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CONTENTS

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THE INDIAN INSTITUTE OF METALS

Thrust Vector Control System of a Missile: C/SiC Composite Jet-vanes

Anil Kumar[a] and Suresh Kumar[b]

Abstract

This article deals with the materials of Jet-vanes required for thrust vectoring control (TVC) system. The TVC is required for quick-action missile-systems where the missile needs to be manoeuvred when its velocity is relatively low and aerodynamic forces are inadequate. Different types of the thrust vectoring systems are described briefly, which includes: role of thrust vectoring systems, different types of the thrust vectoring systems, typical conditions experienced by a material used for the Jet-vanes as TVC, potential candidate materials for the Jet-vanes, brief of the process techniques used for fabricating C/SiC composites Jet-vanes and typical test configuration of the Jet-vanes. This article focuses on the Jet-vane materials, the processing, challenges and the futuristic materials.

1.0 Introduction

Thrust-vectoring, also known as thrust vector control, is the ability of an aircraft, rocket, or missile to manoeuvre the direction of the thrust from its engine to control the attitude (the position of a missile as determined by the inclination of its axis in relation to another object, as to the earth) of the missile. In missile literature, thrust-vectoring is also often referred to as gas-dynamic steering or gas-dynamic control. The missile may be manoeuvered by using the jet of the rocket and by use of the aerodynamic control surface. The jet is preferred to be used when the speed of the vehicle is low while the control surfaces can be used when the aerodynamic forces are adequate to provide the required side forces; usually it happens when the missile speed is high. Use of the flexible nozzle system, flaps, paddles and incorporating auxiliary fluid in the jet results in the thrust-vectoring of the missile.

Aerodynamic control surfaces become ineffective when missiles fly outside the atmosphere; therefore, thrust-vectoring is the primary means for the attitude control. In addition to providing a propulsive force to a flying vehicle, a rocket propulsion system can provide moments (forces) to rotate the flying vehicle and thus provide control of the attitude of the vehicle and the flight path. By controlling the direction of the thrust vectors, it is possible to control the pitch, yaw, and roll motions of the missile. A schematic of the possible moments of a missile is shown in Figure 1. Pitch moments raise or lower the nose of a vehicle; yaw moments turn the nose sideways; and roll moments are applied about the main axis of the flying vehicle / missile. Usually, the thrust-vector of the main rocket nozzle is in the direction of the vehicle axis and goes through the center of gravity of the vehicle. Thus, it is possible to obtain pitch and yaw control moments by the simple deflection of the main rocket thrust-vector; however, roll control usually requires the use of two or more rotary vanes or two or more separately hinged propulsion system nozzles. A typical arrangement of Jet-vanes uses for providing the pitch, yaw and roll moments to the missile is shown in Figure 2. The four Jet-vanes positioned at 90^0 to each other at the exit of the rocket motor nozzle can be rotated individually or in combination.

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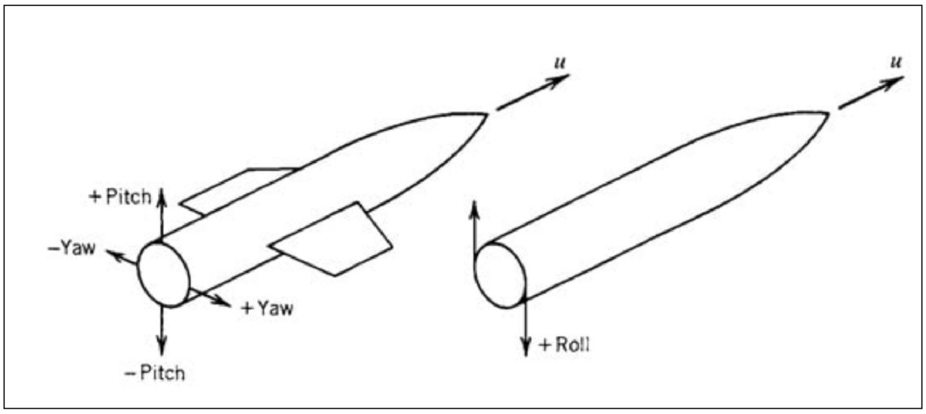

Fig. 1 : Pitch, Yaw and Roll moments of a missile

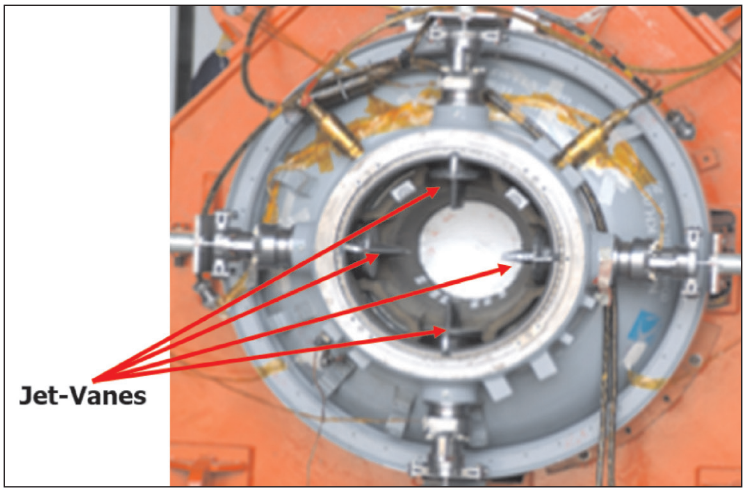

Fig. 2 : Jet-vanes fixed on a solid rocket motor

1.1 Requirements for TVC

Following are the main reasons to use TVC

- To wilfully change a flight path or trajectory (e.g., changing the direction of the flight path of a target-seeking missile)
- To rotate the vehicle or change its attitude during powered flight
- To set right the deviation from the intended trajectory or the attitude during flight
- To rectify the thrust misalignment of a fixed nozzle in the main propulsion system during its operation, when the main thrust vector misses the center of gravity of the flying vehicle

1.2 Mechanisms of TVC

The main TVC mechanisms are described in the subsequent paragraphs.

I. Mechanical Deflection of the Nozzle:

In mechanical deflection of the nozzle or thrust chamber, also called gimbal scheme (a hinge permits rotation about one axis only, whereas a gimbal is essentially a universal joint), the whole engine is pivoted on a bearing and thus the thrust vector is rotated. For small angles, this scheme has negligible losses in specific impulse and is used in many vehicles. It requires a flexible set of propellant piping (bellows) to allow the propellant to flow from the tanks of the vehicle to the movable engine.

II. Insertion of Heat-Resistant Movable Bodies into the Exhaust Jet:

Insertion of heat-resistant movable bodies (Jet-vanes) into the exhaust jet may be used to cause a deflection of a part of the exhaust gas flow for thrust-vectoring. Jet-vanes are pairs of heat-resistant (typically four in a pair), aerodynamic wing-shaped surfaces submerged in the exhaust jet of a fixed rocket nozzle. They cause extra drag and the drag increases with larger vane deflections and erosion of the vane material. The advantage of having roll control with a single nozzle often outweighs the performance penalties. Graphite Jet-vanes were used in the German V-2 missile in World War II and in the Scud missiles fired by Iraq in 1991. Currently, C/C and C/SiC composite Jet-vanes are used in many missile systems of Germany, Russia and India [1-3].

III. Injection of Fluid into the Side of the Diverging Nozzle Section:

Injection of secondary fluid through the wall of the nozzle into the main gas stream forms oblique shocks in the nozzle diverging section, thus causing an unsymmetrical distribution of the main gas flow, which produces side forces. The secondary fluid can be stored as liquid or gas from a separate hot gas generator (the gas would then still be cool enough to be piped), a direct bleed from the chamber, or the injection of a catalysed mono-propellant. It is a low-loss scheme, when the deflections are small, but for large moments (large side forces), the amount of secondary fluid becomes excessive.

IV. Separate Thrust-Producing Devices:

Separate thrust-producing devices which are not part of the main flow through the nozzle like small auxiliary thrust chambers were used in the Thor and early version of the Atlas missiles. They provide roll control while the principal rocket engine operates. They are fed from the same feed system as the main rocket engine. This scheme is still used in some Russian missiles.

Of all the mechanical deflection types, the movable nozzles are the most efficient. They do not significantly reduce the thrust or the specific impulse and are weight-competitive compared to the other mechanical types. The flexible nozzle is a common type of TVC used with solid propellant motors. The molded, multilayer bearing pack acts as a seal, a load transfer bearing, and a visco-elastic flexure. It uses the deformation of a stacked set of doubly curved elastomeric layers between spherical metal sheets to carry the loads and allow an angular deflection of the nozzle axis. The flexible seal nozzle has been used in launch vehicles and large strategic missiles, where the environmental temperature is moderate. At low temperature, the elastomer becomes stiff and the actuation torques increase substantially, requiring a much larger actuation system. There are double seals to prevent leaks of hot gases and various insulators to keep the structure below 90-100 °C.

2.0 Materials for Jet-vanes

The material for jet vane experiences high temperature, high velocity gases, particle impingement and high thermal and mechanical stress. A typical condition experienced by the Jet-vanes is shown in Table 1.

Among the possible material choices, the important properties to make a material appropriate for the Jet-vanes depend on the its melting temperature, strength retention at the functional temperature, erosion resistance capability and its density. Typical properties of some candidate material are shown in Table 2.

A refractory metal like Tungsten is well-suited for the Jet-vanes and is being used for the application where the size of the Jet-vanes is very small and weight penalty due to high density Jet-vanes is manageable. However, the high density of Tungsten limits its use for the Jet-vanes which are

Table 1: Typical conditions being experienced by a Jet-vane material

Stagnation Temperature	>2500 K
Relative Velocity	3000 m/s
Solid particle content in contact gases	Up to 30% by mass
Exposure time	3-20 s
Oxidation environment	Molten metal oxides, CO_2, CO, H_2O and Oxygen etc.

generally large. Though the monolithic ceramics do have high melt temperature and erosion resistance, their use for Jet-vanes is avoided due to their poor thermal shock resistance. The Jet-vanes experience a very high thermal shock as their surface temperature rises to over 2000 ^{0}C within milliseconds of the missile firing. Carbon-carbon composites match the requirements of thermal shock resistance and retention of mechanical strength at the functional temperature but their poor erosion resistance under the solid impinging particles prevents their use for the Jet-vanes required for greater than 4-5 seconds. Hence a fiber-reinforced ceramic matrix composite like Carbon –Silicon Carbide (C/SiC) composite is used for 5-6 missile programs of the country as C/SiC has all the necessary attributes for a Jet-vane material with respect to the density, temperature capability, strength retention at the functional temperature, erosion resistance under solid particle impingement and thermal shock resistance .

