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INDIGENOUS STEEL TECHNOLOGY OF INDIA : WHAT WE COULD LEARN FROM IT

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ABSTRACT

Indigenous steel making technology existed in India since thousands of years. However, the indigenous steel industry withered away, perhaps a few hundred years ago, possibly due to the lack of initiative to cope with change. Worse still, the art of steel making practised in India since antiquity has not been well documented.

In the present paper, the author describes his own efforts in understanding the age–old steel making technology of India. The scientific advantage of the Indian technology is discussed and the need to imbibe from this in order to survive the challenge faced by the Indian steel industry today is highlighted. Further, the development of a new steel making technology, christened 'Ressiness', incorporating the advantages of both the indigenous steel technology and modern steel making practices is described.

Keywords : Indigenous steel technology, Delhi iron pillar, Wootz steel, Oxygen potential, Resiness process.

INTRODUCTION

The Indians had been well versed in the art of production and use of iron and steel since the last four millennia.

They produced steel using a small scale of operation. The Indian steel technology based on this very small scale operation, developed in diverse directions through its various periods of history. Unfortunately, very little of this development is systematically and authentically recorded, except those by the British. But, India's accomplishment in the steel technology development is evident from the well known artifacts and exhibits made during the different periods.

The British records of 18–19th century indicate that even though the scale of production was small, the volume of steel produced prior to this period could be quite significant, since the industry as well as its know-how were geographically dispersed, and active all over the country. But, by the 18th century, the indigenous steel industry had withered and was practically dead.

Even then, as late as 1835, the British engineers evaluated the indigenously made steel products for the construction of a bridge in India, and found it to be: superior in quality, much less expensive, and more easily delivered — when compared to the steel product obtained from abroad.

Indeed, India's achievements and traditions in steel technology have been glorious. At the author's initiative, India's indigenous process of making steel was reconstructed with the help of Birgia tribesmen at Bishunpur (near Ranchi) in Bihar. The author therefore, had an opportunity to study the basic approach and technology used in this process, out of his interest in archeology.

The study also enabled the author: to identify some lessons from which we all can benefit, and learn a very significant lesson in steel making. Accordingly, the specific purpose of this is twofold:

i. To indicate the relevance of some of these lessons in meeting the current compulsions of our national steel industry to achieve international competitiveness in the cost, quality and value of our steel products.

ii. To outline a new steel making route (RESINESS Process) which the author was inspired to concieve and develop, after he discovered, and learnt first hand, the fascinatingly original approach used in India's indigenous steel making process.

NOTABLE FEATURES OF INDIAN STEEL INDUSTRY OF THE 18TH CENTURY

The archeo–metallurgical evidences, the text of the Indian and other epics and Vedic literature show that the Indian sub–continent, as well as some of its immediate neighbours in West Asia and Eastern Mediterranean region, prepared iron and steel commodity and implements, and traded them across regions and countries. They had produced or used steel, as early as 4000 years ago.

In India, the evidences of excellent workmanship with iron based structural members are the Delhi Pillar (300 to 500 AD); the Dar Pillar (1000 AD, near Indore, MP); Konark Temple beams (900 AD) — to name a few; they are well known, studied and documented. During the various periods, steel was made and extensively used to make plough, bullock cart rims, small structural items, and several other tools and implements for a variety of applications. Amongst such applications, the 'wootz' steel made in India was extensively used and also exported for making swords (and probably armours) and special cutting tools. Famous amongst them being the Damascus sword, dating back to about 2500 years or more.

The above is recalled, since the 18th Century Indian Steel Industry inherited and absorbed the tradition and know–how of all that preceded it.

Unfortunately, there are no authentic records of the Indian steel industry or the technology it used, prior to the 18th century. One must pay tribute to the British engineers and investigators, who meticulously and painstakingly recorded whatever they observed and studied about the technology then used in India: the dispersion and size of the industry; trading and marketing in ore, charcoal and steel; and the quality and use of steel. The story stated below is derived from one such record. Some of the British records also lament that the steel industry in India was practically dead. Therefore the British were aware that they were recording the details of the process when the final duration was being drawn on India's indigenous steel industry.

