Manufacturing Process Routes for Reinforcing Steels

1.0 Introduction

In the UK, and in many other parts of the world, reinforcing steels are specified to British Standards, or very similar, which in the main do not specify process routes. As a result, many specifiers, purchasers and users are unaware of the different process routes used in their manufacture. Manufacturing process routes for some of the reinforcing steel products used have changed considerably in recent years, and manufacturers world-wide are introducing new manufacturing processes, as well as continually developing the more mature processes, to optimise cost and performance.

BS 4449 contains no specific requirements for manufacturing processes, although they can have a significant effect on the properties of reinforcing steels. Therefore within a British Standard grade designation, different process routes can produce different mechanical characteristics, with quite different responses to, for example, bending, welding, and other fabrication processes.

The purpose of this part of the Guide is to describe the most common process routes used for the manufacture of reinforcing steels in use today. These process routes link to the mechanical properties of the steels, which are covered in Part 3 of this Guide. This part (Part 2) also considers the control over manufacturers' processes exercised through the CARES scheme.

2.0 Manufacturing process routes

Figure 1 illustrates the most common reinforcing steel process routes. The different process stages can be split into:

- Steelmaking
- Ladle refining
- Continuous casting
- Hot rolling
- Cold processing
- Decoiling
- Fabrication
- Manufacture of welded fabric

