The CARES Guide
to Product Certification

Part 3
2023

Properties of **reinforcing steels**

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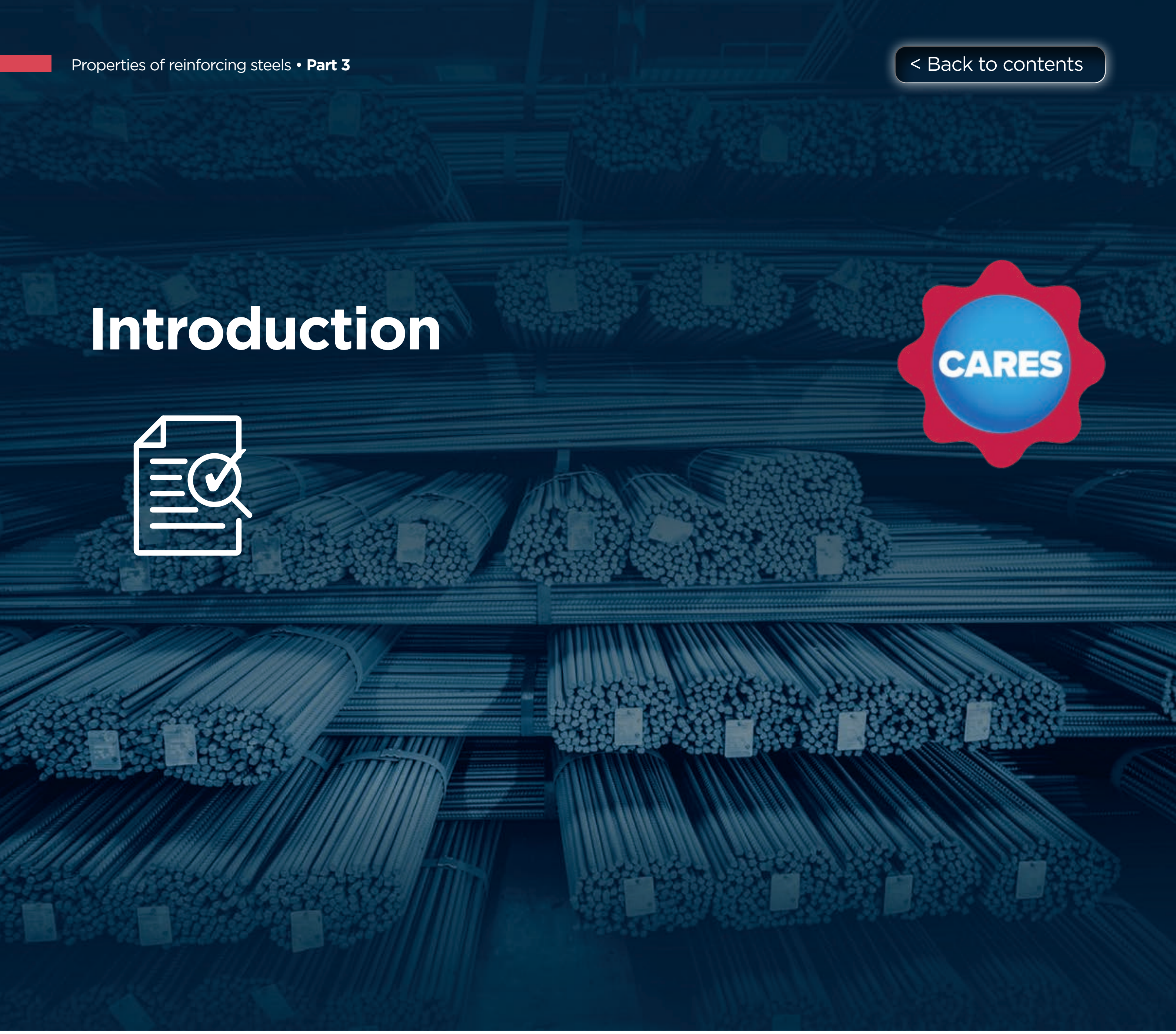
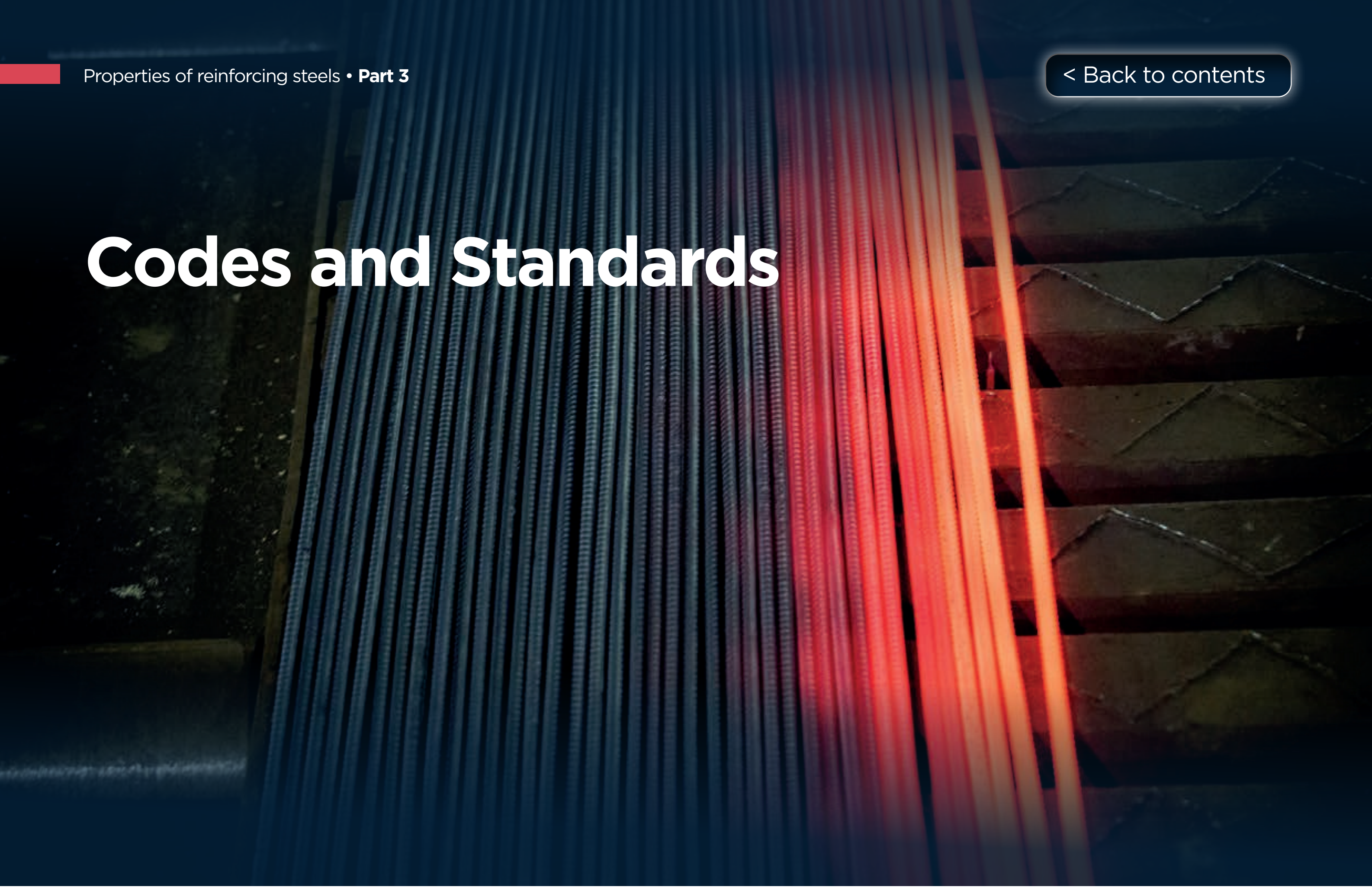


