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, and 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 in the UK have changed considerably in the last 10 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 4449:1997 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 for example to bending, welding, and other fabrication processes.

The purpose of this article is to describe the most common process routes used for the manufacture of reinforcing steels in use in the UK today. These process routes link to the mechanical properties of the steels, which are covered in Part 3 of this Guide. This part 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
- Continuous casting
- Hot rolling
- Cold processing
- Decoiling
- Fabrication
- Manufacture of welded fabric

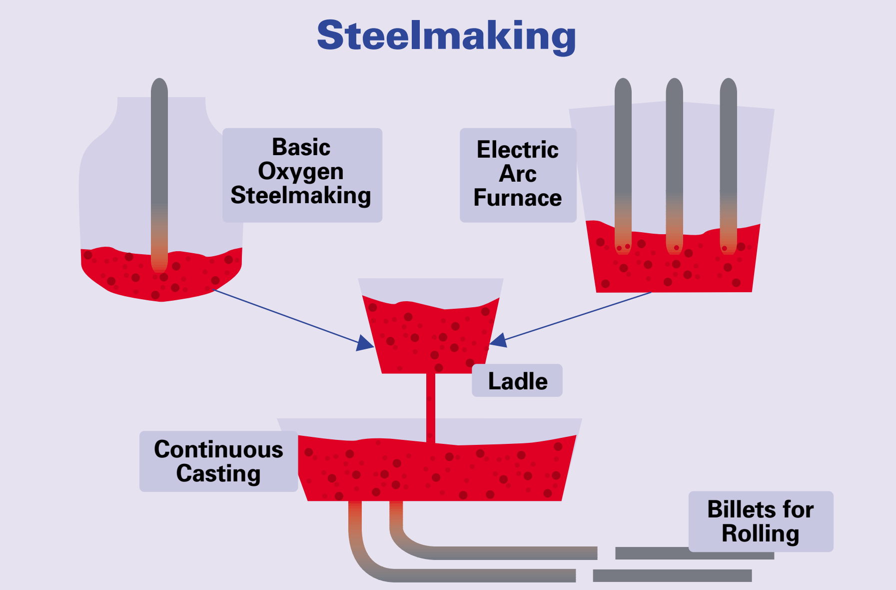

Figure 1

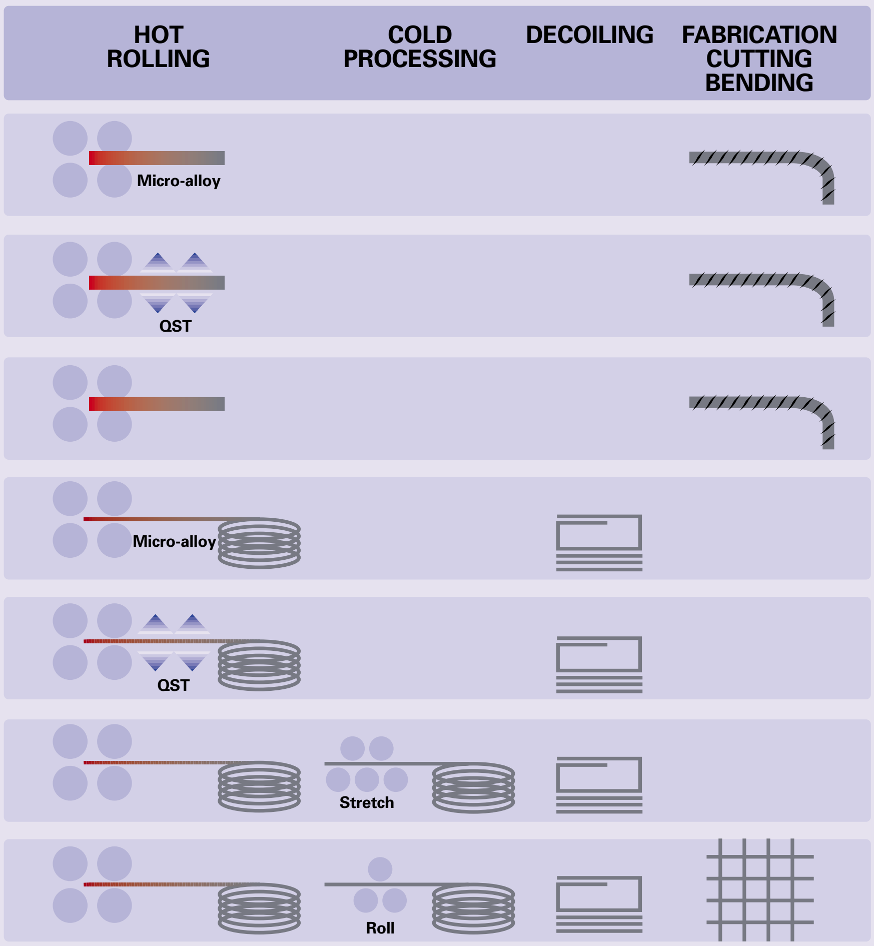

Figure 1

Electric Arc Furnace (EAF) steelmaking

Figure 2 Courtesy of Badische Stahlwerke (BSW) - Germany

2.1. Steelmaking

There are two common steelmaking processes used for reinforcing steels in the UK market. These are Basic Oxygen Steelmaking (BOS) and, by far the most common, Electric Arc Furnace (EAF) steelmaking (**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. 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 operation typically used for the manufacturing of reinforcing steel. In the main an EAF steel shop is linked with a rolling mill, specialising in producing long products, such as reinforcing bar. 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, produced from 100% recycled material, provides 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. Under the CARES Product Certification Scheme, 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. Because it is manufactured from 100% scrap feedstock, EAF steel contains higher levels of residual elements such as copper, nickel and tin, 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. Other