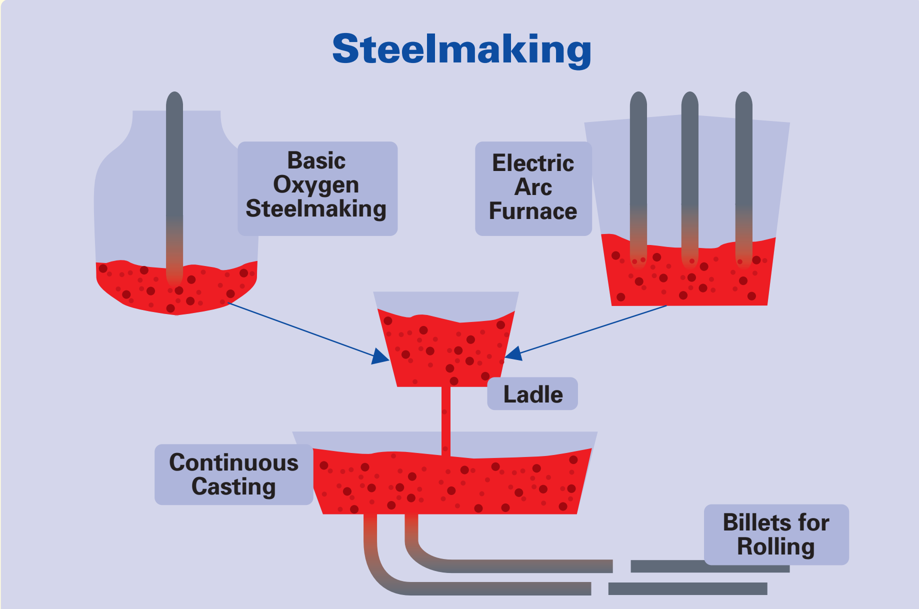

Figure 1

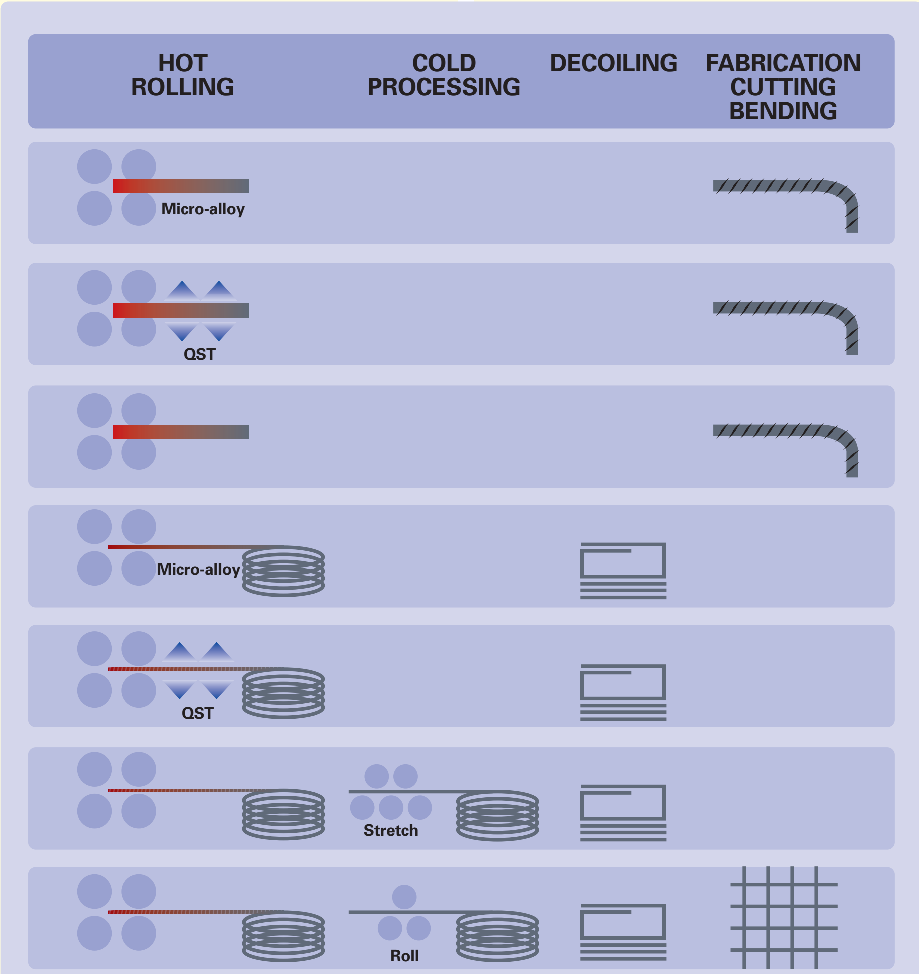

Figure 1

Electric Arc Furnace (EAF) steelmaking

Figure 2 Courtesy of Badische Stahlwerke (BSW) - Germany

2.1. Steelmaking

There are two common steel-making processes used for reinforcing steels. These are Basic Oxygen Steelmaking (BOS) and, perhaps the most common, Electric Arc Furnace (EAF) steel making (**Figure 2**).

In the BOS process, molten iron is first produced by smelting iron ore in a blast furnace. This pig iron is then transferred to a steel making vessel called a converter. Some scrap steel (up to 30% of the charge) may also be added. High velocity oxygen is then blasted into the molten iron, generating heat due to a process of oxidation. Impurity elements are removed, and the iron is refined into steel. The BOS process requires a high level of capital investment, and therefore this type of steelmaking is generally used by large steel producing works, typically with an output of several million tonnes of steel per annum.

The EAF process normally uses 100% scrap metal as the raw material, although other feed materials may be used. Furnace feedstock such as scrap metal is charged into the furnace and heat is applied by means of electrical discharge from carbon electrodes, thus melting the scrap. Whilst little refining of steel occurs in the EAF furnace, subsequent ladle treatment is often employed. An EAF furnace generally produces 0.5 to1.0 million tonnes per annum, making it ideally suited to smaller scale steel making operations typically used for the manufacturing of reinforcing steel. Typically an EAF melt shop is linked with a rolling mill, specialising in producing 'long' products such as reinforcing bars. Such a plant configuration is generally referred to as a "mini-mill". The majority of reinforcing steel to BS4449 is produced in such "mini-mill" plants, and this reinforcing steel, often produced from 100% recycled material, can provide a significant environmental benefit.

