Impact of Technology on Growth of Indian Steel Sector in the Last 75 Years

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Introduction

Though steel usage in India dates to ancient times, production of steel using modern technology began only in the late 19th century with the creation of Bengal Iron and Steel Company, Kulti in 1875. The official establishment of Indian steel industry started with the setting up of Tata Iron & Steel Company, Jamshedpur in 1907 and Indian Iron & Steel Company (IISCO), Burnpur in 1918. Three major steel plants were set up post-independence at Durgapur, Bhilai and Rourkela in the 1960's. A new model for managing the steel plants was approved by the Parliament, with the setting up of Steel Authority of India Ltd. (SAIL) in 1973 and the integrated steel plants at Durgapur, Bhilai and Rourkela came under its fold. Meanwhile, IISCO was taken over by Govt. of India in 1972 and later became a subsidiary of SAIL in 1978. In 1991, GoI liberalized the steel sector by removing iron and steel industries from the reserve list. The deregulation and decontrol of the steel sector led to the entry of private players such as JSW, Essar Steel, Bhusan Steel, JSPL etc., who over the years have provided the impetus to the growth of the Indian steel industry. The new green field plants represented the latest in technology and brought about wider regional dispersion, easing the domestic supply position considerably in the western and southern region. The finished steel production in India grew from a mere 1.1 MT in 1951 to 111MT in 2018-19, with India becoming the second largest steel producer in the world.

Concurrent with the growth of Indian steel industry in the last 75 years, there has been a significant change in the customer's requirement which demands development of clean, quality steel with stringent property requirements. This has prompted steel producers to gradually modernize their steel plants with state-of-art technologies enabling production of high-quality steel with high strength and low impurity level for advanced applications such as automobiles, linepipes, bridges, submarines, nuclear power plants etc., to name a few. The paper outlines the technological advancements in the last 75 years both in terms of new disruptive technologies and products.

Advances in Steel Making

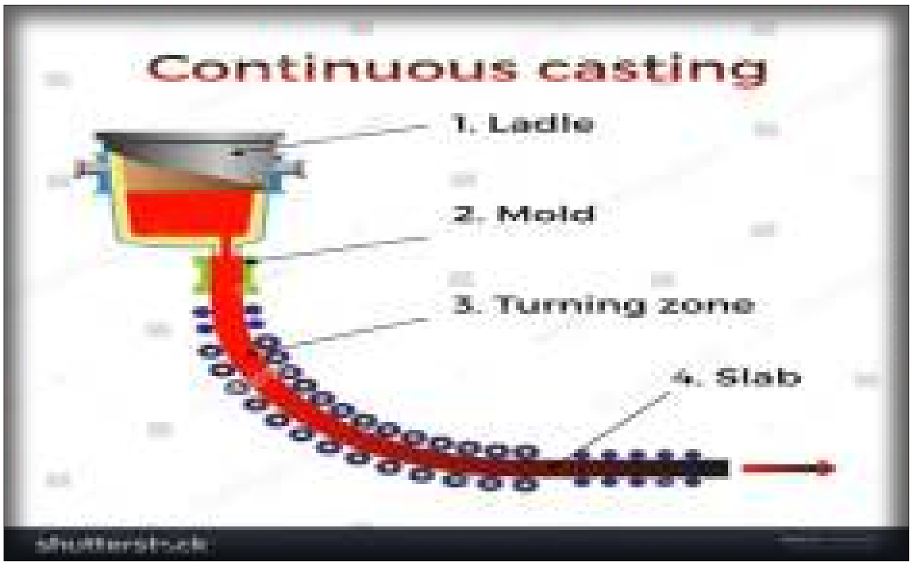
Steel making in the earlier part of 20th century was driven by Bessemer converter and Open-Hearth furnaces. The Basic Oxygen Furnace (BOF), also known as LD furnace, was introduced by Voest Alpine AG in 1952 and revolutionized the art of steelmaking. The process involves blowing with commercially pure oxygen (99%) and led to high productivity, low treatment time and high labour productivity. Sometime in 1976, the combined blowing technology (CBT) involving blowing from top and bottom of the converter was introduced in Indian steel sector. The technology involves oxygen blowing from the top and argon / nitrogen / oxygen blowing from the bottom, leading to better control of P, C and O level in the steel.