Introduction

Part 2 of this Guide describes the most common manufacturing processes to make reinforcing steels. This Part 3 considers the various key performance characteristics of reinforcing steels, and how manufacturing process routes influence them. The intention is to go beyond the information given in design codes and material standards, and give designers and contractors a greater understanding of reinforcing steel materials, and how they behave in practice.

It should be noted that this Guide gives an overview only, and should not be used for contractual or design purposes. Reference should be made to the applicable regulations, codes and standards.



Codes and Standards

The design code for concrete structures in the UK is specified in BS EN 1992-1-1:2004 "Eurocode 2: Design of concrete structures" Part 1.1 "General rules and rules for buildings"[1]. Within this design code (often abbreviated to EC2), the properties of reinforcing steel to be used in conjunction with the code are given in Annex C. BS EN 1992-1-1 contains a wide range of steel classes with six strength levels varying from 400 to 700 MPa, and with three ductility classes; A, B and C. The intention was that these eighteen "classes" would cover the broad range of reinforcing steels available in the European market, and that each country would select the small number of grades appropriate for their local market.

For many years, discussions had been underway in the EU to achieve a common (Harmonised) product standard for reinforcing steels, which would link to EC2, and facilitate the application of the EU's Construction Product Regulation. For various reasons, BS EN 10080:2005[2] was withdrawn from the Official Journal of the EU shortly after publication, so that it did not become a mandatory harmonised European Standard. Each country within the EU therefore retained its own national standard. In December 2021, the national foreword to BS EN 10080:2005 was amended to clarify the situation, and to point users to the three standards to be used in design in the UK, which are:

BS 4449:2005 "Steel for the reinforcement of concrete – Weldable reinforcing steel – Bar, coil and decoiled product – Specification" [3]

BS 4482:2005 "Steel wire for the reinforcement of concrete products–Specification" [4]

BS 4483:2005 " Steel fabric for the reinforcement of concrete – Specification" [5]

It should be noted that the design standard BS EN 1992-1-1, and the European standard for reinforcing steels (EN 10080) are both currently being revised, which will potentially mean changes in the above standards in the future. It is currently envisaged that the revision of EN 10080 will be written in an "open" format, meaning that all EU member states will be able to continue to specify the small number of grades for use within their market. Exactly how the UK will choose to align its national standard with the requirements of EN 10080 is at the moment uncertain.

The CARES Steel for the Reinforcement of Concrete (SRC) scheme includes certification requirements for the three British Standards mentioned above. The appropriate Appendices of the SRC scheme which include these requirements are as follows:

Appendix 1	**Carbon steel bars and coils (BS 4449:2005)**
Appendix 1N	**Carbon steel bars and coils for use in nuclear applications and other mega projects (BS 4449:2005)**
Appendix 3	**Cold worked wire (BS 4482:2005)**
Appendix 4	**Welded fabric (BS 4483:2005)**

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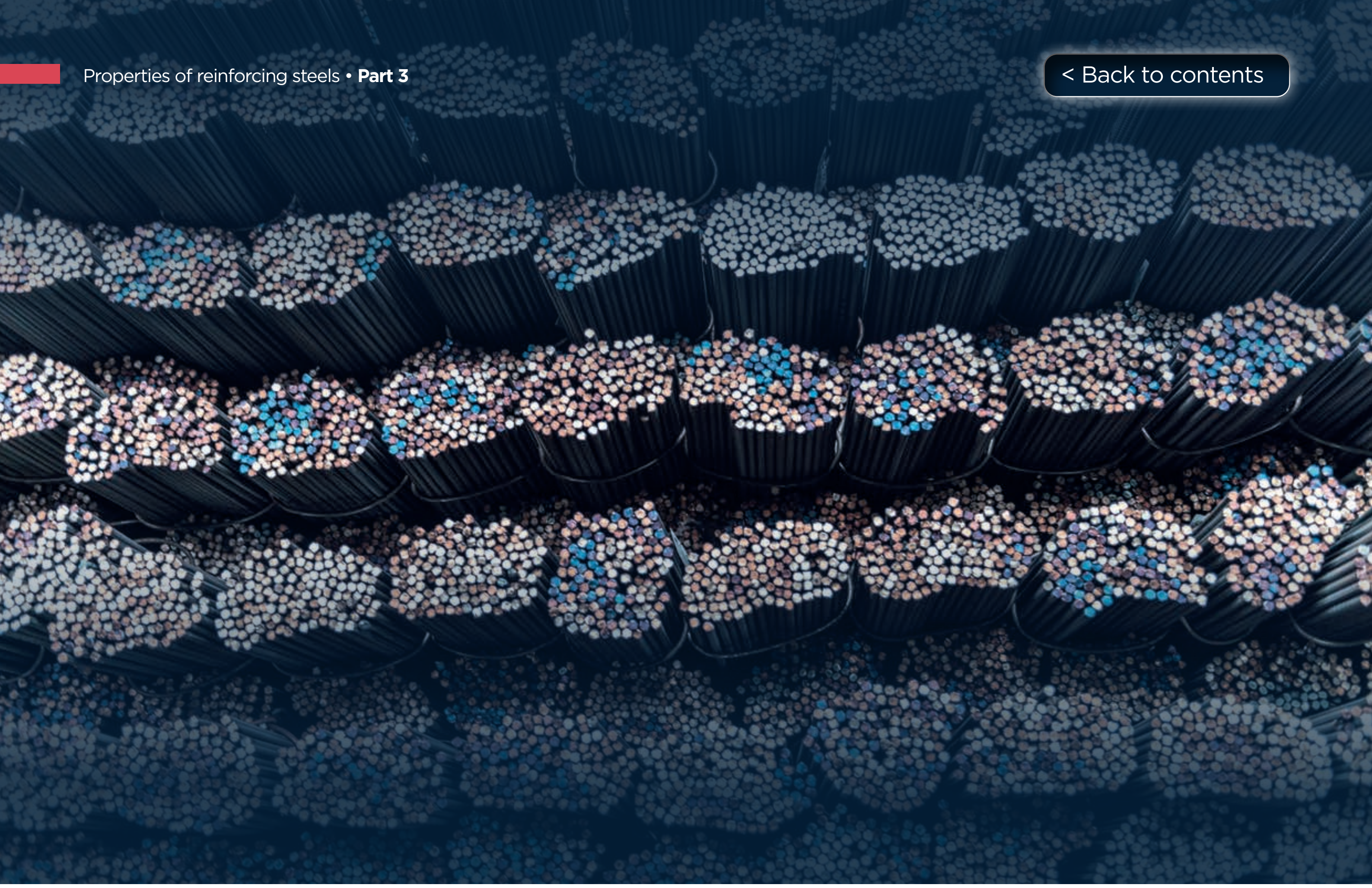

