insufficient to last several generations at the current and projected rates of growth. Added to this would be the environmental footprint of such growth. With respect to thermal coal, the resource position is good. However, the environmental implication of coal as a source of energy makes this option unsustainable. The Indian scenario with respect to petroleum products and natural gas is alarming considering the present demand-supply gap and the projected demand into the future. In the power sector too, supply has not been able to keep pace with increasing demand, causing huge power shortages across the country. The future power situation looks equally grim unless remedial steps are taken soon. From the viewpoint of Indian sustainability, the following goals have to be achieved:

1. Ensure material security for the entire population of the country with respect to the major materials (steel, cement, Al, Cu, Zn, Ni, Cr, Mn etc.) and also for the energy critical elements. Define per capita material requirement for the entire population that strikes a balance between availability of material, living standard, national GDP and environmental footprint.

2. Ensure energy security of the country by aggressively pursuing the nuclear energy option in addition to the fossil and renewable energies. Here again, a realistic and balanced view needs to be taken on the per capita energy requirement. The average global per capita energy consumption is 2800 kWh and for the developed European countries is 9000 kWh and in US it is in excess of 17000 kWh. In India, the present per capita electricity consumption is 779 kWh. If we seek to emulate the developed nations and their energy consumption habits, it would have disastrous environmental consequences. Such energy consumption is not sustainable.

3. Adopt energy efficient technologies especially in the construction, power, oil and gas, fertilizer, iron and steel and non-ferrous metals sector.

4. Prioritize the less energy intensive and high value industries that should be pursued in India and concentrate on recycling especially for energy intensive materials such as Al, Mg, ferro-alloys etc.

5. Place equal emphasis on material conservation as on production and rejuvenation and refurbishment as on manufacturing. Follow the maxim of REDUCE, REUSE and RECYCLE.

6. Evolve industrial policies and export-import policies that concentrates on material and energy security for the country for several generations.

There is likely to be extensive pressure on the developing countries to address global warming and comparisons on per capita basis may not be acceptable. However, any international negotiations on global warming and climate change need not be on a zero-sum basis. In this context, it is appropriate to invoke the Nash equilibrium. “In game theory, the Nash equilibrium is a solution concept of a non-cooperative game involving two or more players, in which each player is assumed to know the equilibrium strategies of the other players, and no player has anything to gain by changing only his own strategy unilaterally. If each player has chosen a strategy and no player can benefit by changing his or her strategy while the other players keep theirs unchanged, then the current set of strategy choices and the corresponding payoffs constitute a Nash equilibrium” (en.wikipedia.org). A group of players are in Nash equilibrium if each one is making the best decision that he or she can, taking into account the decisions of the others.

CONCLUSIONS

Thermodynamically, sustainability for infinite time is achievable only when the rate of consumption of the natural resources equals the rate of replenishment. This ideal situation is not achievable in the time frame of human civilization being considered. Since the rates of replenishment of the natural resources are several orders of magnitude slower than the rest of the stages in a material life cycle, sustainability will depend on the rates of consumption of the natural resources and the extent and rates of change brought about to the environment by the other stages of the life cycle. The lesser the availability of the resource, the lesser the demands of the society (or lower the rate of consumption) and the lesser the energy consumed and changes brought about to the environment, the slower will be the process and more sustainable will be the material cycle.

Sustainability of materials in real terms is a balance between the necessity of a thermodynamic equilibrium between exploitation and replenishment of natural resources vs the kinetic restraint in achieving these balance vs the permanent change brought about to the environment by the nonattainment of equilibrium.

Materials sustainability would possibly be limited by energy availability and environmental impact rather than the availability of material resources. Although emergence of disruptive technological solutions may pave the way for materials sustainability, sociological and political considerations will have a major role. As lucidly put by Green et al (2012) “as global population grows, the most important question might be not how many people Earth can support, but how many people Earth can support sustainably with an adequate standard of living”.

Will the supply of metals run out? This question has been beautifully addressed by Apelian (2012). Quoting Apelian "Thomas Malthus as early as 1700 observed that the population in England was growing geometrically, whereas the food supply was increasing arithmetically. This led him to conclude that a human population would eventually outstrip its ability to find and produce new sources of food, thus leading to a catastrophe that would bring the population down to a more sustainable level. Although agricultural innovations have enabled the support of much larger populations than Malthus could have ever imagined, the real question is whether this can be continued. The answer is clear: only if development occurs sustainably. Of course, the Stone Age did not end because humans ran out of stones, but because they found a better substitute, as our species always has".

From an Indian perspective, there are reasons to be cautious and conservative. Although endowed with abundant natural resources, there are concerns on energy and environment. However, material sustainability in India will be driven equally if not more by socio-economic and socio-political considerations rather than technological.

I will conclude my talk with this splendid Greek proverb:

A society grows great when old men plant trees whose shade they know they shall never sit in.

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Indian Steel Industry: 100 Years Journey and Beyond

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Background

Archaeological site exploration established beginning of metallurgy in Indian sub continent as early as 1800 BC. It flourished greatly leading to development of Wootz steel in around 300 BC which become famous worldwide by the name "Damascus Steel". Wootz steel is mystery even today to steel makers across the world especially for development of unique pattern on it. The traditional steel making science and facilities in India were forced to shut down in colonial era and finally become extinct by 18th century.

After losing all the technological know-how and every manufacturing facilities, Indian steel industry made afresh beginning towards the end of 19th century and established itself with the foundation of Tata Iron & Steel Company (TISCO) at the beginning of 20th century and today it has reached at par with the world steel industry in terms of adoption of state of art technological facilities. The era of Indian Steel Industry can be distinctly divided into four periods namely:

Pre- Independence period

Post – independence period up to 1991

Post liberalization period 1992- 2011

Beyond 2011

Pre –independence period

The establishment of steel industry in India is credited to Sir Jamshedji Tata who founded TISCO (Now Tata Steel) in 1907 in the then Bihar now Jharkhand and in the year 1911-12 first steel ingot was produced through blast furnace –open hearth process route. After TISCO, three more companies were set up in pre independence era. Indian Iron & Steel Company (IISCO) by Burn & Co of Britain was set up in 1918 at Hirapur (later renamed as Burnpur), West Bengal. In the year 1923 Mysore Iron & Steel Company renamed later as Visveswaraya Iron & Steel Limited) was established at Bhadrawati, Karnataka with installation of charcoal based blast furnace for hot metal production followed by Steel Corporation of Bengal adjacent to IISCO in 1939. At the time of independence, India's total steel production capacity was 1.25 Mt and adopted the iron and steel technology prevailing during that time.

Post –independence Period

Post Independence, the Govt. of India under new industrial policy in 1948 declared that new ventures of steel projects would be undertaken only by public sector with the exception of existing steel plants but with restriction to their capacity expansion. It was decided to set up three integrated steel plants each with a capacity of 1.0 Mt /yr. The first of these came up at Rourkela in Odisha followed by other two, one at Bhilai in the then Madhya Pradesh and other at Durgapur in West Bengal. These plants were installed with technology provided by Germany, USSR and Britain respectively. Hindustan Steel Limited (HSL) was formed in 1954 and the above three public sector plants were brought under its control. By this time TISCO has expanded to 2.0 Mt/yr and Steel Corporation of Bengal was merged with IISCO to raise its capacity to about 0.5 Mt/yr of steel ingot.

Until 1956 the only reliable process route known to Indian steelmaker was open heath furnace route. Though TISCO was having Electric Arc Furnace based foundries for production of special steel and was also practicing duplex process where first hot metal was treated in Acid Bessemer converter and then taken to open hearth furnace. It appears that duplex process was not very much convenient and Acid Bessemer converter process was discontinued. In 1956, Basic Oxygen Furnace (BOF) was installed in RSP. Installation of BOF at RSP was very bold step as it was 1st unit in the world outside Europe and it revolutionized the steelmaking concept in India. In 60's TISCO also adopted BOF technology for their steel production.

Bokaro Steel Plant was installed as the Public Sector unit with annual capacity of 2.5 Mt/yr in the then Bihar now Jharkhand and was commissioned in 1972 with BOF furnace for steel production outside the control of HSL. Steel Authority of India (SAIL) was formed on January 24, 1973 and the three plants under HSL along with Bokaro Steel

Plant were brought under its umbrella. To meet the country's ever growing demand of steel, all the four plants under SAIL namely Bhilai, Rourkela, Durgapur and Bokaro were further expanded to 2.5 & 4.0 Mt/yr, 1.7Mt/yr, 1.6 Mt/yr and 4.0 Mt/yr respectively.

Later, Visakhapatnam Steel Plant was set up in the Public Sector under its holding company Rashtiya Ispat Nigam Ltd. (RINL) at Vizag in Andhra Pradesh with a liquid steel capacity of 3.0 Mt/yr and its first converter was made operational in1990.

Post Liberalization Period (1992 -2011)

After liberalization in 1992 when a large number of controls were abolished, some immediately and others gradually – the steel sector yawned into new era of developments. As a result, the domestic steel sector has, since then become market oriented and integrated with the global steel industry. This has helped private players to set up steel plants and bring in new cost effective technologies to improve competitiveness not only in domestic market but also in the global market. Essar Steel Ltd., Ispat Industries Ltd. , Jindal

Vijaynagar now known as JSW, Jindal Steel and Power Ltd. (JSPL) Bhushan Steel and strip Ltd., Bhushan Steel and Power Ltd., etc. have installed modern steel plants with state of the art technologies. As the new green field steel plants became operational in the private sector, the existing steel plants have also renewed itself in terms of modernization and expansion. This is reflected in terms of India's crude steel production capacity which started at about 17 Mt/yr in 1991 to about 27 Mt/yr in 2001 and nearly 72 Mt/yr in 2011 as shown in Table 1.

Table 1: India crude steel production (Post Independence)

Year	Crude steel production Mt
1951	1.50
1961	3.4
1971	6.1
1981	10.8
1991	17.1
2001	27.3
2011	72.5
2012	76.5

There has been unprecedented growth in the last decade which witnessed transformation of Indian Steel industry into technological parlance with global industry.

In technological development, new coke oven batteries with tall oven coupled with high capacity and coke dry quenching facilities have been installed. Large capacity sinter machines and blast furnace of more than 3700 m3 capacity are become order of the day. New smelting Reduction processes have been adopted for hot metal production using non coking coal. Open Hearth Furnace become obsolete , BOF gained established footing and share of electric steel making by private steel producer has increased. In 2011, production by process route of BOF, Electric Arc Furnace and OHF was 44%, 54% and 2% against 44%, 28% and 28 % in 1991.

Secondary Refining concept has now fully evolved. At the beginning in the early 90's when it was limited for special steel production like use of AOD for stainless steel production, by 2011, all the established state of the art secondary refining facilities like RH, RH-OB, VD/VOD, AOD etc. have been installed. Use of Ladle Furnace is now a norm for integrated steel producers.

Continuous casting technology has also fully evolved in India as today nearly 75 % steel is processed through continuous casting machines as compared to only 14% in 1991.

Beyond 2011

The Indian steel industry has entered into a new development stage from 2011 riding high on the resurgent economy and rising demand for steel. Rapid rise in production has resulted in India becoming the 4th largest producer of crude steel and the largest producer of sponge iron / DRI in the world. As per the report of the Working Group on Steel for the 12th Five Year Plan, there exist many factors which carry the potential of raising the per capita steel consumption in the country, currently estimated at 60 kg (provisional) to 130-140 kg in next one decade. These include among others, an estimated infrastructure investment of nearly a trillion dollars, a projected growth of manufacturing from current 8% to 11-12%, increase in urban population to 600 million by 2030 from the current level of 400 million, emergence of the rural market for steel currently consuming only 10 kg per annum and buoyed by projects like Bharat Nirman, Pradhan Mantri Gram Sadak Yojana, Rajiv Gandhi Awaas Yojana among others.

However, based on the assessment of the current ongoing projects, both in green field and brown field as well as new plants under active consideration , it has been projected that the crude steel capacity in the county is likely to be 140-150 Mt by 2020. In order to achieve this target, another 70-75 Mt steel capacity is to be added. This additional capacity can be achieved either by expansion of the existing plants or installation of integrated steel plants at new green field locations. About 45-50 Mt capacity will be added by way of modernization and expansion of existing steel plants and 25-30 Mt by setting up new steel complex. New steel plants will be set up in the range of 3-6 Mt/yr capacity to derive the economy of scale by installing large module units. The details of capacity addition both by brown field as well as green field plants by 2020 are shown in Tables 2 & 3.

Table 2: Capacity addition by Brown field plants

Producers	Production in Mt	
	2011-12	2019-20
SAIL Plants	13.5	35.0
Vizag Steel Plant (RINL)	3.0	10.0
TISCO	7.0	10.0
JSW	7.4	10.0
JSW Ispat, Dolvi	3.0	4.0
Essar Steel, Hazira	4.6	10.0
JSPL, Raigarh	3.0	6.0
BPSL, Rengali	1.8	3.0
BSSL, Meramandali	2.2	6.0
Secondary Producers	27.0	29.0
Total	**72.5**	**123**
Capacity addition		**50.5**

Table 3: Capacity addition by Green field plants

Producers	Production in Mt	
	2011-12	2019-20
Public Sector viz. SAIL – Sindari, NMDC-Nagarnar, Karnataka & JV of BSL & POSCO	–	9.0
Private Sector viz. Arcelor Mittal, POSCO,Tata Steel – Kalinganagar, JSPL(Angul & Patratu)	–	15.0
Capacity Addition		**24.0**
Total capacity addition (Brown field + Green field)		**74.5 say 75.0 Mt**

The major factors which will govern the technology / process route selection for capacity addition both for existing / green field steel plants in future are

- Optimum usage of Land
- Conservation of Water
- Efficient use of Energy
- Preservation and optimal utilization of Natural Resources
- Protection of Environment

Fortunately last two decades have witnessed many technological / processes development and system design in iron and steel technology to address the above issues and the efforts are continuing to achieve more. Options are now available to Indian Steel Makers to introduce these technologies/processes suiting to their requirements. Major technological development have taken place right from raw material preparation to finished products but in view of limited time for this address, I am highlighting the development that have taken in the major production units viz. coke making, sintering, iron making, steel making and casting.

Optimum usage of Land

Acquisition of land for setting up integrated steel plants has become a big challenge therefore future lies to go on high capacity production units instead of installation of number of modules of smaller capacity which requires more space for same volume of production. The examples are high capacity coke ovens, sinter machines, blast furnaces and converters as depicted in Tables 4-7.

Table 4: High Capacity Coke Oven Battery

Parameter	7.0.m tall battery	8.4 m jumbo battery
Oven dimension		
Length, m	15.16	20.80
Height, m	7.0	8.4
Av. Width, mm	410	590
No. of ovens	67	70
Useful Volume,m^3	41.6	93.0
Coke production/battery/yr, Mt	0.88	1.30
Space requirement as compare to 4.3 m tall battery	50%	35%

Table 5: High Capacity Sinter Machine

Parameter		
Sinter machine area, m^2	464	500
Productivity , $t/m^2/hr$	1.3	1.3
Annual sinter production, Mt	4.74	5.10
Under grate suction, mm WC	1700	1700-1800
Sinter bed height, mm	700-750	700-750
Dust content in exhaust gas mg/Nm^3	Below 50	50
Sp fuel consumption, Kcal/t sinter	15000	15000
Sp power consumption, kWh/ t sinter	35	35
Space requirement 320 m^2 machine	70 %	60 %

Table 6: High Capacity Blast Furnace

Parameter		
Blast Furnace Volume, m^3	4060	4500 & above
Productivity, $t/m^3/d$	2.1	2.1-2.5
Annual hot metal production, Mt	3.0	3.3-4.0
Hearth dia, m	13.4	1700-1800
No. of tuyers	36	38
Coke consumption, kg/thm	395	300
Coal injection, kg/thm	150	150-250
Sinter / Pellet % in burden	90	90-95
Hot blast temp, deg C	1150-1200	1250
Oxygen in blast, %	23-28	30-35
Space requirement as compare to 2000 m^3 blast furnace	50%	30%

Table 7: High Capacity BOF Converter

Parameter	
Converter holding capacity, t/ heat	300
Tap to tap time, min	40
Annual steel production, Mt	4.2
Converter availability, d/yr	340-350
Lining life, heats/ campaign	15000-18000
Space requirement as compare to 130 t converter 30 %	

Conservation of Water

In India, the present water resource potential is about 1123 billion m^3 and National Perspective Plan envisaged increase in utilizable water by about 200 billion m3. With increased urbanization and pressure on agriculture sector for higher production, water availability to industries in future will become very limited. The specific water consumption in the integrated steel plants which were installed before 2000 with the technologies prevailing during that time was in the range of 8-12 m^3/t crude steel against the international bench mark of 4-5 m^3/t. In order to conserve the water, many developments have taken place and are in use in developed and developing nations to reduce specific water consumption to the tune of 4-5 m3/t crude steel. Some of these developments are highlighted in Table 8.

Table 8: Water efficient technologies

Technology adopted	**% reduction in make up water consumption**
Introduction of coke dry quenching instead of wet quenching	From 150m^3/hr to 6 m^3/hr
Use of plant blow down water for dust suppression in RMHS	5-10%of total plant make up water
Use of blow down water in mixing and nodulising drum of sinter plant	25-30%
Recovery of water from steam generated during slag granulation in SGP	55-60%
In BF GCP, use of pressure filter and vacuum filter for ensuring dry cake disposal in place of slurry disposal	55-60%
Use of air cooled condenser in power and blowing station	70-80%

Efficient use of Energy

In India, iron and steel industries consume about 10% of total energy compared to about 4% of developed countries. The average specific energy consumption of the integrated steel plants based on BF-BOF route is in the range of 6-8 Gcal /t crude steel as compare to 4.0 Gcal / t of crude steel for the most efficient steel plant and world average of 4.5- 5.0 Gcal/t . Indian steel makers have already giving due importance while selecting technologies/ equipment to bring down energy consumption to match with international level. Some of the energy efficient technologies developed and making inroad in Indian Steel Sectors are shown in Table 9.

Preservation and optimal utilization of Natural Resources

India is endowed with good quality iron ore and the reserve is estimated to the tune of 25.2 billion tones. The production of iron ore in the last four years are given in Table 10.

India has been exporting a huge quantity of iron ore. Considering the projected steel production of 150 Mt by 2020and the export demand, the country has to produce around 400 Mt iron ore annually. While mining the ore, huge amount of fines and slimes have been generated and dumped over the past 5 decades. In addition over the past 50 years high grade ore with + 63 % Fe has been mined and used dumping the lower grade Fe ore. This has not only resulted the limited availability of high grade ore reserve but over looked the future requirement of this precious natural resource for steel industry.

Table 9:Energy saving technologies developed

Energy Saving Technologies	Reduction in energy consumption
Coke Oven	
Control programmed heating	Coking time will be reduced. Sp fuel consumption will reduce by 10%
COG sensible heat recovery	Recovery of 0.07 Gcal /t dry coke in terms of steam production
Coke dry cooling	Energy saving of 0.34 Gcal /t dry coke
Coal moisture control process	Energy saving of 0.07 Gcal/t dry coke
Sinter Plant	
Sinter cooler exhaust gas waste heat recovery	Energy saving of 0.07 Gcal/t gross sinter
Blast Furnace	
Top pressure recovery turbine	Energy recovery of 0.026 Gcal/thm
BF stove waste heat recuperation for preheating combustion air	Energy recovery of 0.024 Gcal/thm
BOF & Continuous Casting	
Recovery of sensible heat from converter flue gas for production of steam	Energy recovery of 0.22 Gcal/ tcs
Hot charging of continuous cast products	Reduction in energy consumption by 0.018 Gcal/t charge
Near Net shape casting (Thin slab casting & Castrip	Reduction in energy consumption by 0.216 Gcal/t product

Table 10: Production of iron ore

Year	Production, Mt
2008-09	212
2009-10	218
2010-11	208
2011-12	245

On the other hand, country does not have enough reserve of coking coal and plants are importing to about 50-60 % of their coking coal requirement. The coking coal imports during last 4 years are given in Table 11.

Table 11: Import of Coking Coal

Year	Quantity, Mt
2009-10	24.7
2010-11	19.5
2011-12	31.7
2012-13	32.2

Fluctuation in international price of imported coking coal and its irregular supply has badly affected the bottom line of Indian Steel makers in the past. . Therefore the time has come for steel producers to adopt newer technologies / processes like FINEX, Itmk3 which utilizes abundantly available indigenous non coking coal and low grade iron ore fines. Pelletisation of low grade iron ore, iron ore fines and tailing/ slimes accumulated over the years at mines after beneficiation is now becoming the most economical feed not only for DR plants but for blast furnace too. It is estimated that the pelletisation capacity in the country will increase from present level of 46 Mt /yr to about 95 Mt / yr by 2020. The shift in iron making technology in future is shown in Figures 1 & 2.

