The CARES Guide
to Product Certification

Part 2
2023

Manufacturing Processes for **Reinforcing Steels**

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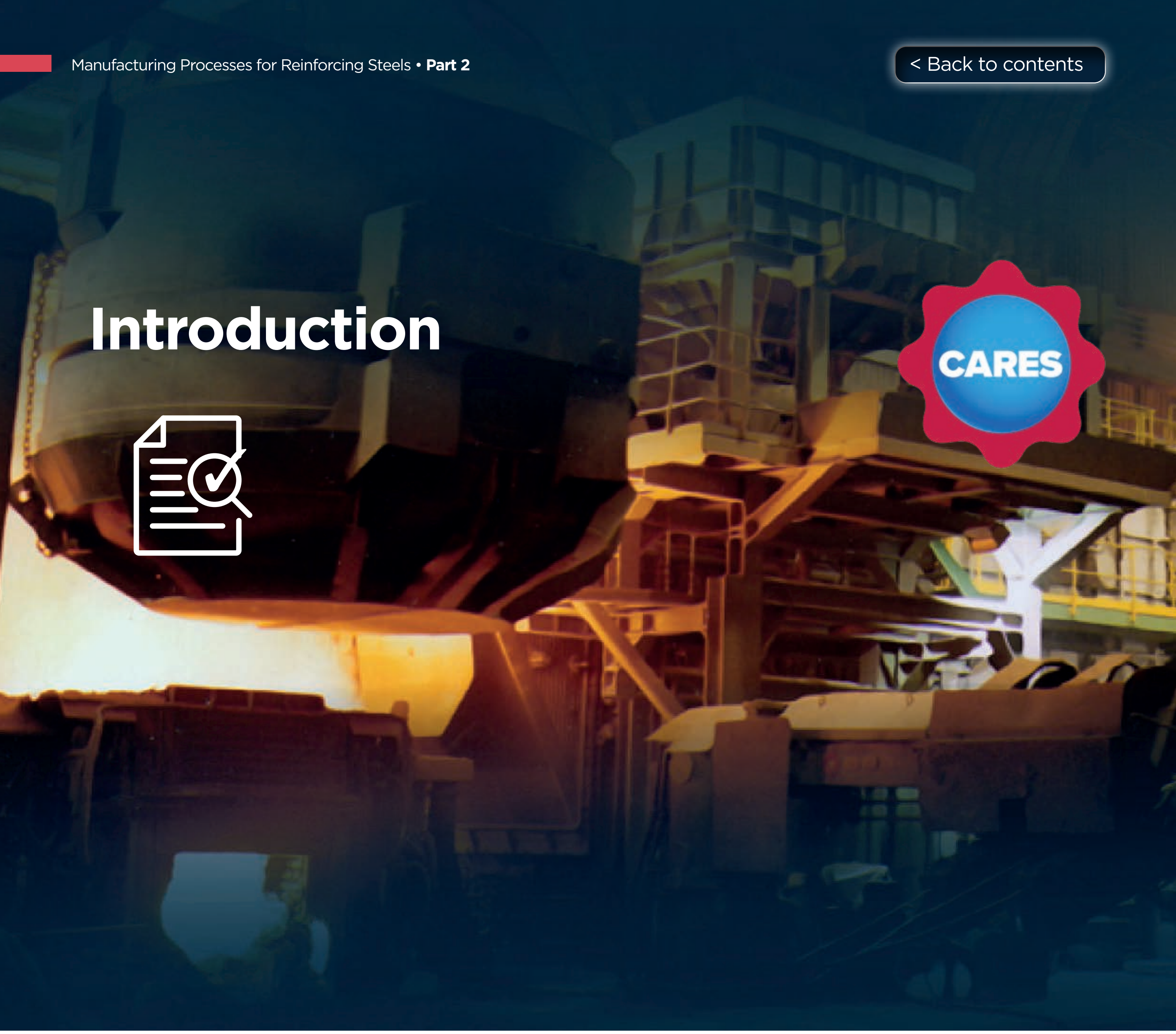

Introduction

Historically, standards for reinforcing steels have not generally specified manufacturing process routes. As a result, many specifiers, purchasers, and users are unaware of the different manufacturing processes used. However, these processes, whether in steelmaking, rolling, heat treatment or cold processing have characteristics which affect the properties of the reinforcing steel. In particular, the various process routes have a strong influence on aspects such as the chemical analysis, the mechanical properties, the consistency of shape and the behaviour in subsequent processing, such as decoiling, bending, threading, or welding. Different process routes are also the single most significant factor that determines the global warming potential of the product.