Various types of secondary refining processes have been introduced in the last 75 years or so, making the steel cleaner and free from intrinsic and extrinsic defects. The early 1950s saw the introduction of inert gas stirring where nitrogen or argon gas is used to rinse the liquid steel in order to achieve homogenous temperature, chemical composition and enable faster slag-metal refining reaction. Argon rinsing also helps in flotation and separation of non-metallic inclusions.

Dortmund Hoerder (DH) and Ruhrstahl Heraus (RH) degassers were introduced in the late 1950s to reduce the nitrogen and hydrogen level in steel. Rail steel for example is prone to hydrogen induced cracking (HIC), when the hydrogen level is beyond permissible limits, and leads to rail accidents and loss of lives and property. To minimize such occurrences, hydrogen level is controlled below 2 ppm and sometimes below 1.6 ppm. Similarly, high nitrogen steel leads to formation of blow holes, nitride precipitates and embrittlement of the steel. In the mid-60s vacuum arc degassing (VAD) was introduced for the first time to control S, H and N in steel while vacuum oxygen decarburization (VOD) enabled deep decarburization and production of ultra- low carbon steels. In the early-70s ladle refining furnace was introduced for temperature, S and inclusion control. Later, in the mid-70s, RH-TOB was developed to produce ultra- low carbon steel (<30 ppm), extra low H (<1 ppm) and low S and N content using multi-purpose top lance. These new technologies have enabled development of a wide variety of new generation steels for critical end-applications.

Continuous casting (Fig.1) has been one of the biggest break-through the steel industry has experienced in the last 50 years. The process has completely replaced the ingot casting route, which involved casting into ingots, soaking, rolling into slabs in a slabbing mill, scarfing, before it can be processed in a plate mill or hot strip mill. The continuous casting process, which converts liquid steel to slabs / blooms / billets in one go, is an order of magnitude faster (30-60 min) compared to 1-2 days in ingot casting for the same volume of processed metal. The inherent advantages of the continuous casting process, which was introduced in the Indian steel sector in the early 80s, helped to achieve higher yield and productivity, improved quality at lower cost. The yield of killed steels improved dramatically from 60-70% in ingot casting to ~ 95% in continuous casting along with improved surface quality and low segregation intensity. Today, more than 95% of world steel production is routed through continuous casting route.

Fig.1: Schematic representation of continuous casting process



Impact of Refining on Residual Impurities

With a thrust to produce clean steel for automobile, linepipe and other strategic applications, remarkable advances have been made to improve the efficiency of desulfurization, dephosphorization and high-speed degassing using state-of –art refining facilities. Table-1 shows the advancements made in steel refining technologies in the last 100 years and its impact on the impurity level in steel. In 1912, Titanic ship was built using a steel containing 0.21% C, 0.069% S, 0.045% P and 130 ppm total oxygen. Today, after 100 years, we are capable to make steel with 5 ppm total O, 5 ppm S, 15 ppm N, 0.8 ppm H and < 30 ppm P.

Table 1: Reduction in level of residuals (ppm) in last 100 years

Element	1912	2000	2020
C	2100(0.21%)	15	10
Ototal	130	<10	5
H	----	<1.2	0.8
S	690	<10	5
N	35	25	15
P	450	50	<30

Thermo-mechanical Controlled Processing (TMCP)

TMCP technology is widely used today in hot rolling mills for the production of high strength steels popularly known as micro alloyed steels or high strength low alloy (HSLA) steels. The earliest studies of TMCP was performed at BISRA in 1950's and 60's. The technology involves combination of micro alloyed additions, controlled rolling and accelerated cooling. Addition of small quantity of micro alloyed elements (MAE) such as Nb, V and Ti have a controlling influence on the recrystallization behavior of austenite, either while in solid solution or as a second phase precipitate. Niobium is a strong grain refiner and leads to concurrent increase in strength and toughness properties. Vanadium on the other hand induces higher strength through precipitation strengthening. Titanium in small amounts (<0.03%) helps in precipitation hardening along with restricting the austenite grain size during reheating.