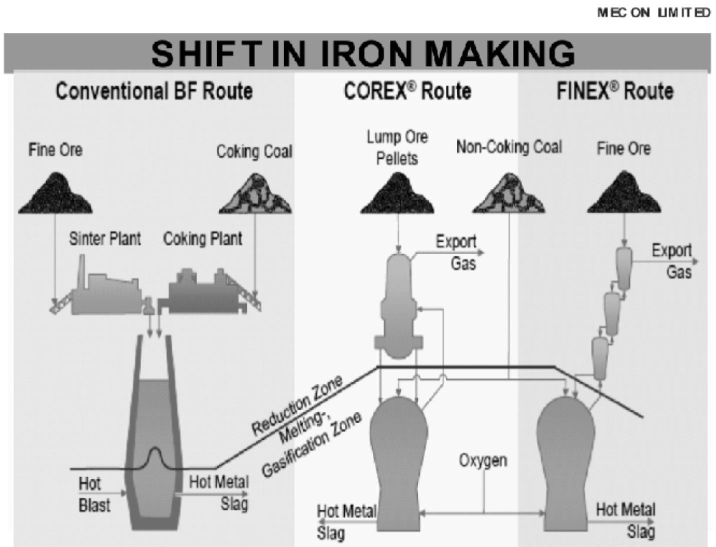

Figure 1: Shift in Iron Making

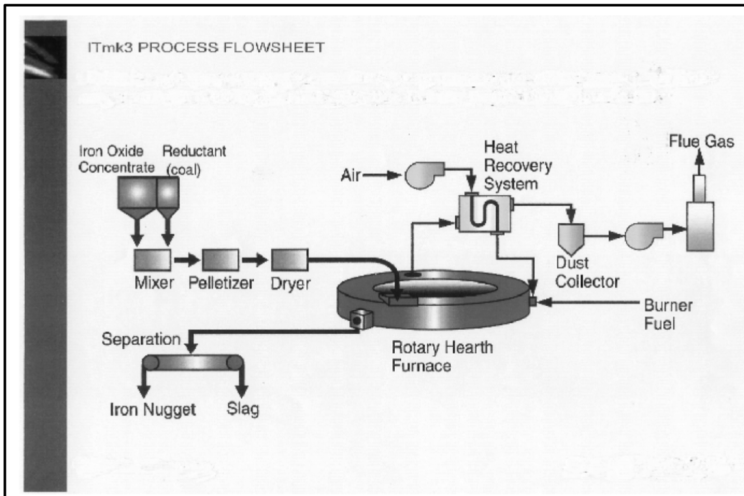

Figure 2: Flow Chart of ITmk3 Process

Protection of Environment

While the industry is expected to accelerate steel production to meet country's growing demand by infusion of additional capacity, global issues like climate change due to higher CO_2 emission by steel industry forced the producers to adopt low carbon intensive routes for steel production. Some of the technologies available / developed to reduce the pollution effectively are listed below:

- Zero leak proof doors and pushing emission control in coke oven battery
- De-sulphurisation of coke oven gas
- Covered cast house in Blast Furnace
- Heat recovery system from sinter cooler
- Dog house in BOF shop
- Dry ESP based GCP of BOF and dry bag filter based GCD
- Low NOx burner for combustion technology

The benefits derived from introduction of these technologies in existing / new plants are given in Table 12.

Table 12: Control of Fugitive Emission in Steel Plants

Unit	Level in existing plant	After introduction adoption of technology	Technology suggested
Coke oven			
H_2S content in raw COG	6000-8000 mg/Nm^3	500-800 mg/Nm^3	COG Desulp
Stack emission SO_x	460mg/Nm^3	111-157 mg/Nm^3	COG Desulp
NO_x control	1700 mg/Nm^3	322-414mg/Nm^3	Staged air heating in combination with internal waste gas circulation
Dust Emission	10-50 g/t of coke	3 g/t of coke	With CDQ
Sinter Plant			
SO_2	1490 g/ t sinter	840 g/t sinter	Off gas is recycled via hood
NO_x	1141 g/t sinter	300 g/t sinter	
Blast Furnace			
Dust emission	8-20 mg/m^3	1-4 mg/m^3	Cast house de-dusting system
BOF Shop			
Fugitive emission	12-14 mg/m^3	2-4 mg/m^3	Dog house de-dusting
Clean gas dust content	50 mg/Nm^3	30 mg/Nm^3	

Conclusion

The Indian Steel Industry has completed its 100 years journey in 2011 with meager production of 1.0 Mt to 72.5 Mt. The growth in steel production was phenomenal during the past one decade. After 2011, Indian steel industry has entered the high growth phase and as per the report of the Working Group on Steel for the 12th Five Year Plan and with positive economic indicators, it is estimated that the demand for steel in the country by 2020 will be around 150 Mt, To meet the ever increasing demand, the country has to add another 75 Mt capacity by way of modernization / expansion of existing steel plants as well as installation of green field plants. The expansion / modernization as well as installation of green field plants needs to take care of the following key factors while selecting the process route / technology and plant capacity.

- Optimum usage of Land
- Conservation of Water
- Efficient use of Energy
- Preservation and optimal utilization of Natural Resources
- Protection of Environment

Many new technologies / processes have been developed to effectively take care of the above issues and adoption of many these developments suiting under Indian condition can make the plants most energy efficient, economically viable , environmental friendly and sustainable.

Advanced High Strength Steels for Light Auto Body : Focus on Third Generation Grades

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General

Automotive is an inseparable part of modern living and accounts for a sizeable share of our economy. Notwithstanding the development of new materials and their increasing use, the iron-base materials still occupy the dominant position amongst the materials of construction of the autocomponents and represent around 64 percent of the weight, in which the share of steel is around 57 percent in a typical passenger car today.

In a passenger car, the weight-ratio of various components is shown in Fig. 1 below :

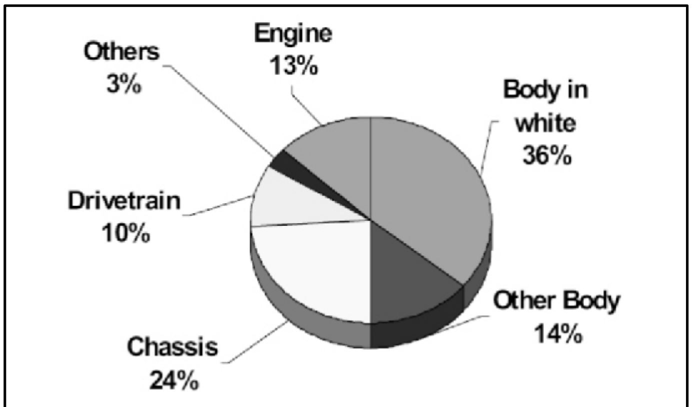

Fig. 1 : Weight Ratio of Various Parts in a Passenger Car

It would appear from Fig. 1 that the body-in-white (BIW) represents a major component in terms of weight. It is also the component that provides safety and comfort to passengers during driving.

The BIW is a complex engineering product today, demanding a wide combination of properties, as shown in Fig.2 .

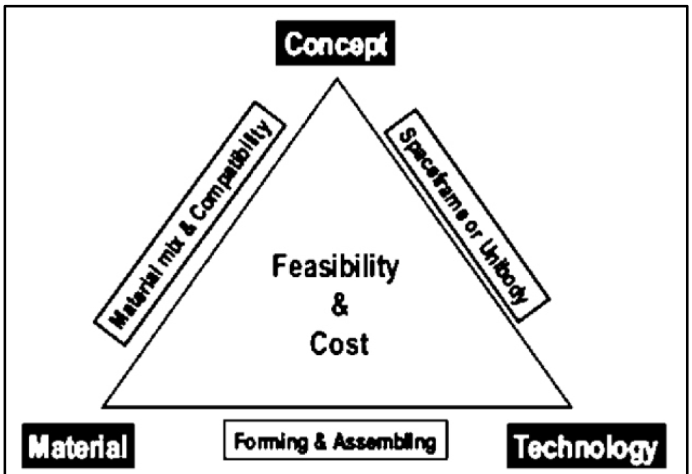

Fig. 2 : Basic Concepts of Modern Car Body (BIW) Design

example : physical characteristics (e.g. strength, stiffness, durability); amenability to production (e.g. formability, joinability, paintability); styling / space optimization (e.g. designing freedom, cross-sections & so on) and over all, environmental impact (e.g. energy consumption, CO_2 emission), costs (e.g. manufacturing, use and maintenance) and safety (e.g. a variety of crash resistance) are all important factors in designing a car body. Further, some of the requirements are apparently conflicting (for example, strength and formability). All these make materials selection for and design of the car body a challenging task. And, it becomes an even greater challenge in view of the ever increasing demand of light weighting without sacrificing safety and with no cost-penalty.

International Consortia for Light- weighting of Car Body : ULSAB & ULSAB-AVC

In early 1994, a consortium of 35 sheet steel producers from 18 countries, called Ultra Light Steel Auto Body (ULSAB) set out to demonstrate a lightweight steel auto body structure that would meet a wide range of safety and performance targets. The Consortium contracted with Porsche Engineering Services, Inc. (PES) to provide engineering and manufacturing management for the ULSAB project.

In September 1995, the Consortium announced the results of the concept phase: a design of a typical mid-size sedan showing a weight savings of up to 36 percent in a steel vehicle structure, and substantially improved performance when compared to benchmarked averages in the same class - at a cost less than that required to produce a typical vehicle structure of that time.

In 1998, the Consortium presented to the world automotive industry, a complete ULSAB body-in-white, which dramatically validated the design concepts. That BIW of ULSAB acted as a focal point of a traveling exhibit that showed how to use high-strength steels to reduce mass in a vehicle structure that is Safe, Affordable, Fuel Efficient and Environmentally responsible (SAFE). The final results of ULSAB are summarized in Table 1 below :

Table 1 : Performance of ULSAB Structural

	BENCHMARK	ULSAB	CHANGE
- STATIC TORSIONAL RIGIDITY(Nm/deg.)	11,531	20,800	+80%
- STATIC BENDING (N/mm)	11,902	18,100	+52%
- FIRST BODY STR MODE (Hz)	38	60	+58%
- MASS (kg)	271	203	-25%
- CRASH RESISTANCE (5 diff. In H. test simulations)	R	R++	↑↑
- COST	~$1000	~$978	NO INCREASE

It may be observed from the Table 1 that a 25% mass reduction, along with improvement in all properties and at no cost penalty was a major achievement. This was possible primarily through : (a) use of laser-welded tailored blanks (b) higher strength (High Strength: >=210 MPa; Ultra High Strength : >= 550 MPa) steels and (c) hydroformed tubes / sheets.

The ULSAB concept confirmed steel's main attributes, and explained why high-strength steel is the fastest growing light weighting material in automotive structures. Steel is inexpensive and strong. It is easy to form into complex shapes and structures, and it is highly suited for mass production of vehicles. Its proven ability to absorb energy in a crash is well known.

The next endeavour was the Ultra Light Steel Auto Body – Advanced Vehicle Concept (ULSAB-AVC) launched as a Consortium, at the conclusion of ULSAB. In this initiative, newer crash requirements set by regulation were incorporated; further, advantage was taken of ultra high strength steels available now in quantity from steel makers. Some of the high strength steels used in ULSAB-AVC are shown in Fig. 3 below :

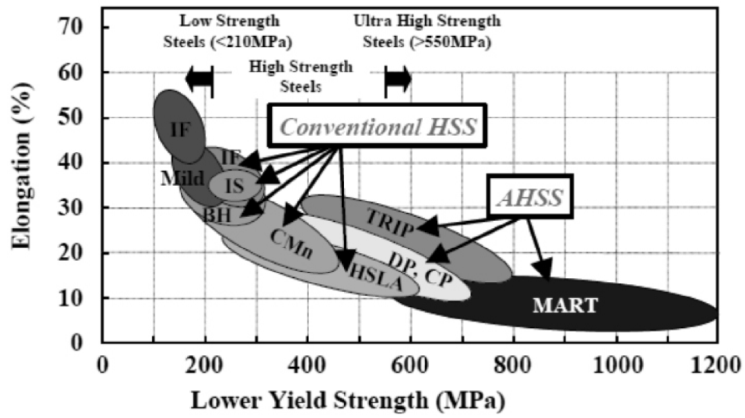

Fig. 3 : Automotive and their Strength- Ductility Properties

An example of the use of high strength steels in making a laser-welded tailore blank for press forming a body side outer is shown in Fig. 4.

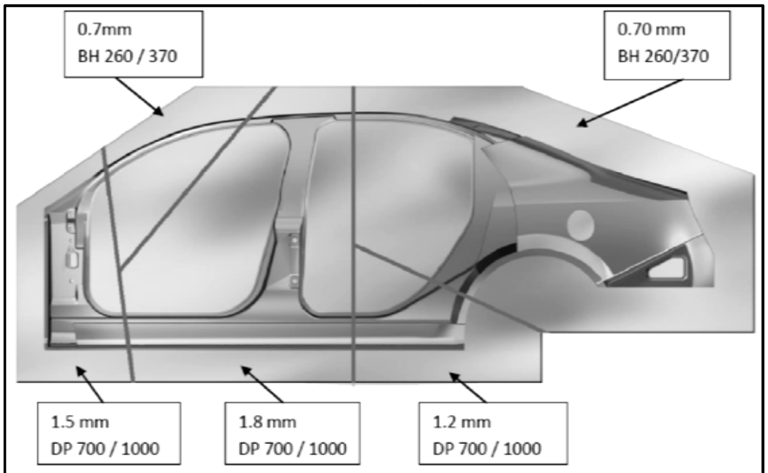

Fig.4 : Lased Welded Tailored Blank with Various High Strength Steels & Thicknesses

It may be mentioned that the steels shown in Fig. 3 such as Bake Hardenable (BH), Dual Phase (DP); Complex Phase (CP) and Transformation Induced Plasticity (TRIP) are conceptually interesting and a great deal of research publications are available elucidating their structure – property behaviour. For instance, the BH-grades include steels that show hardening when exposed to a typical baking (of paints) temperature of 170oC. Thus, these steels can be press formed at a low stress and can be strengthened subsequently during baking. The Dual Phase (DP) steels by virtue of comprising soft and hard phases possess the characteristics of optimum strain partitioning that enable them to avoid yield point phenomenon. The Transformation Induced Plasticity (TRIP) steels on the other hand contain retained austenite (typically, 5-20%) that has the appropriate meta-stability to get transformed to martensite in a desired window of temperature and strain rate, thereby inducing sufficient energy-absorption capability during crash.

Advanced High Strength Steels (AHSS) : Second & Third Generation Grades

The advanced high strength steel (AHSS) grades shown in Fig. 3 were microstructurally classified as AHSS-Generation–I steels. Efforts were then directed towards developing steel grades with even superior strength-ductility combinations to cope with the demand of greater mass saving (up to 35 percent) with high fuel efficiency, better combination of properties compared to First Generation AHSS. For example, one of the newer requirements was the CAFÉ (Corporate Average Fuel Economy) in the USA, requiring a fuel consumption of 34.1 mpg / 14.5 kpl by the model year 2018 [current figure is 27 mpg / 11.5 kpl]. This has led to competition among alternative vehicle technologies.(hybrid, fuel cell, electric …). Some of the hybrid vehicles are shown in Fig. 5.

Fig. 5 : Passenger Cars in Response to CAFÉ (www.hybridcars.com)

Similarly, in the USA, the Roof Crush Requirement is to increase to 3.0 times the weight (currently, 1.5 times) by 2017, roof crush tests shown in Fig. 6.

Fig.6 : Roof Crush Tests (requirement enhanced, phased in to 2017)

To meet the above demands (requiring higher elongations at high strength), newer steels are now sought to be developed. These include austenitic AHSS variety, such as stainless, Twinning Induced Plasticity (TWIP) steels; Al-added lightweight steels with induced plasticity (L-IP), and shear band strengthened steels (SIP steels). These have been designated as 'Second Generation' AHSS steels. The stress-strain characteristics of the Second Generation grades are superimposed on those from the First Generation in Fig. 7.

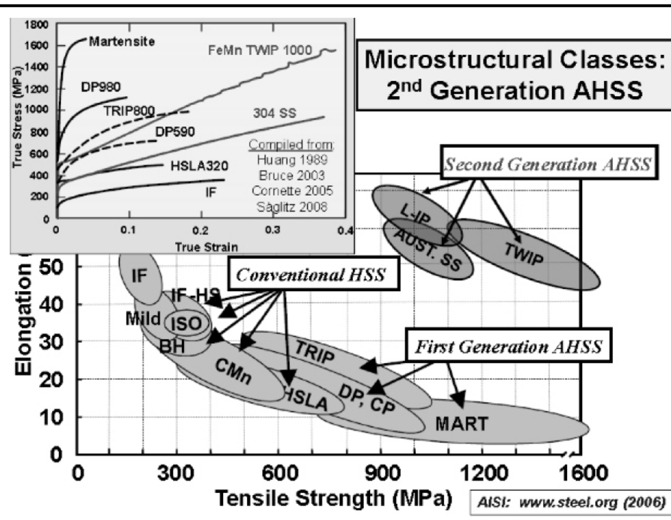

Fig. 7 : Stress – Strain Behaviour of Second Gen. & First Gen. Steels

It may be noted that these Second Generation grades are expensive and therefore it has been attempted to explore grades that are close to these steels in performance (i.e. better than Gen-I) but would be more affordable. The philosophy of this development is shown in Fig. 8.

There are a number of academia and industries launching their efforts in the direction of Third Gen. steels. The U.S. Govt. have supported large programmes in this area. A broad summary of the institutions in the U.S. is given in Table 2.

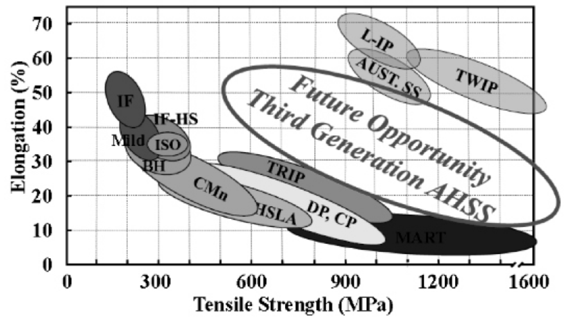

Fig. 8 : Stress-Strain Plot Showing Opportunity for Third Generation Steel Grades

Table 2 : Various Approaches to Third Generation Steels in the U.S.A

University	Professor	Topic
Carnegie Mellon University	Warren Garrison	AHSS through microstructure and mechanical properties
Case Western Reserve Univ.	Gary Michal	AHSS through C partitioning
Texas A & M	Abu Al-Rub Rashid	AHSS through particle size and interface effects
Colorado School of Mines, Ohio State University	David Matlock (CSM) and Robert Wagoner (OSU)	Collaborative GOALI Project Formability and Springback of AHSS
Drexel University	Surya Kalidindi	FEM using crystal plasticity simulation modeling tools
University of Pennsylvania	Ju Li	Multiscale modeling of deformation for design of AHSS
Missouri Inst. Of Science & Tech.	David C. Van Aken	AHSS through nano-acicular duplex microstructures
Wayne State University	Susil K. Putatunda	High-strength high-toughness bainitic steel

One of the interesting approaches to Third Generation grades has been developed by Prof. John Speer & Prof. David Matlock at the Colorado School of Mines. It involves the development of a Quench- Partitioned (Q-P) treatment for bringing in large quantities of retained austenite. Basically, the holding after quenching enhances the carbon content in the retained austenite, making it stabler as Fig. 9 would show.