The Indians used a small shaft smelting furnace, usually with a circular cross–section with air being blown from two bellows from the two sides of the furnace. The shaft furnace 1.5 to 2 meters high above the ground, was filled with alternate charges of iron ore properly sized and charcoal prepared from selected hardwood. At the end of smelting operation, a lump consisting mostly of reduced iron, siliceous and other gangue material containing some entrapped charcoal (and also a small amount of dissolved carbon), was obtained. The lump was cut into two pieces by an axe while in red hot condition and the pieces were then repeatedly hammered to squeeze out the gangue and to shape it into the form of a nugget or a rod or a bar — for refining and forging it later into useful articles as ordered by a customer.

Prior to the 18th century, the Indian steel industry based on the above technology, thrived in the different regions in India, to deliver steel that was needed locally.

The records show that the raw material was mined, sometimes from the underground. The sale of raw material such as iron ore and charcoal was decentralised in some of the regions. It is reported to have been sold in baskets in the village fair of Birbhum (West Bengal). In Karnataka, during a certain period of its history, the trading was centralised, as a single merchant is reported to have controlled the entire distribution of iron ore.

Even though its main features were common, the technology used in a given region differed in terms of the process details, the furnace and equipment, and in technique, from that used in the other regions. Obviously, the technology used, was developed, to adopt to the raw materials; and material of construction available; and the market needs of the region. For instances, the furnaces and scale of operation in Kerala was larger than the furnaces used in Tamilnadu or Bihar *etc.* Even though the steel produced mainly met the local needs, some of it, particularly the special steels, were traded across the region. A typical example is the wootz steel. It was indeed considered to be very special even as late as in the 17th, 18th and 19th centuries. This is evident from the fact that the different European nations appointed about half a dozen commissions during this period to study, record and learn the technology of making wootz steel, which was exported outside India to make swords since 2500 years age.

The steel industry in India was widely dispersed in the 18th century. One estimate has stated that as many as 20,000 small furnaces operated in India on a regular basis. The total quantity of steel made could then be quite significant. The steel produced was either sold directly to the user or to a trader who had to buy it in larger quantity.

The steel made, being in small scale however, was customised to the individual order and requirement. The ordinary steel was made to conform to four different specifications to match four different classes of applications. However, the special wootz steel was not made by all; the technique was known only to some, who kept it as a closely guarded secret. This steel was specifically made to order only for selected end users. The different European commissions appointed report with dismay that the Indians did not reveal the complete know-how to make the wootz steel. This is rather surprising since the inducements to do so would have been quite attractive !

WHY INDIA'S INDIGENOUS STEEL INDUSTRY WITHERED ?

The reasons why the Indian Steel Industry withered during the 18th and 19th century are not known. Therefore, one can conjecture only in general terms. It is interesting to explore what these could be. The large scale availability of hardwood charcoal in the local areas, on which the steel making was so critically dependent, would have been a natural constraint both on the survival and growth of the industry. The Europeans overcame this constraint by switching on to an alternative raw material — coal, and later coke when the BFs grew in size. The development of this major main line steel technology did not taken place in India.

The other reason is the absence of any technical forum in India where the professionals would meet regularly, to exchange and share freely the knowledge gained through their direct hands–on experience in the various technical arts such as steel making; founding; and forging. These forums thrived in U.K. in the 18–19th century. These forums provided to the producers, entrepreneurs, and traders the key inputs which facilitated the survival and growth of those arts in UK at that time. On the other hand, evidences show that the knowledge gained and technique developed in India, was held by everyone concerned (the then steel technologists and professionals) as a closely guarded secret. They hardly met, let alone communicated, to define response to the common adversity.

The above three reasons are just conjectures. But there is one clear reason which is evident from the following fact.

As late as 1835, the British engineers evaluated the indigenously made steel product — both in the mints of Calcutta and Jabbalpur and later on in UK. The Indian steel was superior in property and quality to the steels made in UK or even Sweden. It was less expensive in terms of the going price in the Indian market. The British engineer had recommended that the Indian steel product be used to construct a bridge in India, not only because of its quality and price but also because the delivery would be immediate and assured. The steel those days were shipped from UK and shipping those days required a long time and the ships were often wrecked during the voyage, dislocating all supply commitments. The other reason stated by him was that purchase of the Indian steel would revive the indigenous steel industry which was almost dead, and restore the living standard of the inhabitants of the townships. The inhabitants had earlier become prosperous though the manufacture and trading of steel and had currently been reduced to penury. The decision to import the steel from UK to build the bridge, was made through the political power wielded by the British to benefit its own steel industry and economy. Obviously, the Indian steel producers, traders, professionals and users, failed to organize themselves to protect their own interest. Compare this with the response of the leadership of British textile industry which faced the threat to its survival at that time in UK.