The CARES approach to product certification is now also applied to a number of national and international standards outside the UK. A brief summary of how these standards compare is as follows:

Hong Kong Construction Standard CS2:2012 "Steel reinforcing bars for the reinforcement of concrete"[6]. The performance characteristics of CS2:2012 are closely aligned with BS 4449:2005 grades B500B and B500C. The standard also includes a 250 grade plain round bar.

Singapore Standard SS 560:2016 "Specification of steel for the reinforcement of concrete- Weldable reinforcing steel – Bar, Coil and Decoiled Product"[7]. This is an adaptation of BS 4449:2005, but also includes three grades B600A, B600B and B600C, with yield strength of 600 MPa.

International Standard ISO 6935-2:2015 "Steel for the reinforcement of concrete – Part 2-Ribbed Bars"[8]. This is designed to be a broad standard upon which national standards can be based. It therefore includes a wide range of strength levels (300 to 600 MPa), grades and chemical analysis. It includes both weldable and non-weldable steels.

ASTM Standard A615/A615M-22 "Standard Specification for Deformed and Plain Carbon Steel Bars for concrete reinforcement"[9]. This is a general standard for reinforcing steels. It includes four grades with yield strength ranging from 280 MPa to 690 MPa. Other than for phosphorus, chemical analysis is not restricted, and these steels are regarded as non-weldable. There are also significant differences in the performance characteristics specified.

ASTM Standard ASTM A706/A706M-22a "Standard Specification for Deformed and Plain Low-Alloy Steel Bars for Concrete Reinforcement"[10]. This is a more restrictive standard than A615/A615M-22, and includes only grades 420 and 550 MPa. Although the scope states that these steels are weldable, the carbon equivalent (CEV) limits are different from those used outside the USA.

The rest of this Guide concentrates on the British Standards stated above, but makes reference to the other standards where helpful. Again, this is a summary document, and should not be regarded as fully comprehensive. For design or contractual purposes, reference should be made to the standards themselves.