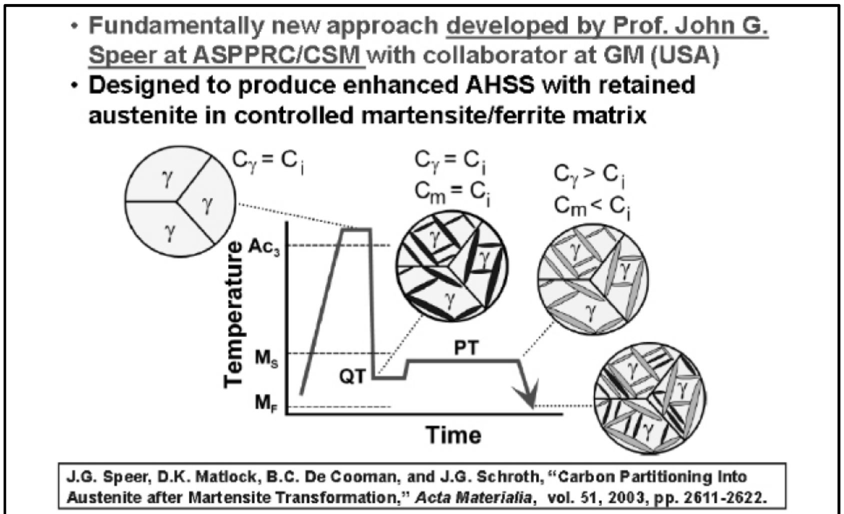

Fig.9 : The Concept of Quenching & Partitioning (Q+P) Steel at Colorado School of Mines

Present Scenario of High Strength Steels Auto Body

In terms of microstructural features, it may be broadly observed that High Strength Steels (HSS) comprise single phase ferrite; Adv. High Strength Steels (AHSS) – Gen. I grades contain ferrite multi phase; AHSS – Gen.II steels contain austenitic phase; and finally AHSS – Gen. III steel grades are based on austenitic multi-phase. The actual use of some of the AHSS grades has started in Europe, Japan, USA and other countries. One such example is the B-Pillar from a Q+P variety of steel, shown in Fig.10, below.

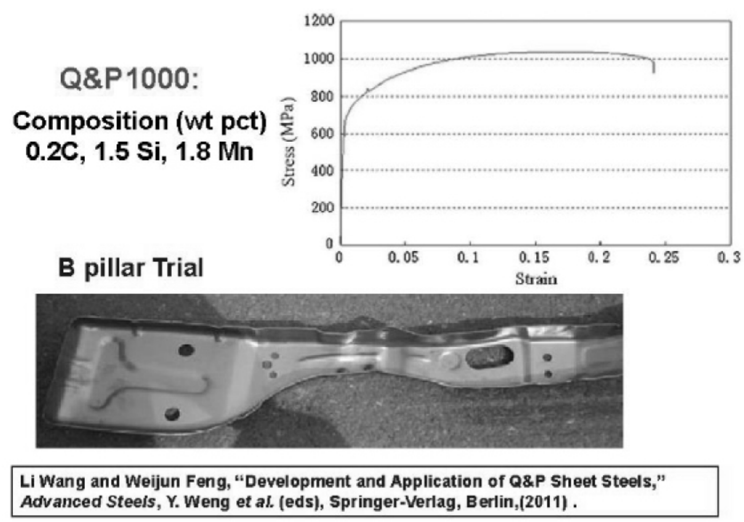

Fig.10 : B-Pillar Made from Quench & Partitioned Steel in Bao Steel, China (courtesy: Matlock)

Although one finds examples of AHSS – various generations in use in automotive already, they are yet to gain popularity, as demonstrated in Fig. 11.

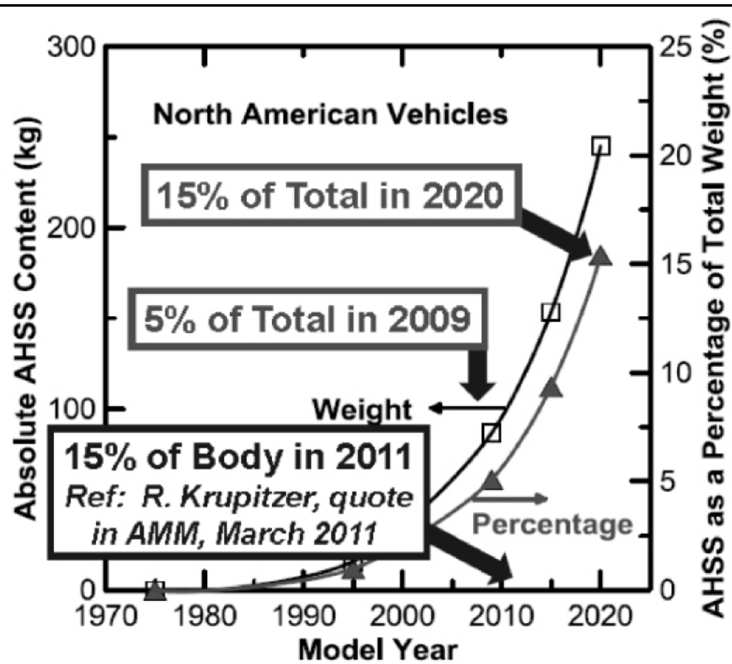

Fig. 11 : Use of AHSS in Vehicles in the USA

Concluding Remarks

From the foregoing, it would be established that although steels as a class of materials have completed nearly a century of application, yet it is only during the past two – three decades that a variety of grades have been developed that possess properties, unattainable as a mere extrapolation of their predecessors. The increased use of AHSS grades can lead the way in reducing mass (hence lower fuel consumption and reduced carbon-foot print) and increasing crash safety. Steel is thus at the core of the green economy. This, together with the cost-effectiveness of cold forming results in very attractive solutions for body-in-white structural parts, as well as safety parts such as door impact beams, bumper systems and seat structures. Thus, while many believed that the steel industry belonged to the 'sun-set' sector, this is clearly showing signs of rejuvenation, displaying features of an ultra-modern material, able to meet the challenging demands of present-day automotive.

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Aim Zero Loss to Innovate Operational Excellence

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INTRODUCTION

A sense of loss in life and/or work can only permeate the sensibilities of a person if he or she is alive to the impacting influences of the magnitude of losses. For the disdainfully oblivious, losses of any hue or colour is meaningless , until they are life-threatening! It would be highly preposterous and hence outrageous to assume that a qualified professional can vow to shut his eyes against the innumerable big and small losses in his daily world, simply because he loves to be bereft of stress, free of tensions. Those stresses would quietly accumulate to snowball into a gigantic Frankenstein ready to engulf him , leaving him unguarded and dishevelled in due course.

In today’s context I would argue for those of us in the Management cadre of steel plants to open their eyes wide for once (metaphorically speaking) and ask for himself as to why is it that while most industrial sectors have gone in for targeting Zero Loss philosophy and thus profit, the steel plants almost never wanted to adopt any of the techniques to push LOSS making practices centrestage, amlify and magnify them and finally eliminate them ? This inspite of continuous loss-making fiscal years, despite buying best of foreign equipment and technologies and employing best available technical hands? Where lies the ambivalence, the misgivings , the lethargy, the ubiquitous neglect ? This while the nation bleeds for lack of growth and development!

COMMON LOSSES IN A STEEL PLANT

How Good Is Your Machines & Equipment?

What is your Breakdown Record?

How Efficient are Your Operations?

What Is Your Customer Complaint Scenario?

How Is Your Cycle Time Scene?

What Bothers You In Terms Of Inventories?

How Low Is Your Productivity?

What Is The Lag In Training Skills Amongst Your Employees?

How Many Accidents You Are Faced with, Each Year?

How Dirty/Ugly/Polluting/Hazardous/Unsafe does Your Plant Look?

How Many Years Have Passed Since You Installed/Commissioned/Operated A New Machine/Production Line?

For each of the above issues, there are answers and actions but steel sector has somehow been reticent & reluctant to confess and attack them. If MTBF-MTTR is applicable to denote breakdown situation, 5 ‘S’ is for a clean/green/safe plant; if 5W-1H/Why-Why Analysis/Pareto /Ishikawa can show you the root causes for a failure or problem (and hence devise innovative technical/technological/design solutions through Kaizens, then SQC/SPC/TPS/JIT/Kanban can help you tide over efficiency/inventory/cycle time, related issues and so on. Efforts to help you gain a world standing in terms of market share and productivity can be ensured through deeper introspection and hence innovativeness through QC stories/PDCAs/Daily Work Management(DWM)/Flow Charting/Target Setting/Hinshitsu Hozen/Policy Management, etc.

In this paper I will dwell upon Quality aspects only, in view of the vast spectrum of initiatives already undertaken by pragmatic Indian industries , bypassing steel sector as a laggard in the race.

REWORK & REJECTION : AS A LOSS

The customer is king, not God. While God can forgive, kings generally don‟t!! All the current hullabaloo about exceeding customer expectations or “delighting” the customers, don‟t mean a dime if an organisation aspiring to be

WORLD CLASS fails to ensure it has adequate capability to test and certify what it produces through internationally recognised systems. Even if a company produces "right the first time and every time", the credibility can be established only if a standard, unbiased, impartial, in-house testing laboratory assures lack of variability in properties, to an extent acceptable under international norms. Unfortunately such intrinsic awareness on the part of the supplier and stringent quality demands from the discerning customers, are only recent phenomena in India.

There still exists an ominous lack of awareness (besides a blatant violation of procedures) with regard to Quality Measurements and Measurement of Quality. Paradoxically if you can't measure Quality, you can't improve it either. Hence proper testing and analytical systems with traceability to international standards is essential and such laboratories need to function at corporate level such that there is no element of manipulation through biasness or duress from the departments. Besides, the documentation should be unprejudiced. Such a laboratory needs to have a complete range of calibrated equipment and accredited systems, manned by technicians of the desired skill levels.

PRODUCT QUALITY AND TESTING QUALITY

The variability of product quality can be and has to be controlled (better eliminated) to achieve manufacturing excellence. Hence flawless inspection and QC systems need to be in place, which can establish Six Sigma as well as SPC/SQC techniques to take their cause further ahead towards Quality. In case the organisation practices TPM, it can always take resort to Quality Maintenance activities which basically comprises Ishikawa (4-M Analysis), Q-A and "Q" Component Matrices, PM Analysis, FMEA, FTA, Taguchi Technique (Quality Engineering) and DOE (Economic Experimentation). Annexure – I shows how PM Analysis (Phenomenological) can be contemplated for eliminating product defects (as a loss). In case Six Sigma is in vogue in the company, the DMAIC can be used as a tool which involves Define, Measure, Analyse, Improve and Control, to reduce defects to ppm ranges.

However, if the testing process itself has to be examined, monitored and improved, then tools like proficiency testing and Z-Score can be effectively utilised as is being professed by the Govt. of India's Department of Science and Technology (DST) through NABL.

LABORATORY COMPETENCE AND CONFIDENCE

During recent times hundreds of testing and R&D laboratories from Indian organisations, big and small, have utilised the proficiency testing tool through use of inter-laboratory comparisons, based on a central nodal laboratory. Standard samples of known parametric variations are codified and tested by the participating laboratories and the results are matched, to indicate the level of excellence. The greater the variability, known-as outliers on Z-Score, the lesser is reflected to be the competence level of lab. Accordingly the ranking of the labs are done, guidelines provided and efforts made to reduce the extent of deviation from the standard values (known as Z-Score).

CONCEPT OF UNCERTAINTY

If a laboratory is scoring very poor marks on the Z-Score spectrum it has to delve into the depths of the reasons. These reasons are actually uncertain entities during measurement. The measurement scientists are yet to come to terms with estimating uncertainty. Identifying uncertainty source and quantifying the components, converting these to standard deviations, calculating combined uncertainty and expanded uncertainty, uncertainty contribution from each factor specifying measurand and the method, etc play vital roles for finding out the extent of uncertainty involved in Quality Measurements. In these calculations, the role of CRM (Certified Reference Material) is crucial, in order to assess the calibration errors. Thus estimating uncertainty and capturing it while measuring quality, consequently affects the extent of reliability in decision making.

Adequate infrastructure for measurements, periodic surveillance audits by third party and timely upgradation of skills of laboratory personnel, are crucial to maintain and accredit the in-house laboratory, such that one does not receive defective goods, produce defective goods and pass on defective goods, out to the customer, if the steel company wants to heave a sigh of relief from suspecting visits by customers.

While drawing up board room strategies for brightening up steel business prospects based on modernisation of plants and technological advancements, the undeniable realisation has at last dawned upon the managements that quality initiatives like TQM/TPM/training and development, etc. can no longer be shunted to the backyard of the company.

EMPLOYABILITY AND ATTRITION : AS A LOSS

Is our "available" manpower "employable" enough? While the educated Indian personnel are well qualified to serve the needs of the steel industry, as engineers and technicians, the concern seems to be genuine in terms of the lower level of workforce. Indians are known to be characterized with the high-intelligent genes and hence after the grinding through various Universities and Institutes, they are reasonably enabled to deliver the required output. And the country has seen a surge in the number of educational institutes/ technical and management institutes for the young boys and girls to avail of. On the other hand, even though there has been a proliferation in the number of industrial technical institutes (ITIs) / polytechnics for the "less-qualified" and "less-privileged" classes in the society, attention has never enough to ensure that these young minds receive the kind of industrial-technical training that they are ideally supposed to. Even though a lot remains to be done in the higher education sphere too, in case of the ITls, the progress has been dismal.

The above pitfall, over the years, has resulted in severe dearth of employable italics manpower. On the other hand, the industry needs a paradigm shift, because a lot has changed both in the SMEs and in the large industrial sectors: technologies, equipment, process flow, input supplies, quality demand, testing norms, cost competitiveness, foreign collaborations, strategic partnerships, automation, environmental laws, excise laws, Govt. tariffs and regulations, logistics issues, etc. A combination of these factors has been playing crucial roles (sometimes even creating havoc!) amongst managements and plant managers to get the best out of the minimum. Obviously pressures have started mounting on requirements for newer skills / better skills / effective skills from its workforce, as one of the means to arrest the adverse impact of the skyrocketing material costs, power cost, water cost, gas cost, transport cost, etc.

Under such a scenario the steel units have suddenly woken up to a raw realization that it doesn't really have the kind of capable workforce that is ideally suited to their newly drawn up Vision, Mission, Values, Targets, etc. Thus employability has become a buzz word since the past couple of years.

The underlying theme would be to:

 Upgrade the facilities at the ITIs.

 Organise advanced training programmes for the faculty who can in turn impart knowledge to the students (Training the Trainers).

 Building up additional facilities for a better ambiance at the institute.

 Modify course curricula, as relevant to the current requirements in the industry (specifically to the local neighbouring organizations).

 Help initiate entrepreneurial skills, based on which the institute could also earn by undertaking external jobs, as a return on investment.

Obviously the World Bank fund as well as the PPP collaboration is a golden opportunity for:

 Enhancing employability as a fundamental necessity.

 The youth of the nation, with intelligent characteristics so typical of Indians, need to be channelized in a manner such that:

 They are encouraged to equip themselves with effective skills and thus prevented from "dropping out" midway through training programmes.

 Ensured of a decent livelihood for their families.

 Guided in preserving their self-esteem by being able to serve their clients in the best possible manner.

 The job scene in the country would then remain healthy through a demand pattern for skilled, employable workforce, the youth would remain well directed, while the industry profits.

HIGHER EDUCATION TUNNEL : AS A LOSS (?)

Higher Education, if pursued in the true spirit and if guided with the true equanimity, may not directly result in delivering outstanding achievers in a fly-by-night situation but can nucleate the seeds to grow, lf nurtured. Does the mundane rigmarole in a steel campus allow that? On the other hand, it is high time that the academic institutes" curricula include many more industry friendly and application oriented programmes of study.

Whom the Industry Needs? If by "higher education" we mean persons with postgraduate degrees in science or engineering or management or those with a Ph.D, the percentage of steel industries that have started hiring them, are in very minor bracket. The type of jobs carried out in the routine process lines or office jobs do not really call for higher education. Graduate or even diploma engineers or B.Sc.s/B.Com.s suffice in fulfilling the regular requirements. So where are they needed? It is mostly in the industries or organizations where the policy is aligned towards business excellence in terms of manufacturing efficiency or product quality or stakeholder satisfaction or HRD including CSR (Corporate Social Responsibility). These companies can plan to utilize them in INNOVATIVE approaches over the routine. The need can also arise from the recent emphasis towards IT implementation/ process automation/ office automation/ energy conservation/ clean or green development mechanisms! TQM Models, which are pivoted on rapidly developing or dynamic technological expertise can follow suit. The significant achievements in a steel mill through improvement activities like Kaizens and PDCAs are shown in figs 1 and 2, as examples.

But such kind of steel units are not many in India even today, as against the teeming millions emanating out of universities and mushrooming educational institutes. Therefore to make a match between the numbers on one side and the requirements of the industry on the other, one would obviously look for a filtration process to pick up only the most suited ones for the job in question. Obviously that would leave a large number of de-rated ones, branded as the "unwanted", with an uncertain future. Ironically though there are companies which would rather scramble for these lower category pass-outs such that they would have to shell out lower compensation packages. There would still be unemployed youth aggregates who even after passing through the so called higher education tunnel, would remain largely disillusioned. All sectors are not IT.

The other lacunae in the system is that quite often an industrial unit doesn't really have a definite career plan or path for absorbing and orienting the executives who join through the "higher education" tunnel. Consequently it is quite likely that the man or woman in question feels out of place and dismayed by the goings-on around, so different from the classroom teachings or the laboratory research from where he or she has freshly emerged. This is besides the anticlimax of the comfortably pristine confines of his educational campus, against the hazardous, dusty, fuming, high temperature rigours in a typical Indian steel campus. Therefore the need for suitable training, guidance, orientation, counselling and displaying respect to whatever higher studies/ research that the person concerned must have been exposed to, as a background. Then integrate it with the current job profile. Thus there is a delicate mapping and matching of the academic specialization/ research potential on one side and the practical industrial paraphernalia on the other. Name it Knowledge Management of the other kind? Or else the imbroglio continues. With the dreams of deriving satisfaction remaining an enigma, the personal productivity of the person may dither and decline, once his self-esteem is hurt, gradually pushing him to a zone of inefficiency and high-stress anguish.

UNSAFE AND POLLUTING: THE DUAL THREAT (AS A LOSS)

It would be unjust not to make a mention of the double barrel attack of two potential dangers today, in the form of safety and pollution, in a steel company. Safe working practices, stricter safety norms, safety permits, safety gears, accident mapping, near-miss accident cases (Heinrich principles), Poka Yoke principles (mistake-proofing), On-the-job-trainings (OJTs) emphasising Do's and Don'ts, are all aimed at making the workplace a safe, comfortable and hazard-free area today. Companies have to inevitably take cognizance of the safety of even the contract labour, an unmistakably large community in steel premises. OHSAAS (ISO-14000) based SOPs (Standard Operating Procedures) are a must today if a steel plant wants business from Global Players.

On the other hand, the dangers of global warming and environmental pollution are looming large on our future generations. The steel companies having century old practices of not being bothered about its hazardous emissions, dust and noise levels, solid particulate pollutants, water and air pollution, subsoil damage through effluent, sludge and slag, mill scale and chips, etc can no longer be permitted to be oblivious today. Therefore, as a compulsion they have to turned towards EMS (environmental management systems) of monitoring pollutants and doing all that is needed to curb and abate the same, through clean development mechanisms (CDM), besides practicing the eminent 5-'S' principles of housekeeping, another Japanese wonder. However, only a small percentage of steel units has adopted these sincerely or sustainably.

Fortunately, tackling these two threats head on, consequently leads to a much improved and efficient organisation in the long run with better economic parameters, besides proving itself to be an organisation responsible towards Kyoto protocol on LCAs (Lite Cycle Assessments) and Greenhouse emissions, besides carbon credits, to win over global customers. Merely cutting down the flab of a steel company by downsizing or trimming down manpower by embracing lean manufacturing, doing BPR (Business Process Reengineering) through application of ERP (Enterprise's Resources Planning), etc. may not bring about that kind of enhanced key performance indices (KPls) than those achieved through the hardcore, proven and quantifiable Japanese initiatives like TPM and Deming.

CONCLUDING REMARKS

- INNOVATIONS do not mean only discovering new ideas and concepts; opening up old and ineffective machinery & practices and establishing brilliant modes of operation, also can be innovative.

- The conventional philosophy of looking at a business only from the myopic perspective of enhancing profits through more sales and hence more production, has now undergone a radical transformation in terms of the other vital parameters contributing towards higher profitability, directly or indirectly.
- Quality management is one such movement, on the wings of which many companies have been flourishing remarkably in their overall performance, year-after-year. What about the rest?
- Developing ability to attract talent and retaining them and integrating safety/environmental measures into the board-room concerns should now be on the agenda of Excellence-seeking steel plants organisations, to make our "Make In India" dream come true!