The purpose of this part of the Guide is to describe the most common manufacturing processes used to make reinforcing steels and the assessment of manufacturers' processes exercised through the CARES product certification scheme. These process routes link to the mechanical properties of the steels, which are covered in Part 3 of this Guide.

Manufacturing process routes

Figure 1. Reinforcing steel process routes.

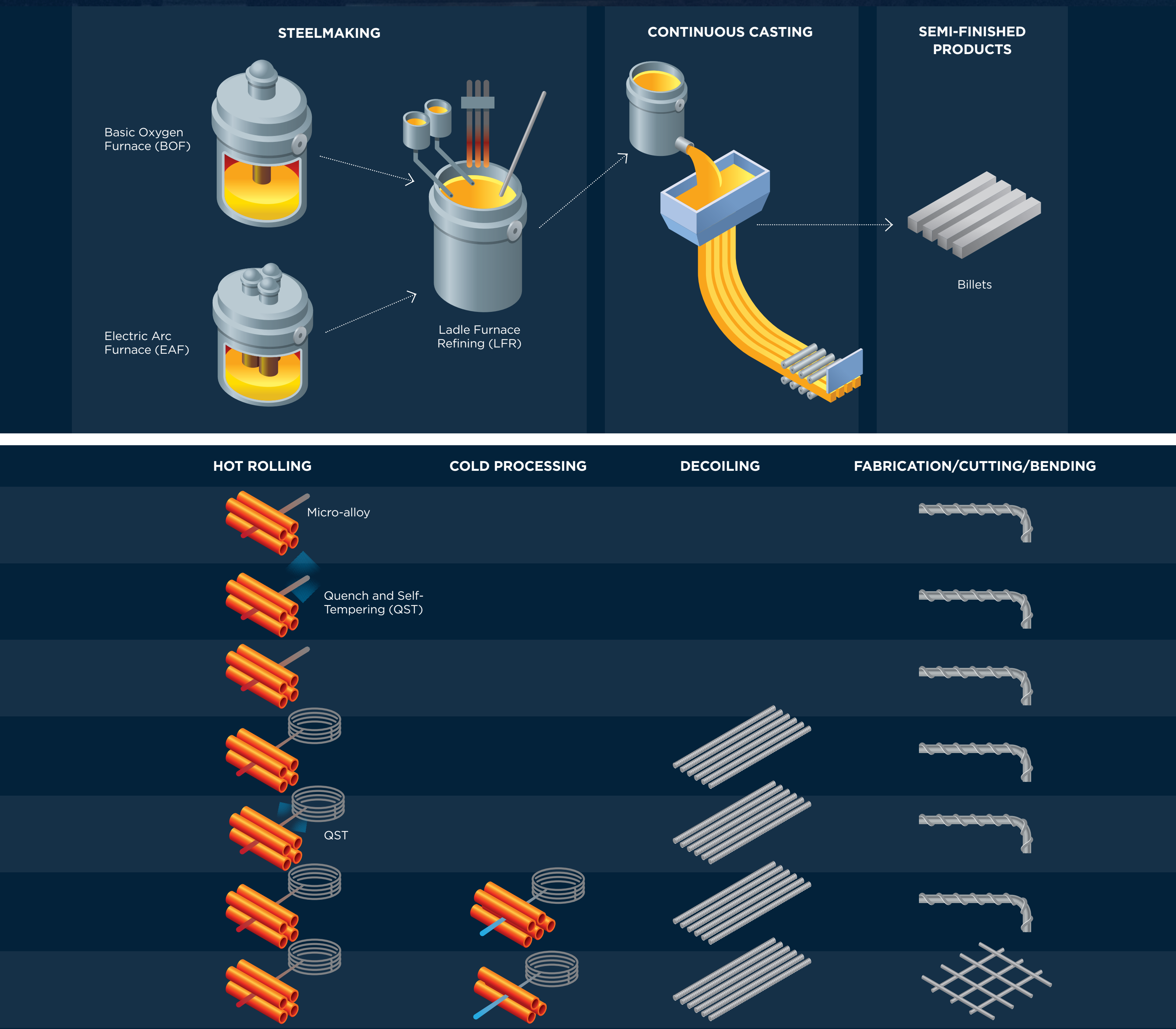

Figure 1. illustrates the most common reinforcing steel process routes. The different process stages can be split into:

- **Steelmaking**
- **Secondary steelmaking (ladle refining)**
- **Continuous casting of billets**
- **Hot rolling of billets (with or without in-line heat treatment)**
- **Cold processing (stretching or rolling)**
- **De-coiling**
- **Fabrication (cutting and bending).**
- **Manufacture of welded fabric.**

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Steelmaking

Although the steelmaking and refining processes used are significant, they are generally neither specified nor restricted in reinforcing steel standards. They are sometimes described in BS 4449:2005[1] as "at the manufacturers discretion". Nevertheless, the various steelmaking processes used have characteristics which affect the performance of the reinforcing steel products, and in particular the chemical analysis.

Probably of even more significance for processors and end users is the process route employed by the steel manufacturer to obtain the required mechanical properties in the product. This relates to the hot rolling and subsequent processing of reinforcing steels. Recognising this importance, the British Standard BS 4449:2005[2], which is the basis of the CARES product certification scheme for reinforcing bars and coils[2] requires that the manufacturing process route (used to achieve the mechanical properties) is stated on the manufacturer's test certificate.

The new draft European Standard (EN10080)[3] goes further and restricts the manufacturing process route for reinforcing bars and coils to:

- Hot rolled (with no further treatment)
- Hot rolled and heat treated
- Hot rolled and cold stretched
- Cold deformed (drawn or rolled)

Although the situation in the industry is slightly more nuanced, with some combinations of the above processes sometimes used, this classification provides a helpful way of describing the various process routes currently employed to produce the mechanical properties in the finished product.

Process route is important for some downstream processing, such as welding, and some coupling systems, where procedures have to be qualified for each steel manufacturing process route used.

There are two common steelmaking processes used for producing reinforcing steels (Figure 1):

- Basic Oxygen Steelmaking (BOS)
- Electric Arc Furnace (EAF) steelmaking

Figure 1. Reinforcing steel process routes

In the BOS process, molten iron is first produced by smelting iron ore with coke in a blast furnace. This produces "pig iron", which is essentially cast iron, and contains much higher levels of carbon (about 3-4%) than is appropriate for steel. The liquid iron is then transferred to a steelmaking vessel called a converter. Some scrap steel (up to 30% of the charge) is also generally added. High velocity oxygen is then blasted into the molten iron, generating heat due to oxidation of the carbon present in the molten iron, producing carbon monoxide (CO) and carbon dioxide (CO_2). Some impurity elements are removed by the oxidation process, and the iron is refined into steel, with a carbon content of about 0.2%. The BOS process requires a high level of infrastructure and capital investment, and therefore this type of steelmaking is generally used by large steelworks, typically with an output of several million tonnes of steel per annum.

The EAF steelmaking process (see Figure 2) normally uses 100% steel scrap as the raw material, although other feed materials such as direct reduced iron (DRI) and hot briquetted iron (HBI) may sometimes be used. Furnace feedstock (normally a mix of different grades of steel scrap) is charged into the furnace and heat is applied by means of electrical discharge from graphite electrodes, thus melting the scrap. An EAF furnace generally produces 0.5 to 1.0 million tonnes per annum, making it ideally suited to smaller-scale steelmaking operations typically used for the manufacture of reinforcing steel. Often an EAF melt shop is linked with a rolling mill, specialising in producing 'long' products such as reinforcing steel bars and coils. Such a plant configuration is generally referred to as a "mini-mill".