Figure 2 shows the schematic representation of a typical controlled rolling process practiced in the industry. Deformation is carried out in two stages, namely, deformation in austenite-recrystallization zone (stage- 1) and deformation in the austenite non-recrystallization zone (stage-2). Deformation in Stage-1 leads to repeated recrystallization and formation of fine austenite grains. Deformation in stage-2 leads to elongation of austenite grains and formation of deformation bands within it. The finish rolling temperature controls the final state of austenite conditioning. Accelerated cooling refines the ferrite grain size and helps to achieve a wide array of microstructures and properties. Figure 3 shows the changes in microstructure associated with different stages of TMCP process.

Fig. 2: Schematic representation of TMCP process

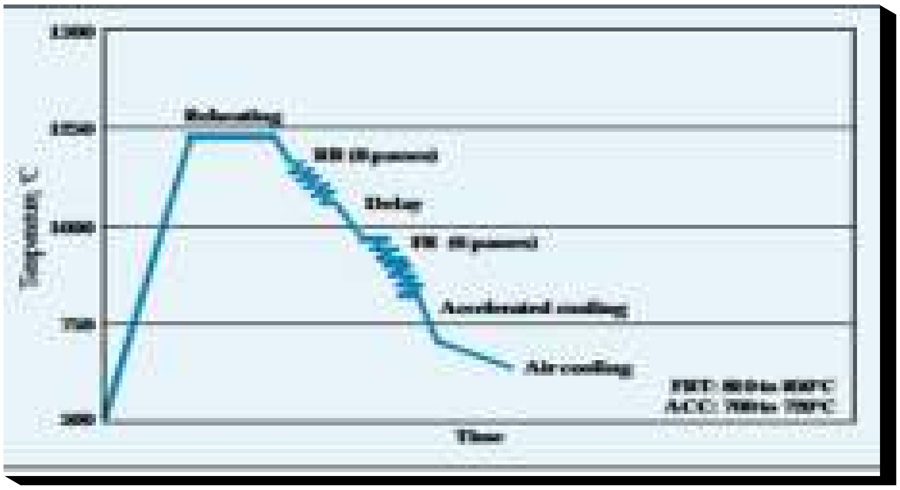
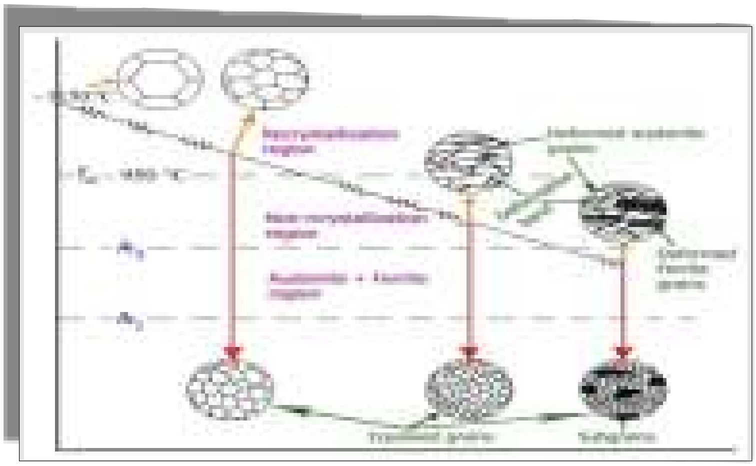
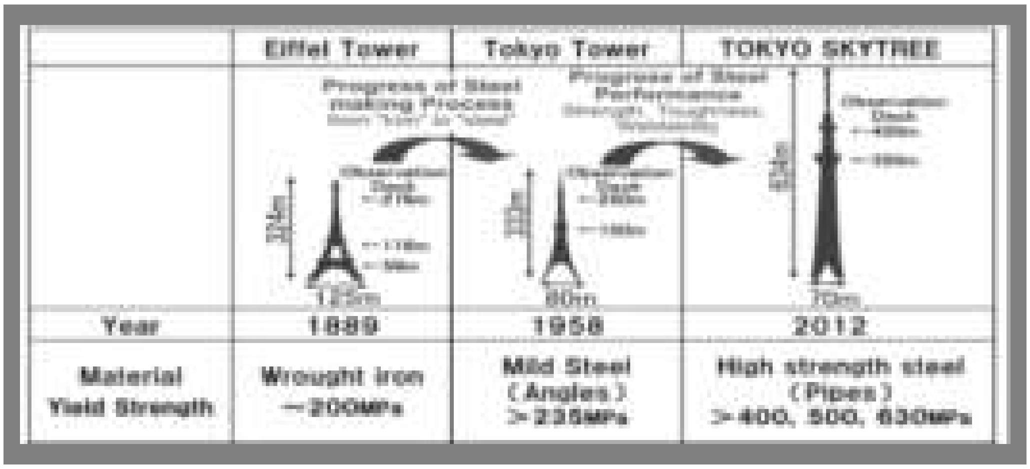