ANNEXURE I

A Mukand Mumbai Case Study Results Set

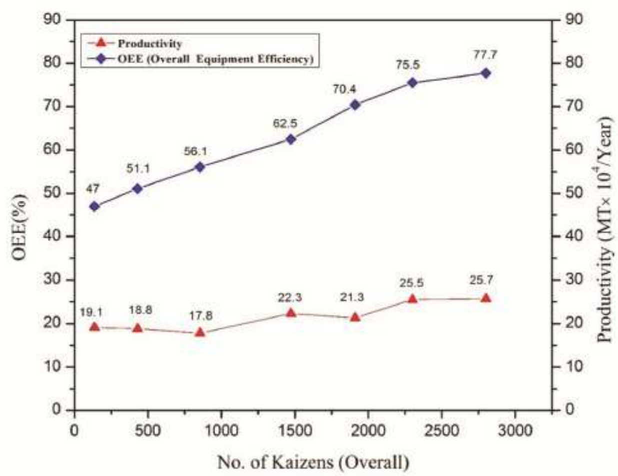


Fig.1 Impact of creative activities (Kaizens) by staff & workers of Hospet Steels on enhancing Efficiency (OEE) & Productivity.

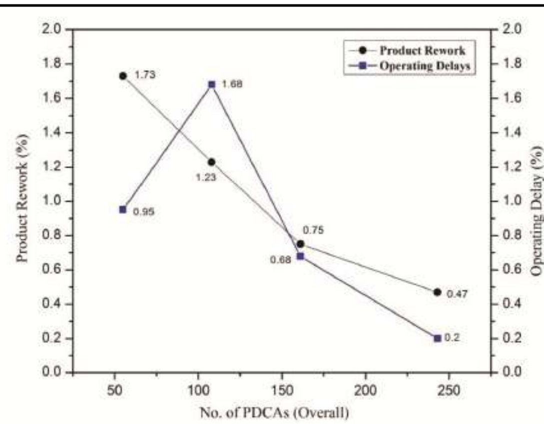
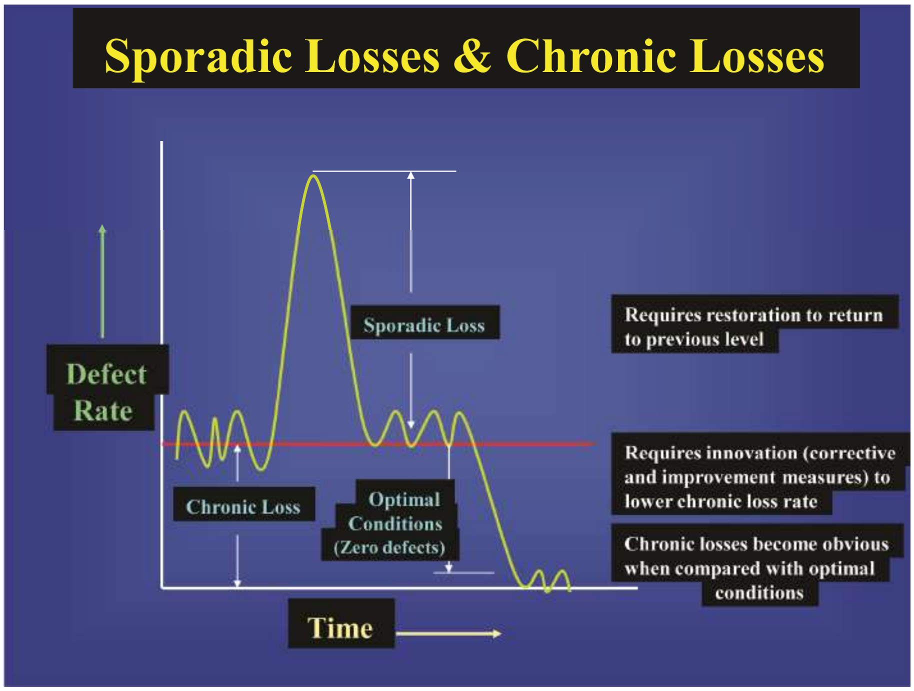
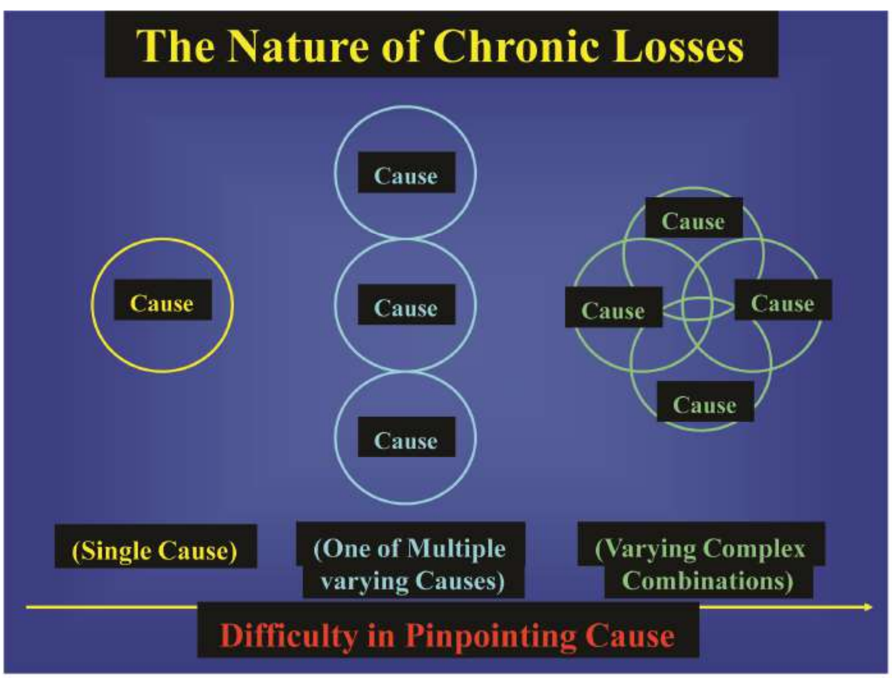


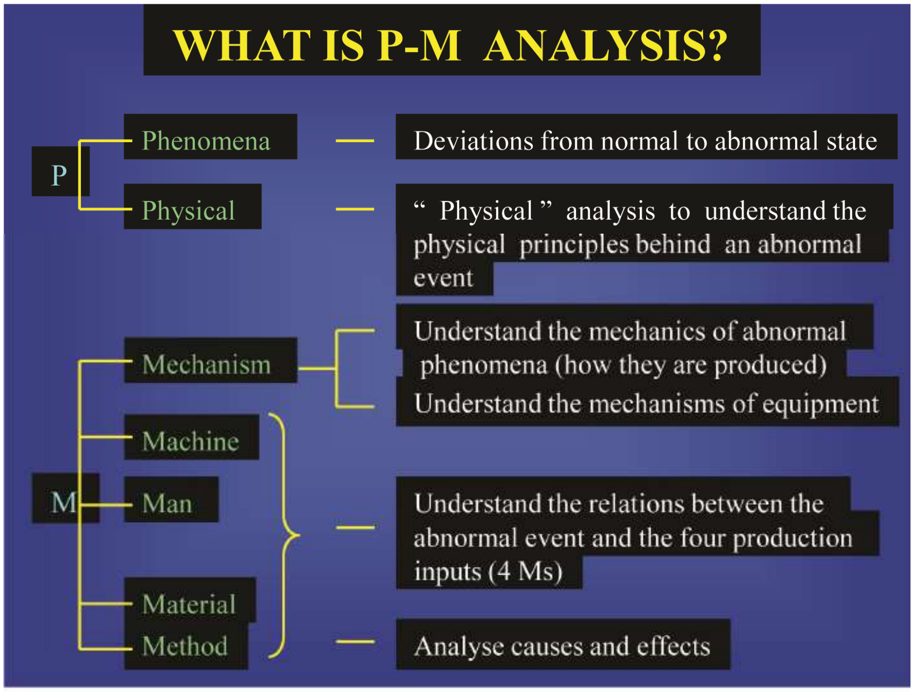
Fig.2 Indications on how Quality Management (Plan-Do-Check-Act) helped Mukand Steel in reducing rework/rejections and lowering process delays.

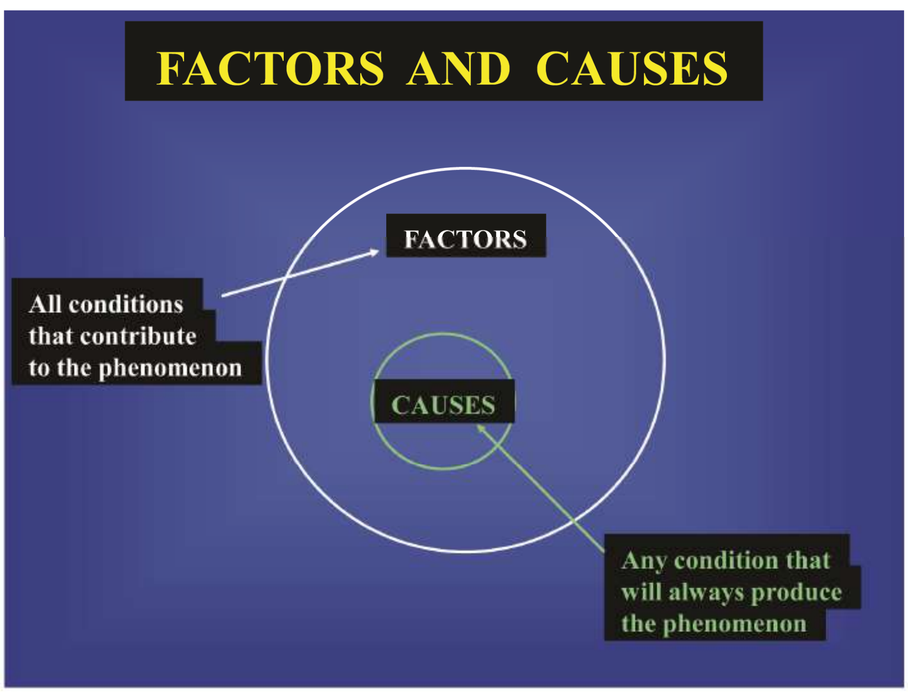
ANNEXURE – II

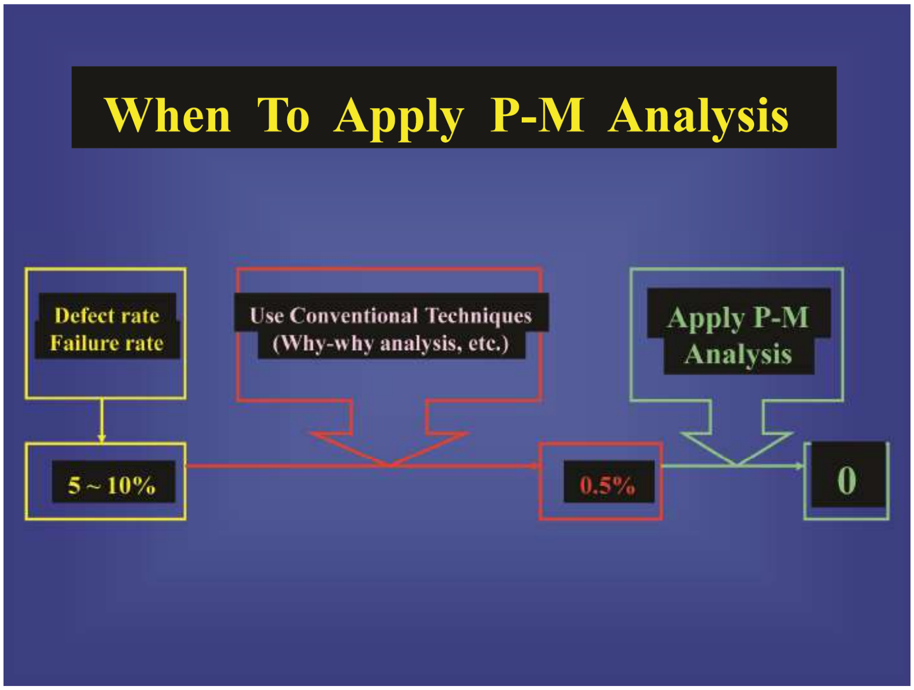
PM Analysis for Defect Reduction

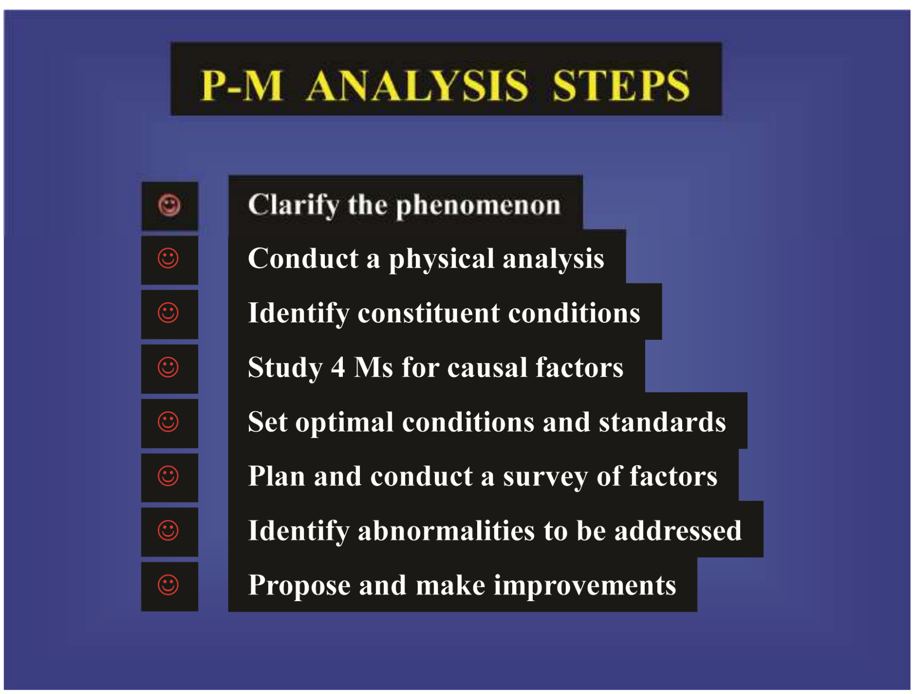


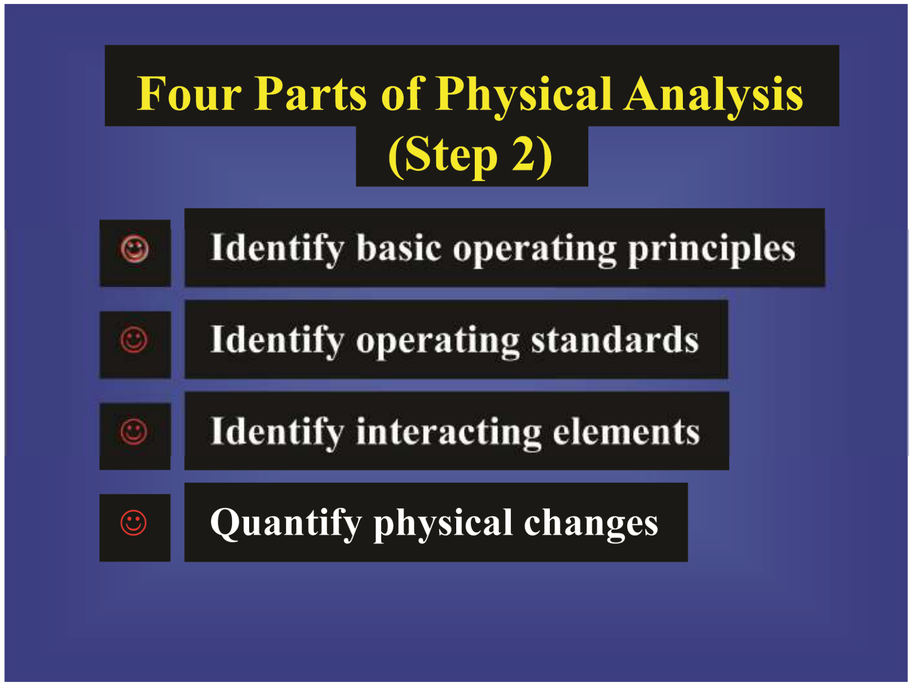


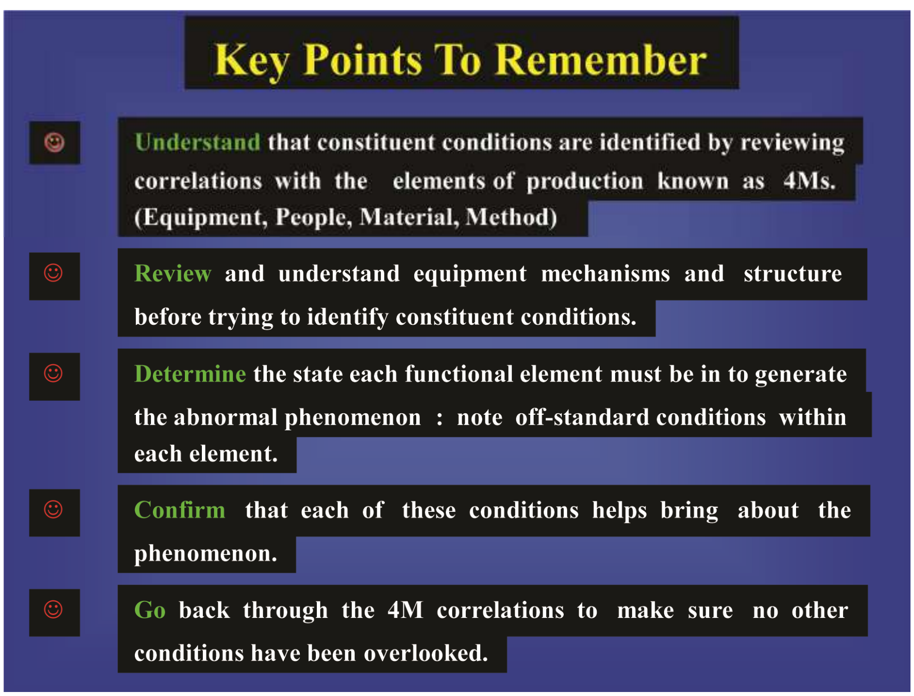

WHAT IS P-M ANALYSIS?
P
Phenomena
Deviations from normal to abnormal state
Physical
" Physical " analysis to understand the physical principles behind an abnormal event
M
Mechanism
Understand the mechanics of abnormal phenomena (how they are produced)
Understand the mechanisms of equipment
Machine
Man
Material
Method
Understand the relations between the abnormal event and the four production inputs (4 Ms)
Analyse causes and effects


FACTORS AND CAUSES
FACTORS
All conditions that contribute to the phenomenon
CAUSES
Any condition that will always produce the phenomenon


When To Apply P-M Analysis
Defect rate
Failure rate
Use Conventional Techniques
(Why-why analysis, etc.)
Apply P-M
Analysis
5 ~ 10%
0.5%
0


P-M ANALYSIS STEPS
Clarify the phenomenon
Conduct a physical analysis
Identify constituent conditions
Study 4 Ms for causal factors
Set optimal conditions and standards
Plan and conduct a survey of factors
Identify abnormalities to be addressed
Propose and make improvements


Four Parts of Physical Analysis
(Step 2)
Identify basic operating principles
Identify operating standards
Identify interacting elements
Quantify physical changes


Key Points To Remember
Understand that constituent conditions are identified by reviewing correlations with the elements of production known as 4Ms. (Equipment, People, Material, Method)
Review and understand equipment mechanisms and structure before trying to identify constituent conditions.
Determine the state each functional element must be in to generate the abnormal phenomenon : note off-standard conditions within each element.
Confirm that each of these conditions helps bring about the phenomenon.
Go back through the 4M correlations to make sure no other conditions have been overlooked.

Playing with Ordering: A Pathway for Developing New Alloys

Dr K Chattopadhyay

Department of Materials Engineering, Indian Institute of Science Bangalore

Introduction

I was hesitant when Prof N.R.Bandopadhyay and Dr Sanjay Sen asked me to deliver the V.Subramony memorial lecture. There are two reasons for my hesitation. The first one was the backdrop of this lecture. My contribution to steel is nominal and as I have told to the organisers, I feel very uncomfortable to give a public talk based on things in which I am not involved in research. You will all agree that it is difficult to give a lecture in the name of Mr. Subramony without talking about steel. The second hesitation was something that I was afraid of and never the less became reality after I agreed to give the lecture. I was requested to give a write up of my talk. This is a more difficult task since I am one of those speakers who finishes the last slide few minutes before the talk is delivered. Thus writing a lecture that will be delivered later is a very difficult task. Therefore, there is no guarantee that what I pen here is what I shall be actually delivering and I seek pardon from the reader. Of course it is a privilege to give a memorial lecture instituted in the name of Mr. Subramony. I distinctly remember the 1983 NMD celebration at BHU, our Alma Mater, and the function for distinguished alumni award. Many years later, I shared the award myself.