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EAF Steelmaking

Figure 2. EAF steelmaking

With both main steelmaking process routes, it is now common for a secondary steelmaking operation to be employed. The ladle of molten steel from the BOS or EAF process is transferred to a separate ladle steelmaking station, where the steel can be heated very precisely by means of graphite electrodes, and the chemical analysis can be adjusted by the addition of alloying elements in the form of granules or wire. This ladle refining step allows the steelmaker to control very precisely both the chemical analysis (to ensure the steel meets both the chemical analysis of the required standard), and the temperature (to ensure efficient, defect-free casting).

Whichever process route is used, the manufacture of steel is a batch process. Each time the BOS converter or EAF furnace is tapped into a ladle, and then processed in a ladle furnace a batch of liquid steel of relatively homogeneous chemical analysis is produced. This batch is referred to as the “cast” or “heat”, and it has its own unique batch identification, which is used for traceability through all subsequent downstream processing.

Controlling the chemical analysis is vital to ensure that subsequent hot rolling processes achieve a product of suitably consistent mechanical properties, meeting the requirements of the various product standards. Under the CARES product certification scheme therefore, traceability to batch is maintained throughout all subsequent downstream manufacturing operations to the actual construction project.

The principal differences between reinforcing steels from the BOS and EAF process routes are due to the feedstock materials. EAF steel that is manufactured from 100% scrap, generally contains higher levels of residual (impurity) elements such as copper, nickel and chromium, as compared with BOS steels. BOS steels also normally have lower levels of sulphur, phosphorus and nitrogen. Typical analyses of reinforcing steels produced for the Quench and Self-Tempering (QST) process from the two steelmaking 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 mechanical properties of the steel. They may affect:

- Strength. With similar C and alloy levels, EAF steels tend to be stronger but less ductile than BOS steels.
- Weldability. High levels of residual elements in EAF steels, particularly copper can cause problems in welding.
- Bendability. High levels of nitrogen can cause embrittlement on bending through a process called strain ageing. For this reason nitrogen is restricted to 0.012% maximum, in the cast analysis and a rebend test is included in the standard

In March 2016, an amendment was introduced into BS 4449:2005 requiring that all other intentionally added elements shall meet the requirements of BS EN 10020[4]. This clause was specifically introduced to control additions of boron.

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. Typical analysis (weight%) of BOS and EAF reinforcing steel for QST process

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Continuous casting

Figure 3. Continuous casting

Reinforcing steel is now manufactured using the continuous casting process (Figure 3). Here, the molten steel is cast from the steelmaking ladle into a tundish, and then from the tundish into a number of oscillating water-cooled moulds. These moulds are normally of square section, and the semi-solid product is withdrawn from the bottom, in a continuous operation. After leaving the mould the solidifying strands are cooled with water, and then cut to length with a gas torch, to produce the billets for subsequent rolling. The billets are usually stamped to retain the batch identity from the steelmaking through the reheating and rolling process.

Hot Rolling - Bar

In the hot rolling process, the billet is reduced in cross-section to the finished bar size. At the same time, the structure is refined, improving the mechanical properties, and internal defects are sealed up. 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 passed through a rolling mill to reduce its cross-section (Figure 4). A rolling mill consists of a series of stands, each of which has 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 (maintaining batch identity), and labelled for despatch. Labels are important to ensure batch traceability, and have to state the information required by the product standard, and in the case of CARES approved steels, the manufacturers CARES logo the CARES Static QR Code and mill mark.

Figure 4. Hot rolling

Hot rolling

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 to meet the dimensional requirements of the product standard, and for consistent bending performance on fabrication. The variation in section is normally controlled to much closer limits than the 4.5% (+/- 6% for 6-8mm diameter reinforcing bar) 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 often 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,
• micro-alloying additions.

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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.

Figure 5. Quench and Self Tempering (QST) process.