Whichever process route is used, the manufacture of steel is a batch process. Each time the BOS converter or EAF furnace is tapped, a batch of liquid steel of homogeneous analysis is produced. This batch is referred to as the "cast" or "heat", and it has its own unique chemical analysis. Knowledge of such chemistry is vital to ensure that subsequent processing conditions achieve a product of suitably consistent properties. In the relatively rare case where billets for rolling have become detached from the full system of cast traceability prior to rolling, CARES requires that there is a process at the manufacturer to ensure that cast 'reconsolidation' is achieved. Under the CARES Product Certification Scheme therefore, traceability to cast is maintained throughout all subsequent downstream manufacturing operations.

The principal differences between steels from the BOS and EAF process routes are due to the feedstock materials. EAF steel that is manufactured from 100% scrap, contains higher levels of residual (impurity) elements such as copper, nickel and tin, as compared with BOS steels. Because of the refining effect of the oxygen being lanced into the molten iron, BOS steels normally have lower levels of sulphur, phosphorus and nitrogen. Typical analyses of steels from the two routes are given in **Table 1**.

In both processes, carbon, manganese and silicon are deliberately controlled alloying additions. The other elements are present as impurities, which can have a significant effect on the final properties of the steel. They may affect:

Typical analysis (wt%) of BOS and EAF reinforcing bar

Process	C	Mn	Si	S	P	Cu	Ni	Cr	Mo	Sn	N
BOS	0.20	0.80	0.15	0.01	0.005	0.03	0.02	0.02	0.01	0.010	0.006
EAF	0.20	0.80	0.15	0.03	0.02	0.30	0.15	0.15	0.05	0.025	0.010

Table 1

- Strength. EAF steel tends to be stronger and less ductile than BOS steel.
- Weldability. High levels of residual elements, particularly copper, can cause problems in welding, although this is not a problem with the levels normally found in EAF steels.
- Bendability. Excessive levels of nitrogen can reduce bending capability, due to an effect called "strain ageing". For this reason, the nitrogen level in BS4449 is restricted to a maximum of 0.012% by weight, and a rebend test is included in the standard.

2.2 Casting

Traditionally, after melting and refining, steel was cast into ingot moulds in order to solidify. These moulds were then stripped, and the solidified steel was transferred to a mill for rolling in at least two stages; first to billet, then to the finished product. Due to a segregation of impurities to the top of the ingot, which required removal before further processing, a significant yield loss occurred making this process relatively inefficient.

Consequently, most reinforcing steel is now manufactured using the continuous casting process (**Figure 3**). Here, the steel is cast into a water-cooled mould, normally of square section, and the semi-solid product is withdrawn from the bottom, in a continuous operation. The steel is directly cast into billet for direct rolling to the final product, and does not contain the end defects associated with ingot casting. This process is therefore more economic and has quality advantages compared with the ingot casting previously used.

Continuous casting of billet

Figure 3 Courtesy of Allied Steel and Wire

2.3 Hot Rolling-Bar

Whichever casting process is used, the as-cast product always contains defects such as internal cracks, porosity and segregation, which are a result of the solidification process. All reinforcing steels therefore go through a hot rolling operation in order to consolidate the product, as well as change its shape. The reduction of cross-sectional area from the ingoing billet to the finished bar must be sufficient to weld up any internal defects, and improve the homogeneity in the product.

In the hot rolling process, the cast billet is reheated to a temperature of 1100- 1200°C, and then rolled through a rolling mill to reduce its cross-section (**Figure 4**). A rolling mill consists of a series of stands, each of which consists of two cylindrical rolls into which grooves are cut to accommodate the material being rolled. The sizes of the grooves are progressively reduced through the mill, so that the cross-sectional area of the product is continuously reduced as it is rolled. Hot rolling is a constant volume process, so that as the cross-section is reduced the product is elongated. At the end of the rolling mill, the product is sheared to the required length, bundled on a cast by cast basis, and labelled for despatch. Such labels are important to ensure cast traceability.