After a lot of introspection, I have decided to talk about a topic which is not only very close to my heart but also occupying most of my time. There is nothing more exciting to a metallurgist than developing a new alloy. The process touches almost every aspect of the knowledge of metallurgy that we learn as a part of growing up in this profession. The basis of such developmental process can be varied. However, for this speaker, ordering in alloys fascinates. Initially, as an electron microscopist, I was charmed by the richness of the ordered microstructure. The breaking of symmetry and changes in crystal structure as well as the possibilities that emerges during the ordering process formed the basis for a lifelong attraction.

At a much later stage, I realised the power of order hardening and the enormous possibility that they have in the alloy development. This talk will dwell on some of these and how we can utilise these to develop newer high performance alloys.

Any talk that is being delivered in Ranchi needs to start with steel. Unfortunately, as mentioned earlier, it occupies a very small place in my research profile. The reasons are many, not the least the difficulty of getting an open end funding for steel research. The funding in this field, somehow, always get connected to what is happening today in the industry, particularly in the Indian context. These are mostly on incremental improvements in the area of processing as well as minor tinkering of existing materials to suit our needs and requirements. Although these are important, it prohibits working on any radically new line of thought. The extraordinary emphasis on these aspects and not taking chances for a new development which mayor may not succeed have led to a continuing drought in the discovery and innovation space.

Steel and ordering

Let me, therefore, start with some examples in the domain of steel in recent time where the ordered particles are playing key roles. In fact there exist one class of materials where precipitation of ordered particles is of paramount important. The Maraging steel which our space and missile programme have extensively used in early time is strengthened during secondary heat treatment by the precipitation of hexagonal intermetallic phase Ni_3Ti which has close resemblance with the structure of ordered Ni_3Mo. A typical microstructure of the ordered precipitates taken from the work of Prof. Vasudevan from University of Cincinati is shown in fig. 1. Initially Maraging steel use to contain large amount of Co and Mo that resulted in higher cost. For a long time the attempt in the Maraging community is to reduce the expensive alloying additions without sacrificing the strength.

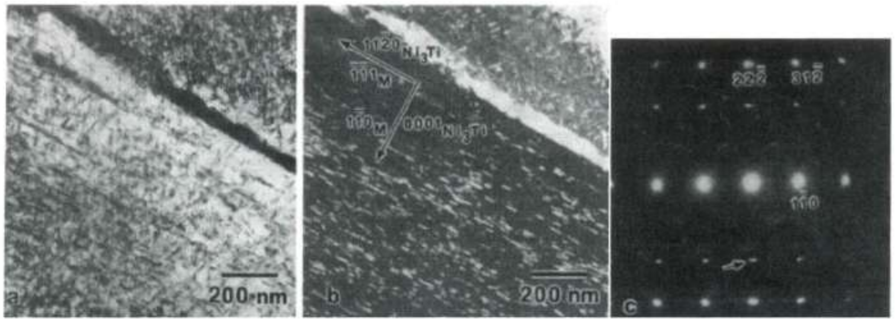


Fig 1

However, in the last five years there is a dramatic development with the push for ultrahigh specific strength steel. With the advent of Laser assisted processing, the amount of solute that can be pushed in the alloy steel have increased and much finer precipitates can be obtained in this processing route. The strength in many of these cases originate from the ordered precipitates. This coupled with tremendous development of 3D atom probe tomography (APT) has ushered in a new revolution in the development of ultra-high strength steel. The compositions of the strengthening precipitates can be more accurately determined that provide greater insight to nature of the ordered intermetallic compounds. In fact these newer steels are actually an evolution of old Maraging steel with significant reduction of alloying content. One of the latest works is by Jiao and co-workers where a high strength steel is reported with the composition Fe-2.12Cr-9.05Ni-0.35Ti-0.7Al-2Mo-0.05Si (See Jiao et ai, Materials Today, 2017). The fact that fascinates me is the realisation that some of the steel composition is remarkably close to some of the Ni based and cobalt based superalloys. I shall come to this at a later point.

Let us now move into another area of steel where ordering may play important role in future. With increasing demand of power due to increasing population growth, the requirement of high quality electrical steel will increase. Currently these steels contain -3% of Si or less. As is known to these audience, this steel is used in thin laminate form. Thus both the magnetic property as well ability to produce thin sheet plays important role.

There exist two variants. One in which grains are not oriented in the final product, called non grain oriented steel (CRNGO). In the higher grade the sheets are having Gauss texture to maximise the magnetic properties in the rolling direction (CRGO). These steels are developed more than sixty years back by ARMCO in the United State and since then saw tremendous advancement. The Japanese industries are at the forefront of this effort with orientation control through secondary and tertiary recrystallization through the addition of sulphur by ippon steel and Selenium addition by Kawasaki steel. In India we have limited success of producing CNGO steel while. if my information is correct. a CRGO plant is currently in operation as a subsidiary of a major European company. If my understanding is correct, a large push is being contemplated for producing both the grades of steel in India. There are two modem alternatives to CRGO steel. The first one is amorphous steel or the metallic glass. These are now produced in a large scale and is the first choice for large distribution transformer. The Indian research in this area was contemporary in the developmental stage. However, we had very little idea of the methods for scale ups and difficulties of taking a research to market place and in particular the IP, prototyping and related issues of business models and capitals. The second alternative to CRGO steel is Fe-6.5 Si steel. It has excellent properties and can compete provided the technical issue of brittleness can be overcome. The entire issue is intimately connected to ordering. We have started working on the nature of ordering in early eighties. The ordering reaction in Fe-Si system is complex. The system exhibit a triple point in terms of structural ordering (Fig. 2). The ordering reaction can be first order or second order depending on the composition and temperature history. There are two types of ordering reaction. Starting with disordered structure, a second order B2 ordering can take place. The B2 structure can further order leading to a DO_3 structure (fig3).

However, as the phase with DO_3 order is cooled from high temperature, it can undergo immiscibility and consequent conditional spinodal. The single phase DO_3 can phase separate into two phase having coexistence of two ordered structure either by nucleation and growth or by a spinodal transformation.

These complex ordering processes provide a rich variety of ordered microstructure affecting both magnetic and mechanical properties. The understanding of the ordering is particularly important as the brittleness owe its origin in ordering reaction and success of the achieving thin sheets of Fe-6.5Si alloy depends on reducing the order parameters during the mechanical deformation at intermediate temperature through processes like warm rolling (fig.4).

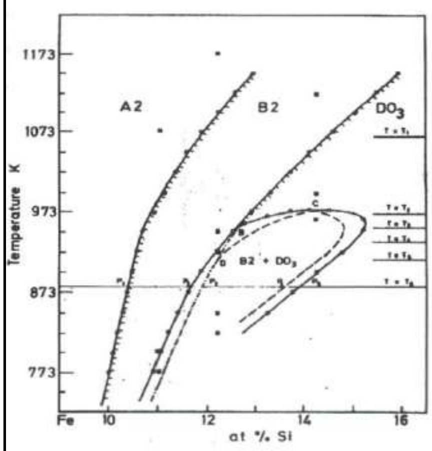


Fig.2

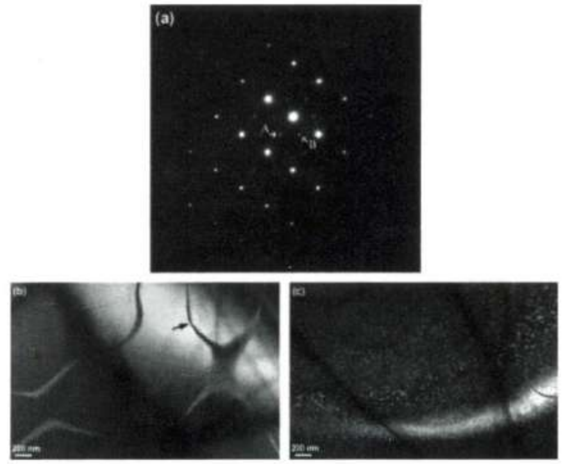


Fig.3

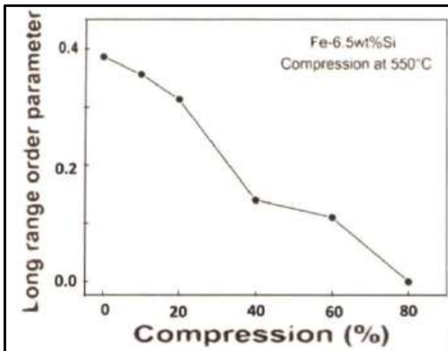


Fig.4

In fact a success in this direction will eliminate the need of complex processing and controls associated with CRGO steel with a product with superior properties.

Ordering in Fe-Si, unlike Maraging steel, not desirable. However, like the development of Maraging steel, we have recently used ordered precipitates to develop high temperature high strength aluminium and cobalt alloys with outstanding properties. In the rest of this lecture we shall present a part of these results to give a flavour of this new development which have enormous potential in developing next generation alloys.

Development of high temperature aluminium alloys

The aluminium alloys are generally age hardened to yield superior mechanical properties. The aging leads to the nucleation and growth of precipitates that strengthen the matrix. The classic examples of precipitation hardening alloys are those containing the copper rich Al-Cu precipitates. However, in spite of the fact the precipitates like D" and D' that are responsible for strengthening the alloy and have high solvus temperatures, the maximum operating temperatures for such alloys range from 150C to l80C. This is primarily because the precipitates coarsen rapidly above 200C leading to loss of strength. One of the keys to develop high temperature aluminium alloys is to restrict the coarsening of these precipitates.

The alloys can also be strengthened by precipitates that are stable at high temperature. In such a scenario, ordered precipitates can playa role. The mechanism of hardening by the ordered particles at high temperature does not depend on the coherency strain but often derives from order hardening.

Through extensive experimentation, we have succeeded to develop a new class of alloys that contains both Zr and Cu as alloying additions through a novel process. This involves precipitating the ordered Al_3Zr coherent particles first at higher temperature followed by solutionising the copper at higher temperature through optimisation of the kinetics of dissolution. The solutionise alloys containing coherent Al_3Zr particles are further aged at lower temperature (I90C) to precipitate the 'θ' or θ'' phases that are responsible for the further transformation (fig.5).

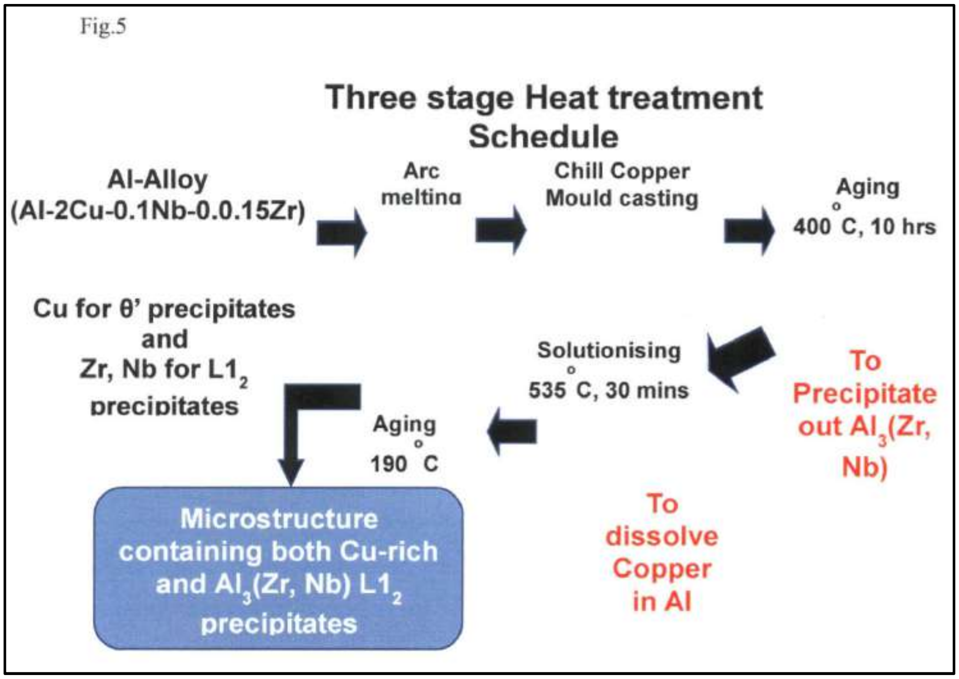


Fig.5

In the presence of Al_3Zr precipitate, the plate shaped copper containing precipitates nucleate heterogeneously on pre-existing Al_3Zr thereby developing a strain compensating microstructure (fig.6a-c). This allows development of an alloy that is stable and retains strength even at 250-300C while providing outstanding mechanical properties at high temperatures.

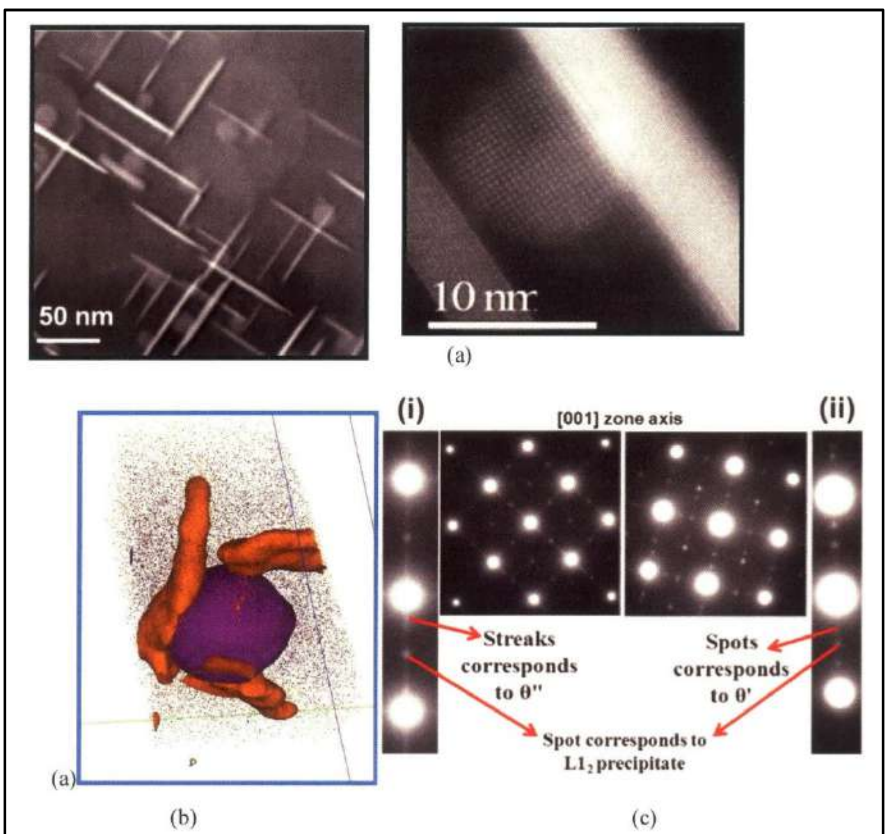


Fig.6

The last example of this talk has to be our recent work on cobalt based super alloys. Although expensive, these alloys are indispensable for use near the high temperature zones like burners. However, unlike nickel based super alloys, they are not strengthened by the ordered Ni_3AI precipitates. They are mostly solid solution strengthened with some carbides for creep resistance. Hence, they are not used in dynamic components. It is shown that addition of tungsten in Co-Al alloys can produce Ll_2 ordered Co_3Al precipitates that can strengthened the alloy through this ordered precipitates similar to that happens for nickel based super alloys. Unfortunately however, the amount of tungsten required is large and hence the alloy density becomes very high. Since specific density is one of the most important parameter in high temperature applications, particularly in aerospace and energy conversion systems, significant attempts were made in the last decade to find an alternate to tungsten. However, all such attempts failed and it was a consensus in the community that tungsten addition is essential for getting γ - γ' -' microstructure in cobalt based super alloys.

In a series of three articles in 2015, we have challenged this wisdom of the community and have announced a series of alloy where with the addition of molybdenum and a small amount of quaternary addition of either Nb or Ta, it is possible to produce a γ - γ' microstructure that yield high strength.

A typical microstructure of these super alloys us shown in fig 7.

The initial alloy, however, had a very low solvus temperature and hence not suitable of high temperature applications. However, it is possible to adopt the classical metallurgical approach of alloying to increase the solvus temperature. For example addition of nickel can increase significantly the solvus temperature (fig.8).

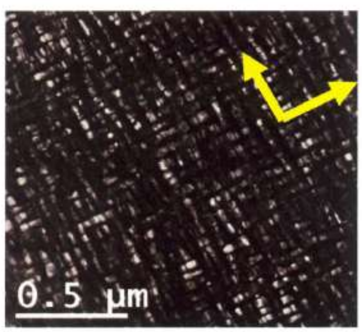


Fig 7

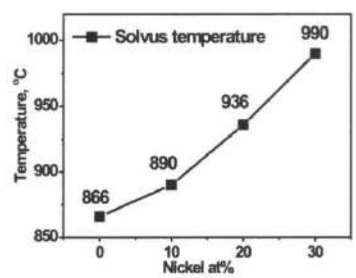
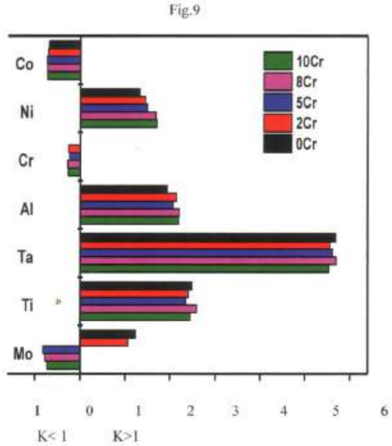


Fig. 8

A further development of these alloys require systematic analysis of solute partitioning between 0 and 0' phases and how they affect the stability of the alloys. Fortunately, the advent of transmission electron microscope with very high composition resolution and the 3D atom probe tomography (APT) allow us to determine the partition of solutes very accurately. In fig. 9, we show the partitioning of varying alloying addition during aging between the two phases. This knowledge allows us to design alloys with high solvus temperatures. A summary of mechanical properties of these alloys in comparison to other available alloys are shown in fig. 10.

Fig.9



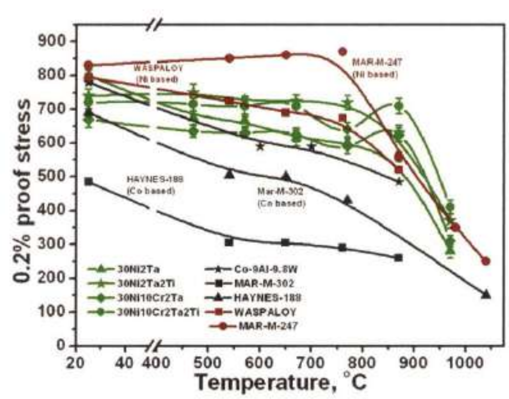


Fig.10

As one can see these alloys can one of the few success stories for this country to develop a new alloy for the world community. However, alloy development requires a long term effort. As stated earlier, it requires various level, not the least from industry as they can bring rare insights which are not known to academician. In my limited interaction with my peers at General Electric, T could get understandings which T could not have got in any other ways. Fortunately for me DRDO has extended a helping hand in this effort strong support to this effort. The alloy development, I have now realised cannot be done alone or by one group. Fortunately my peers have rallied behind me in a big way.

Final comments

The potential for developing new alloys through ordered precipitates is enormous. With the research getting more focussed in multicomponent alloys in recent time, the phenomenon of ordering and ordered precipitates can play an important role. We have not yet fully exploited the ordered precipitates except in nickel based super alloys. It is my belief that much more is in store and in future, we shall even see steels with ordered precipitates that can rival superalloys. However, the alloy development requires many different skills. India is short of active scientists in any given field. We are often subcritical. The lesson that I have learned in the 40+years in profession is that we need to work together to make an impact. Any high impact work today is the results of large number of authors. Sooner we embrace this culture, better it is for all of us.

Role of Stakeholders in Development of Road Map for Steel Vision: Focus on the Secondary Steel Sector

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ABSTRACT

The use of steel is all pervasive and is a dominant factor in measuring the industrial output as well as development index of a nation. Steel derives its demand from other important sectors like infrastructure, construction, engineering, capital goods, automobile, oil & gas, defence, ship building, packaging, etc. As on date, the secondary steel sector (also now being referred to as MSME) accounts for roughly 39-40 % of the overall Indian steel capacity.