Fig. 3: Evolution of micro-structure during TMCP process



The first micro alloyed heat was attempted in Rourkela Steel Plant in the end of 1970s. With a better understanding of the hot rolling process, the technology is today exploited by all the major steel producers in the country. Today, more than 20% of the steel is produced through the TMCP route in the country and this is expected to increase two-fold in the next 10 years. Figure 4 shows how introduction of HSLA steels have resulted in dramatic weight reduction of steel structures and buildings in the last 100 years. Eiffel Tower, built in 1889 using wrought iron (YS:200 MPa) needed 7100 tons of steel for the 324 m high tower. Seventy years later in 1958, Tokyo Tower was built using mild steel (YS:235 MPa), where the 333m high structure needed 4200 tons of steel. Fifty years later, Tokyo Skytree was built in 2010 using high strength steel of YS:400, 500 and 630 MPa. The 634 m tower required only 4100 tons of steel.

Fig. 4: Transformation of steel products in the last 100 years

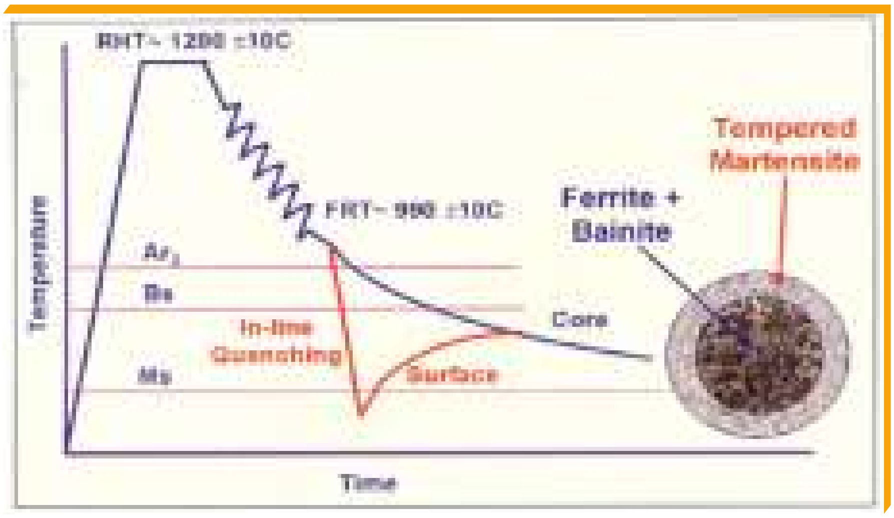


	Eiffel Tower	Tokyo Tower	TOKYO SKYTREE
Year	1889	1958	2012
Material Yield Strength	Wrought iron ~200MPa	Mild Steel (Angles) >235MPa	High strength steel (Pipes) >400, 500, 630MPa