residual elements deriving from the steelmaking process, whilst allowed within limits by both the British Standards, BS4449, BS4482 and the forthcoming European Standard, EN10080, can have a marked effect on the final properties of the steel. This is of particular relevance to those involved with the subsequent processing of the steel. Examples of such affects are:

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

- Coldworking. The reaction to further cold working, of steels produced by the BOS and EAF routes, eg in the drawing or rolling of plain round wire into ribbed reinforcing bars, can be markedly different, affecting both strength and ductility. The operators of cold working process must recognise this to ensure that finished products consistently comply with product standard requirements.

- Weldability. High levels of residual elements, particularly copper, can cause problems in welding. Reinforcement fabricators, approved by CARES to weld reinforcing steel, deal with this by setting limits within their welding procedures. This is described in some detail in Part 6 of this Guide.

- Bendability. Excessive levels of nitrogen can reduce bending capability, due to an effect called "strain ageing". For this reason, the nitrogen level in the above standards is restricted to a maximum of 0.012% by weight, and a rebend test is included.

Continuous casting of billet

Figure 3 Courtesy of Allied Steel and Wire

Hot rolling of billet into bar/coil

Figure 4 Courtesy of Allied Steel and Wire

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 produced worldwide 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.

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. The reduction of cross-sectional area from the ingoing billet to the finished bar must be sufficient to weld up any internal defects, and ensure 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