The National Steel Policy 2017 (NSP 2017) has set an ambitious target of attaining crude steel capacity of 300 MT by 2030-31. The Indian steel industry is broadly structured on categories based on route-wise production, viz., BF-BOF, DR-EAF/ IF and of late BF-DR-EAF/CONARC routes. The BF-BOF route is the most preferred route for large integrated steel plants (primary producers) and is expected to contribute to around 60-65 % of the crude steel capacity by 2030-31. This calls for a capacity augmentation of the secondary steel sector from the present 45 MTPA to around 80-85 MTPA by 2030-31.

Thus the contribution of the secondary steel sector in the gross national steel capacity projection is going to be very significant. In fact appreciating the role played by MSME in the growth of Indian steel sector, NSP 2017 envisages emergence of a modern, technologically efficient, highly productive, energy efficient and environment friendly MSME which will be encouraged to set up new capacities on a cluster approach in proposed industrial corridors for optimal utilization of land & achieving economies of scale.

This sector, as also Indian steel industry is presently undergoing tremendous stress due to varied factors. Some of the important issues are non-availability of raw materials and its costs, of late non-availability of railway rakes impacting on the production or bringing plant to near closure, high logistic cost, high electricity cost, high energy consumption, technological backwardness, low efficiency, non-availability of multiple financing options, high cost of capital, product quality, lack of high end product mix & lack of adequate governmental support ,etc.

My talk shall focus on challenges & plaguing issues faced by the secondary steel sector & suggest remedial measures.

ABBREVIATION

BPNSI : Biju Patnaik National Steel Institute

DMI&SP : Domestically manufactured Iron & Steel Products

MSME : Medium & Small Manufacturing Enterprises

MMSCMD : Million standard cubic metre per day

NIMZ : National investment & Manufacturing Zones

NSP 2017 : National Steel Policy 2017

SRTMI : Steel Research & Technology Mission of India

INTRODUCTION

The National Steel Policy 2017 (NSP 2017) of the Govt. of India rightly states that, “Steel is a product of large and technologically complex industry having strong forward and backward linkages in terms of material flows and income generation”.

The use of steel is all pervasive - steel is the preferred material to build climate resilient cities and for coastal protection. Steel protective designs are increasingly used to minimize the impact of natural disasters. Steel is essential for energy production & transmission. Mining equipment, equipment for oil & gas exploration, transportation systems, etc., in fact the entire capital goods sector, cannot be imagined without steel providing the backbone. Today steel is one of the most important & strategic products of any industrial nation.

As per statistics, in India, steel has an output multiplier effect of nearly 1.2X on GDP and employment multiplier factor of 6.8X. Historically also, a vibrant steel industry has been the bedrock of a nation's rapid industrial development.

The infinite recyclability of steel without loss of property and enormous range of properties with slight variation in chemical composition, makes it an unique material to make modern society sustainable. Steel saves energy over its many life cycles through its 100 % recyclability, durability & lightweight potential.

The National Steel Policy 2017 (NSP 2017) has set an ambitious target of attaining crude steel capacity of 300 MT by 2030-31.

The Indian steel industry is broadly structured on categories based on route-wise steel production, viz., BF-BOF, DR-EAF/ IF and of late, BF-DR-EAF/CONARC routes. The BF-BOF route is the most preferred route for large Integrated Steel Plants (ISP) who are generally referred to as the “Primary Producers” utilizing mainly iron ore (lump/ fines) and coke (coking coal) to convert iron ores to steel.

A very typical feature of the Indian steel industry is the presence of large number of small steel producers, referred to as secondary steel producers or MSME characterized by the prevalence of the IF/ EAFs utilizing sponge iron (DRI or hot briquetted iron i.e. HBI, scrap, small quantity of pig iron etc. as the solid charge materials in their steelmaking process. However, EAFs are known to accept a considerable amount of hot metal as charge material (typically 40-60%) along with other solid charge.

Apart from the above two, other manufacturing units, viz., independent pig iron producing units utilising small blast furnaces, hot & cold rolling units, re-rolling units, galvanizing & tinning units, pipe manufacturing units, etc. are also covered under the secondary steel producers or secondary steel sector category. They largely produce long steel products, primarily meant for building & construction industry.

As on March, 2017, there were 320 sponge iron units, 48 Electric Arc Furnaces (EAF) & 1,126 Induction Furnaces (IF) that use sponge iron and/ or melting scrap to produce semi-finished steel and 1,166 re-rollers that roll out semi-finished steel into finished steel products for consumer end use.

As per NSP 2017 projections, BF-BOF route shall typically contribute to about 60-65 % of the crude steel capacity by 2030-31, about 33-38 % by EAF and IF route and remaining 2 % by new emerging processes such as Finex, ITmk3, etc.

The Indian steel industry is currently operating at a capacity level of ~128 MTPA. The present capacity utilization is hovering around 76 %. As per NSP 2017 projection, crude steel production by 2030- 31 is expected to be about 255 Mt with a capacity utilization of 85%. Considering 60-65 % contribution coming from the BFI BOF route, it would account for about 155-165 MTPA steel & the EAF/IF route shall account for 85-95 MTPA production. This calls for a capacity augmentation of the secondary steel sector from the present 45 MTPA to about 80-85 MTPA by 2030-31.

COMPOSITION OF THE INDIAN SECONDARY STEEL SECTOR

The Indian secondary steel sector is a diverse heterogeneous conglomeration, widely dispersed throughout the country. They have widely varying product range, human skill levels, technologies & scale of operation. Figure 1 below depicts the concentration of secondary steel producers in terms of capacity across different parts of the country.

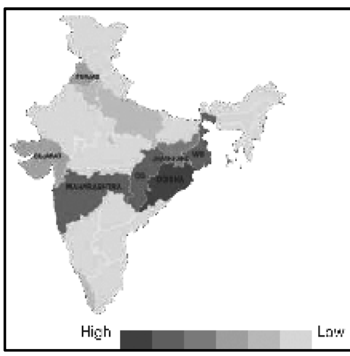

Figure 1 : Concentration of Secondary steel producers (capacity-wise) across different parts of the country

The secondary steel sector includes the following major industry segments:

- Mini Blast Furnaces (MBFs) producing pig iron
- Sponge iron units
- Stand alone beneficiation cum pellet producing units
- Electric Arc Furnace (EAF) steelmakers
- Induction Furnace (IF) steelmakers
- Standalone Cold Rolling Mills (CRMs) producing sheet &
- coils
- Re-rollers with Hot Rolling Mills (HRMs) producing long
- products
- Standalone Galvanizing Pipe (GP)/ Galvanizing Coil (GC) producers
- Standalone Colour Coated sheet steel/ coil producers
- Wire drawing units
- Standalone Tinplate producers
- Standalone pipe producers.....etc.

The units included under the secondary steel sector generally produce a basic intermediate input raw material for steelmaking, viz., pig iron/ sponge iron or else, convert a semi finished/ intermediate steel product to a product of higher value. The sector also includes crude steel semi finished producers like ingot, billets & blooms. Most of the manufacturers employ the EAF or IF route for steelmaking using scrap and/or DRI, hot metal/pigs and their average capacities are less than 0.5 MTPA. The segment-wise capacity & production of the secondary steel sector during 2016-17 is as follows:

Type of Industry	No. of Units	Annual Capacity (000 t)	Production (000 t)	Capacity Utilisation (%)
Blast Furnaces	44	2107	412324	58.5
Sponge Iron Units	315	33, 388	21,461	64.3
Pellet producers	25	49,100	36,150	73.6
EAFs	42	17,127	13,187	77.0
Ifs	1,126	39,621	26,972	68.1
Re-Rolling Mill Units	1,157	43,463	36,527	84.0
Wire Drawing Units	52	1,462	888	60.7
HR Products	14	12,619	7,119	56.4
CR Products	60	13,693	8,085	59.0
GP/ GC Sheets	16	3,902	2,988	76.6
Colour Coated Units	12	1,635	1,257	76.5
Pipes	15	2,630	1,938	73.7
Tinplate	2	530	314	59.2

OUTLOOK FOR THE INDIAN SECONDARY STEEL SECTOR

The present low per capita finished steel consumption of around 63 kg as compared to the global average of 208 kg signifies enormous opportunity to increase steel consumption in the country. In fact NSP 2017 envisages a per capita steel consumption of 160 kg by 2030-31. This offers a huge potential for the growth of secondary steel sector.

Steel consumption in India is highly biased towards urban areas. The rural steel consumption stands at paltry low level of 11-12 kg per capita. By targeting captive consumers, especially in rural & semi-urban areas and meeting specific local demands, the secondary steel sector can contribute significantly in meeting the objectives of NSP 2017.

The secondary steel plants have the inherent advantage of lower capital cost, no (minimal) requirement of coke/ coking coal, smaller land footprint, etc. However, the advantages are severely offset and hampered in terms of its adaptation of modern green, cost effective and energy efficient technologies. Further product quality in line with global quality requirement, must occupy a centre stage in technology adaptation and operational practices. In this respect, development of cost effective refining methods is a vital task to make the secondary steel sector at par with the quality steel requirements. Besides, secondary steel sector must concentrate or development & production of niche products so that it can operate in a premium steel market.

CHALLENGES FOR THE INDIAN SECONDARY STEEL SECTOR

The global steel industry after passing through the bottom of the sinusoidal curve, seems to be looking up, however, issues like global excess steel capacity, subsidy leading to market distortions and dumping of steel, continue to pose serious challenge to its revival, growth and sustenance. Barring India & a few other countries, either growth trend is negative or at best marginal.

The problems of the secondary steel sector which need to be addressed on priority may be generally listed as below:

- Obsolete & inefficient technologies
- Limitations of economies of scale (most units are either small or medium sized & dominantly family owned)
- Lack of corporate vision and long term entrepreneurial outlook
- Lack of professionalism and near absence of professional management of steel plants.
- Lack of cohesiveness in the industry as a whole
- Lack of adequate skilled manpower availability
- Casual approach in hiring skilled manpower
- Lack of incentives & motivation as well as facilities provided to the work force
- Poor R&D spending & awareness / inclination to modern technologies

All these issues directly affect the industry's top & bottom line labelling it as having poor investment potential. These only compound their problems and restrict access to easy & softer credit, making the industry more vulnerable to inefficient operations. Some benchmarking indices of the secondary steel sector vis-à-vis global small scale steel industries are presented below:

Parameter	Unit	Indian Standard	Industry Benchmark
Oil Consumption	Litres/t	45	30
Coal Consumption	Kg/t	80	50
Gas Consumption	Nm^3/t	50	30
Furnace Productivity	Kg/ m^2/t	150	350
Scale Loss	%	3	1
Power Consumption	kWh/t	100	80
Yield	%	90	95
Mill Utilization	%	70	85

The added disadvantages of the secondary steel sector are:

- Raw material security
- Trade related issues
- Quality issues
- Financing challenges
- Market related issues

Raw Material Security

Coking Coal: India is deficient in coking coal. Though India has the fourth largest proven coal reserves of the world, yet these are low quality & around 83 % is non-coking coal. Today, coking coal constitutes around 22 % of total coal imports. Access to coking coal is likely to have a huge impact on the margins of steel manufacturers. About 85 % of coking coal requirement of the Indian steel industry is being met through imports. In secondary steel sector, only small blast furnaces producing hot metal/pigs require coking coal or metallurgical coke. The secondary steelmakers require around 10 MTPA coking coal and/or eqv. coke which are mostly imported.

Non-Coking Coal: The sponge iron production from coal based units ideally require B to C grade non-coking coal, but they can easily accept up to E grade with/without beneficiation. However, mostly they receive F to G grade coals having very high ash (nearing 50% and sometimes exceeding 50%). These coals invariably require beneficiation and even thereafter, would not be able to meet the desired specifications. Though availability of good grades of non-coking coal are dwindling fast in the country, there should be prioritization in allocation of good grade of non-coking coal to sponge iron sector as compared to power sector. The secondary steel producers like sponge iron manufacturers could not participate in the recent mining bidding/ auction process as they were not eligible. At the same time, Coal India Limited (CIL) has fallen short of its production target last year. The bulk of coal produced by CIL is earmarked for the power sector. This leaves the sponge iron manufacturers in a constant state of uncertainty & shortage with respect to availability & price. Availability of limited linkages through fuel supply agreement (FSA) and dependence on spot auctions (irrespective of the grade), often necessitate part import of non-coking coal to meet the steel sector requirement. Imported non-coking coal generally comes with higher price and affects viability of coal based sponge iron plants.

Iron Ore: Uncertain & inadequate supply security is potentially jeopardizing the prospects of sponge iron units. The present eligibility rules prohibit participation of smaller players for iron ore auction on individual or consortium basis due to the requirement of very high net worth. Therefore, rules need to be revisited to allow their participation, at least on consortium basis. Securing an iron ore mine through auction by a group of mini steel plant entrepreneurs, will go a long way in mitigating supply related issues of iron ore. The sponge iron plants continue to be dependent on the merchant miners, who most of the times dictate on quality & price. Of late rake availability for supply of iron ore & coal has become a major issue leading to extremely low inventory of raw materials in steel plants – putting intense pressure on plants to operate at lower production levels or face closure. Hence issue like rake availability and other logistics need to be sorted out quickly to remove barriers on the path of fast growth of Indian steel sector.

Under-utilisation of low grade iron ore : As per the policy of Govt. of India, to ensure long term raw material security, judicious use of iron ore with a mix of high & low grade , need to be used and promoted. Large amount of low grade fines, dump fines/slimes, of the order of 90-100 Mt are lying unused in mine heads causing environmental hazard, blockage of space and wastage of useful resources. While on one hand, we are incentivising the use of beneficiation and pelletisation, on the other hand, due to prevailing price structure fixed by IBM for low grade iron ore fines (55-58% Fe) vis-a-vis high grade iron ore fines, it is not economical to beneficiate low grade iron ore to higher Fe level and use in the form of pellets. Payment of high royalty even on the low grade iron ore, which is one among the highest in the world, has further compounded the problem. This has adversely impacted the cost competitiveness of the pellet industry. Instead of using such ores for pellet making, there is large scale attempt to export. This is the reason that export of low grade iron ores has seen sharp jump in recent times.

Natural Gas: The sharp increase in production of sponge iron from gas based DRI plants is an indication of higher capacity utilization of existing plants besides coming up of new capacities in JSPL, Angul and JSW, Toranagallu using coal gasification and coke oven gas respectively. Due to limited availability of natural gas and its price, DR plant at JSW, Dolvi is also modified to use coke oven gas. Further, compared to earlier years, there has been decrease in natural gas price, which has come down to US $ 6-8/MMBTU. The long range demand supply scenario for natural gas indicates huge deficit, to the tune of 272 MMSCMD and therefore, current situation still does not favour emergence of gas based DR plants in a big way and hence no new capacity is being planned on the same.

Other Materials: Key ingredients for stainless steel include ferro chrome, ferro nickel, charge chrome, ferro molybdenum, pure nickel, etc. Some of these are not available domestically & expose the secondary steelmakers to global uncertainties.

Trade Issues

2014-15 & 2015-16 have been the tough years when India could see sudden surge in imports, which was accentuated by prevailing Free Trade Agreements (FTA) with ASEAN region and countries like Japan & South Korea. All these put the secondary steelmakers, who are generally small & disintegrated producers, at a great disadvantage. However, some quick trade remedial measures by the Government such as imposition of MIP, safeguard and antidumping duty, brought relief to the Indian steel industry.

India has operational FTAs with ASEAN region & Korea since 2010 and with Japan from 2011. India is also a partner country for the Regional Comprehensive Economic Partnership (RCEPASEAN). As part of the tariff concessions offered under these agreements, India has lowered import duties on stainless steel flat products.

Although there has been a lowering of duties on raw materials as part of these ongoing FTAs, the same has not yielded positive benefit since most of the imports (raw materials) are from outside the RCEP region.

As per available data, India imported 9.32 Mt & 11.71 Mt of finished steel in 2014-15 & 2015-16 respectively, out of which > 75 % has originated from China, Korea and Japan combined. This has impacted badly on secondary sector steel makers as declining prices eroded their profitability leading to reduced production and declining capacity utilization, etc. However, things have become better in 2016-17 and current financial year 2017-18 when India has become net exporter of steel.

The sponge iron producers have also been affected by the rising volumes of scrap import.

Import of metal scrap also faces various hurdles like CENVAT credit, pre-shipment inspection certificate, logistics costs, customs issues, disposal issues, access to Inland Container Depot (ICD), etc. Preference to domestic manufacturers over imported products in Govt. procurement.

Indian manufacturers, particularly those in the secondary sector, often lose out to their foreign competitors in global bids, due to predatory pricing / volume strategy. To provide preference to domestic iron & steel manufactured products in Govt. procurement, Ministry of Steel, Govt. of India came out with a concept of domestic value addition and accordingly, DMI&SP policy was framed and approved by the Indian cabinet.

Product Quality Issues

Quality is a persistent festering issue with the secondary steel sector.

Most of the existing Induction Furnaces (IFs) do not have facilities for secondary refining, so their product cannot be competitive in the domestic market. BIS stipulations call for LRF/ VD or EAF routes of steelmaking, making most of the products from IFs & standalone rolling mills as non-compatible.

There is an acute lack of understanding of the quality issues being faced by the secondary steelmakers who need access & patronage of centralized testing & quality control laboratories, R&D units, etc.

There are inadequate laboratories approved by BIS for testing ferrous & other materials as per the BIS standards & specifications in order to improve the quality of the products that these secondary steelmakers are producing. Similarly, it is time consuming & cumbersome to obtain the test reports of the samples from already existing laboratories, which is detrimental to smooth functioning of the industry.

Operational Issues

In our country, the transportation & power costs are very high compared to other major steel producers. The recent increase in electricity charges announced by various states specifically for the steel industry is having a detrimental impact on the secondary steel producers.

In the last few years, it has been found that any steel producer faces extreme difficulty to start a green field project or even brown field expansion as it involves various issues ranging from cumbersome, lengthy & costly land acquisition to a number of government clearances from the state & central governments, which take an unduly long time, thus escalating costs. Until such clearances are streamlined & made time-bound, meeting the vision of 300 MTPA will remain extremely challenging.

Financial Issues

Poor demand growth for steel & cheaper imports to India are putting pressure on the prices offered by the domestic producers. The prices are approaching closer to the cost of production which is adversely impacting the profitability of the domestic secondary iron & steel makers. Given the high interest cost which is prevalent in India, profitability is not even enough to cover interest costs & debt servicing is being negatively affected. The banks are reluctant on taking further exposure to the steel sector, especially for the secondary steel producers. This is resulting in huge shortage of funds & delay in investments.

Technology Issues

The secondary sector employs a mix of old, obsolete and new technology, with lack of required forward & backward integration. Established technologies are available for this sector such as oxygen assisted melting, oxygen fuel burner, EBT, etc. but adoption is restricted due to high CAPEX. Lower economies of scale are restricting the adoption of better technology units. For the very small re-rolling segment, adoption of energy efficient technologies is practically not economically viable.

RECOMMENDATIONS & THE WAY FORWARD FOR THE INDIAN SECONDARY STEEL SECTOR

The ambitious "Make in India" initiative by the Govt. of India has rekindled hopes of a bright future. Few steps in the right direction, viz., New Manufacturing policy raising the share of manufacturing from 16 to 25 % by 2022, setting up of SEZ, National investment & manufacturing zones (NIMZ), concepts like skill India, Digital India, Start-up & Stand up India, smart cities, mega investment in roads & highways, bridges & railways, Sagarmala &

Bharatmala project to provide last mile road & rail connectivity, dedicated freight corridors, impetus on housing & construction sector, defence, automobiles, ship building, packaging, etc. have the potential to spur the domestic steel demand.

Raw Material

- Priority allocation of iron ore & non-coking coal of good quality to the secondary steel sector
- Participation of secondary steel producers in the proposed auction of iron ore mines through consortium
- The current price structure fixed by IBM for low grade iron ore fines (55-58% Fe) makes the beneficiated fines much costlier than the high grade iron ore (sinter grade) fines. This has adversely impacted the cost competitiveness of the pellet industry. To alleviate the problem and to provide level playing field, there should be reasonable price differential between low grade iron ore fines and high grade iron ore fines. Prima facie, a differential of Rs. 800-1000/t could be looked into. Further, to encourage use of low grade dump fines/slimes, reduced royalty may be fixed in comparison to royalty charged for high grade iron ore fines. Against a normal royalty rate of 15 %, reduced royalty @5-7.5% could be thought of.

