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Influence of steel-making processes on the quality of reinforcement

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It is widely appreciated that steel reinforcement plays a critical role in influencing the structural behaviour of members and correct detailing of reinforcements is imperative if the structures are to fulfill their assigned roles. Most engineers tend to take the properties of reinforcement for granted and more often than not remain blissfully ignorant about the influence of the metallurgical and production characteristics on the mechanical properties of structural steel. Given the liberalised import regime and the large-scale conversion of imported scrap in the form of scrap rails, automobile scrap, defence scrap, scrap from ship breaking, etc of unknown or unsuitable quality, into steel rebars, possibly under less-than controlled conditions, raises apprehensions about the quality and reliability of steel rebars used in the construction industry. To be able to take informed decisions about the quality of steel rebars in a holistic manner, it is imperative that structural engineers are conversant with the steel-making characteristics that have a bearing on the mechanical properties of the rebars. In this write-up the production processes for steel rebars are briefly reviewed, followed by a discussion of commercial aspects in the manufacture of reinforcement steel. The current state-of-the-art relating to TMT bars is also presented. Need for pre-qualification criteria for selection of vendors for supply of rebars is highlighted.

The annual turnover of construction activity the world over exceeds US $ 3 trillion per annum with an annual growth rate of 6-9 percent. Growing at a rate of 10 percent per annum, the Indian construction industry accounts for about 5 percent of the gross domestic product (GDP) against a figure of 6-9 percent for most countries. Recent economic surveys, particularly that conducted by Standard and Poor in 1999, indicate that the Indian construction sector with the current investment of around US$ 37 billion will attain considerable growth in the next 5 to 10 years and will compete with some of the advanced and emerging economies in the Asia-Pacific region, as shown in *Table* 1[1].

Table 1: Construction markets in the year 2010

Country	1999 construction investment, US$ billion	Average annual growth rate	2010 construction investment, US$ billion
South Korea	64	12.3	233
UK	164	1.90	245
Japan	675	2.30	1002
China	346	10	1310
India	37	10.4	125

Given the traditional reluctance to exercise the option of steel-intensive construction in India, except in railway bridges and industrial structures to some extent, the primary source of consumption of structural steel in the construction industry has been reinforced concrete (RC) construction. Steel consumption in India is about 20 to 22 kg per capita which is very low as compared to the average consumption of 600 to 700 kg per capita in the developed countries. Up to the beginning of the 1980s, the manufacture of steel with very few exceptions, was the exclusive preserve of the public sector and the field was dominated by big players like SAIL, TISCO etc., with TISCO dominating the private sector and imports complementing the demand for specialised products. Since the mid 1980s, there has been an exponential growth in the secondary steel sector in the country and large capacities have been created in the private sector.

The secondary sector has been primarily involved in recycling steel scrap either through the re-rolling route or later through melting-ingot/billet route using the electric arc furnace (mini steel plant). A mushroom growth of the induction furnace industry for production of ingots was also witnessed in the 1980s. In the post-liberalisation scenario, with the opening up of imports, re-rolling mills based on recycling of imported re-rollable steel scrap and ingots account for a significant proportion of the production of steel rebars in the country. A total of 0.195 million tonnes (mt) of re-rollable scrap was imported by the secondary steel producers for direct rolling of bars and rods for the construction sector during the year 2001-2002. Out of the total production of bars and rods (including wire drawing) of 9.8 mt during 2001-2002 in the country, major companies like SAIL, TISCO and RINL produced 3.8 mt (38.77 percent) while the rest (6.0 mt) was accounted for by the secondary steel producers.

To be cost competitive, several units in the secondary steel sector resort to recycling of steel of doubtful veracity and rolling of untested ingots, scrap such as rails, etc, instead of tested billets, which due to the mandatory quality specifications, are fairly costly. A major portion of the steel consumption is accounted for by procurement by state and central government agencies through the tender route in which lowest cost is often the sole criteria. In many cases, large amount of untested and unsuitable quality steel is passed on to government buyers as tested steel by the unorganised secondary steel sector. Whenever tests are carried out, the quality of steel is more often judged on the basis of its tensile strength, expressed as the ultimate strength. Tests on other mechanical and metallurgical properties which may have a bearing on the service performance of the rebars are generally omitted. Structural engineers need to appreciate the fact that in addition to strength, the rebars should also possess adequate ductility which will be invaluable in earthquake resistant construction and bendability which will aid in the fabrication of the reinforcement cages for field placement.