3.0 Processing of C/SiC Composites

C/SiC composites exhibit excellent thermo-erosive properties up to 2000 ^{0}C [4-7]. Their high strength-to-weight ratio and oxidation resistance make them ideal candidates for highly demanding engineering applications such as high performance heat shields, structural re-entry components, ultra-high temperature heat exchanger tubes, rocket nozzles, Jet-vanes and brake discs [1,3,4]. The choice of silicon carbide as a matrix is based on its high melting point (~2500 ^{0}C), excellent mechanical properties at high temperatures related to its covalent character, relatively good oxidation resistance up to about 1500 ^{0}C and stability in fast neutron environments [6]. Also, silicon carbide can be easily inserted into a fibre preform by a variety of techniques such, chemical vapor infiltration (CVI) or chemical vapor deposition (CVD) technique, polymer impregnation and pyrolysis (PIP) technique and reactive metal infiltration (RMI) technique.

3.1 Chemical vapour impregnation (CVD/CVI)

In CVD/CVI, the solid matrix gets deposits on the preform fibre surfaces owing to a vapour phase reaction of the precursor gases under appropriate conditions. For CVI of C/SiC composites, methyltrichlorosilane (MTS) is generally used as precursor for SiC [8-9]. The deposition of SiC takes place between 850−1200 ^{0}C in vacuum. The process requires several weeks of continuous deposition in order to obtain a dense C/SiC composite. The CVD/CVI process yields mostly β-SiC deposit with controlled composition and microstructure which in turn results C/SiC composites which have better thermal and mechanical properties compared to PIP and RMI based C/SiC composites. At times, CVI is not preferred due to its long process cycles which typically takes over 200 hours to densify a 4-5 mm thick carbon preform to get composite density around 2.1 g/cc.

3.2 Polymer infiltration and pyrolysis (PIP)

PIP process uses polycarbosilane, which is a ceramic precursor that converts into SiC if heated

Table 2: Typical properties of some candidate material of Jet-vanes

Material	Density, g/cc	Melting Point / Dissociation temperature / Max service temperature, ^{0}C	Tensile Strength, MPa
Molybdenum	10.2	2620	50-55
Tungsten	19.3	3410	200-220
C/C Composite	1.8	3000 (Inert atmosphere)	70-100
Boron Nitride	2.2	3000 (Dissociate)	250-400
Silicon Nitride	3.3	1900 (Dissociate)	250-700
Alumina	3.9	2050	280-500
Silicon Carbide	3.2	2400 (Dissociate)	250-600
C/SiC Composite	2.2	2500 (short duration)	100-150

under an inert atmosphere or in vacuum above 1200 ^{0}C [10-14]. The PIP process provides good matrix composition control and can be used to join different parts of a complex-shaped component. However non-availability of the ceramic precursor in large quantities and large shrinkage of the matrix during pyrolysis are few challenges which need to be addressed before selecting the process for fabricating a large number of products.

3.3 Reactive Metal Infiltration (RMI)

RMI is a popular technique where a molten metal is infiltrated into a porous reactive carbon composite. The reaction of metal and carbon yields a stable metal carbide at a relatively lower process temperature. Fabrication of silicon carbide by reacting molten silicon with carbon is termed as liquid silicon infiltration (LSI). LSI has been used to fabricate C/SiC composites for different shapes, size and fiber architecture at much lower costs than the CVI and PIP processes. LSI is the most common method to fabricate C/SiC composites of acceptable quality, especially for short-life components. The processing by LSI consists of the infiltration of a porous C/C composite preform with molten silicon using a vacuum or inert gas furnace. Carbon and silicon react to form SiC at temperatures in the range of 1450-1650 ^{0}C in inert or vacuum. LSI-based, 3D-stitched, 3D-woven and 4D-C/SiC composite technology and product development work have been carried out extensively in India by Suresh Kumar et al. [2,5,15,16]. Several products have been realized using the process: two of these are, Jet-vanes for thrust vector control of rocket motors and a throat insert for a liquid-propulsion based rocket motor.

The steps involved in LSI processing of the carbon silicon carbide composite are shown in Figure 3. The first processing step is the making of the continuous fibre skeleton called fiber preform which can be a 3-D or a 4-D; D-represents the direction of fiber in the preform. The next step is to insert the matrix in the porous carbon preform. In the RMI process, SiC matrix is developed in two steps, first the carbon matrix is generated by infiltration of coal tar pitch or petroleum pitch, followed by pyrolysis (carbon-carbon composite) or by chemical vapour infiltration with a carbonaceous gas like methane, ethane, or propane. Secondly, molten silicon is infiltrated into the pores of the carbon matrix where silicon reacts with carbon and SiC gets generated (siliconization). A typical scheme to fabricated C/SiC composite using RMI is shown in Figure 2.

In the siliconization step, silicon metal lumps are heated above 1450 ^{0}C and kept in contact with the porous carbon-carbon composite. The molten silicon rises into the pores of carbon matrix by capillary action and reacts with the surrounding carbon to form silicon carbide. It is extremely important to control the process and design it in such a way that only the carbon matrix reacts with the silicon and not the carbon fibre. If the fibre reacts with the silicon, the composite becomes brittle and its mechanical properties get deteriorated. In the final process, the as-fabricated C/SiC composite is machined to its intended dimensions by special tooling like Electrode Discharge Machining (EDM) wire cutting and grinding, using diamond tools.

3.4 Jet-vanes for missile

As stated, the Jet-vane materials must have good erosion resistance to particulate flow in addition to high thermal shock resistance (i.e. high thermal conductivity, low CTE and good strength). Erosion of the Jet-vanes depends on the fibre architecture, the ratio of fibres to matrix, and testing/operation conditions. The formulation of the composite microstructure requires optimizing the conflicting demands for high fracture toughness (high carbon content) and high resistance to abrasion/erosion (high SiC content). ASL, Hyderabad has

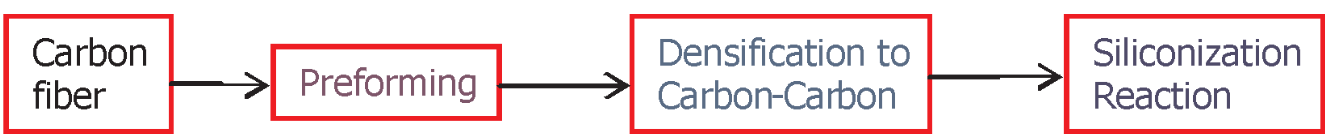

Fig. 3 : Processing of Carbon –Silicon Carbide composite using LSI/RMI

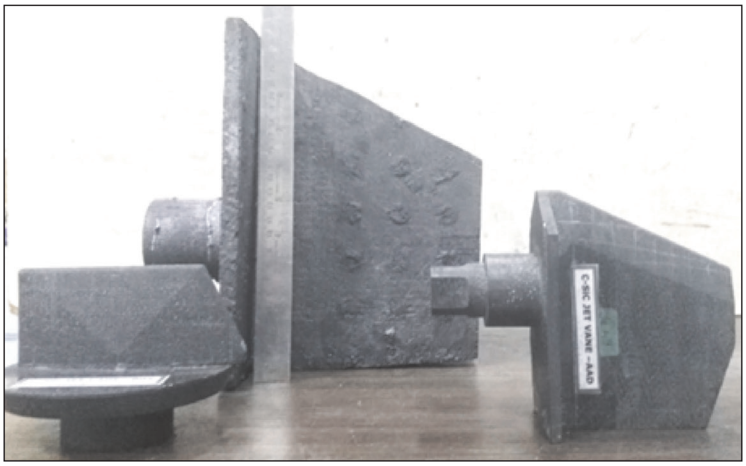

Figure 4: Typical Jet-vanes used for a thrust vectoring system

developed RMI technology for fabricating Jet-vanes using 3D-stitched C/SiC composites having excellent thermal and mechanical properties and good resistance to erosion by solid rocket motor (SRM) plumes [2]. Different missiles require different shape and different size Jet-vanes where the smallest size is about 120 mm and the largest about 250 mm. Typical Jet-vanes fabricated for three different missile systems are shown in Figure 4.

4.0 Conclusions

Thrust vectoring system, especially the Jet-vane based TVC can be used effectively for generating the required moments for all pitch, yaw and roll. Though the Jet-vane based TVC creates some drag, its performance outperforms the penalty. The material requirements for Jet-vanes are stringent and the Jet-vanes made of faulty material can be mission critical. Therefore, it is a must to select the material based on the laid down performance criteria in the following order: Temperature capability and strength retention at the service temperature, thermal shock resistance, erosion resistance against the solid rocket motor plume, density, processing ease and cost. The C/SiC composites have been under investigation for a long time. Several leading agencies around the world have developed appropriate facilities for the reinforcements, preforming, processing and characterization of these composites. Several products have been realized for defence and aerospace applications under the aegis of NASA, Russia, and the European Union. In India, a significant amount of work has been done in the last two decades for different defence programmes. Technology for C/SiC composite Jet-vanes have been developed using the RMI process. The PIP and CVD/CVI processes have also been employed to obtain C/SiC composite specimens and test articles. Research has been continuing to develop a reliable design methodology, automation of the preforming process, non-destructive testing, life estimation, and joining of C/SiC composites with other materials.