The reasons stated above for the decline of the Indian steel industry are not comprehensive. Instead, they are rather generic and superficial in nature. They do not represent the root cause. The root cause is probably related to our inability to cope with rapid change, arising from our 'cultural fixity'. The identification of the root cause would require a thorough and detailed study of the indigenous technology, and its development, growth and decline in the context of social and economic forces during this period in India. Such a study is outside the scope of this paper.

But, the causes identified above, even though superficial, haunt the Indian steel industry even today. Indeed, the question of survival of the Indian steel industry has again come to the fore due to new challenge the Indian steel industry face today.

CHALLENGE BEFORE THE INDIAN STEEL INDUSTRY TODAY

After the indigenous tradition of steel making practice disappeared by 1850s, Jamshedji Nusserwanji Tata, a pioneering visionary wh[illegible] produce steel by the turn of that century, had to import technology and a plant from the West to set up TISCO where the current meeting is being held. About 50 years later, and after independence, Jawaharlal Nehru, the architect of modern India, perceived steel as a strength and set up the public sector: BSP, RSP and DSP — based again on imported plants and technology.

During the past four decades since 1950, the steel consumption (and production) in India, has approximately doubled every 10 years. A model to predict the steel consumption indicates that the consumption of steel in India, during the next few decades, would double within a time span which is shorter than 10 years! Thus India would consume an increasingly larger quantity of steel during the next three or four decades. The question is, would this increasingly larger quantity of steel be met from the imported or the domestic source ? Would the Indian steel industry decline like in 18–19th century or would it develop its technology to survive the competition.

In the controlled steel market which existed prior to 1991, the customer had very limited option to buy steel and both the price and supply of steel were partly or fully controlled. Therefore, there was no urgency or impetus to intelligently acquire, use, absorb and develop steel technology. Then came the liberalization of 1991, which removed the restrictions on the price and import.

During 1991–96, the input cost into making the domestic steel increased by 39–43% and the prices were correspondingly increased by 38–48%. The duty on imported steel during the same period decreased from 65–70% to 25–30%. But, fortunately for the domestic producers, the effective duty amount more or less remained the same, due to the devaluation of the rupee and an increase in the international price of steel. Therefore, even though the quality and value derived by the customer from an imported steel were often superior, its landed price was higher than that of the domestic steel, during this period. This protected the Indian steel industry from the pressure on steel price till 1996.

The post 1997 scene is very different. The input cost into domestic steel will continue to rise. On the other hand, the duty on the imported steel (if the past trend is to be followed) will decrease or remain the same. The imported steel will therefore become more competitive — not only in quality and in value, but also in price !

Unless the steel producers, and equally important, the steel users, come together to collectively define a framework and a long term policy in which the input cost, duty, tariff, tax, excise and subsidies, are rationalised and suitably positioned to confer competitiveness on the domestic steel–based activities, and at the same time induce them to improve their inherent competitive strength — the price and cost will be engaged in an irrational mutual chase, as has happened during the last 5 years. The politics of the steel industry must be channelised to accomplish this if the Indian steel industry is to avoid its pitfalls of the past and develop along healthy lines. Fortunately, unlike two centuries ago, today the steel industry leadership can collectively organise itself to generate enough clout to leverage such channelisation.

The domestic steel industry enjoys a natural advantage of its lower cost of raw material and labour, when compared to its international competitors. In spite of this, the domestic steel may not be competitive in quality, value and price. This is so because the 'technological performance indices' of the shops and units of most of our steel plants are 50 to 60% of the international norms.

Several 'incremental improvements of technology' have been achieved during the last decade and a half, as result of which the 'plant performance indices' have been improved to impressive levels, through entirely indigenous efforts. However, such achievements are used only in a few shops and plants. Unless the concerned domestic steel technologists and professionals meet freely and periodically, to define a plan and organise themselves to horizontally transfer such 'incremental improvement of technology' across all our plants and units, the 'technological performance indices' of our steel industry cannot reach the international norms. If they did not share ideas and experience, as happened a couple of centuries ago, their common adversity will overtake them.