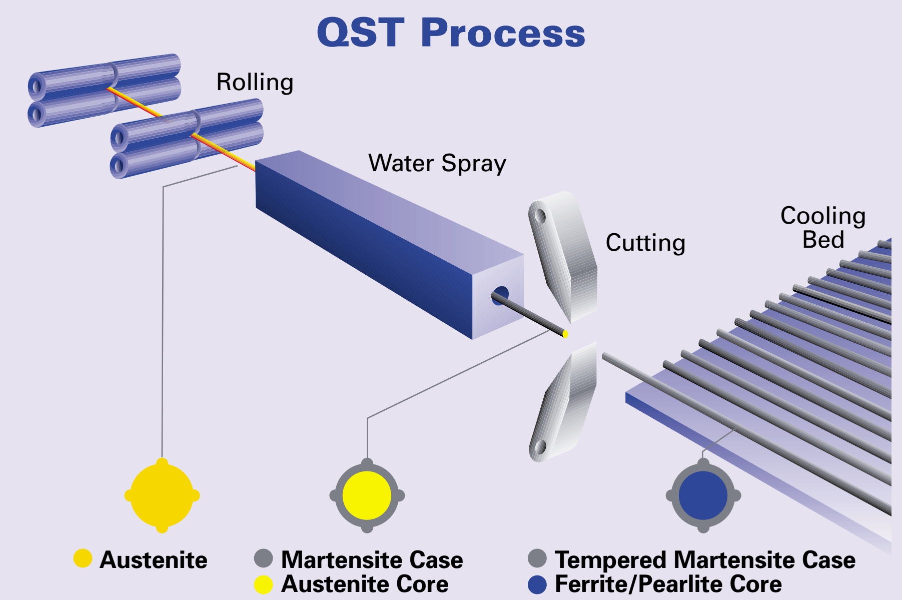

Figure 5

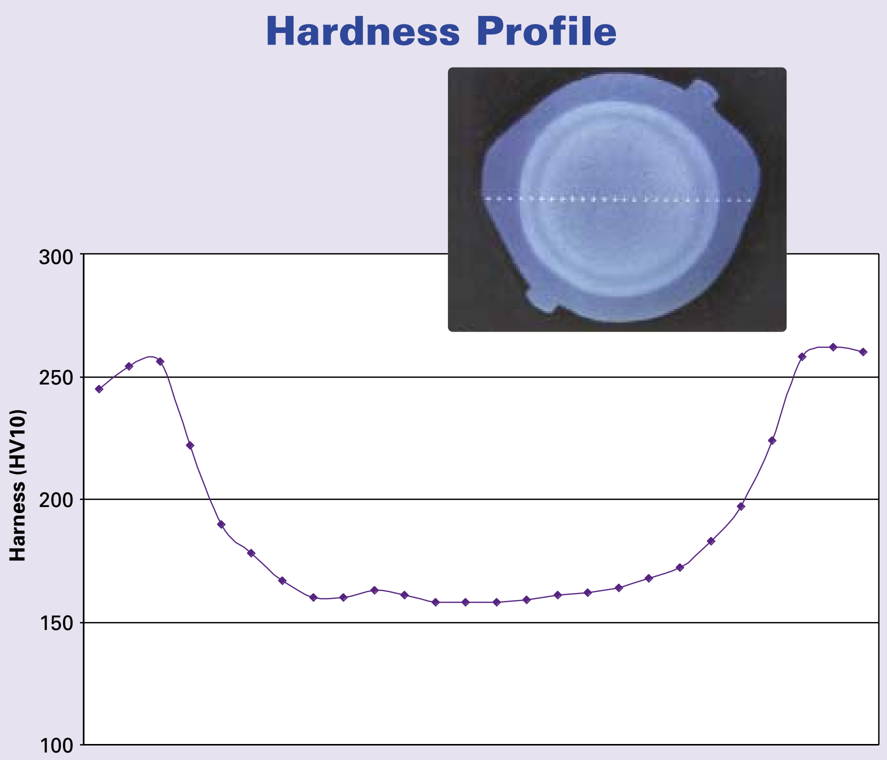

Figure 6 Courtesy of R-Tech Services

a mill to reduce its cross-section (**Figure 4**). A 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.

Modern rolling mills are highly automated processes, with sophisticated process control, with finishing speeds as high as 100 m/s. Control of the 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 rib profile 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, these are formed by allowing the product 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**).

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

Over the last 30 years, since its introduction, the QST process has become the most common method of manufacturing hot rolled reinforcing bar, mainly due to the cost of alloying elements used in the micro-alloying route. In this process, the strength is achieved by the addition of small amounts of specific alloying elements, which have a strong effect on the

Stretched, layer wound coils

Figure 7 Courtesy of Badische Stahlwerke (BSW) - Germany

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 section.

2.4 Hot rolling-Coil

As well as rolling products into cut straight lengths, steel manufacturers also roll billets into coil in the smaller sizes (8-16mm). 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 in the UK over the last 20 years.

Some coils, for use directly in cutting and bending, are produced by hot rolling, the properties being achieved in a similar way to those described above for bar. In other cases, the required mechanical properties are achieved after rolling, by applying further work to the coil, usually by cold stretching (see Figure 1). In this case, the shape is produced in the hot rolling operation, and the stretch produces around 3-4% reduction in cross-sectional area. The stretch is normally 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 bending machines, improving efficiency and providing better consistency of product.

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 to BS 4482, for the manufacture of welded fabric, but can also be used for cutting and bending applications to BS 4482 or BS 4449.

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

In cold rolling, 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 process, the rolls have grooves machined in them, such that three rows of ribs are formed on the cold rolled wire. Cold rolled wire has lower ductility than hot rolled steels, but has the advantages of good section control and coil presentation.

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 in some process, before they can be used. Sometimes this is done as part of the processing on an automatic link-bending machine. Other reinforcement fabricators have de-coiling machines for producing straight lengths for further processing.

De-coiling processes are generally of two types; "roller" straightening and "spinner" straightening. In roller straightening, the coil product 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. In spinner straightening, 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 realise that all de-coiling processes will have some effect on the final material properties. In some cases, the effect will be marginal. If badly performed, de-coiling can have a significant detrimental effect.

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 Scheme for Steel for Reinforcement of Concrete.

The operation of the CARES scheme for steel for the reinforcement of concrete has been described in Part 1 of this Guide. Inherent in the scheme, is a thorough understanding of the process routes being used around the world 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.

The 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 producer 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 CARES approved materials, customers can be confident that manufacturing processes are fully capable of meeting the requirements of the specification.

References

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