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TECHNICAL PROGRAMME

Session - I : Venue - Director's Conference Hall, DMSRDE, DRDO, Kanpur
Please Join us using the weblink: https://meet.google.com/wwy-obtp-ytw

10:00 hrs.	**Inauguration of the Product Exhibition by a National Dignitary**
10:05 hrs.	**Release of Souvenir and Declaration of Product Exhibition Open to Students (Coordinator: Shri J. N. Srivastava, DMSRDE)**
10:15 hrs.	Welcome by Dr. S. M. Abbas, Additional Director, DMSRDE, Kanpur, India
10:25 hrs.	Address by Prof. V. V. Kutumbarao, Vice President, TRAERF, Hyderabad, India
10:40 hrs.	Address by Prof. P. Venkitanarayanan, IIT/K, Kanpur, India
10:50 hrs.	Address by Dr. Kamachi U. Mudali, Trustee, ASM International, India
11:00 hrs.	Address by Dr. Samir V. Kamat, DS & DG (NS&M), DRDO, Visakhapatnam, India
11:10 hrs.	Keynote Lecture by Prof. Rajiv Prakash, IIT(BHU), Varanasi, India
11:40 hrs.	Invited Lecture by Prof. R. Koteshwara Rao, HCU, Hyderabad, India
12:05 hrs.	Invited Lecture by Prof. Kantesh Balani, IIT/K, Kanpur, India
12:30 hrs.	Invited Lecture by Dr. Debmalya Roy, DMSRDE, Kanpur, India
12:55 hrs.	Vote of Thanks by Dr. Ashish Dubey, DMSRDE, Kanpur, India
13:00 hrs.	Lunch

Session - II : Venue - Auditorium, DMSRDE, DRDO, Kanpur
Product Exhibition Open to Students (Venue - Multiutility Facility, DMSRDE)

14:00 hrs.	Welcome by Shri Amit Saraiya, DMSRDE, Kanpur, India
14:10 hrs.	Address and Release of Special Souvenir by a National Dignitary
14:30 hrs.	Keynote Lecture by Shri Hari Babu Srivastava, DG (TM), DRDO, New Delhi
14:50 hrs.	Defence Products & ToT Road Map for DMSRDE by Shri J. N. Srivastava, DMSRDE, Kanpur, India
15:10hrs	Felicitations to ToT Holders (Coordinators: Shri A. S. Parihar and Shri Subhash Mandal, DMSRDE)
15:30 hrs.	High Tea
16:00 hrs.	Visit to Product Exhibition

Session - III : Venue - Director's Camp Office, DMSRDE Transit Facility, Kanpur
Please Join us using the webLink: https://meet.google.com/fgb-fjmy-dnp

17:00 hrs.	Welcome by Dr. Ashok Kr. Tiwari, Chairman, ASM International India National Council
17:10 hrs.	Address by Prof. C. Suryanarayana, University of Central Florida, Orlando, USA
17:20 hrs.	Address by Shri Pradeep Goyal, President (Elect), ASM International [2023-'24]
17:30 hrs.	Introduction of the Speakers by Dr. Kingsuk Mukhopadhyay, DMSRDE, Kanpur, India
17:40 hrs.	Keynote Lecture by Dr. R. J. H. Wanhill, Emmeloord, Flevoland, the Netherlands
18:10 hrs.	Invited Lecture by Dr. Priya Munagala, University of Bristol, Bristol, UK
18:30 hrs.	Aerospace Materials: A journey of 4 Decades by Dr. N. Eswara Prasad, DMSRDE, Kanpur, India
19:00 hrs.	Invited Lecture by Dr. Meghana Akella, Boston Sci. Corp., MN, USA
19:20 hrs.	Invited Lecture by Prof. K. A. Padmanabhan, Anna University, Chennai, India
19:40 hrs.	Keynote Lecture by Prof. P. M. Ajayan, Rice University, Houston, USA
20:10 hrs.	Felicitations to Dr. N. Eswara Prasad (Coordinator: Shri Alok Kr. Dixit, DMSRDE, Kanpur, India)
20:25 hrs.	Vote of Thanks by Dr. Debmalya Roy, DMSRDE, Kanpur, India
20:30 hrs.	Cultural Programme (Coordinators: Smt. Jyoti Srivastava & Dr. Kavita Agarwal, DMSRDE, Kanpur, India)
22:00 hrs.	Dinner


Prof. Rajiv Prakash


Prof. R. Koteshwara Rao

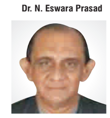

Prof. Kantesh Balani


Dr. Debmalya Roy


Dr. R. J. H. Wanhill


Dr. Priya Munagala

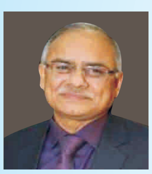

Dr. N. Eswara Prasad


Prof. K. A. Padmanabhan


Dr. Meghana Akella


Prof. P. M. Ajayan

Dr. N. ESWARA PRASAD, a B.Tech. (1985) and Doctorate (1993) from IIT(BHU) Metallurgical Engineering Department, is an Outstanding Scientist of DRDO and Director of DMSRDE, DRDO, Kanpur. His contributions to DRDO and Indian Defence are numerous. Dr. Prasad's wide range of S&T and R&D contributions on the extensive fundamental scientific research on aerospace materials have led to >700 publications and more than Rs. 1650 Cr. worth Defence Materials / Store. For these accomplishments, Dr. Prasad received 15 major awards and >60 honours and recognitions including FIIM, FAeSI, FInSIS, FAPAM. He will be felicitated in this symposium, on the occasion of his superannuation.


Shri Hari Babu Srivastava

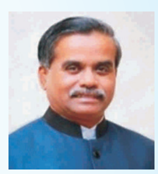

Dr. Samir V. Kamat


Dr. G. Satheesh Reddy


Dr. V. K. Saraswat


Dr. P. Rama Rao


Shri Pradeep Goyal


Dr. Kamachi U. Mudali


Dr. A. K. Tiwari

Indian Steel: Present Scenario & Future Prospect

S K Dutta*

1. Introduction

Steel is unrivalled in combination of strength, rigidity and workability, ultimately leading to its broad applications. Indian steel industry has acquired a significant status in the world and from 2018 ranked as 2nd largest steel producer. The consumption of finished steel in India has increased significantly from a level of around 64.9 million tonnes (Mt) in 2010 to 102.6 Mt in 2019[1]. Apparent consumption of finished steel registered a growth of 6.5% per year from 2010 to 2019. Similarly per capita consumption of steel in India has increased from 53 kg in 2010 to 75.1 kg in 2019 (Figure 1); against that of world average of around 204 kg in 2010 and 230.3 kg in 2019 respectively[1]. Due to the influence of the pandemic, per capita consumption of steel is decreased to 64.2 kg for India, as well as 227.5 kg for world in 2020. Through Indian per capital steel consumption is relatively low yet the potential for growth, given the vast domestic demand, is immense. However, compared to the huge potential of the Indian rural market, domestic steel consumption has been rather on the lower side.

The crude steel production in the world steadily increased to 1877.5 Mt in 2020, which was 1.3 times production of 2010. At the same time, India produced 111.4 Mt in 2019 (Table 1), which was 1.6 times that of the production of 2010. The finished steel consumption in India drastically increased from 2000 onwards (26.3 Mt in 2000) to 64.9 Mt in 2010 and 102.6 Mt in 2019, which were respectively 2.5 and 3.9 times with respect to 2000. Overall growth in 19 years was 15.3% per year. Due to the influence of the pandemic, Indian production as well as consumption of steel were decreased in 2020.

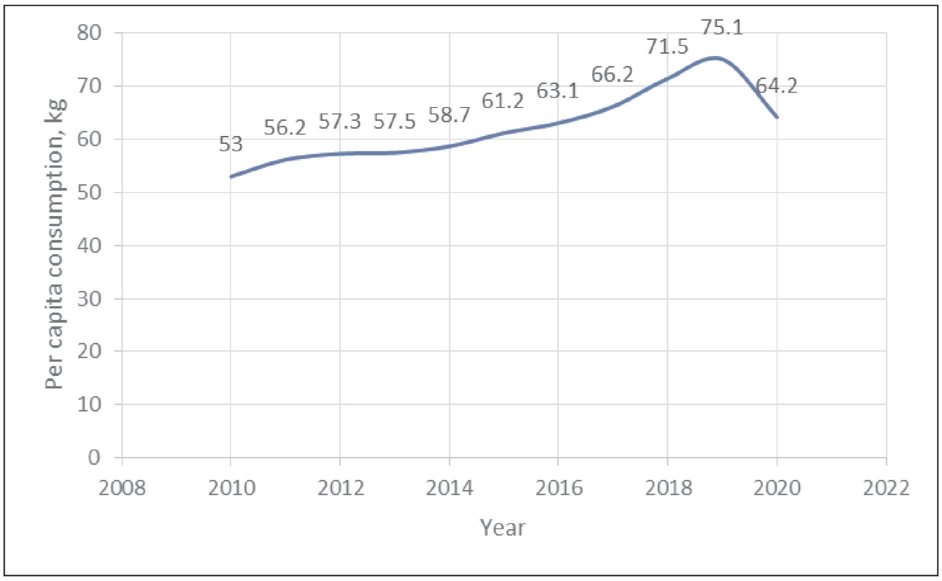


Fig. 1 : Per capita consumption of steel in India

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Table 1 : World and Indian Crude Steel Production and Finished Steel Consumption.						
	Crude Steel Production, Mt			Finished Steel Consumption, Mt		
Year	World*	India (Position in World)*	Indian Growth rate per year, %	World*	India*	Indian Growth rate per year, %
2010	1433.0	69.0 (4)		1310.5	64.9	
2011	1538.0	73.5 (4)	6.5	1415.4	69.8	7.6
2012	1562.3	77.3 (4)	5.2	1445.6	72.4	3.7
2013	1652.3	81.3 (4)	5.2	1544.6	73.7	1.8
2014	1674.0	87.3 (4)	7.4	1549.9	76.1	3.3
2015	1625.1	89.0 (3)	1.9	1504.9	80.2	5.4
Average for 5 years			**(5.2)**			**(4.4)**
2016	1632.8	95.5 (3)	7.3	1522.8	83.6	4.2
2017	1735.9	101.5 (3)	6.3	1637.3	88.7	6.1
2018	1825.5	109.3 (2)	7.7	1711.6	96.7	9.0
2019	1874.4	111.4 (2)	1.9	1775.1	102.6	6.1
2020	1877.5	100.3 (2)	-9.96	1771.8	88.5	-13.7
Average for last 5 years			**(2.65)**			**(2.34)**
* Source: World Steel Association						

Till the recent past, Indian steel industries were mainly used higher grades of iron ore and a higher proportion of lumps due to their easy accessibility and availability. High grade iron ores are running out fast throughout the world. Although India has got good reserves of high-grade iron ores, with time these reserves of high-grade iron ores are bound to be depleted. However, there is a pressing need to utilize low grade iron ores including slimes and dump ore fines which are stockpiled at different mine sides [2]. Indian iron ore deposits are partly soft and friable in nature. Hence, they contain a good amount of superfine (-150 µm) rich in iron content (65% and above), known as blue-dust. Iron ore fines are generated during processing as well [3]. During mechanized mining, 60 to 70% output is generated as fines below 10×10^{-3}m size. Fines are also generated during transportation and handling [2]. The low-grade ore fines are lying at mine sites of captive iron ore miners. These fines create pollution to the environment, which are not desirable. Utilization of these fines for extracting metal is of vital concern for resource conservation and pollution control.