Hot rolling of billet into bar/coil

Figure 4 Courtesy of Allied Steel and Wire

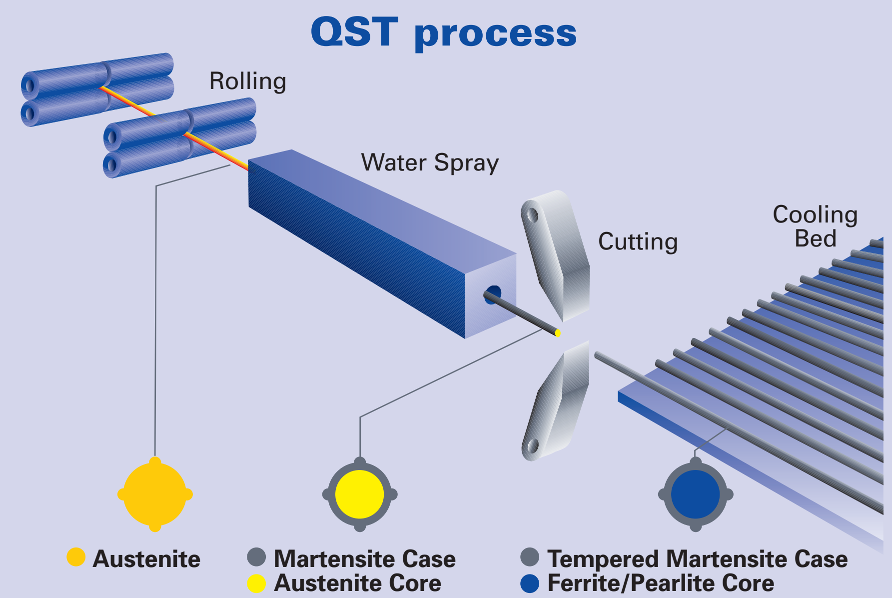

Figure 5

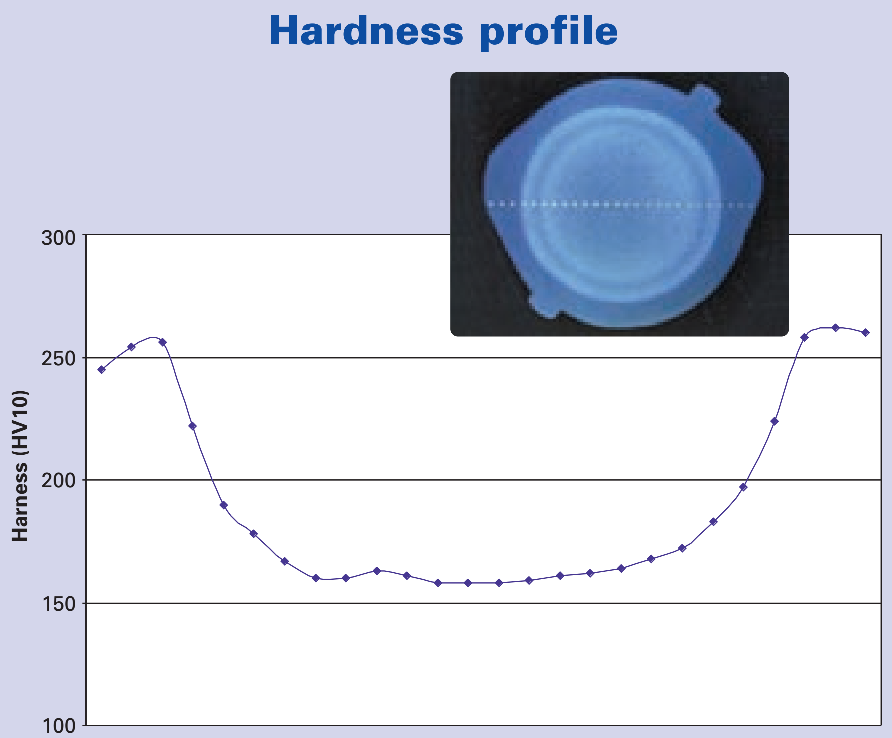

Figure 6 Courtesy of R-Tech Services

Modern rolling mills are highly automated processes, with sophisticated process control and high finishing speeds. Control of the rolling process is vital to ensure consistency of product shape, which is important for consistent bending performance on fabrication. The variation in section is normally controlled to much closer limits than the ± 4.5% allowed by BS 4449. This is important for both quality and commercial reasons.