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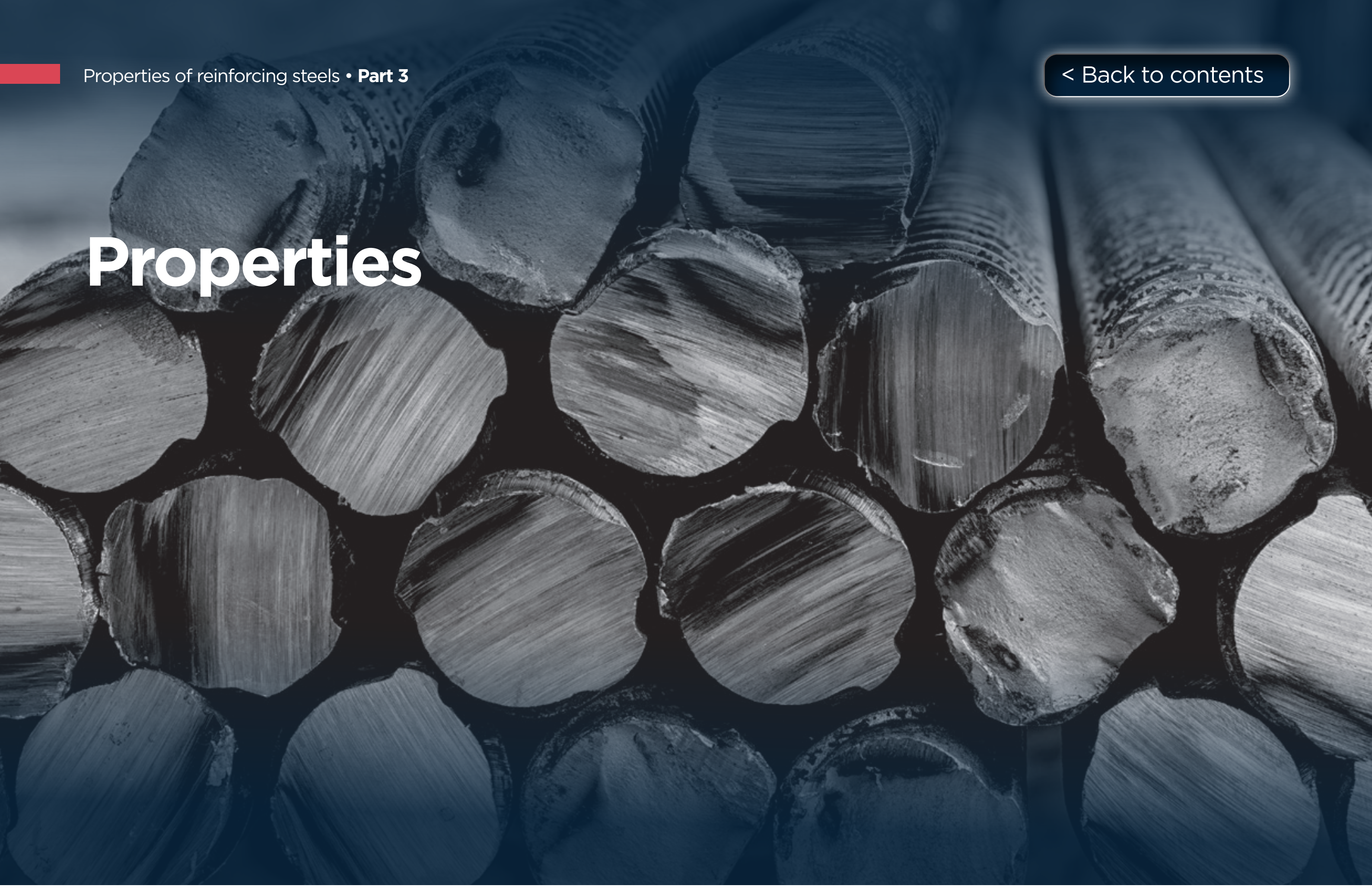

Properties

The main performance characteristics required of reinforcing steels in BS 4449:2005 may be categorised as follows:

- Tensile behaviour, including yield strength, tensile strength/yield strength ratio and elongation.
- Rebend.
- Fatigue.
- Bond (rib dimensions).
- Weldability (chemical composition).

Tensile properties

Table 1 shows the tensile properties which are currently specified in BS 4449:2005. These are for the results of tensile tests which are measured by the steel producer or an independent laboratory when conducting tests on full section bar samples.

In BS 4449:2005, as in EN10080, all of these properties are described as characteristic values, and they have a statistical basis, rather than being a guaranteed minimum value. For yield strength, the specified value of 500 MPa is based on a characteristic with p=0.95. This means that there is a 90% probability that over an infinite series of tests, 95% will be at or above this value of 500 MPa. For tensile strength/yield strength ratio (Rm/Re) and for uniform elongation (Agt) the values in Table 1 are based on characteristic values with p = 0.90. This means that in an infinite series of tests there is a 90% probability that 90% of the test results will be at or above the characteristic values.

A manufacturer must demonstrate statistically that the long-term behaviour of their test results meets these statistical requirements, and assessing this long-term performance forms part of the CARES assessment of a manufacturer's capability. The benefit of this approach is that it encourages manufacturers to focus on the consistency and control of their processes to meet the long-term quality requirements.

Table 1. Specified characteristic tensile properties.