TMT Process for Reinforcement Bars

Prior to early 1990s, cold twisted deformed (CTD) bars, also known as Tor steel, was extensively used for the construction of buildings, flyovers, dams and other RCC based structures. The CTD bars are cold twisted after the rolling process to impart additional strength but concurrently led to lower ductility, bendability and weldability properties. This led to frequent premature failure of the structures. To overcome this problem, thermo-mechanically treated (TMT) rebars involving a unique combination of rolling, quenching and auto-tempering process was introduced for the first time in the country. Figure 5 shows a schematic representation of the TMT process. As can be seen, a composite microstructure of tempered martensite rim and ferrite-pearlite/bainite core is formed. The tempered martensitic rim provides the strength while the ferrite-pearlite core imparts the desired ductility and bendability properties.

Fig. 5: Schematic representation of TMT process and microstructure



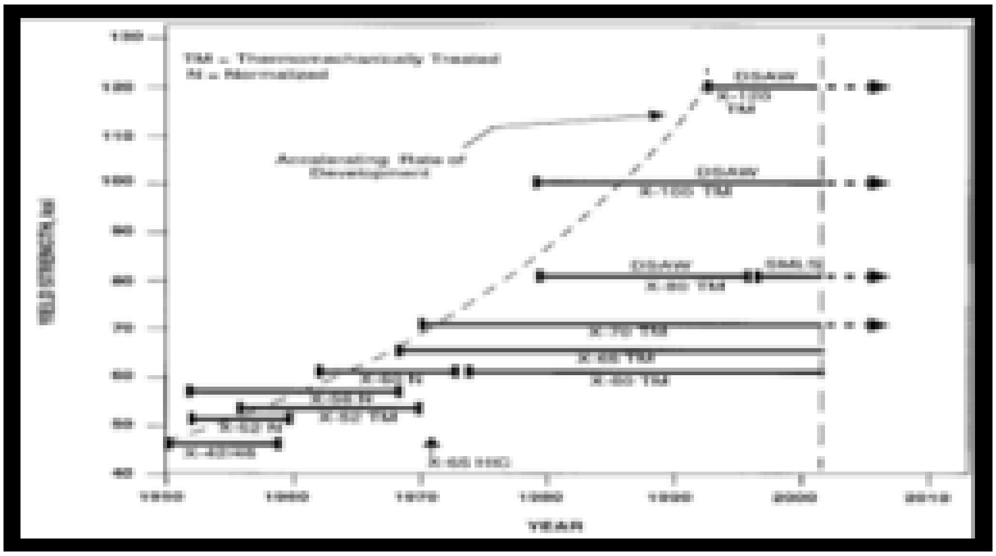
Over the last two decades, TMT rebars have completely replaced the CTD (Tor steel) rebars in the construction sector. TMT rebars are today produced using three commercially established technologies, namely, Thermex process, Tempcore process and Stelmor process. The annual demand of TMT wire rods/rebars in India today is to the tune of 42MT.

Product Innovations

To maintain a competitive edge in the steel sector, it is imperative to continuously innovate and develop new grades of steel at competitive cost for existing and new applications. Product development efforts in India has been driven by the major steel industries, SAIL, Tata Steel, JSW, JSPL and Essar Steel (now AM/NS India). A wide variety of new grades have been developed over the last 75 years catering to the needs of construction, infrastructure, automobile, hydrocarbon and defence sector. Weather resistant steels have replaced mild steel for fabrication of railway wagons and coaches. Today, the metro rail coaches are exclusively made of stainless steel having excellent aesthetic appeal and corrosion resistance. To meet the requirement of Indian Railways, the steel industry has developed 90 UTS rails, followed by 110 UTS (1080 MPa) and 120 UTS (1175 MPa) rails recently using head hardening (HH) technology for use in high-speed corridors, higher axle loads and increased traffic density. Other innovations in this sector includes long rails of 260m and thick web asymmetric rails used at "crossover" points in the railway track.