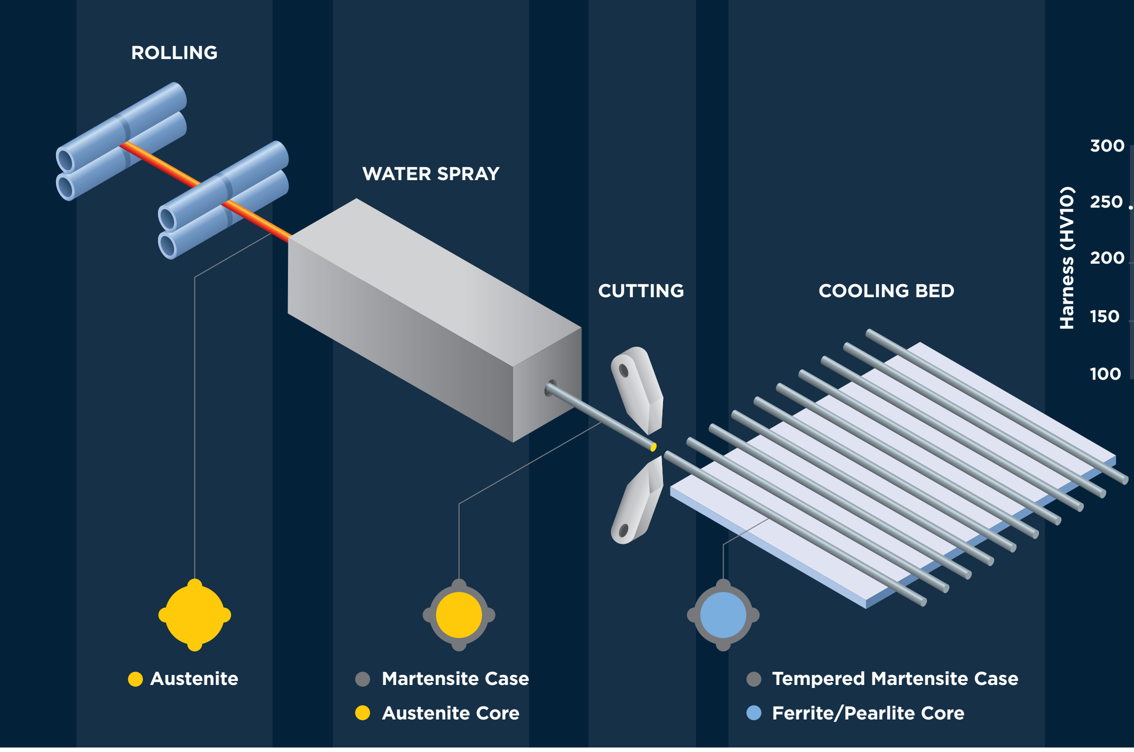
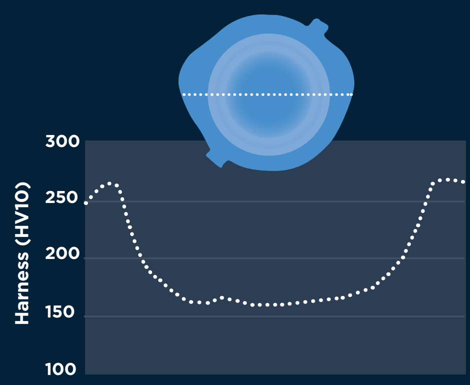


Figure 6. Hardness profile of QST



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 alternative 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 in reinforcing steels is vanadium, although other alloys such as niobium and titanium can also be used. 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 up to 100 MPa. Unlike QST bar, the properties of micro-alloy bar are relatively homogeneous through the cross section.

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, and sometimes 20mm). A coil is a single length of bar, rolled from one billet. Such coil is ideal for fabrication in automated processes, and its use has been steadily increasing.

Hot rolled coils for use directly in automated cutting and bending processes are produced by hot rolling, in a similar way to those described above for bar, using either microalloying or QST processes. 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 shape is produced in the hot rolling operation, and the stretch produces around 3-4% reduction in cross-sectional area. The stretch is usually 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.