The finished rib profile of the bar/coil is rolled onto the steel in the last stand of the hot rolling operation. Notches are cut into the grooves of the rolls, so that the hot steel flows into them in the rolling process, forming the transverse ribs on the reinforcing bar. Similarly, the dots and dashes of the CARES mark are formed by cutting marks between the notches, into which the steel flows, producing raised marks on the finished bar.
If longitudinal ribs are rolled onto the bars, which is generally the case, these are formed by allowing the hot metal to overfill the final pass.

There are currently two common methods for achieving the required mechanical properties in hot rolled bar; in-line heat treatment, and the use of micro-alloying additions.
In-line heat treatment is sometimes referred to as Quench and Self Tempering (QST). In this process, high pressure water sprays are directed onto the surface of the bar as it exits the rolling mill. The short duration of the quench transforms only the surface of the bar to a hard metallurgical phase, whilst leaving the centre of the bar untransformed. After leaving the quench, the core cools slowly, transforming to a softer, tougher metallurgical phase. The heat diffusing out from the core tempers the hard phase at the surface. The result is a relatively soft, ductile core, with a strong surface layer (**Figure 5**) thus providing the desired reinforcing steel properties.

An example of such a bar, showing the hardness profile across the section is given in (**Figure 6**).

Since its introduction, the QST process has become the most common method of manufacturing hot rolled reinforcing bar, mainly due to the high and often variable cost of alloying elements used in the micro-alloying route. In the micro-alloying process, strength is achieved by the addition of small amounts of specific alloying elements, which have a strong effect on the strength of the as-rolled bar. The most common element used is vanadium.
On cooling from the hot rolling temperature, small particles of vanadium nitride are formed within the steel. These particles, of the order of nanometres in size, produce a significant strengthening effect in the steel. Vanadium additions of only 0.05-0.1% by weight can increase the yield strength of the bar by 100 MPa. Unlike QST bar, the properties of micro-alloy bar are relatively homogeneous through the cross section.

Stretched, layer wound coils

Figure 7 Courtesy of Badische Stahlwerke (BSW) - Germany

2.4 Hot rolling-Coil

As well as rolling products into cut straight lengths, steel manufacturers also roll billets into coil, typically in the smaller sizes (8-16mm). Developments are in progress to increase the bar diameters rolled into coil form. A coil is a single length of bar, usually rolled from one billet. Such coil is ideal for fabrication in automated processes, and its use has been steadily increasing.

Most coils for use directly in automated cutting and bending processes are produced by hot rolling, the properties being achieved in a similar way to those described above for bar. Less frequently the required mechanical properties are achieved after rolling, by applying further work to the coil, for example by cold stretching (see **Figure 1**). In this case, the final shape is produced in the hot rolling operation, and the stretch produces around 3-4% reduction in cross-sectional area. The stretch is may be applied by putting the coil through a series of bending rolls, after which the product is' layer wound' onto spools (**Figure 7**). Layer winding enables improved processing by automatic cutting and bending machines, improving the efficiency of that process and providing better consistency of the resulting product.

More recently, reinforcing steel bars manufactured in coil form by the hot rolling process undergo a process called 're-spooling' which also results in a layer wound coil. The objective here is to manufacture a coil which can improve the subsequent automated cutting and bending process.

2.5 Cold processing

In addition to those processes described above, there are reinforcing steels in which the properties are achieved by cold processing. The two methods commonly used are cold rolling and cold drawing. The feedstock material for both processes is a hot rolled, round section rod. These processes are usually used for producing wire for the manufacture of welded fabric to BS4483, but can also be used for cutting and bending applications to BS 8666.