The production processes and commercial aspects in the manufacture of steel have an important bearing on the quality of steel reinforcement and its subsequent performance and it is imperative that engineers are aware of the ramifications of the same so as to make informed choices in the selection of reinforcement for structural applications.

Production process

Without going into the intricate details and technical aspects of the production processes, structural engineers would be well informed to know the following.

Production of re-rollable steel

The modern steel industry is now over one hundred years old. The Bessemer, the open hearth and the electric furnace processes are often referred to as conventional processes of steelmaking. The LD, the Kaldo, the Rotor and their modifications are known as oxygen steel making processes[2]. They are also commonly called basic oxygen furnace processes because of their basic nature. IS :1786 allows manufacture of reinforcing steel by the open-hearth, electric, duplex, basic-oxygen or a combination of these processes[3]. All the above processes are essentially bulk steel making processes and are employed by the primary producers (or main producers) for manufacturing billets. Reinforcement bars are subsequently rolled from these billets.

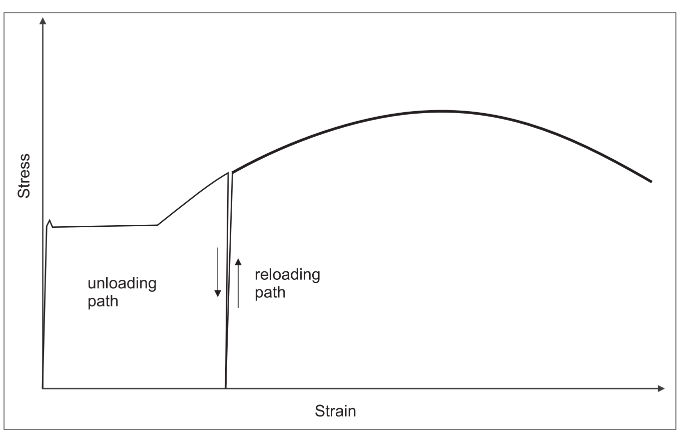

Fig 1 Effect of cold-working on mild steel rebars

Billets or re-rollable steel can also be produced either by melting scrap and refining in the electric arc furnace or through the blast furnace-convertor route. Electric arc furnaces in secondary sector have become unviable due to competition from induction furnaces and the high cost of power. Therefore, many renowned producers like SAIL, IISCO, TISCO, etc continue to be the main source of re-rollables (billets). At the production stage, the chemistry of billets must be maintained as per recommendations of IS 228[4]. Steel must be refined properly so as to remove all impurities and trace elements. Physical defects such as internal piping, porosity, cracks, seams and refractory inclusions are to be eliminated at this stage. The desired limits on the chemical composition of steel are given in IS 1786[3].

Rolling of re-rollables into rebars

Various types of rolling mills are employed for rolling of re-rollables. Continuous or automatic mills are recommended as these mills are capable of maintaining close dimensional tolerances, surface finish and rib pattern. The older type manual scrap re-rolling mills are not suitable for rolling good quality rebars. The rolling temperature, ideally, should be 900°C, hence "hot rolling", and the reduction ratio should be a minimum of 1:20 and the rib pattern must be in conformity with the requirements of IS 1786 so as to provide adequate bond between steel and concrete[3]. The end result of this process is the production of mild steel (MS) bars with proof strength of 250-MPa. Nowadays, plain MS bars are less commonly used in reinforced concrete because of their relatively lower strength, though they cost almost the same as high strength deformed bars. However, they are frequently employed in practice where nominal reinforcement is called for, as for example the distribution reinforcement in the case of one way slabs. Low strength is also preferred in cases where deflections and crack widths need to be controlled or where excessive ductility is required as in earthquake-resistant design.