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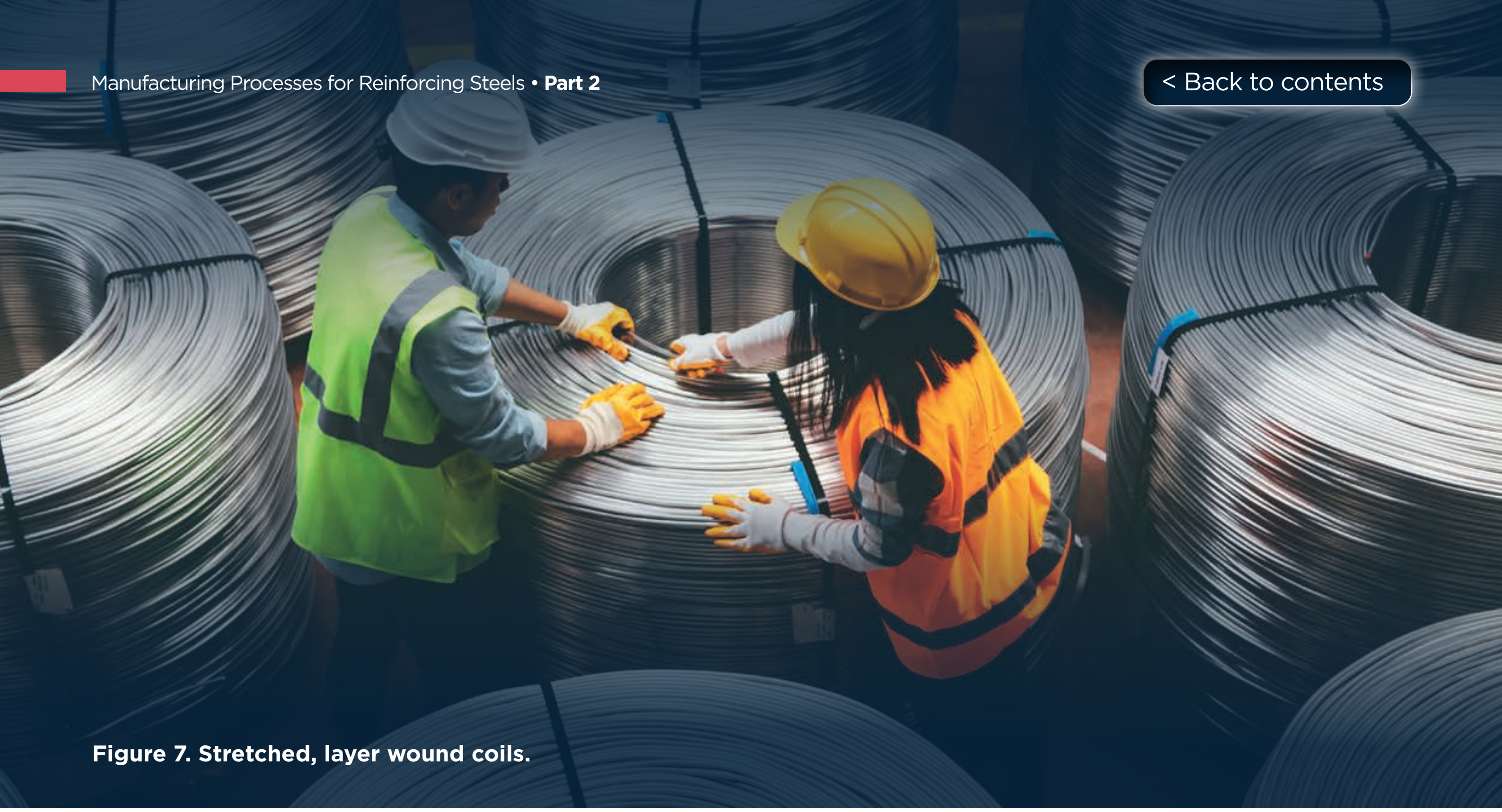


Figure 7. Stretched, layer wound coils.

Sometimes reinforcing steels manufactured in coil form by the hot rolling process (QST or microalloy) undergo a secondary re-spooling process, which also results in a layer wound coil. The objective here is to manufacture a coil with improved processing in subsequent automated cutting and bending processes.

Cold processing

In addition to those processes described above, there are reinforcing steels in which the properties are achieved by cold processing, i.e. at ambient temperature. The two methods commonly used are:

- cold rolling
- 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 BS 4483:2005[5], but can also be used for producing reinforcing steel in coil to BS 4449:2015+A3:2016 grade B500A and sometimes B500B.

In cold rolling, typically used to manufacture bars in coil of diameters 16 mm and below, the rod is deformed by passing it through a short series of rolls. The material is forced into the gap between the rolls, and so is compressed and extended. As in the hot rolling 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 significantly lower ductility than hot rolled bars, but has the advantages of good section consistency and coil presentation, and therefore improved automated processing.