Wastes are generated at various stages of iron and steel making processes. The disposal of wastes are the major concerns of world steel industries. These wastes need processing as they cannot be used directly for iron and steel making. This has led to develop of zero-waste technology. The zero-waste technology is developed for recycling and utilization of iron and steel plant wastes. In several iron and steel making processes different type of wastes are generated; about 500 kg of solid wastes are produced per tonne of steel production [4]. Again, significant quantities of coal fines and coke breeze are also produced during coal mining and coking of coal.

Low-grade ores and solid wastes are characterized and beneficiated for up-grading of iron content. Solid wastes generated from process units are generally characterized by their uniform size and composition. Low moisture content, high levels of metallic and non-metallic values (e.g. CaO, C etc.) content in wastes, are the factors that makes these suitable for recycling within the plant after beneficiation or to be sold out to consuming industries.

Therefore, a novel concept of agglomeration of ore fines, or concentration of low-grade ore/waste by cold-bonding technology is developed. Energy is conserved by using the cold-bonding technique compared to the conventional hardening by firing of pellets. Composite pellets/briquettes were prepared in the laboratory by cold-bonding technique, with the mixture of iron ore fines or concentration of low-grade ore/waste and coal fines.

This paper highlights the overview of iron ore fines and utilization of steel plant wastes by producing iron ore/oxide-coal composite pellets/ briquettes, subsequently using them for cast iron and steel making.

2. Raw Materials

The industrial development programme of any country is based on its natural resources. India is fairly rich in reserves for production of steel at low cost. As estimated by World Steel Dynamics, India belongs to the club of the lowest cost producers consisting of members like CIS, Brazil, China, and Mexico. This strength emerges from the fact that India possesses sizable reserves of iron ore [5]. The major raw materials required by integrated steel plants are (i) iron ore, (ii) coking coal, and (iii) limestone/fluorspar.

2.1 Iron Ore

India is fortunate to have vast reserves of high-grade iron ores. The basic reserve of the iron ore is about 33.3 billion tonnes (Bt), out of which there are about 22.5 Bt of hematite and 10.8 Bt of magnetite ore (Table 2), according to the estimates done by the Ministry of Mines, as on 1st April 2015[6]. About 42% of the total hematite reserves are lumps, that of fines is about 34%, while lumps and fines together constitute about 10% and 11% of the prospective resources. The remaining 3% is blue dust[5]. Since many Indian iron ore resources are located in the natural reserves or in the jungles and mountains, it is difficult to exploit all these; hence actual total reserves of iron ore is supposed to be much lower than the estimated total reserves, that cannot last long.

2.2 Coal Resources

India ranks second amongst the coal producing countries of the world in terms of annual coal production. However, in respect of coal resources, it is endowed with less than one per cent of world coal resources. 316.74 Bt of Indian coal resources occur up to a depth of 1200 meters, ~ 143.65 Bt fall under proved or confirmed category (Table 3). This constitutes about 9% of the world proved coal resources [7].

Due to the very nature of deposit Indian coals, in general, are of inferior quality owing to high ash content, when compared with coal available in the international market. Despite this, Indian coals in general, merit better environment friendly use because of:

- Low Sulphur content,
- Low chorine content and
- Low toxic trace elements content.
- Additional advantages for industrial use of Indian coal are higher ash-fusion temperature, low iron-content and refractory nature of the ash produced.

2.2.1 Coking Coal

Metallurgical coke is a critical input in blast furnace. The furnace productivity, hot metal quality and cost of production depend to a great extent on the quality of the coke used. Quality of metallurgical coke in turn depends on quality of

Table 2 : Reserves of Indian Iron Ore (in Mt) as on 1.4.2015

Type of Ore	Proved	Indicated	Inferred	Total
Hematite	5,421.750	6,514.599	10,550.616	22,486.965
Magnetite	52.699	302.973	10,433.483	10,789.155
Total	**5,474.449**	**6,817.572**	**20,984.099**	**33,276.120**

*Source: Annual Report Ministry of Mines, Government of India, 2018-19

Table 3 : Coal Reserves in India (in Mt) as on 01.04.2017				
Type of Coal	**Proved**	**Indicated**	**Inferred**	**Total**
Prime Coking	4,614	699	0	5,313
Medium Coking	13,501	12,133	1,879	27,513
Semi Coking	519	995	193	1,707
Sub-total	**18,634**	**13,827**	**2,072**	**34,533**
Non Coking	124,423	125,485	30,706	280,614
Tertiary Coal	594	99	895	1,588
Total	**143,651**	**139,411**	**33,673**	**316,735**
Lignite	6,540.7	26,014.4	12,143.0	44,698.1

coal used for coke making. India is not endowed with good quality coking coal reserves [8]. Table 3 shows the total reserves of Indian coking coal is 34.53 Bt, out of that 18.63 Bt fall under proved or confirmed category [7].

To bridge the demand-supply gap for the indigenous production, India imports coal, especially low ash coal, from a few select countries. As per the Indian import policy 1993-94, coal has been put under Open General License (OGL) and therefore importers are free to import coal, based on their requirement. Table 4 shows the specific consumption of imported coking coal during the last few years [8].

Quantity of coking coal import can be reduced by about 20%, if hot metal is not used as a charge material in EAFs [8]. This, however, is not possible; since several EAF based plants have set-up blast furnace/Corex process to supply hot metal to their EAFs. Another way to reduce coking coal import is by using higher proportion of indigenous coking coal.

2.3 Limestone/Fluorspar

Limestone and fluorspar (i.e. fluorite) are the fluxing materials for steelmaking. India has limestone reserves in Andhra Pradesh, Karnataka, Madhya Pradesh, Chhattisgarh, Bihar, Jharkhand and Odisha. These are of blast furnace grade, where higher amount of insoluble is acceptable. For steelmaking superior grade of limestone is required to control the slag volume and improve productivity. IS: 10345 Grade 1 specification for limestone suggests: CaO should be 53% minimum, 1.5% maximum MgO, 1.5% maximum SiO_2, 2% maximum total insoluble and 0.2% maximum alkalis. This grade is available in Rajasthan, Himachal Pradesh and Sikkim. Movement from these areas involves high transportation cost. Hence, Indian steel industry imports limestone; industry needs ~100 kg/t of liquid steel. As on 01.04.2015, the proved reserves of SMS-grade limestone is around 138 Mt, but not complying with the specification above [8].

Fluorspar (i.e. fluorite) contains calcium fluoride (CaF_2). Metallurgical grade should have 85% CaF_2 (IS: 4574-1989). Reserves are only 0.29 Mt occurring mostly in Gujarat and Rajasthan [8]; so this material is also imported. It is used @15kg/t of liquid steel in steelmaking for removal of sulphur and phosphorous and to improve fluidity of slag.

Table 4 : Import of Coking Coal by India (Mt)					
Particulars	**2015-16**	**2016-17**	**2017-18**	**2018-19**	**2019-20***
Coking Coal Import	43.506	41.644	47.003	51.838	55.881
Coke Import	2.965	4.290	4.499	4.831	2.910
Equivalent Coking Coal	4.561	6.600	6.921	7.432	4.477
Total Coking Coal	**48.067**	**48.244**	**53.924**	**59.270**	**60.358**
*Provisional					

3. Projected Estimation

The average growth per year for crude steel production in India on the 5 years (2010 to 2015) was about 5.2% and that of finished steel consumption for 5 years was about 4.4% (Table 1). Indian crude steel production has shown a steady growth. The average growth per year for crude steel production in India between 2016 and 2019 was about 5.8% and that for finished steel consumption for those 4 years was 6.1%. Considering 6, 8, and 10% compounded annual growth rate (CAGR), the author projected crude steel production [9] as shown in Table 5. Actual Indian steel production was 111.4 Mt in 2019, which is almost close to the prediction by the author of 6% growth rate (112.9 Mt). The National Steel Policy - 2017 envisaged creation of 300 Mt of steel capacity in the country by 2030-31 as against existing capacity of 138 Mt [10]. India plans [2] for about 300 Mt steel production in 2030. By considering 6% CAGR the crude steel production should reach ~ 160 Mt in 2025 and 215 Mt in 2030 respectively (author's estimation). This is a more realistic approach and based upon practical conditions in India.

To produce one tonne of crude steel, 1.62 t of iron ore is needed. In turn, to produce 1.62 t of processed iron ore, 2.52 t of geological reserve of high grade iron ore is consumed, taking into account that processed ore will be of 80% of run of mine (ROM) ore and the mineable ROM ore will be around 80% of the proved reserve [5].

Table 6 shows the projected requirement of iron ore, coking and non-coking coals for 2025 and 2030 to produce 160.3 Mt and 214.5 Mt crude steel respectively. For that geological iron ore reserve requirement will be 404 Mt and 541 Mt for 2025 and 2030 respectively; coking coal requirement will be 104 Mt and 139 Mt and limestone requirement will be 16 Mt and 21 Mt respectively.

Day by day, high-grade iron ores are fast depleting; fines, low-grade iron ores and plant's wastes, which were not used earlier, can now be utilized after upgradation/beneficiation. Upgraded/beneficiated concentrates can be used as charge materials for palletisation/briquetting to produce composite pellets/briquettes. The composite pellets/briquettes serve as the raw material for ironmaking.