Domestic steel industry has to meet the challenge of global competitiveness through the pursuit of 'incremental improvement of technology' to accomplish either one or more of the following strategies: cost reduction; quality improvement; and value addition. The pursuit of these strategies requires the Indian steel producer to acquire, manage, use and develop technology with significantly more understanding and purpose than it has done in the past.

We are yet to learn how to manage and use steel technology, let alone develop an entirely new (or major) one. This is evident from the long time we take to stabilise the new steel plants acquired to a level of performance as specified in the 'Detailed Project Report'. This is so because our steel plants and technology are all imported; and our inability to develop plant and related technology breeds a diffidence in our subconcious which inhibits us to fully internalise, own and absorb them. Instead, we should draw inspiration from our glorious achievements in steel technology — not just to absorb and improve the imported ones, but to develop new steel technology which match our raw material, market and applications.

In several policy making forums, the anthor has been asked a stock question: why the Indian technologists have failed to develop a single major steel making technology during the last 50 years — which they can call their own and is exportable ? This question needs to be addressed; all the more since our steel industry declined two/three centuries ago as a result of our inability to develop the mainline steel making technology.

DEVELOPMENT OF NEW STEEL TECHNOLOGY

Steel Industry, by its inherent nature, yields a low financial return; therefore, the return has to be steady and for a long period. Accordingly, to succeed in usage, any steel technology developed has to satisfy three requirements:

i. the scale of operation of the new technology has to be large, so that it can survive competition for a long period with the existing technologies

ii. the technology must survive obsolescence and not be overtaken by other emerging technology of the future, for a long period

iii. the new technology must be demonstrated in a large enough scale, before anyone would agree to invest on a plant based on the technology; such scaled–up demonstration requires large resources and for a long time. Since very few funding agencies would make such large resources available for a long period, very few major technologies have been developed in steel.

Indeed, an examination of all the technologies developed during the last five hundred years in each of the areas of steel technology, would bear this out. As discussed below, only a few of the major technologies developed are in actual use.

For instance, in the iron making area, only four major technologies were developed during the last five hundred years which are currently in use. Similarly, in the steel making area, only five major technologies developed during the last 140 years are currently in use. The corresponding figures for casting; flat rolling; and shape rolling are respectively, four technologies in last 140 years; five technologies in 345 years; and five technologies in 245 years.

Unless India decides right now, to put in large resources for a prolonged period to develop a few major steel technologies, it can not expect its technologists to produce during the next 50 years a technology which it can call its own. The large resources apart, such pursuit requires very innovative organisation and management of the development work involved.

APPROACH USED IN INDIA'S INDIGENOUS STEEL MAKING TECHNOLOGY

India's indigenous steel making process technology uses iron ore as the starting material; this has a partial pressure of oxygen of $\sim 10^{-3}$. In the indigenous process, the ore is directly converted into steel. As a result, the partial pressure is progressively decreased by a million times; the partial pressure of oxygen in steel being $\sim 10^{-9}$.

The indigenous process is quite unlike the conventional BF–BOF route, which is the steel making practice followed all over the world. In the conventional BF–BOF route, the ore is at first 'over–reduced' to pig iron wherein the partial pressure of oxygen is $\sim 10^{-15}$ — a decrease of trillion times ! To convert it into steel, the pig iron has to be re–oxidized by a million times, since the partial pressure of steel is of the order of 10^{-9}. The conventional BF–BOF technology route, obviously requires 'back and forth traverse' across the different levels of oxygen potential. Naturally, such a process would require that a lot of redundant chemical and metallurgical work be done. Such redundant work, in turn, requires additional input of cost, energy, labour, material and time and would obviously decrease the efficiency, if steel is made using this approach.

India's indigenous process technology avoids this redundant metallurgical and chemical work, in order to convert the ore into steel.

The author recalls that the above thought occurred to him in the late 1980s while examining the microstructure of the steel sample prepared by the Brigia tribesmen, using India's indigenous process. The author marvelled at the discovery of this unique achievement of India's indigenous steel technology; more so because it was not an isolated and singular example of an experiment carried out in a laboratory; but it was extensively used in the thousands of furnaces, geographically dispersed all over the country for millennia. Others might have made similar discoveries, but soon realised that the techniques used in the indigenous process cannot be scaled up, unless one follows the conventional BF–BOF route which then requires the redundant steps of over–reduct ion followed by reoxidation.