Linepipe steel conforming to American Petroleum Institute (API) is used extensively for the transportation of oil and natural gas. These are covered under API 5L specification and are commercially produced in a wide range of grades. Figure 6 shows the chronological evolution of API grade steel since 1950. API grade steel pipe production started with API X-42 (YS: 289 MPa) grade in the 50's and gradually with the development of TMCP technology and alloy concepts, today it is commercially available in a number of steel grades upto API X-100 grade (YS; 690 Mpa), while X-120 grade is under development. In India, production of API grade started in the end 70's with X-42 and X-46 grades, and today API grades upto X-80 are commercially produced in the country.

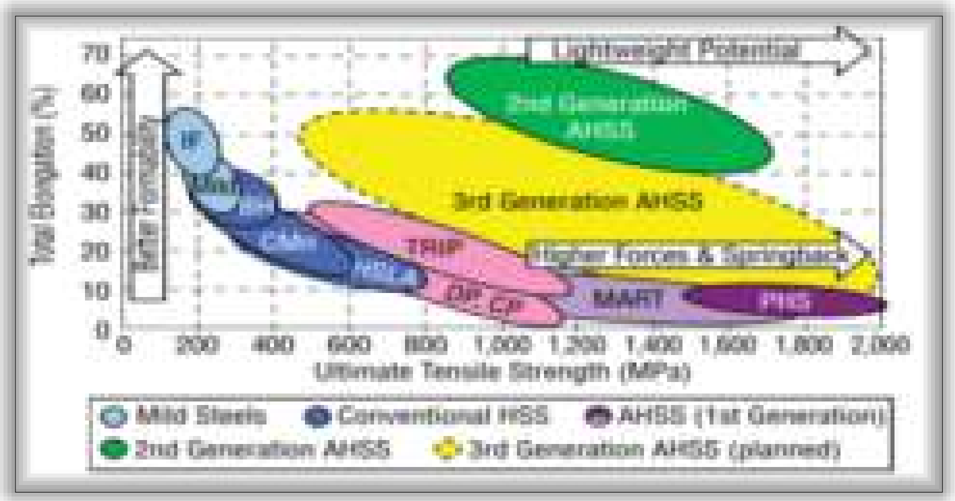
Fig. 6: Evolution of linepipe steel in the last 70 years



The automotive segment is the fastest growing segment in India and is continuously striving towards development of new designs and materials for achieving weight reduction, lower fuel consumption and improved safety standards for vehicles. In the early 60's and 70's, low carbon (<0.08% C) drawing (D) and deep drawing (DD) quality steels were used in passenger vehicles. These steels having lower ductility and formability properties, were required in thicker gauges, thus increasing the dead load of the vehicles. Later, extra deep drawing (EDD) quality steel with 0.04%C and interstitial free (IF) steel with ultra- low C (40-50 ppm) and low N (~30 ppm) was developed, which resulted in soft, ductile and highly formable steels. Small amounts of Nb and / or Ti was added to these steels to stabilize the interstitial C and N atoms.

In the last three decades, several new grades having high strength along with good ductility and formability properties such as dual phase (DP), TRIP, precipitation hardening (PH), bake hardening (BH), multiphase (MP), complex phase (CP) etc. have been developed and used for the manufacture of lighter and safer passenger and commercial vehicles in India. Figure 7 shows the chronological development of automotive steel grades. Presently, efforts are in progress to develop a new class of steel known as "Advanced High Strength Steel" (AHSS). These steels are based on the concept of quenching and partitioning (Q&P), TRIP aided bainitic ferrite (TBF), nano- structured (NS) and nano- precipitation (NP).

Fig. 7: Evolution of automotive steel grades



Concluding Remarks

- Steel has remained the "Material of Choice" in view of its multifarious properties, low cost and recyclability.
- The steelmaking and processing technologies have undergone dramatic changes in the last 75 years keeping pace with the increasing demand in terms of quality, product attributes and new applications.
- Continuous casting and TMCP are the two major technological break-through the steel industry has experienced in the last 75 years.
- Innovation and technology driven development is the guiding philosophy of modern steelmaking, pushing the horizon of knowledge to the unknown and unexplored territory.

Note: Inputs & Views are personal of the author (s) and not necessarily of FICCI