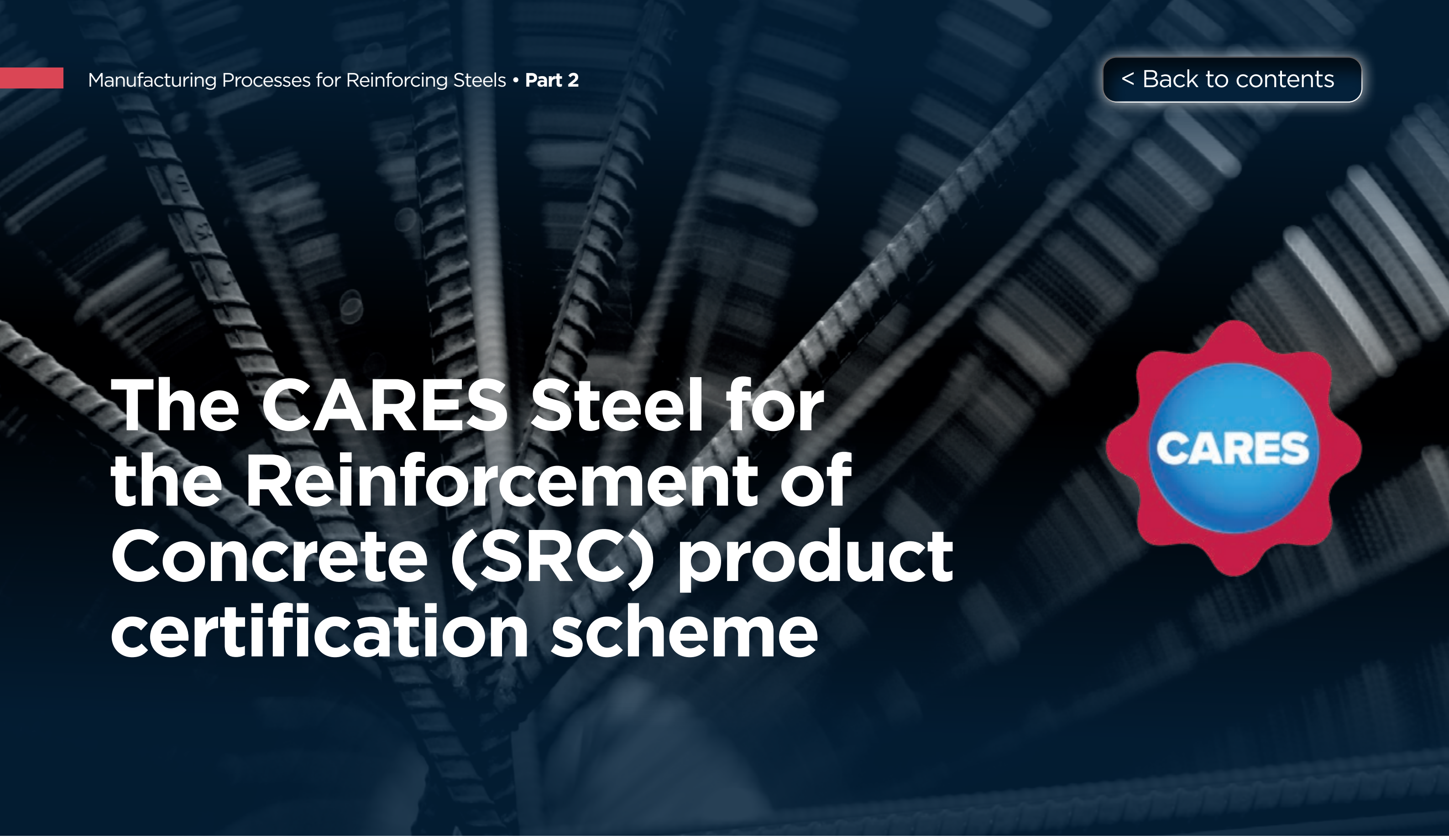
In drawing, the hot rolled rod of plain round section is drawn through a series of carbide dies of reducing cross section. The resultant wire has a plain round section, which is very consistent for bending. Because strengthening is achieved by applying cold deformation, these steels have relatively low ductility. They are covered by BS 4482:2005[6], and are not generally specified for structural concrete.