Table 5 : Projected Indian Crude Steel Production (Mt)

Year	6% CAGR	8% CAGR	10% CAGR
2015	89.4		
2016	94.8	96.6	98.3
2017	100.5	104.3	108.1
2018	106.5	112.6	118.9
2019	**112.9**	**121.6**	**130.8**
2020	119.7	131.3	143.9
2021	126.9	141.8	158.3
2022	134.5	153.1	174.1
2023	142.6	165.4	191.5
2024	151.2	178.6	210.7
2025	**160.3**	**192.9**	**231.8**
2026	169.9	208.3	255.0
2027	180.1	225.0	280.5
2028	190.9	243.0	308.5
2029	202.4	262.4	339.4
2030	**214.5**	**283.4**	**373.3**

Table 6 : Projected Requirement of Iron Ore, Coking, Non-Coking Coals and Limestone
[All figures of requirement are in million tonne]

Year	Projected Crude Steel Production, (with 6% CAGR)	Processed Iron Ore	Run-of–Mine Ore (ROM)	Geological Ore Reserve	Coking Coal Require-ment	Non-Coking Coal Require-ment	Lime-stone Require-ment
2025	**160.3**	259.69	323.81	403.96	104.20	38.47	16.03
2030	**214.5**	347.49	433.29	540.54	139.43	51.48	21.45

4. Composite Pellets/Briquettes

The term composite pellet describes a pellet consisting of a mixture of fines of iron-bearing oxide and carbonaceous material (like coal, coke, or char), to which cold bonding techniques have imparted sufficient green strength for subsequent handling [3]. The pellets should have enough strength to withstand high temperature and stresses during reduction in a furnace.

Interest in iron ore-coal composite pellets technology had been there for many years without any significant successful application in ironmaking. The principal technological problem was to produce such composite pellets at low cost. Advances in cold bonding technology have brightened the prospects. Interest in composite pellets has grown from the 1980s, because of the following advantages [11]:

(i) Fast rate of reduction (as established in laboratories and pilot plants), as the carbonaceous reducer is in intimate contact with ore fines.

(ii) Iron ore fines, generated at mine sides, mill scale etc. are cheaper than lumps. Traditional pellet-making is costly due to need of heat hardening in furnace. On the other hand, cold-bonded composite pellets do not require costlier heat hardening process.

(iii) Composite pellets can also utilize cheap and readily available reductants such as coal fine, coke breeze, coal char fines, or wood char fines.

(iv) Resource utilization and lower environmental pollution.

Dutta and co-workers [12-16] produced iron ore – coal composite pellets/briquettes by cold-bonding technique from iron ore and coal fines. Various binders such as lime, $Ca(OH)_2$, slaked lime, dextrose, molasses, fly-ash etc. were used for making composite pellets/briquettes. Slaked lime and dextrose mixture as binder produced the highest strength amongst the various binders employed for producing composite pellets/briquettes.

By using lime and dextrose as binder, the maximum dry strength obtained 357 N per briquette [12]. Dutta and Chokshi [13] observed that the average strength of briquette increased with increasing of molasses for a fixed amount of fly ash and lime after CO_2-treatment. They observed that CO_2-treatment was helpful to increase the strength of the briquette, due to the formation of carbonate bond. The strength of 404 N per briquette was obtained with the binder combination of fly ash, slaked lime and molasses with CO_2-treatment.

The compressive strength of briquette increased with increasing of molasses quantity for a fixed amount of fly ash (Thermal Power Plant, Wanakbori, Gujarat), molasses and slaked lime (462 N per briquette). CO_2 -treatment was helpful to raise the compressive strength of the briquette, due to the formation of carbonate bond in briquettes. CO_2-treatment was beneficial as also observed by the result of shatter index and drop strength. Using Polyvinyl alcohol (PVA) as the binder achieved the highest strength (i.e. 978 N per briquette) due to gel formation; however, it is much costlier than the fly ash and other binder [14].

Table 7 : Results with various beneficiation processes				
	LD Dust		Sludge	
	$Fe_{(T)}$, %	Final $Fe_{(T)}$, %	$Fe_{(T)}$, %	Final $Fe_{(T)}$, %
Original Sample	38.77		51.64	
Centrifugal Classifier		45.77		53.15
Cyclone Classifier		46.24		52.03
Tabling Concentrate		45.57		60.45
Two stage beneficiations		61.13		62.89

Jha and Dutta [15] worked on the iron and steel plant's (Jindal Steel Works, Bellari, Karnataka) waste, like LD dust and sludge. Sludge was associated with moisture and non-homogeneous particles. Initial total iron ($Fe_{(T)}$ %) content was very low, 38.8% for LD dust and 51.6% in sludge. Along with iron (as oxide) other gangue such as CaO and SiO_2 were also present in LD dust and sludge. The samples were ground in ball mill before beneficiation, to achieve uniform sizes (to some extent). The ground samples then went through various beneficiation methods, such as hydro-cyclone, cyclone classifier and Wilfley table, without using any chemical reagent.

By beneficiation, the total iron content increased by decreasing the gangue content. After the centrifugal classifier the total iron content increased to 45.8% for LD dust and 53.2% for sludge respectively; and after the cyclone classifier the total iron content increased to 46.2% and 52% for LD dust and sludge respectively (Table 7). But by combination of the cyclone classifier and Wilfley table, the enrichment of iron further improved to 61.1% and 62.9% for LD dust and sludge respectively [16]. After beneficiation enriched iron oxide of LD dust and sludge were used for composite pellets production.

5. Non– agglomerated Sinter Cake

Chokshi, Sompura and Dutta [17] produced non–agglomerated sinter cake from mill scale and charcoal fines. Initially mill scale was placed at the center of the metal mould and surrounded by charcoal fine. Lime was used for slag bonding in between the particles. Sintering operation was carried out in a laboratory scale electrically heated muffle furnace. Quantity of charcoal and lime was varied for the non-agglomerated sinter cake production. Compressive strength and degree of reduction of the sinter cakes were measured.

6. Reducibility

6.1 Composite Pellets/Briquettes

The degree of reduction of iron oxide can be obtained by reducibility studies through weight loss method when a gaseous reductant is used. For reduction of iron oxides by carbon, the degree of reduction cannot be found out directly from the weight loss of the sample, since both oxygen and carbon are loosened during reduction. For iron oxide-coal composite pellets, the weight loss of the sample arises not only from oxygen and carbon loss, but also from the loss of volatile matters and residual moisture present in pellets [12].

Initial reduction rate for JSW dust (i.e. LD dust from Jindal Steel Works, Bellari) and Vizag sludge (i.e. sludge from Vizag Steel plant, Vishakhapatnam) were slow indicating that the volatile gases (from coal) diffuse to the iron oxide particles boundary. Iron oxide is reduced by volatile gases and H_2 (generated by cracking of hydrocarbons present in coal). It was found [18] that the effect of H_2 in the volatiles on the reduction of the iron oxide - coal mixture is significant. The fraction of reduction increased with time. At a particular time, the rate of reduction for Vizag sludge is faster than JSW dust. Overall reduction rate for Vizag sludge is more than JSW dust. Details are given elsewhere [18].

6.2 Sinter Cake

Reduction studies of sinter cake were done at 950^{0}C for one hour. As the carbon percent increased, the degree of reduction of sinter cakes also increased. Highest degree of reduction was achieved in sinter cake of 10% excess charcoal of stoichiometry with 20% lime. Overall, addition of lime is favorable for the strength as well as degree of sinter reduction which are required as flux for steelmaking. Details can be seen elsewhere [17].

7. Smelting for Iron/Steel Production

7.1 Composite Pellets/Briquettes

Sah and Dutta [19] investigated the reduction kinetics and dissolution behavior of iron ore–coal composite pellets in liquid cast iron bath in an induction melting furnace. The smelting reduction of iron ore–coal composite is complex with respect to simultaneous reaction steps due to a system consisting of all three phases, i.e. solids, liquids, and gases. The movements of reactants and products at the interface are affected by several factors and control the rate of reduction.

It was observed [19] that the fraction of reduction increases with decrease of Fe_{tot}/C_{fix} ratio; a decrease in this ratio means the carbon present in the composite pellet increases, that is, more reductant material is present in the pellet and hence more reduction takes place. For composite pellets of Fe_{tot}/C_{fix} ratio of 4.0, that is, where the carbon content is less in the composite pellets, at the final stage reduction, the carbon from the melt (molten cast iron: carbon saturated) diffuses toward the pellet–melt interface and takes part in the reaction:

$$FeO + \underline{C} = \underline{Fe} + \{CO\}$$

For 16-17×10^{-3}m diameter composite pellets, the time required for complete dissolution in fully immersed condition in liquid cast iron bath was observed to be 83-90 seconds [20]. For 19-21×10^{-3}m and 13-15×10^{-3}m diameter composite pellets (from LD dust and sludge), the time required for dissolution in fully immersed condition in liquid steel bath was observed to be 28-30 seconds[16]. Again, for 25×10^{-3} m diameter composite briquette, the time required for complete dissolution in liquid steel bath was observed to be 45-50 seconds [20]. Since the molten steel bath was at a higher temperature than the molten cast iron bath, the dissolution of composite pellets was faster in steel bath.

7.2 Sinter Cake

Initially TMT rods were melted in an induction melting furnace to produce a molten bath and the non-agglomerated sinter cakes were charged in different proportions (10 to 20%) to make steel. TMT rods (as a scrap) and non-agglomerated sinter cake were charged in varying proportions. Sinter cake was slowly charged into steel bath and that was dissolved in molten bath, lime was also added as a fluxing agent. After proper control of the bath temperature, the molten steel was poured into the sand mould [17]. As the percent of non-agglomerated sinter cake increased in melt, carbon percent in produced steel also increased from 0.22% to 0.29%.

8. Summary

1. Although Indian per capital steel consumption is still low, there is a potential for growth due to the vast domestic demand from the rural market in near future.
2. The author estimates that by considering 6% CAGR, crude steel production will reach t ~ 160 Mt by 2025 and 215 Mt by 2030.
3. For achieving that target, the geological iron ore reserve requirement will be 404 Mt and 541 Mt for 2025 and 2030 respectively.
4. Since high-grade iron ores are fast depleting, fines, low-grade iron ores and plant- wastes, which are not used earlier, can be gainfully utilized.
5. For extracting metal, utilization of fines is of vital concern for resource conservation and pollution control.
6. The zero-waste technology will be developed for recycling and utilization of the steel-plant wastes.
7. Low-grade iron ores and plant' wastes can be beneficiated; these upgraded concentrates can be used thereafter as charge materials

for palletisation/briquetting to produce composite pellets/briquettes by cold-bonding techniques.