Further limits can be imposed on the stockpiling of low grade fines/slimes at the mines head, so that miners are compelled to sell these low grade fines along with high grade ore or set up their own pellet plant for their utilization. Regular audits can be taken to ensure enforcement of the limits.

- Priority from railways in rake availability & freight pricing
- NMDC and other state Mining Corporations, may preferentially supply iron ore on a cluster based approach to mini steel producers keeping in view the proximity of mines from such clusters e.g. Raipur-Durg cluster can be fed from NMDC's Baildilla mines.
- PSUs like NMDC to act as canalizing agency to supply high grade coal with/ without washing to this sector
- Promoting ship breaking industries & developing mechanism for segregation of scrap of various qualities. MSTC can play an important role in this area.

Trade

- Import restrictions (anti-dumping) to safeguard the domestic players
- Curtail import of sub-standard steel (Quality control order is an effective measure already undertaken by MoS, GOI)
- Imported steel to be quality compliant as per the BIS
- Implementation of DMI&SP policy has brought much relief to Indian manufacturers mostly belonging to secondary steel sector, which has raised the capacity utilization of their plant as well as provided opportunity to preferentially supply their products in all government procurement. The immediate effect has been seen in bidding of long distance pipeline projects of GAIL where domestic pipe manufacturers could get the contract over the foreign (Chinese) suppliers.

Operations

- Various government clearances for doing business to be made efficient & time bound
- MoS should take initiative for setting up common state-of-theart laboratory cum testing facilities for secondary steel sector, preferably at Raipur and Bhiwadi, Rajasthan to meet the requirement of eastern, central, northern & western regions. This will go a long way in tackling the quality related issues. Some initiative is already under way on this matter.
- MoS should also take initiatives with the help of BIS to promote & educate the buyers for acceptance of BIS mark product without specifying any route.

Transport and Logistics

- Alongwith the development of roadways, focus should be given on strengthening coastal/ waterways for domestic transport, which is relatively cheaper. The government is seriously pursuing this through Sagarmala project.
- Railways to treat the secondary steel industry as a priority sector
- One environmental friendly & convenient way to transport iron ore from the mines to the plants elsewhere is through the slurry pipelines. However, in India we do not incentivize this method of transportation, which we need to, if we are to save on fuel and already overburdened Indian Railways.

Finance

- Availability of funds for modernization of secondary steel sector at a cheaper cost.
- Maximum limit of financial exposure for availing RBI's facility of Flexible Restructuring of existing long term loan policy should be brought down to `200 Crore from the existing `500 Crore limit.

Technology

- A technology mission need to be set up exclusively to critically examine the health of the secondary steel sector, to assess its technology level and suggest changes required to make them technologically sound and energy efficient at par with the best while ensuring environmental compatibility.

R&D Needs

- There is a pressing need to evolve a separate institutional mechanism to address the R&D needs of the secondary steel sector/MSMEs in the country. This should also provide the necessary ground work for fostering innovation for continuous technological improvement of the sector. The Steel Research & Technology Mission of India (SRTMI) could have a separate wing exclusively dedicated to secondary steel sector.
- Institute like Biju Patnaik National Steel Institute (BPNSI) located in Puri, can be upgraded to a National centre of Excellence in separate location at Bhubaneswar, to additionally meet the R&D needs of secondary steel producers in Odisha, Jharkhand & Chhattisgarh region.

Skill development

- For the states like Odisha, Jharkhand & Chhattisgarh, where secondary steel sector has a large presence, a state-of-the-art skill development centre can be set up for generation of skill inventory as well as generating opportunities for employment of local populace through skill enhancement.

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iv. In-house Database of MECON

Challenges in the Production of Aerospace Grade Niobium and Nb-W-Zr Alloys for Structural Applications at High Temperature and Oxidative Conditions

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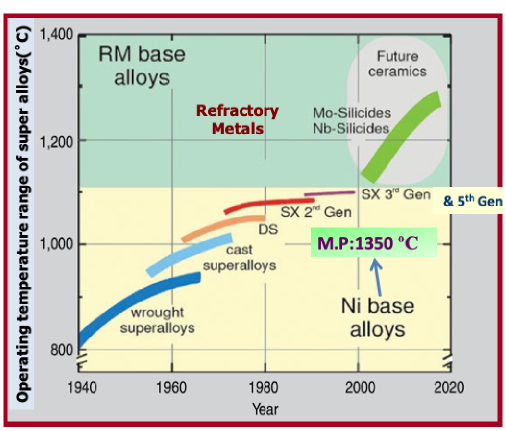
Abstract

Niobium alloys represent the last frontier in high temperature metallic materials, since their temperature capability exceeds that of nickel based superalloys. They have been used in rocket nozzles of space vehicles and are identified for scramjet construction of hypersonic vehicles. However, Nb alloys oxidise rapidly above 500 C, where the oxidation is internal as well as external, depending on the ambient conditions. Being a refractory metal with high melting point, production of Nb based alloys is a non-trivial matter.

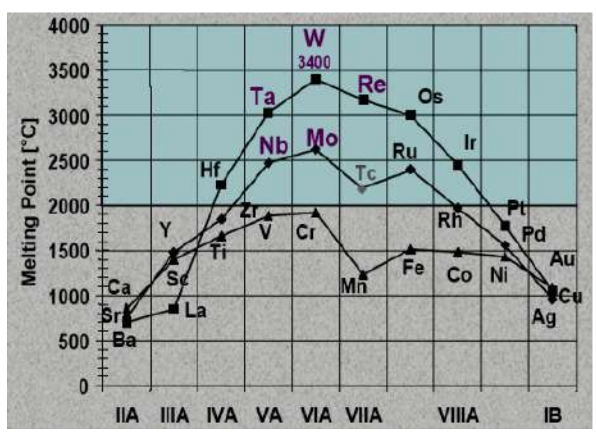
In this article, issues pertaining to the production and processing of pure Nb and Nb-W-Zr alloy Cb752 will be presented. Results of recent work done in DMRL will be highlighted. The work carried out so far has established a viable production route to make alloy ingots of the required integrity and with impurity levels below permissible limits. Their processing to plate and sheet forms, and coatings for oxidation protection have also been demonstrated.

1. Introduction

The high temperature capability of nickel base superalloys in the form of single crystal investment castings is saturating near about 1100-1125 C. The temperature capability of refractory metal (e.g. Nb) based alloys and intermetallics and of ceramic composites exceeds 1200 C (see Fig. 1a). Compared to other members of the family of refractory metals like W, Re, Ta and Mo, which are used in other engineering applications (Fig. 1b), Nb has the lowest density (g/cc) which is slightly greater than the density of pure Ni (g/cc). Compared to the other refractory element Ta which has the next lowest density, Nb DBTT is lower by more than 100 C and imparts better toughness even at room temperatures. Nb alloys can be electron beam welded. In spite of this, the usage of Nb is presently more as an alloying element in steels as well as non-ferrous alloys, and its use as Nb based alloys is only about 5%. This is mainly due to difficulties in making them and because of their poor oxidation resistance.



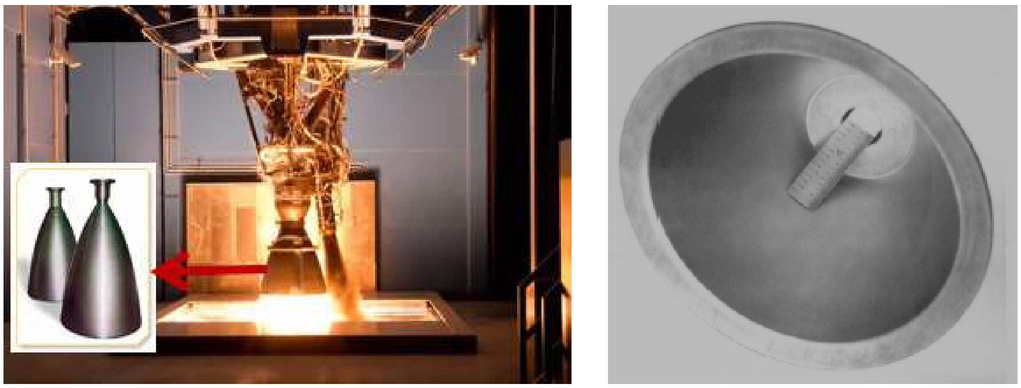
(a)



(b)

Fig. 1: (a) Progress in high temperature capability of refractory metals, intermetallics and ceramics in relation to Ni Base superalloys; (b) Melting points of refractory metals in relation to other common engineering metals.

Some of the important applications of aNb-Ti-Hf alloy C-103 are in the combustion chambers of rockets and as rocket thruster cones (see Fig. 2). More recently, Nb alloys with active cooling are being considered for the construction of scramjet combustors of hypersonic vehicles, due to their very high combustion temperatures (> 2200 C).



(a) (b)

Fig. 2: (a) Combustion chamber for satellite thrusters, (b) rocket thruster cone.

Niobium ores contain pyrochlor and columbite as the main minerals which are first calcined to niobium pentoxide and then aluminothermically reduced to commercial purity niobium (called 'thermits'). The flow chart for these steps is shown in Fig. 3.

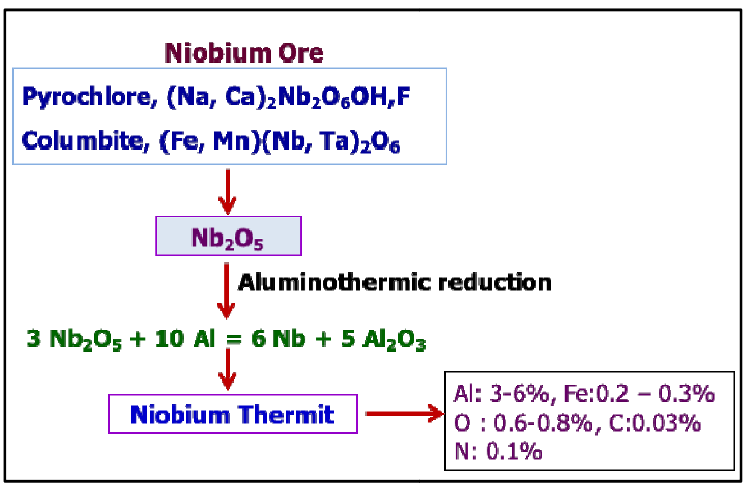
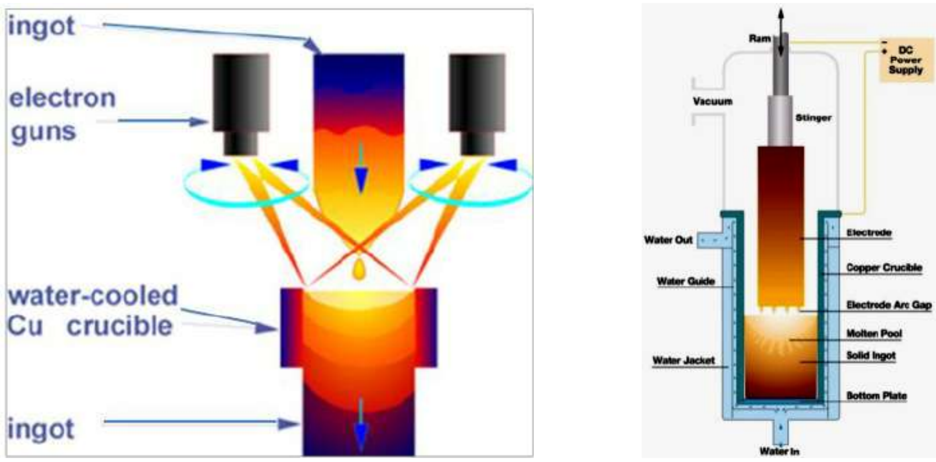


Fig. 3: Flow chart for mineral to niobium metal 'thermit'

2. Melting of Niobium

The conventional techniques such as air induction melting and vacuum induction melting are not suitable for niobium due to its high affinity to oxygen at high temperatures and chemical reactivity with many refractory materials. Therefore, electron beam melting (EBM) and vacuum arc remelting(VAR) are resorted to, due to the fact that the metallic crucibles are water cooled and a solid layer quickly forms on the surface avoiding further reaction with the molten niobium. These techniques are schematically shown in Fig. 4.

In electron beam melting, thermit niobium nuggets and other alloying elements are dropped continuously into the vacuum sealed chamber containing the water cooled crucible where they melt and solidify somewhat directionally from the water cooled bottom towards the electron beam source. A single or multiple electron guns may be used. Although alloy formation takes place in the first stage, the homogeneity of the composition is not adequate, and a second stage melting is carried out using the first stage ingot as the feed material. These stages of melting are shown schematically in Fig. 5. For specific alloys, a third stage EB melting or VAR may be required.



(a) (b)

Fig. 4: (a) Schematic diagrammes of electron beam melting and (b) vacuum arc melting.

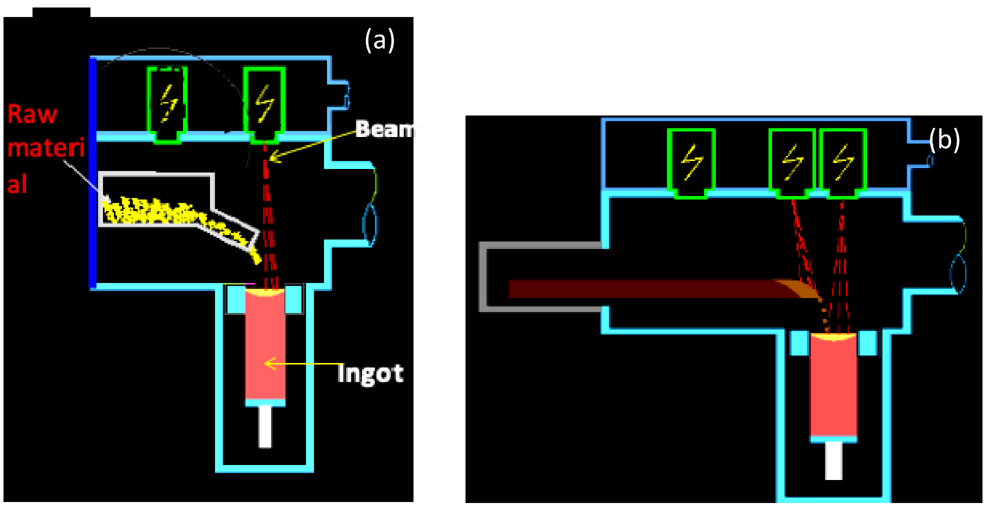


Fig. 5: (a) First stage electron beam melting of niobium nuggets, (b) second stage melting using first stage ingots.

3. Melting and refining experimental results

EB melting experiments were conducted using thermit Nb nuggets. A typical ingot is shown in Fig. 6. Table 1 shows impurity levels in the thermit Nb, the specified upper limits and the reduced levels of impurities after first and second stage EB melting. It can be seen that the impurity contents in the thermit are quite high, and unacceptable with respect to the permitted limits. The impurities are reduced significantly as a result of EB melting, and brought down below the upper limits specified.

Fig. 6: Typical electron beam double melted niobium ingot of 50 mm dia × 130 mm size.

Table 1: Impurity levels before and after EB melting, and the related specifications

Before melting			After melting	
Elements	Impurities	Maximum limit	First EBM	Second EBM
Al (%)	3.98	6	110	<10
Fe (ppm)	1860	3000	<500	<10
Ni (ppm)	196	-	<10	<10
O (ppm)	4600	7000	<760	<250
C (ppm)	250	-	50	<25
H (ppm)	10	150	<5	<5

Impurity removal during EB melting is due to a combination of high temperature and high vacuum under which most elements vapourise relative to niobium.

4. Alloy design approach

Yield strength of pure Nb decreases with temperature as shown in Fig. 7. It is seen that the YS drops significantly around 500 C. In order to strengthen Nb, substitutional solid solution strengthening by elements like Mo, W, V and Ta has been attempted. In addition, reactive elements like Zr, Hf and Ti have been added to form compounds with interstitial elements (such as C and O) present in the alloy. Various alloys produced commercially by firms are listed in Table 2.

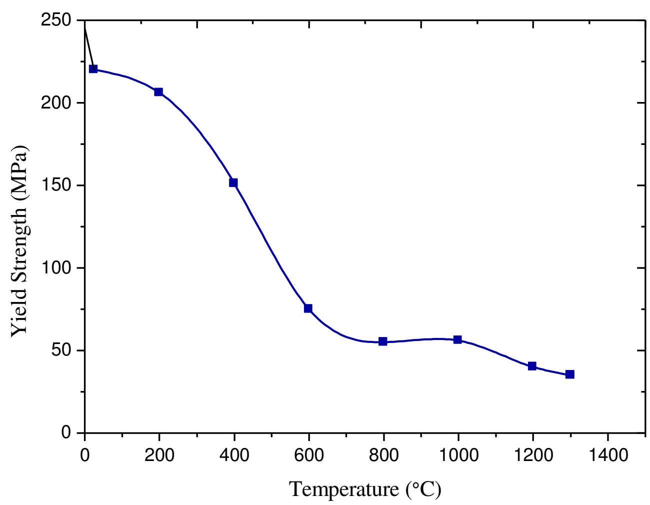


Fig. 7: Yield strength of pure Nb as a function of temperature.

Table 2: Code names, nominal compositions and firms producing varioius Nb alloys.

Alloy code	Composition	Manufacturer
Low strength and high ductility		
Nb-Zr	Nb-1Zr	Superior Tube Co, USA
PWC	Nb-1Zr-0.1C	Superior Tube Co, USA
C-103	Nb-10Hf-1Ti	Wah Chang/ Boeing
Medium strength medium ductility		
Cb752	Nb-10W-2.5Zr	Union Carbide USA
C-129Y	Nb-10W-10Hf-0.1Y	Wah Chang/ Boeing
WC3009	Nb-30Hf-9W	Wah Chang/ Boeing
FS-85	Nb-28Ta-10W-1Zr	Fan Steel Metallurgical Co USA
High strength and low ductility		
FS-48	Nb-15W-5Mo-1Zr-0.05C	Fan steel Metallurgical Co, USA

5. Establishing the alloy production and processing capability

As there is interest within DRDO and ISRO in developing hypersonic vehicles which are either totally atmospheric or of re-entry type, there is a requirement of scramjet propulsion. Since scramjet combustion temperatures are typically in excess of 2200 C, the materials for construction of scramjet chambers (Fig. 8) have be of sufficiently high temperature capability or need to be internally cooled by the fuel. C-SiC composites, Ni base superalloys and Nb alloys have been considered as the candidate materials for the same. Among these three classes of materials, Nb alloys present opportunities which combine the advantages of higher temperature capability than Ni base superalloys and ease of fabrication compared to C-SiC composites. As the strength of pure Nb is not adequate, alloys of Nb must be resorted to. Fig. 9 shows the high strength tensile strength of the commonly used alloy C-103 as a funtion of temperature, and compares the same with another competing alloy Cb-752. It can be seen that at higher temperatures, Cb-752 properties exceed those of C-103, although processing of the former poses considerable difficulties due to the presence of high melting W and Zr elements, and large density differences between W and Nb. The nominal composition of Cb-752 alloy along with upper limits on concentration for impurities is given in Table 3.

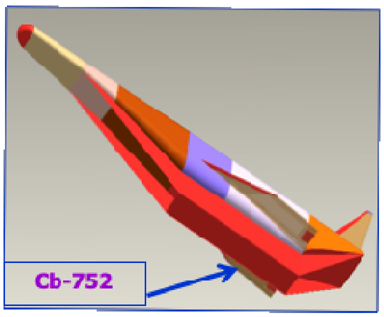


Fig. 8: An artist's conception of an atmospheric hypersonic vehicle. The arrow points to the scramjet combustion chamber for which Nb alloys are candidate materials.

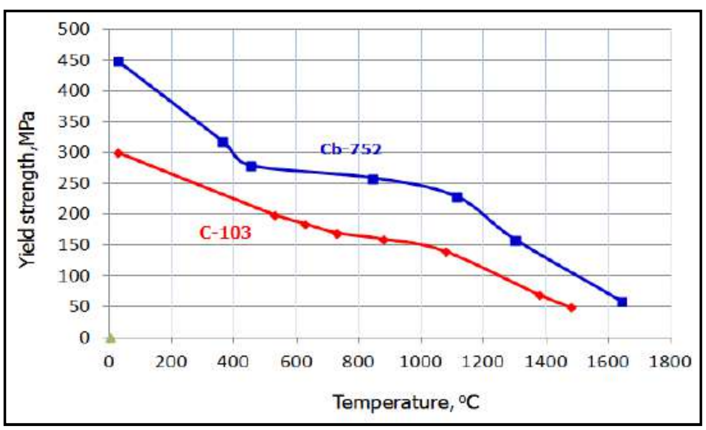


Fig. 9: High temperature Yield Strength of two Nb alloys: C-103 and Cb-752.