De-coiling

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 bent shapes on an automatic link-bending machine. Other reinforcement fabricators, or sometimes steel producers, 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, often 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, and on the rib dimensions. If properly controlled, the effects can be marginal. If badly performed however, de-coiling can have a significantly detrimental effect on the finished product. BS 8666:2020[7] therefore includes a requirement for testing the change of properties on straightening on an audit basis, and this also forms part of the CARES surveillance of straightening operations.



The CARES Steel for the Reinforcement of Concrete (SRC) product certification scheme

The CARES Steel for the Reinforcement of Concrete (SRC) scheme aims to meet the needs of users of steel products for the reinforcement of concrete. The scheme covers all stages in the supply chain from the receipt of raw materials, the manufacture and processing of the steel through to the delivery to the end user/customer. The scheme is based on the application of three essential elements:

- The suppliers' management system as defined by BS EN ISO 9001.
- Independent verification of product compliance and auditing of the control of the manufacturing processes to ensure the product consistently complies with the specified requirements.
- Product Traceability: the steel goes through many production and logistical stages between the producer and the end user. There is a mechanism for tracing it from the approved producer through each stage in the supply chain to provide certainty that the product about which the claim is being made is linked to a specific batch from an approved producer or supplier.

How does a supplier achieve product certification to the CARES SRC scheme?

CARES assesses the capability of the supplier to provide products which consistently comply with the stated published standards (principally BS 4449, BS 8666, BS 4482 and BS 4483). CARES uses ISO 9001[8] (Requirements for quality management systems) as the basis for determining the quality management system of the supplier as a major requirement for entitlement to a CARES certificate of approval.

To be granted a certificate of approval the supplier must submit an application. This is followed by a three-part assessment and certification process:

- Assessment of the applicant's quality management system to ISO 9001 and system for maintaining full product traceability.
- Compliance with the relevant CARES schedules.
- Independent product testing to determine compliance with the relevant product standards.

Holding CARES approval status is a continuous process and requires at least two audits per year. Product samples are selected by the CARES auditor and witness tested in the manufacturers' laboratory and duplicate samples are tested at selected UKAS accredited laboratories. CARES role is to check, amongst other matters, that the testing has been carried out correctly and consistently to the highest standards. If these audits demonstrate that the company continues to comply with the requirements of the CARES SRC scheme, a certificate of approval will be re-issued at the beginning of each year.

The British Standard for reinforcing steel, BS 4449, has requirements for the long-term quality level of tensile properties. Where the steel is covered by a third-party product certification scheme, the verification of this statistical capability is covered by the scheme. Where material is not covered by such a scheme, BS 4449 specifies an extensive sampling and testing regime for each batch supplied.

In specifying CARES certified reinforcing steels, purchasers can be confident that all of the performance characteristics are being adequately controlled. There is therefore no need to implement testing on receipt of material, saving significant time and cost.

Your guide to specifying
Learn how to procure CARES certified steel products

To specify CARES certification that meets government and private sector quality assurance and responsible sourcing requirements use the text from the guide in your project specifications.

specification guide

References

[1]BS 4449:2015+A3:2016 "Steel for the reinforcement of concrete. Weldable reinforcing steel. Bar, coil and decoiled product. Specification" British Standards Institution London

[2]UK CARES "Steel for the Reinforcement of Concrete certification scheme"

[3]Draft European Standard prEN10080 "Steel for the reinforcement of concrete- Weldable reinforcing steel – General CEN (Please note this is not a publicly available document)

[4]BS EN 10020:2000 "Definition and classification of grades of steel" British Standards Institution London

[5]BS 4483:2005+A1:2007 Amendment 1 "Steel fabric for the reinforcement of concrete - Specification" British Standards Institution London

[6]BS 4482:2005+A1:2007 Amendment 1 "Steel wire for the reinforcement of concrete products – Specification" British Standards Institution London

[7]BS 8666:2020 "Scheduling, dimensioning, cutting and bending of steel reinforcement for concrete – Specification" British Standards Institution London

[8]ISO 9001:2015 "Quality management systems – Requirements" International Organisations for Standardisation Geneva

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