8. Enough strength of composite pellets/ briquettes can be achieved by the various mixture of binders.

9. Composite pellets/briquettes can be charged for ironmaking/steelmaking.

10. As the rate of reduction is very fast for iron ore/oxide-coal composite pellets/briquettes, they can be effectively used as feed materials in Rotary Kilns for sponge iron production; ITmk3, smelting reduction process, for production of pig iron nuggets; Cupola for cast iron, Blast Furnace for ironmaking; and induction melting furnace for steelmaking.

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Tata Premier League: Tata Steel beats TCS in net score

Tata Steel reclaimed its profit-leadership credentials in the Tata Group after being overshadowed for a decade by Tata Consultancy Services (TCS), underscoring the bottom-line impact of an unprecedented global commodities upcycle that has coincided with robust economic recovery in India.

Record inflation in Europe and the US in the aftermath of ultra-loose monetary policies has boosted commodity companies, while technology services have encountered higher competition and lower-than-expected profit expansions due to spiralling costs and an unceasing global war for top talent.

Through FY22, Tata Steel reported a consolidated profit after tax of ₹ 41,749 crore. The crown jewel of the coffee-to-cars conglomerate since its public listing a decade-and-a-half ago, TCS reported a net profit of ₹38,327 crore.

To be sure, the market capitalisations of both entities are still at the opposing ends of the earnings-based valuation spectrum. At nearly ₹13 lakh crore, TCS is India's second-most valuable company, while Asia's oldest steel maker is valued at around ₹1.6 lakh crore.

Tata Steel reported a 37% increase in consolidated net profit at ₹9,835 crore in the last quarter of FY22 on the back of improved sales volume across its businesses. "In India, steel demand rose by 4% QoQ. The performance was broad-based with all segments doing well in terms of demand," said TV Narendran, chief executive officer of Tata Steel.

The Economic Times

Tata Steel to complete NINL acquisition in current quarter: CEO

Tata Steel will complete the acquisition of Neelachal Ispat Nigam Limited (NINL) by the end of the current quarter its CEO and MD T V Narendran said.

The acquisition of NINL is critical for Tata Steel to build a dedicated long products complex.

On January 31, Tata Steel announced winning the bid for acquiring 93.71 per cent stake in Odisha-based steel maker NINL for Rs 12,100 crore.

In a conference call with reporters, Narendran said, “The acquisition of Neelachal Ispat Nigam Limited will be closed in 1QFY23 and we will scale it up rapidly to drive expansion of our high-value retail business.”

Operations at the 1.1 million tonne integrated NINL plant at Kalinganagar, where Tata Steel has a steel plant, are suspended at present.

NINL has its own captive power plant to meet the internal power requirement and air separation unit for producing oxygen, nitrogen and argon. Besides, the company also has its own captive iron ore mines which are under development.

The Times of India

SAIL declares financial results for FY’22, revenue crosses Rs 1 lakh crore

Steel Authority of India Limited (SAIL) has declared its financial results for the quarter and year ending 31st March 2022 (FY’22).

During FY’22, the company has clocked its best-ever performance in production and sales while achieving an all-time high revenue from operation of Rs 1,03,473 crore and EBITDA of Rs 22,364 crore.

According to the key highlights, in FY 2021-22, there has been a remarkable improvement in financial performance due to robust operational performance, the Ministry of Steel said in a statement.

According to the key highlights, SAIL emerged as the topmost buyer on GeM amongst all CPSEs in FY’22. SAIL has supplied steel for various projects of National importance like Central Vista Delhi, Mumbai-Ahmedabad High-Speed Rail, Delhi-Meerut RRTS, Polavaram Irrigation project, Kaleshwaram Irrigation Project, Purvanchal Expressway, several Metro Rail Projects across the Country, etc.

The Statesman

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Hyderabad Chapter

The 28th Tamhankar Memorial Lecture was organised by the IIM Hyderabad Chapter at DMRL on May 5, 2022. Prof B S Murty, Director, IIT Hyderabad delivered the lecture on "High Entropy Alloy – A new wave that we should not miss". He emphasised on the importance, history and processing aspects of high entropy alloys and the present status of R&D in India.

Rourkela Chapter

1. The AGM of IIM Rourkela Chapter was organised on May 7, 2022 at Rourkela Club. The Executive Committee of IIM Rourkela Chapter for FY 22-23 is as follows:

Chairman	Mr. Sharad Suryawanshi
Vice-Chairman	Mr. C R Mohapatra
Secretary	Mr. Atish Chandra Sarkar
Treasurer	Mr. Pratap Kumar Swain

2. The IIM Rourkela Chapter organised Metal Quiz-2022 – a quiz program on Metal and Materials Sciences, at Research and Control Laboratory Conference Hall on 28th May 2022 in collaboration with the two major entities of the organisation viz., SAIL, Rourkela Steel Plant and National Institute of Technology, Rourkela.

At the outset Mr. A. C. Sarkar, CGM(Quality) and Secretary, IIM Rourkela Chapter delivered the inaugural address. The Chief Guest of the programme Mr. S R Suryawanshi, ED (Works), SAIL-RSP and Chairman, IIM Rourkela Chapter who was present during the final rounds of the Quiz and handed over the trophies and mementoes to the winners and finalists of the Quiz Competition. In all 43 teams, each comprising 2 members, took part in the competition which involved executives, employees of SAIL-RSP as well as students of NIT, Rourkela. Around 130 participants attended the programme.

The team comprising, Mr. R Kiran, GM (RCL) and Ms. Khushboo Mishra, Manager (RCL), emerged as the winners of the competition. The 2nd position holders were Mr. Anup Agarwal, Manager (HSM – 2) and Mr. Shiba Sankar, Student (NIT, Rourkela).

Notably, the quiz had two rounds. The 1st screening round was of written type with 20 MCQ type questions. Seven, out of the participating

forty three teams, qualified for the finals. The final round was oral and virtual audio visual in nature. In the special audience rounds, good number of prizes were won by members who also actively participated in the Quiz, making the programme vibrant and energetic. Mr. Sampad Mishra, Senior Manager (Refractory Engineering) was the quiz master.

During the programme, an induction ceremony of new Life Members of IIM was also held that was graced by the Chief Guest. Many new members submitted their filled-in Life Membership forms and received a token memento of encouragement from the Chairman, IIM Rourkela Chapter.

Speaking on the occasion Mr. S R Suryawanshi commended the efforts of the organisers in organising such programme. He said that such programmes would keep the employees abreast with the recent happenings and developments in the metals sector. He urged all to keep the IIM chapter vibrant with such various activities throughout the year for the benefit of both the professionals of the steel plant as well as the students of NIT.

At the end, Mr. B K Behera, AGM (IED) proposed a formal vote of thanks. Ms. Anindita Mohapatra, DGM, MM (Stores) coordinated the entire programme.

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Crude Steel production by region

	Apr 2022 (Mt)	% change Apr 22/21	Jan-Apr 2021 (Mt)	% change Apr 22/21
Africa	1.2	-5.4	5.0	-3.6
Asia and Oceania	121.4	-4.0	452.6	-7.7
EU (27)	12.3	-5.4	48.9	-4.7
Europe, Other	4.2	0.5	16.1	-3.8
Middle East	3.3	-14.5	13.5	-5.3
North America	9.4	-5.1	37.4	-2.3
Russia & other CIS + Ukraine	7.3	-18.4	31.3	-11.0
South America	3.6	-4.8	14.3	-3.2
Total 64 countries	**162.7**	**-5.1**	**619.1**	**-7.1**

The 64 countries included in this table accounted for approximately 98% of total world crude steel production in 2021. Regions and countries covered by the table:

- **Africa :** Egypt, Libya, South Africa
- **Asia and Oceania :** Australia, China, India, Japan, New Zealand, Pakistan, South Korea, Taiwan (China), Vietnam
- **European Union (27)**
- **Europe, Other :** Bosnia-Herzegovina, Macedonia, Norway, Serbia, Turkey, United Kingdom
- **Middle East :** Iran, Qatar, Saudi Arabia, United Arab Emirates
- **North America :** Canada, Cuba, El Salvador, Guatemala, Mexico, United States
- **Russia & other CIS + Ukraine :** Belarus, Kazakhstan, Moldova, Russia, Ukraine, Uzbekistan
- **South America :** Argentina, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela

Top 10 steel-producing countries

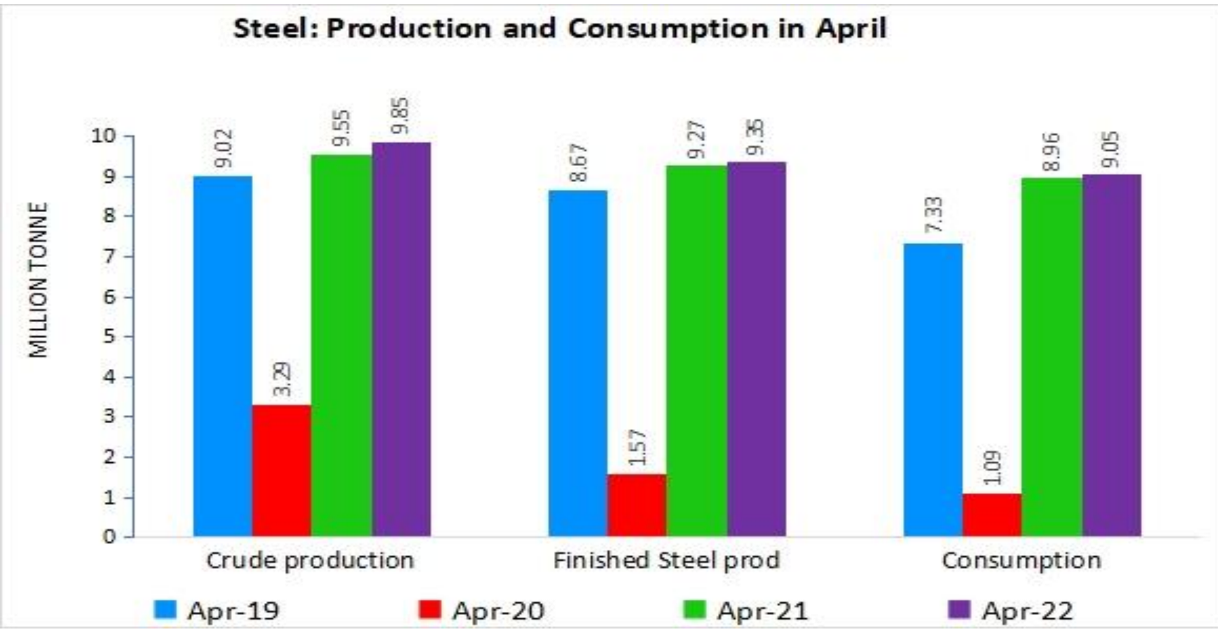
	Apr 2022 (Mt)	% change Apr 22/21	Jan-Apr 2022 (Mt)	% change Jan-Apr 22/21
China	92.8	-5.2	336.2	-10.3
India	10.1	6.2	42.3	6.5
Japan	7.5	-4.4	30.5	-3.3
United States	6.9	-3.9	27.1	-1.7
Russia	6.4 e	0.6	25.1	-0.7
South Korea	5.5	-4.1	22.4	-4.0
Germany	3.3	-1.1	13.1	-3.0
Turkey	3.4	1.6	12.8	-3.2
Brazil	2.9	-4.0	11.6	-1.7
Iran	2.2 e	-20.7	9.1	-8.9

e - estimated. Ranking of top 10 producing countries is based on year-to-date aggregate