Post-rolling process for imparting strength

Basically three processes, briefly explained below, are employed for imparting strength to the rebars.

Cold mechanical working

The process of 'cold working' involves stretching and twisting of mild steel, beyond its yield plateau, and subsequently releasing the load, as indicated by the thin line in *Fig* 1. The end product is the familiar cold twisted deformed (CTD) bars. Although stretching and cold twisting results in a residual strain in the steel, it also results in an increased 'proof strength'. Upon reloading, the steel follows a linear elastic path (with the same modulus of elasticity, E_S as the original mild steel) up to the point where the unloading started — the new raised 'yield point'. This point of yielding is not likely to be well defined if the point of unloading lies beyond the yield plateau of the MS bar. After the 'yield point', as can be seen from *Fig* 1, the material enters the 'strain hardening' range, following the path indicated by the thick line in *Fig* 1. It should be noted that although the process of 'cold-working' effectively increases the 'proof strength' of the steel, it also reduces the ductility in the material. This is perhaps the price to be paid in exchange for higher strengths.

It will be easily appreciated that higher proof strengths for 'cold-worked' bars can be achieved by suitably selecting the point of unloading in the mild steel strain hardening range and also by using higher grades of mild steel to begin with.

Cold mechanical working is a simple process involving minimum costs. It is reliable and is widely employed in India. The correct application of the process can be verified simply by visual inspection. However, adequate care needs to be exercised so as to verify the pitch of twisting since over twisting or under twisting can give undesirable results.

Micro alloying

This method involves inclusion of strengthening micro alloys such as *Nb*, *V*, *B* and *Ti* in steel during billet production As this method is expensive, it is generally not followed in our country though it is the prevalent practice in developed countries.

Heat treatment

In this method advanced heat treatment techniques such as controlled water quenching are applied on the red hot rebars as they come out of the rolling mill and the end product is known as "thermo mechanically treated" (TMT) rebars. Though this is the standard practice in developed countries, it has recently been introduced in India and TMT bars manufactured by SAIL, TISCO and the Vizag Steel Plant are commercially available in the country. Considerable care has to be exercised in the application of water quenching as improper application can lead to brittle and hard rebars. Thermo-mechanical treatment has helped produce reinforcement bars of high strength, superior ductility, weldability, bendability and thermal resistance creating a virtual revolution in reinforcement engineering.

The thermo-mechanical treatment process involves rapid quenching of hot bars through a series of water jets after the bars come out of the last rolling mill stand. The short residence time in the water jacket provides intensive cooling of the surface layer, transforming it into a hardened structure. The bars are then cooled in the atmosphere so that the temperature between the core which is still hot and the cooled surface layer is equalised. The heat extracted from the core tempers the peripheral hardened structure, while the rebar core cools down slowly to turn into a ferrite-pearlite aggregate. The strength of the bars is carefully controlled by optimising the water pressure for their specific alloy chemistry and bar diameter. The composite structure of the ductile ferrite-pearlitic core and the tough surface rim of tempered martensite provide an optimum combination of high strength, ductility and toughness.

The absence of any cold worked structural zone and the specific design of steel chemistry in the form of tempered martensite layer on the rebar surface, imparts high thermal resistance to the rebars, even at elevated temperatures of up to 600°C. These rebars are ideal for use in places prone to fire hazards. They possess excellent bendability due to the unique feature of uniform elongation and can withstand bending and rebending better than conventional CTD bars. These bars have very good weldability and do not suffer from loss of strength at the weld joints and can be easily welded with CTD bars. No pre-heating or post-heating is necessary during welding. TMT rebars are commercially available in strengths of 415, 500 and 550 MPa.

Commercial aspects

In general, steel rebars can be rolled out from either of the following re-rollables.