In cold rolling, typically used to manufacture bars in coil of diameters 12mm and below, the rod is deformed by passing it through a series of rolls. The material is forced into the gap between the rolls, and so is compressed. As in the hot rolling

Percentage change in characteristics after decoiling

Coil Process	Decoiling Method	Yield Strength (R_e)	Tensile Strength (R_m)	Uniform Elongation (A_{gt})	Cross Sectional Area	Rib Height
QST	Roller	+ 2.5 %	+ 1.8 %	+15.7 %	- 0.2 %	-11.8 %
Stretched	Roller	+ 2.3 %	+ 0.6 %	+ 3.4 %	- 0.1 %	- 6.9 %
QST	Spinner	+ 6.0 %	+ 0.6 %	- 14.2 %	- 0.9 %	-10.3 %
Stretched	Spinner	- 3.1 %	- 1.1 %	+ 10.7 %	+ 0.1 %	- 3.8 %
Cold Roll	Spinner	- 3.1 %	- 2.3 %	+ 14.9 %	- 0.2 %	- 2.0 %

Table 2

process, the rolls have grooves machined in them, such that normally three rows of ribs are formed on the cold rolled wire. It is important to note that cold rolled wire has lower ductility than hot rolled bars, but has the advantages of good section control and coil presentation, and therefore improved automated processing.

In drawing, the hot rolled rod is drawn through a series of carbide dies of reducing cross section. The resultant wire has a plain round section. Because strengthening is achieved by applying cold deformation, these steels also have relatively low ductility.

2.6 Decoiling

All coil products have to be de-coiled before they can be used. Sometimes this is done as part of the processing of cut and cut and bent shapes on an automatic link-bending machine. Other reinforcement fabricators, or perhaps even steel mills, use de-coiling machines for producing straight lengths for further processing.

De-coiling processes are generally of two types; "roller" and "spinner". In the roller type, which is the more common, the coil is passed between two sets of rolls in a 'serpentine' fashion. The product undergoes reverse bending stresses, and the rolls are adjusted so that the final product is straight, mostly followed by automatic bending to the desired shape. In spinner straightening, which typically is used to produce straight lengths, the coil passes through a set of rotating dies. The offset of the dies is adjusted along the length of the straightener to produce a straight product at the exit.

It is important to note that all de-coiling processes will have some effect on the final material properties. In most cases, the effect will be marginal. If badly performed however, de-coiling can have a detrimental effect on the finished product. CARES therefore requires that all of its approved fabricators be aware of this and operate their processes accordingly.

A study conducted by CARES shows the order of the effects of the decoiling processes on various performance characteristics.

Table 2 shows that certain combinations of coil process and decoiling method may result in changes to property characteristics which might be significant to the compliance of the steel with the product standard. Because of this, all CARES approved reinforcement fabricators are required to establish the capability of their decoiling processes in this respect.

3.0 The CARES Steel for the Reinforcement of Concrete certification Scheme

The structure and operation of the CARES scheme for Steel for the Reinforcement of Concrete has been described in Part 1 of this Guide. Inherent in the operation of the scheme, is a thorough understanding of the process routes being used for the manufacture of reinforcing steels.

The CARES scheme includes specific process requirements for each step of the manufacturing operation, from steel making through to delivery of steel to the construction site. CARES assessors have extensive knowledge of steel making, rolling and fabrication methods, enabling them to assess not just paperwork systems, but also the technical competence and manufacturing capability of CARES approved suppliers. All processes are assessed.

This CARES scheme requires that all layers of the supply chain for reinforcing steel, from steel making through to delivery of the final product to the construction site, involve approved manufacturers. Full manufacturer and product traceability applies throughout this approved chain, so that any job delivered to site can be traced back to the original steel making cast from which it was produced. All inspection and test data is retained throughout the supply chain.

In specifying materials from CARES approved firms, customers can be confident that manufacturing processes are fully capable of meeting the requirements of the specification.

References

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