Source : worldsteel.org

Production and Consumption Scenario:

i. A comparison of production and consumption of steel during the month of April over four years indicate that production of crude and finished steel as well as consumption of finished steel during April'22 is higher than that in the corresponding month of the last three years as may be seen from following Graph:



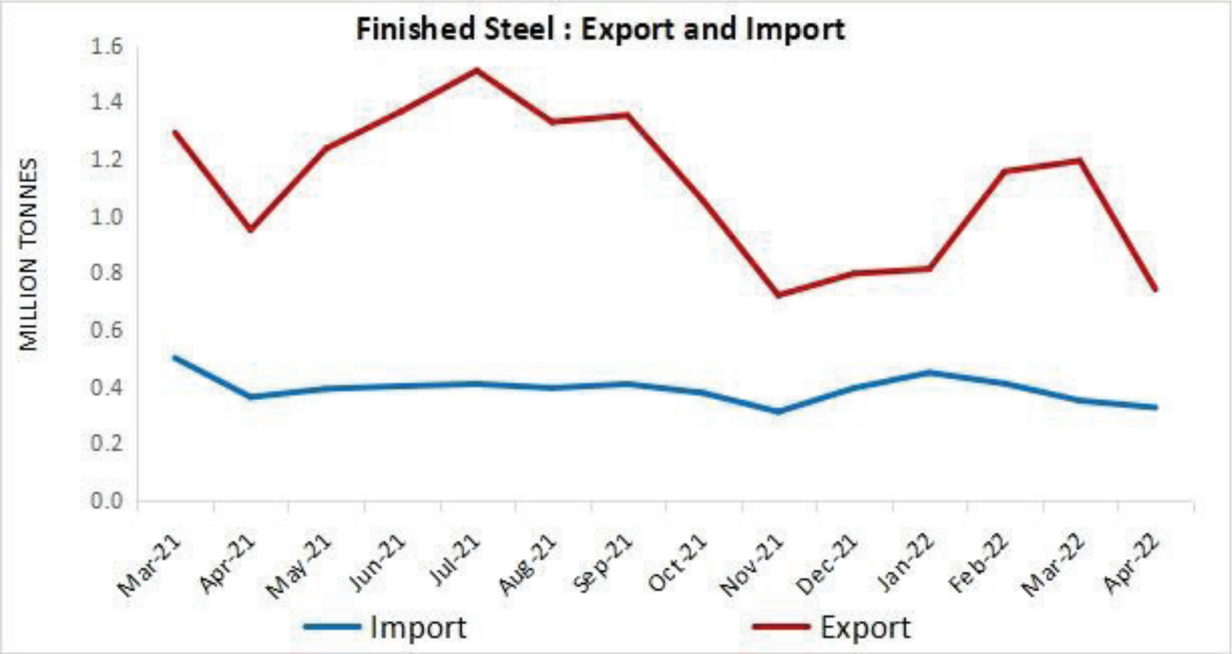
ii. Production of crude steel in April'22 at 9.85 MT increased by 3.1% over CPLY but declined by 10.9% M-o-M.

iii. Production of finished steel in April'22 at 9.35 MT was 0.9% higher over its production during CPLY but decreased by 12.9% M-o-M.

iv. Consumption of finished steel in April'22 at 9.05 MT is higher by 1.0% over its production during CPLY but lower by 8.1% M-o-M.

v. Inventories of the finished steel with the steel producing companies at 7.87 MT the end of April'22 was lower by 1.4% M-o-M and 9.3% over CPLY.

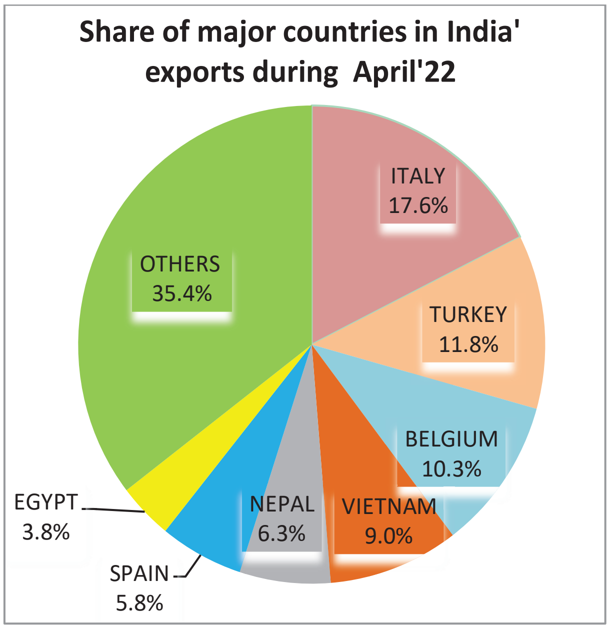
Export-Import Scenario : The month-wise trend in export and import of finished steel during recent months shows that India's export during a month has consistently exceeded import during that month. Also, export of finished steel from India has shown more pronounced M-o-M variation while imports have been relatively stable as may be seen from the graph below.

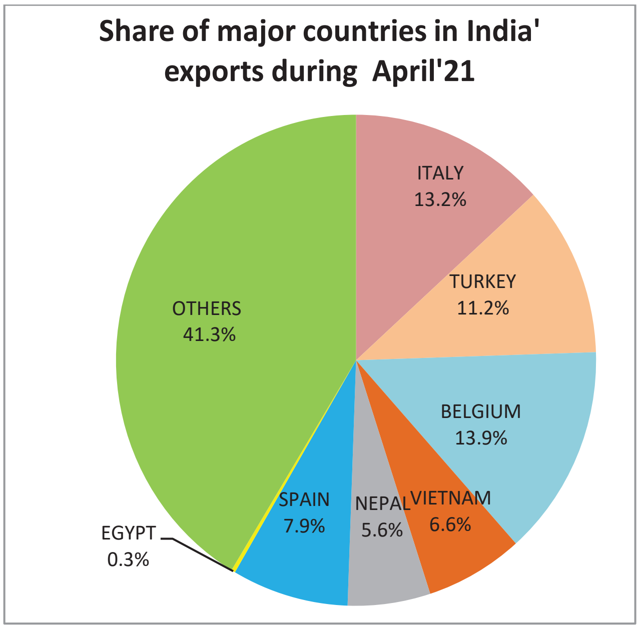


i. Export of finished steel during April'22 at 7.43 LMT declined by 21.9% while import at 3.27 LMT declined by 10.2% over CPLY. M-o-M, export and import of finished steel decreased by 37.8% and 6.8%, respectively.

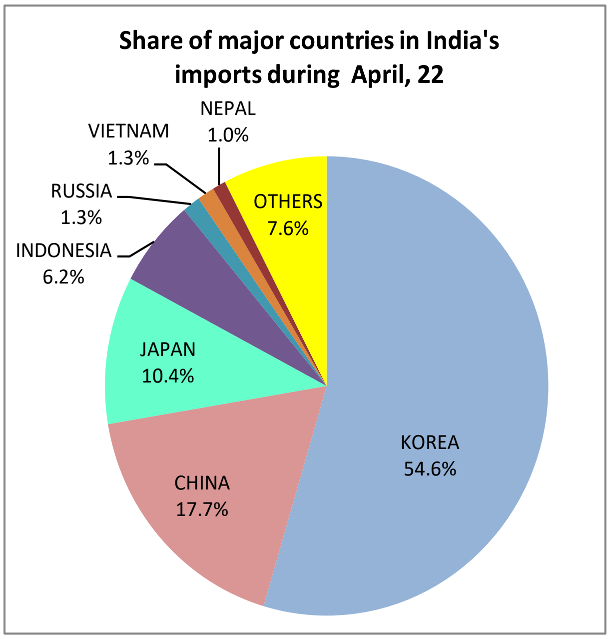
ii. India was net exporter of finished steel recording a net trade surplus of 4.16 LMT in April'22.

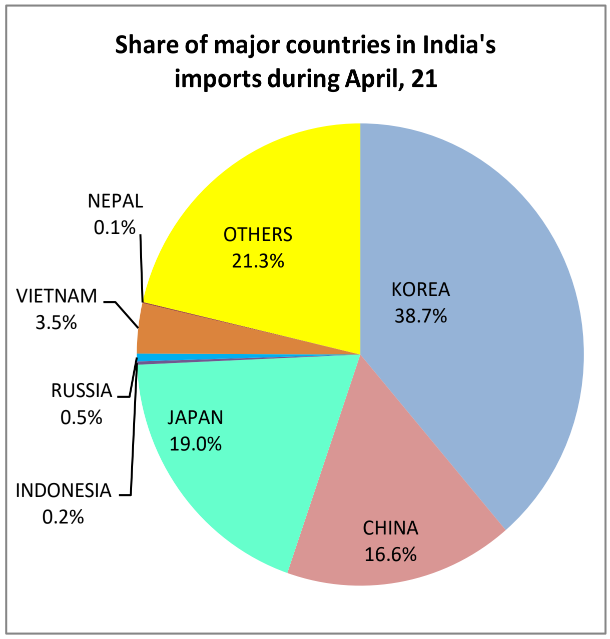
iii. Share of Italy, Turkey, Vietnam, Nepal and Egypt in total steel export from India was higher in April'22 as compared to April'21. However, share of Belgium and Spain in India's total steel export declined over the same period as may be seen from the following graph.