(i) Used scrap rails, automobile scrap or defence scrap

(ii) Defectives from steel plants

(iii) Scrap generated from ship breaking or discarded structures

(iv) Ingots from induction furnaces

(v) Tested billets from mini steel plants and main producers

The insistence on lower prices and the lack of awareness about quality aspects in the manufacture of rebars have lead to many unhealthy practices creeping into the manufacture of steel rebars. The commercial aspects governing the rolling of steel rebars are examined below.

Used scrap rails/automobile scrap/defence scrap

Scrap represents more than 50 percent of the iron used for steel production in Europe and a significant amount in India as well and hence it becomes imperative that its quality and consistency should be as high as possible to achieve high yields of finished steel[5]. Modern steel making process control demands accurate information regarding the quality of all feed stock materials, including scrap. Thus, sampling and testing techniques should be established though merchant scrap can be very heterogeneous and is often virtually impossible to sample. In the USA, for example, scrap is given Institute of Scrap Iron and Steel (ISIS) Code numbers that relate to 29 different types of scrap, whilst in Europe the Committee of National Scrap Federations and Association of the Common Market (COFENAF) has another similar system. Hence, though use of ferrous scrap in steel making is inevitable, these systems ensure a degree of control on the type of scrap used for the same.

In India, in the absence of any such specifications relating to the type and quality of scrap, virtually any type of scrap is being used as feed stock in many units in the secondary sector. For example, used rails are sold as scrap by the Railways in bulk quantities through tenders and these are re-sold in the open market. These rails have a very high percentage of carbon, typically in the range of 0.55-0.68 percent which makes these rails completely unsuitable for production of good quality ductile steel and its use should be discouraged. Similarly, the high carbon content in automobile scrap like leaf springs, axles, etc., and defence scrap such as bomb shells and high alloy steel scrap are unsuitable for use in the manufacture of steel bars.

Defectives arising from steel plants

During the manufacturing process in steel plants, steel scrap is generated due to operational faults. This scrap is known as 'internally circulating steelworks scrap' and is associated with liquid steel conversion to semi-finished and fully finished products prior to dispatch to the customer. The products of the conversion process are cropped to eliminate defects arising from mechanical deformation of steel slabs, billets, bar sections together with trimming to standard lengths and can result, in exceptional circumstances, up to 50 percent of the original liquid steel product returning for further refining, although 30 percent is the more usual figure. This scrap may be used in-house or is sold as re-rollables. Many steel rolling mills use it as a raw material for rolling steel bars. This scrap may have inherently inferior physical and metallurgical characteristics and hence may be unsuitable for rolling good quality rebars.

Scrap from ship breaking/ discarded structures

The gross tonnage of ferrous scrap recycled by the world's shipbreaking industry is estimated to be around 9 mt a year. It has been estimated that in the last decade of the previous millennium, some 85 million gross registered tonnes of shipping has been scrapped yielding about 43 mt of ferrous scrap. India has an extensive ship breaking industry concentrated along the Western coast, especially in the state of Gujarat where one of the largest ship breaking facilities is located at Alang. Ship breaking is a labour-intensive activity and a variety of steel scrap in re-rollable sizes is generated. Scrap arising from shipbreaking is usually of very high quality and vessels now being taken out of service for breaking are normally 20-25 years old. For countries with little indigenous scrap, the attractions of unwanted ships as raw materials for steelmaking are overwhelming. A word of caution, though, must be added. The chemistry of this scrap is often unknown, though often for commercial reasons this scrap is rolled directly into reinforcement steel bars. Naturally this steel does not have consistency in its chemical composition and the physical properties of this steel cannot be guaranteed although it is available at fairly low prices in the market.

Ingots from induction furnaces

Induction furnace is practically the only commercial process for making steels on a small scale. In northern India for example, induction furnace equipped rolling mills are located in Mandi Gobindgarh in Punjab and Muzaffarnagar in Uttar Pradesh. The induction furnace route is essentially a process of melting graded scrap and hardly any refining takes place. Ingots are produced in induction furnaces by melting steel scrap and occasionally, sponge iron. Since induction furnaces do not have the facility to refine the molten steel and control its chemistry, the end product is of inconsistent chemical and metallurgical properties and is a virtual reflection of the characteristics of scrap used as the raw material. As this steel is not refined, the desired percentages of carbon, sulphur, phosphorus, manganese, silicon, etc are not controllable. Naturally the end product is of unreliable quality and the Bureau of Indian Standards (BIS) has not issued certification to any producer who manufactures ingots from induction furnace. The ingots are subsequently re-rolled into steel bars. A big percentage of the output of these units is employed for construction of dwelling units and commercial buildings where the consumer who requires at the most a few tonnes of steel may not care more about the quality of the rebars.