The discovery of this achievement simultaneously inspired the author to conceive of a new process which has an approach identical to the India's indigenous steel making process, but is quite different from it in terms of the techniques used to accomplish the steel making. Obviously, the techniques have to be amenable to the scale up required.

This new process uses three basic metallurgical techniques: Reduction (RE), Sintering (SIN) and Electro Slag Smelting (ESS) — in succession, one after another, to convert the iron ore directly into steel, without any use of oxygen and in one continuous operation. Accordingly, the acronyms of the three processes given within the brackets, are joined together to christen the new process 'Resiness'.

RESINESS PROCESS

In this process, a mixture of the powders of iron ore (blue dust) and coal (fines) are mixed together and charged into a retort which is externally heated. This unit is termed as the RESIN unit. The column of charge mixture contains perforated steel tubes at its centre to carry up the gases generated during the reduction. The charge is mechanically pushed down together with the perforated tube, through the retort, as the reduction and sintering progresses. A red hot reduced and sintered iron rod emerges at the bottom of the RESIN unit. The rod contains 2 to 5% gangue; about 2 to 3% oxygen; and 2 to 3% unreacted carbon and the balance is iron.

The red hot rod directly enters the electro slag smelting (ESS) unit located immediately below the RESIN unit. The ESS unit contains a thick layer of slag which is kept molten by the passage of current through the slag. The rod melts in the form of droplets each of which undergoes further reduction and refinement

(S&P are removed) and also picks up carbon, as it descends through the slag, to form molten steel which collects at the bottom of the ESS unit.

The concept of RESIN process was at first extensively tested to produce rods of 10 mm in diameter and in batches of a few gms in the laboratory. Later, the process was successively scaled up, to produce rods which were about 300 mm in diameter weighing 70 to 100 kg. Simultaneously, batch size trials were conducted separately in the ESS unit using the rod as a feedstock. The trials conclusively demonstrated that steels of different compositions could be produced from the rod when electro slag smelted. These trials clearly showed that steel could indeed be produced directly from the ore without using oxygen. These trials also demonstrated that one can adopt modern metallurgical process techniques, to produce steel using the approach of India's indigenous steel making process.

The key questions were: can the rod production be made continuous and can the RESIN and ESS be successfully coupled — both metallurgically and operationally ?

To answer these questions, an apparatus was designed, fabricated and installed in one of the sheds of NML in 1990. The apparatus conclusively demonstrated that the DRI rod could be made continuously and fed into the ESS bath to produce steel.

The small scale of the apparatus used prevented its operation for long periods. The operations were disrupted due to fluidisation, sticking and most often due to mechanical breakdown. It was obvious that these limitations could be overcome and the adequate set of safety and improved design features could be built in, only in a scaled up version of the process equipment.

All over the world (Japan, USA, Russia, Australia and Europe), very large resources have been put in during the last one and half decades, to develop the Reduction–Smelting Processes. The main purpose of these processes are to switch (two centuries ago they made a similar switch from charcoal to coke which we failed to do and therefore declined!) to non–coking coal instead of the metallurgical coke which is used now in producing steel. The important point is that these processes, unlike India's indigenous process follow the over reduction–reoxidation approach with inherently lower efficiency.

In the context of these developments, the RESIN process trials demonstrate that modern metallurgical techniques can be adopted to produce steel, using the highly efficient approach of India's indigenous steel making process. This is interesting and significant since several other alternative techniques which use this approach, should be explored and fully developed — so that we too produce a mark on our glorious Heritage in Iron and Steel.

CONCLUDING REMARKS

India's indigenous steel making process technology and industry flourished and later declined in the 18th century. An analysis as to why it failed to survive, can give important leads to India's steel industry as to how it can overcome the current challenge to its survival.

The Indians excelled in the cost, quality and delivery of steel, just 150 years ago. We need to recall that and draw inspiration from it. We can do it again to become the very best !.

India's indigenous steel making process used an approach where the steel was produced by progressively reducing the oxygen potential of the ore — to directly convert if into steel. This approach is metallurgically and energetically highly efficient and can be adopted to suit the modern metallurgical process techniques.