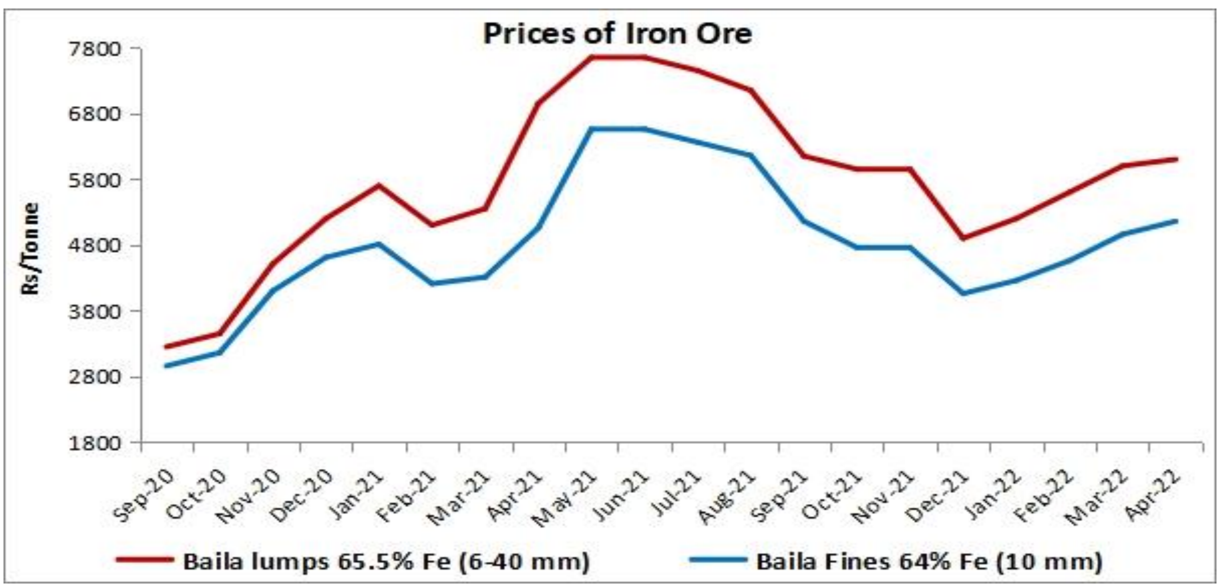


iv. Share of Korea, China, Indonesia, Russia and Nepal increased in total steel import of India in April'22 as compared to April'21 while share of Vietnam and Japan declined over this period as may be seen from the following graph:





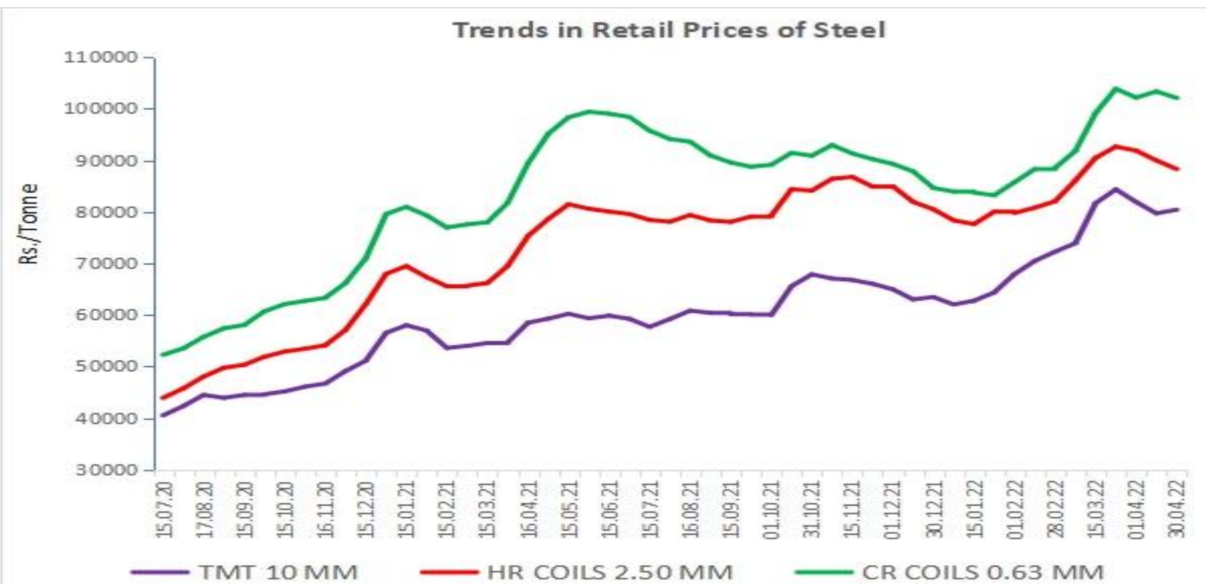
Price scenario: Prices of iron ore, after hitting peak in May-June'21 followed a declining trend since July'21 till December'21 but started increasing again from January'22. However, the rate of increase in prices of iron ore moderated during April'22 as may be seen from the graph below:



i. During the month of April'22, prices of iron ore lump increased by 1.7% to Rs.6100/tonne and that of fines by 4.0% to Rs. 5160/tonne over their respective prices in March'22.

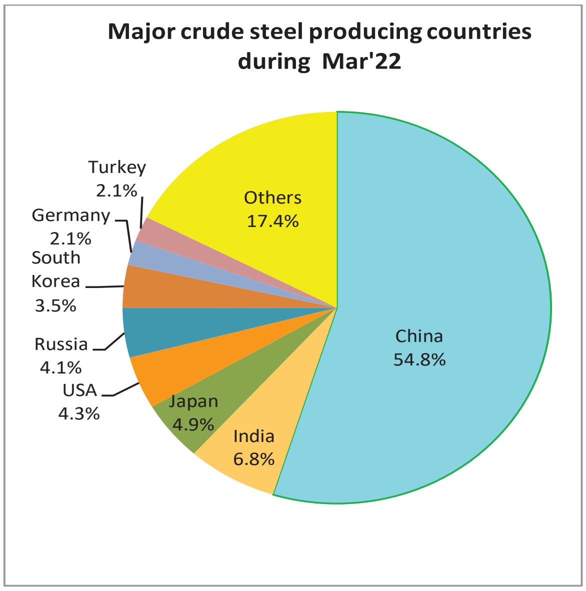
ii. In April'22, NMDC achieved production of 31.49 LMT and sales of 31.2 LMT of iron ore which are higher by 0.6% and 1.0% respectively than that in the CPLY. However, production and sale of iron ore by NMDC in April'22 is lower by 36.6% and 25.9% respectively over March'22. During the month SAIL produced around 27.29 LMT of iron ore which is a decline of 4.2% M-o-M and 1.0% over CPLY, respectively.

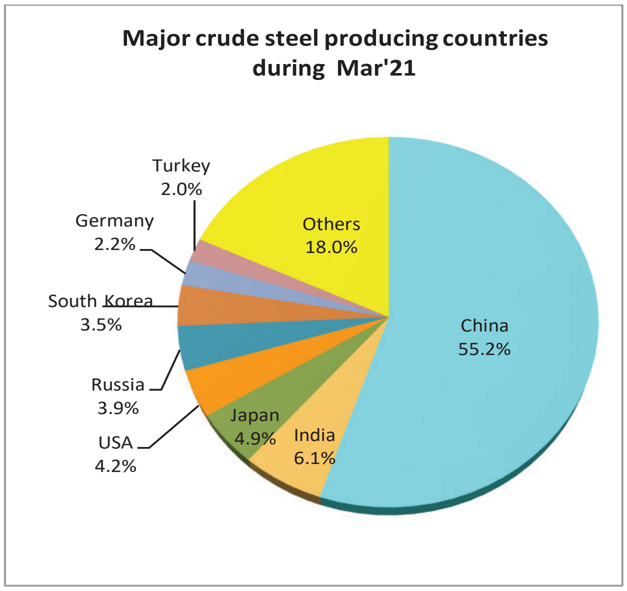
iii. The higher input cost, specially that of coke and improved international demand as reflected in a more than 25% increase in export of finished steel during FY22 over FY21 may have put pressure on the domestic prices of steel keeping them at elevated levels. It is seen from the following graph depicting prices of steel product categories viz., Rebar, HRC and CRC that prices of CRC which was on an uptrend since February'22 has moderated in April'22. In case of HRC and Rebar also, where retail prices started rising from mid-Janauary'2022, have shown signs of moderation during April'22 but still remains elevated. To moderate the impact of higher steel prices for the steel users specially in SME and export sector, Ministry of Steel and Ministry of Commerce and Industry jointly negotiated with the integrated steel producers (ISPs) for offering steel to SME users at a lower price, providing them a relief of Rs. 2500 per tonne, on purchase of steel by them.



iv. The retail prices for Rebar (10mm), HRC (2.50mm) and CRC (0.63mm) in Mumbai on 30th April'22 at Rs. 80390/tonne, Rs. 88270/tonne and Rs. 102070/tonne were 1.8%, 3.9% and 0.1% lower than their respective prices at the start of the month.

As per the data released by World Steel Association (WSA), India is the only country among top 10 steel producing nations of the world, which has registered growth in steel production during January to March 2022, as compared to corresponding period last year. Further WSA data also indicate that the global production of crude steel decreased by 5.8% in March'22 over March'21 due mainly to a decline in production in China and Ukraine. In addition, few other major steel producing countries viz., Japan, Russia, South Korea, Germany, Turkey, Italy, Iran and USA also reported decline in production during the month over CPLY. The major producing countries (with production of 1 million tonne for the month) which contributed to the enhanced global production in March'22 over March'21 include India, Brazil and Taiwan. As regard the share of major producing countries in the global production of crude steel (Graph below), it is seen that due to decline in production in China and uptick/less steep decline in production in some of other major producing countries, share of China, Germany and Turkey declined while that of India, Russia, and USA, increased during this period.





Source : https.// steel.gov.in

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