Tested billets from mini steel plants/main producers

Billets from main producers are manufactured using either of the conventional processes or the basic oxygen furnace processes. In the widely employed open hearth process, a shallow basic lined vessel heated by either liquid or liquid and gaseous fuels is used as a furnace. The 'raw material' consists of scrap and molten pig iron and refining is carried out by blowing oxygen gas through the 'lances'. The scrap is initially heated to its approximately softening point and molten pig iron from the blast furnace is poured onto it. The molten steel is cast into 'billets' of cross section 90 mm x 90 mm, 140 mm x 140 mm with 95 mm x 95 mm and 115 mm x 115 mm sizes being ideally suited to feed mills producing round bar and small sections.

In mini steel plants, billets are produced in electric arc furnaces. The electric arc furnace is a key element of mini-steel plants. The steelmaking temperature of 1600-1700^{o}C is maintained by an electric arc struck between the electrodes and the metallic feed stock. The electric arc furnaces have the ability to refine the molten steel and are capable of controlling the steel chemistry. The production of steel billets using the electric arc furnace is an energy intensive process and due to high cost of electricity, the production cost using this method is steep.

Tested billets of approved specifications are available from main producers. The tested steel billets are the only suitable material for producing consistently good quality steel. The main producers provide BIS test certificates containing the detailed chemical and mechanical properties on purchase of billets.

The cost of steel billet manufactured using either the electric arc furnace or the open hearth process is higher than the re-rollables or semis manufactured using the techniques described in the previous sections. Naturally, the cost of reinforcing steel rolled out of billets will be higher than the rebars rolled out of other semis as listed in the previous sections.

Rolling

Rolling mill products can be classified into four main categories: rods and bars, sections, flats and alloy products. Rod and bar products form the largest market and they include sizes varying from 5-mm to 45-mm diameter in the case of MS and 36-mm maximum diameter in the case of deformed bars, besides carbon wire for manufacturing nails, screws fencing materials and reinforcement meshes, etc. The material to be rolled, the steel stock, is either cast as ingots (coming from induction furnaces) or comes from a continuous casting plant (main producers) as slabs or billets. Most rolling mills employ billets with cross sections varying between 80 mm x 80 mm and 130 mm x 130 mm. Ingots are more difficult to handle in rolling mills as they are not of uniform section and have lower metallic yields. For a good quality end product the control of rolling temperature is critical and in this connection the weight of steel to be raised to rolling temperature determines the most important design characteristic of rolling mills.

Defects in rolled steel: Bar inspection and testing

In order to produce satisfactory rebar products it is important that an adequate quality control system be established and maintained. This system should include mechanical and metallurgical testing as required, and the inspection for surface and other defects. The inspection of the bar product can be divided into two stages:

(i) Mill inspection and

(ii) Finished product or final inspection.

Mill inspection is performed during the rolling process and is the means of minimising or preventing discrepancies at the source. The adverse effects of these discrepancies if allowed unchecked, are later on reflected in the poor mechanical characteristics of the bars in terms of in adequate strength, low ductility and inconsistent bar geometry and surface quality.

Surface defects as well as other defects which cause the rejection of merchant bar products may be the result of steel-making practices which carry through from the ingot or may be caused by the rolling mill equipment used to produce the product. Some of the most regularly-occurring mill defects are:

- slivers (loose or torn segments of steel rolled into the surface of the bar),
- fire cracks and roll marks (impression on the product caused by over heated, cracked or spalled mill rolls),
- scratches (long nicks or indentations on the surface of the bars),
- camber (deviation of the side edge of a bar from a straight line),
- pipe (small round cavity located in the centre of an end surface),
- shear distortion (mashed or deformed end of a bar caused by defective or improperly adjusted shearing equipment),
- buckle and kink (corrugated and wrinkled surface condition caused by worn out mill rolls) etc.