Table 3: Specified composition of Cb-752 alloy along with upper limits on impurity levels.

Elements	Concentration (wt %)
O	0.02
N	0.01
C	0.015
H	0.001
Zr	2.0-3.0
Ta	0.15
W	9.0-11.0
Hf	0.01
Ti	0.01
Nb	Bal

The challenges in the melting and alloying of Cb-752 alloy can be readily understood by comparing the melting points, densities and the vapour pressures at the typical melting temperatures, as shown in Table 4.

Table 4: Melting temperatures, vapour pressures and densities of Nb and the alloying elements in Cb-752.

Metal	Melting Point (C)	Density (g/cc)	Vapur pressure at melting point of Nb (torr)
Nb	2469	8.57	1×10^{-3}
W	3410	19.3	5×10^{-6}
Zr	1852	6.49	1

Broadly, the melting routes for making Nb alloy Cb-752 can be classified into two routes: (a) rod route and (b) powder route. In the rod route, small dia rods of high purity W and Zr of suitable weight are welded to previously refined (as described earlier)high purity Nb rod in the length direction to prepare the electrode for EB melting. Typical melting parameters are given in Table 5.

Table 5: Typical EB melting parameters

Electrode dia (mm)	Ingot dia (mm)	Power kW	Vacuum (mbar)	Melt rate (kg/h)
30	60	40-45	$1\times10^{-4} – 1\times 10^{-3}$	5
		70-75		

It is seen in the X-ray radiograph of Fig. 10 that the alloying elements have not completely dissolved in the Nb matrix. The undissolved regions were later confirmed to be of W. The problem of W not dissolving fully was encountered in Vacuum Arc Remelting too. Hence an alternate route based on powder based electrode melting was attempted.

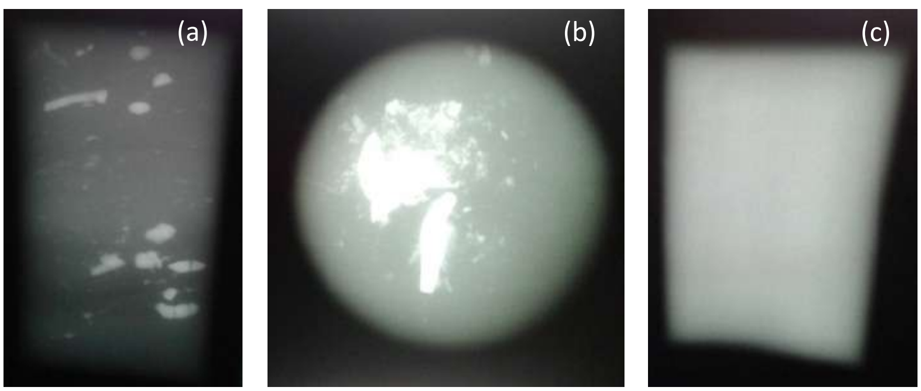


Fig. 10: X ray radiograph of an EB melted and solidified alloy Cb-752 made by rod route under (a) low power (longitudinal section) as well as (b) high power melting (cross section). The bright regions are identified as due to undissolved W; (c) X-ray radiograph of the EB melted ingot made by powder route, showing no evidence of unmelted Zr regions (longitudinal route).

In the powder route, powders of d_{50} approximately 50 µm were mixed in a rotating jar mixer and compacted using cold is ostatic pressing and vacuum sintered to make primary electrodes for EB melting. A series of short electrodes were fastened through a series of male-female joints and further welded to make longer electrodes of sufficient handling strength. When these electrodes were EB melting under conditions similar to those mentioned in Table 5, no evidence of unmelted Zr regions were found (see Fig. 10 (c)).

After having established the capability of melting W during EB melting using the powder route, the second step of VAR followed to achieve better homogenization of chemical composition. Although another EB melting step is possible, it results in excessive elemental loss due to high vacuum levels used and poor control on the composition. VAR as the secondary melting step was successfully implemented, which resulted in ingots of 110 mm dia. The chemical compositions of the ingot after EB melting and after further VAR are given, along with specified limits in Table 6. The table shows that the except for O and Zr, the composition conforms to the specifications, and that after further VAR all compositional specifications are met.

Table 6: Chemical composition of the Cb-752 alloy following powder EB melting and EB + VAR melting

Elements	Alloy compositions (wt%)			
	Primary electrode	EB melted ingot	EB + VAR melted ingot	Specifications
C	0.03	0.006	0.004	15 max
H	0.08	0.0007	0.0002	0.001 max
N	0.04	0.0092	0.0035	0.010 max
O	0.50	0.0268	0.013	0.020 max
W	8.5	10.28	10.82	9-11 wt %
Zr	12.5	4.8	2.43	2-3 wt %

Macrostructures of pure Nb and alloy C-752 in the EB melted condition are shown in Fig. 11 (a) and (b). As expected, the macrostructure is coarser in case of pure Nb than for the alloy. Alloying elements are known to cause grain refining through 'solute effect'.

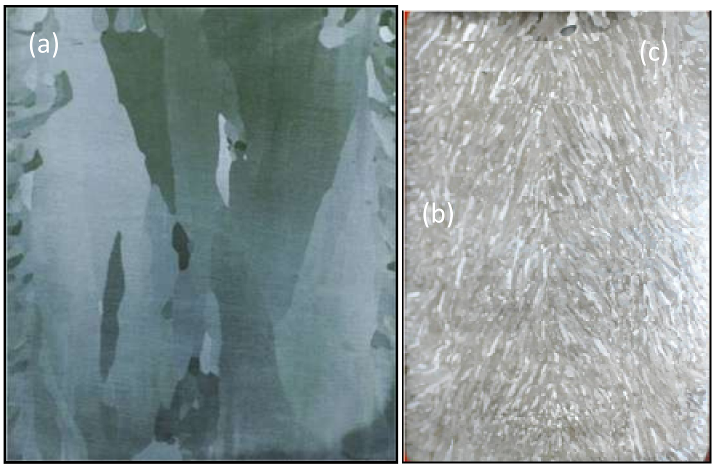


Fig. 11: Macrostructures of EB + VAR melted (a) pure Nb and (b) Cb-752 110 mm dia ingot.

6. Thermomechanical working

The EB and VAR melted ingots are then mechanically worked to obtain mill forms such as plates and sheets. While pure Nb can be worked at room temperature being sufficiently ductile, Nb alloys have to be necessarily worked at high temperatures. However, due to their high tendency for oxidation, the ingots have to be encapsulated in a suitable material such as stainless steel or coated by an oxidation protective coating and then vacuum heated prior to working. Fig. 12 shows a silicide coated ingot prior to forging, the billet after upset forging at 1250ºC and then the same billet after further forging to plate.

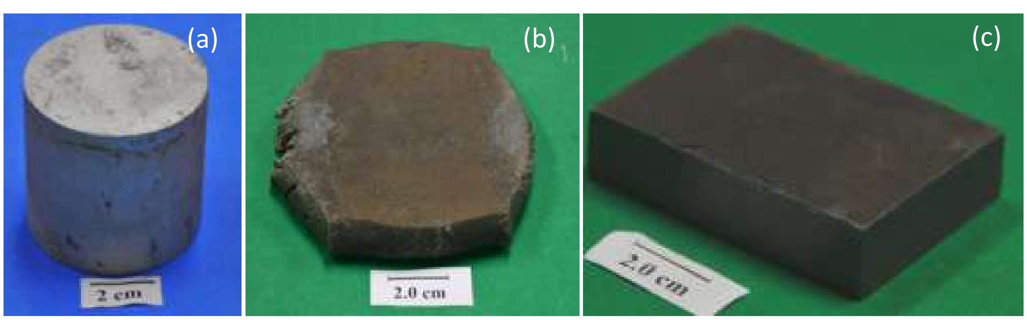


Fig. 12: Cb-752 alloy (a) as solidified ingot, (b) after hot upset forging and (c) after further forging to plate form.

The forged plate was cold rolled from 18 mm thickness to 7 mm thickness. However, the cold rolled sheets were found to develop transverse cracks due to poor workability. Therefore, the 18 mm thick forged plate was rolled at 1000ºC. No cracks were found after hot rolling (Fig. 13).

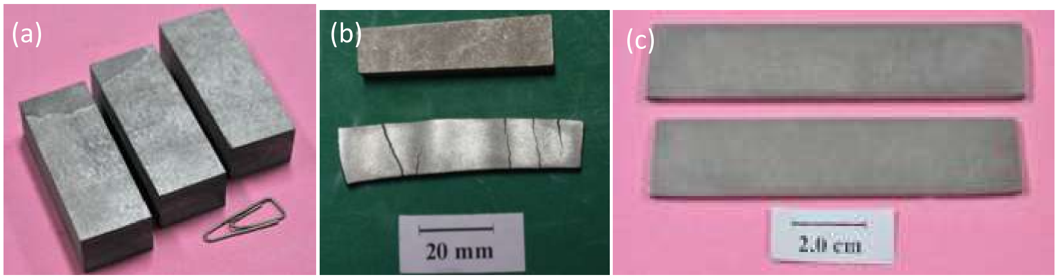


Fig. 13: (a) Forged plates, (b) cold rolled sheets and (c) hot rolled sheets of Cb-752 alloy.

The tensile properties were evaluated in the rolled and annealed (1350 C/1h) condition, and presented in Table 7.

Table 7: Tensile properties and corresponding specifications of Cb-752 alloy.

Type of property	Property hot rolled (HR)	Reference (HR) values	Property cold rolled (CR)	Reference (CR) values
Yield Strength (MPa)	401	400	413	400
UTS (MPa)	528	540	543	540
%elongation	32	20	33	20
Hardness	170	165	172	165

The hot rolled sheets could, however, be cold rolled to 2 mm thickness without cracking. The optical microstructures in various conditions show that fully recrystallized grain structure develops after annealing (Fig. 14). The properties of the cold rolled and annealed sheets are given in Table 6.

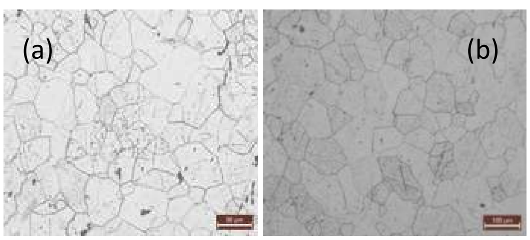


Fig. 14: Optical microstructures in (a) hot rolled and (b) cold rolled and 1350 C/1h annealed conditions.

The tensile fractographs corresponding to the hot rolled and cold rolled sheets are shown in Fig. 15. In both cases, a mixed mode of fracture comprising of trans-crystalline shear and ductile fracture is seen.

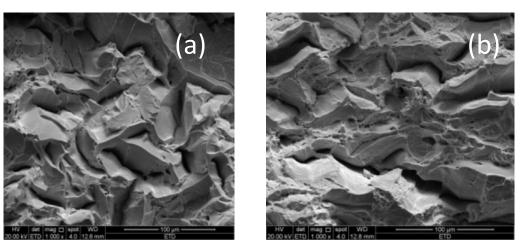


Fig. 15: Tensile fractorgraphs in (a) hot rolled and (b) cold rolled and annealed conditions.

7. Scientific studies

Preceding content gives a brief account of production and processing issues to make Nb alloys from impure niobium up to mill forms. Over and above, detailed scientific studies have been carried out on pure Nb and Cb-752 alloy which have been widely published by the present authors in the open literature. Highlights of these studies are presented below.

7.1 Effect of oxygen content on pure Nb

The effect of oxygen on microstructure and mechanical properties of niobium has been investigated. Niobium samples containing 50–800 wt. ppm oxygen have been prepared by absorption and diffusion techniques. The samples were characterised with respect to chemical composition, microstructure and mechanical properties. Niobium containing up to 800 wt. ppm of oxygen exhibited essentially single phase microstructure with no precipitates. The hardness and strength increase with increase in oxygen content. The increase in strength is marginal up to 400 wt .ppm oxygen and significant from 400 to 800 wt .ppm oxygen [1].

7.2: Effect of internal oxidation on C-103 alloy

The effect of internal oxidation on the microstructure and mechanical properties of niobiu malloy, C-103 has been investigated. Tensile specimen sand test coupons of alloy containing different levels of oxygen (100–2500 ppm) were characterized with respect to microstructure and mechanical properties. It has been observed that for oxygen contents in the range ~400 – 1000 ppm, hafnium oxide precipitated exclusively along the grain boundaries, while for oxygen content of ~2500 ppm, precipitates formed both at the grain boundaries and with in the grains near surface region of the alloy. The internal oxidation has resulted in embrittlement of the alloy resulting in considerable lowering of strength as well as ductility. Further, the strength and ductility are found to decrease progressively with the increase in average oxygen content of the alloy [2].

7.3: Oxidation resistance of silicide coated C-103

A Fe-Cr-alloyed silicide coating has been formed on a commercially available Nb-alloy called C-103 by using as lurry-based technique followed by vacuum diffusion treatment at 1380°C. The coating microstructure reveals a three-layer structure with the outer layer consisting of $NbSi_2$ phase and the inner interdiffusion layer consisting of lower silicides such as Nb_5Si_3 and Nb_3Si. The intermediate layer of the coating is comprised of a Fe-Cr alloyed Nb-silicide phase and $NbSi_2$. The coating provides good short- term protection to the substrate against high temperature oxidation in air at 1100 and 1300°C. It is found that the presence of the coating increases the tensile strength of the alloy [3].

7.4: Vacuum arc melting parameter optimisation

The relation between arc length and arc voltage during vacuum arcremelting has been established. Further, the arc length was optimized to produce and maintain a stable arc during the VAR process. Other process parameters such as arc current and fill ratiowere also optimized to produce sound and directionally solidified ingots of pure niobium. It hasalso been demonstrated that sound ingot could be produced without discontinuity in spite of interruption in the process using higher process current. The VAR conditions do not have any significant influence on the tensile properties.

The effect of thermo-mechanical processing on the structure and mechanical properties of pure VAR melted niobium ingots was investigated. The forging response of VAR melted pure Nb at room temperature, 250°C and 900°C was excellent. All the forged sections could be cold rolled from 30 mm to 2 mm without any intermediate annealing. Processing of as-cast VAR ingot has resulted in significant improvement in tensile properties. The processing conditions do nothave any significant influence on the tensile properties. The tensile properties of all the niobiumsheets produced by different conditions are superior to the data reported in the literature and of the ASTM standard [4].

7.5: Optimisation of EB melting parameters of pure Nb

Pure niobium metal, produced by alumino-thermicreduction of niobium oxide, contains various impuritieswhich need to be reduced to acceptable levels toobtain aerospace grade purity. In the present work, anattempt has been made to refine niobium metals byelectron beam drip melting technique to achieve purity confirming to the ASTM standard. Input power to theelectron gun and melt rate were varied to observe their combined effect on extend of refining and loss of niobium. Electron beam (EB) melting is shown to reduce alkali metals, trace elements and interstitial impurities well below the specified limits. The reduction in the impurities during EB melting is attributed to evaporation and degassing due to the combined effect of high vacuumand high melt surface temperature. The % removal of interstitial impurities is essentially a function of meltrate and input power. As the melt rate decreases orinput power increases, the impurity levels in the solidified niobium ingot decrease. The EB refining process isalso accompanied by considerable amount of niobiumloss, which is attributed to evaporation of pure niobiumand niobium sub-oxide. Like other impurities, Nb loss increases with decreasing melt rate or increase in inputpower [5].

7.6: Melting, processing and characterisation of Cb-752

Cb-752 (Nb-10W-2.5Zr) alloypancakes were prepared by non-consumable arc melting process under argon atmosphere using thoriated tungstenelectrode. In view of the very high melting point of tungsten as compared to niobium, it was found necessary tomelt the pancake multiple times to ensure complete dissolution of tungsten in the alloy. The temperature of hot forging as well as method for oxidation protection during hot forging was optimised. It was observed that the alloy could be hot forged at 1300ºC. It was further found thatthe silicide and aluminide coatings, and evacuated stainless steel jacket protected the alloy from oxidation during hot forging. The forged pancakes were cold rolled to 1.5 mm thick sheets. The room temperature mechanical properties of Cb-752 alloy sheet produced from the pancakes were comparable to the data reported in literature [6].

7.7 Effect of additions of W and Zr on the properties of Nb

The individual and combined effects of W and Zr additions on macrostructure, microstructure and mechanical properties of Nb have been investigated. Nb, Nb-10 wt% W, Nb-2.5 wt% Zr and Nb-10 wt% W-2.5 wt% Zr alloy ingotswere prepared by electron beam drip melting using high purity Nb, W and Zr rods. Additions of W and Zr resultedin significant improvement in hardness and room temperaturetensile strength. It is seen that the effect of 10 wt% W addition is more than that of 2.5 wt% Zr addition in improving room temperature strength of Nb, although on 'per wt% addition' basis, Zr is a more effective strengthener than W. Itis also observed that the cumulative effects of 10 wt%W and 2.5 wt% Zr on grain refinement and strengthening are morethan their respective individual effects [7].

8. Summary

Development of melting, refining, casting and rolling practices have been evolved for niobium alloy Cb-752, which is challenging because of the high melting temperature of alloying element W, oxidative nature of Nb and large density differences between Nb and W. A route comprising of electron beam melting, vacuum arc remelting, hot forging, hot rolling and cold rollling has been evolved to produce a variety of plate and sheet mill forms with acceptable chemistry and tensile properties. Many tasks remain unfinished, however, consiting of kinetics of oxidation, its dependence on crystal orientation, relation between internal oxidation and cracking and high temperature mechanical properties. These will be the subjects of ongoing investigations in the authors laboratory and institute.

9. References

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Options for Lowering Carbon Footprint and Improving Sustainability in Indian Steel Plants

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SYNOPSIS OF LECTURE

Alarming increase in greenhouse gas (GHG) emission worldwide, presently in excess of 415 ppm, is an area of concern for sustainable development. The CO_2 emission is likely to breach 450 ppm concentration level by 2030 primarily due to over dependence and usage of fossil fuels for energy generation.

The fall out of such unacceptably high CO_2 concentration is already having catastrophic effect in terms of climate change by way of melting of glaciers, rising sea water levels and higher ambient temperatures. Such unabated and irreversible global warming will lead to a 'domino or cascade effect' that will eventually threaten human existence. Our planet has 'already reached climate change tipping points'. Scientists have identified the need to reduce greenhouse gas emission, one of the primary tipping point, as other key tipping points that have not yet been activated could soon be hit. Other tipping points not currently activated include heating up of deep water in the Antarctic, and the release of methane stored in the Ocean in polar regions, reduction in rainfall in the Indian monsoon, and a major loss of oxygen in the ocean, reductions in the size of the Amazon rainforest and the great ice sheets of Antarctica etc.

The global steel industry is estimated to account for around 6-7% of the total anthropogenic CO_2 emission. According to International Energy Agency (IEA), global iron and steel industry is one of the most energy intensive industry and accounts for the largest share, approximately 27%, of the CO_2 emissions amongst all global manufacturing sectors. The iron and steel industry, per force, has to be sensitive towards curtailment of CO_2 emission in order to facilitate sustainable development.

India and China have maintained continuous growth in steel production and are under intense global scrutiny for reducing emission norms in their manufacturing streams. India has surpassed Japan in becoming the second largest steel producer after China, and shortly is expected to be the second largest steel consumer surpassing USA. Steel industry, in India, is the fifth largest emitter of CO2 equivalent after electricity, transport, residential and cement as per the report published in May 2010 by Indian Network for Climate Change Assessment (INCCA).

Towards lowering the carbon footprint in the steel industry, it is imperative to seriously consider and implement technological measures for energy efficiency. The approach to be adopted by Indian steel industry hinges on innovating and incorporating technologies to realize energy conservation and emission reduction in steel plant operations along with development of high strength/advanced high strength steels that support energy reduction in downstream industries like automobiles, construction, oil and gas, space etc. In the Indian context, beneficiation of input raw materials, incorporation of waste/sensible heat recovery systems, adoption of commercially available energy efficient technologies across the entire domain of the manufacturing spectrum, ensuring materials efficiency and evaluation of emerging green technologies utilising iron ore fines and non coking coal, rapid assimilation of high end process and product models, automation, IT and expert systems besides development of ultra high strength steels will hold significance not only for ensuring energy efficiency and a cleaner environment but also reduce production cost as well.

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