Numerous tests have to be made during the finishing operations on the rolled bars. Their purpose is to reveal defects otherwise impossible to detect during surface inspection. These tests ensure that rebars of consistently high quality reach the hands of the consumer. In addition to the familiar mechanical tests like the tensile test and the bend test, other notable tests commonly employed are the:

- pickling test (to detect surface defects),
- eddy-current,
- ultrasonic and magnaflux tests (to detect crevices in steel) and
- etch test (to determine the soundness of internal structure) etc.

Conclusion

Ultimately, all efforts made in carrying out a rigorous analysis and design and careful detailing will come to a naught if poor or substandard materials are employed in construction, more so in the case of reinforcement where a plethora of different brands of reinforcement is available in the market, and more often than not, the quality of steel is taken for granted. It is important that quality norms are exercised in the case of reinforcement bars which should invariably have been rolled from tested billets.

To ensure reliable supply of good quality steel, the structural engineer need not overburden himself with the intricacies and nuances of steel production, though familiarity with the same is an asset. In addition to adhering to Codal quality control norms the following pre-qualification criteria for selection of vendors for supply of reinforcement steel, also suggested by Mase and inter-alia adopted by many public and private sector organisations are proposed[6]:

(i) The supplier should submit an explicit undertaking that all reinforcement for a particular tender shall be rolled from tested quality of steel billets only.

(ii) The supplier should produce a valid agreement or MOU with any supplier of tested billets for purchase of tested quality billets. The quantity of billets covered under such linkage should at least be two times the tendered quantity. This will avoid disruptions in supply. The supplier should have conversion arrangement with at least two main producers of steel for conversion of their billets into reinforcement bars. If the main producers are enlisting the supplier as a conversion agent for a regular basis then it ensures the credibility of the supplier.

(iii) The supplier should have the technical capability to reroll tested quality billets. This should be certified in terms of the quantity of billets rerolled by the supplier in the preceding three years. Supplier should have a full fledged quality assurance department as per BIS standards. Supplier's rerolling facilities should be suitable for rolling billets at a correct rolling temperature and supplier should furnish details of the temperature control devices installed in the reheating furnace in his premises.

(iv) The supplier should have the capacity to roll at least 3 times the quantity of reinforcement ordered. This will enable the supplier to complete the order within the stipulated time frame without any delay and will also ensure that only reliable and dependable suppliers are considered for procurement of steel.

(v) The primary criteria to be satisfied by the steel bars are the mass per metre run. The IS 1786 specifies batch rolling tolerances in the range of +/- 7 to 3 percent depending on the diameter of the bars. It is very well possible to control the weight of the rebars within these limits and if it is specified that steel should be supplied in the minus tolerance range only then substantial savings in the weight of steel could be effected. Though a premium of 1 to 2 percent may be charged for this, it is possible to save up to 7 percent of the cost of steel.

(vi) Steel bars may be purchased in standard lengths of say 11 m so that wastage can be reduced to a minimum. If the bars are purchased in random lengths (anything between 5 to 13 m) then wastage to the tune of 5 to 7 percent may be

encountered. IS 1786 : 1985 permits tolerances of +75/-25 mm when bars are cut to specified lengths but when minimum lengths are specified than minus tolerance is reduced to zero.

(vii) Many organisations insist that the supplier should have rolled and supplied a minimum of 5000 mt of steel rebars as per BIS Grade in at least one financial year in any of the preceding 7 years to government or major private sector organisations and should furnish documentary evidence of having paid the minimum marking fee for the above tonnage to BIS. This shall establish that the supplier has been consistently producing and supplying requisite quality of steel in the past.

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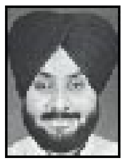

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