Standard	Grade/Class	Yield Strength Re (N/mm^2)	Tensile/Yield Ratio R_m/R_e	Total Elongationat Maximum Force A_{gt} (%)
BS 4449:2005	B500A	500	1.05	2.5
BS 4449:2005	B500B	500	1.08	5.0
BS 4449:2005	B500C	500	1.15 to 1.35	7.5

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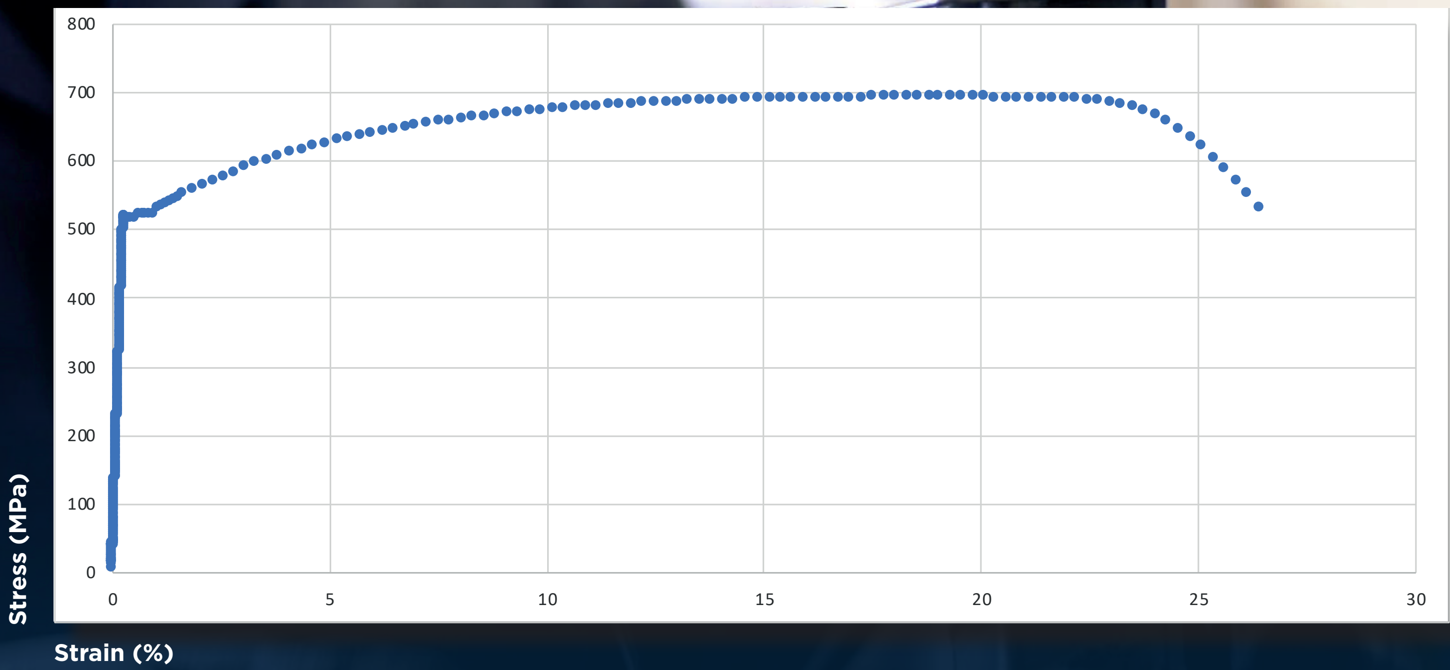


Figure 1. Stress-strain curve of a QST bar. (Figure courtesy of R-Tech Materials)

BS 4449:2005 also includes requirements for the assessment of the results of testing of batches of material, whether in production or independent testing. For production, tests are specified at a frequency of one every 30 tonnes of a batch, often referred to as a 'cast,' being rolled into one size, with a minimum of three tests per batch. The average of the yield strength results of the batch must be above 510 MPa, whilst the average of the tensile/yield ratio and the total elongation at maximum force, must be above the specified values in Figure 1 courtesy of R-Tech Materials. There are also absolute minimum values for each of the test parameters below which no result for a batch may fall without a retest. The 510MPa average is only applied if any of the results are below the characteristic value but above the absolute minimum.

It is worth noting that other standards use different parameters for the measurement of elongation. ISO 6935-2 has an alternative measurement of A5. This means elongation measured across the fractured bar after the tensile test with an initial gauge length of 5 times the bar diameter. ASTM A706/A706M-22a use a measurement of elongation after fracture over a gauge length of a fixed 200mm. It should be noted that the different methods of measuring elongation give very different results, and cannot be used interchangeably.

Figure 1 shows a stress-strain curve for a reinforcing bar produced by the quench and self tempered process route (QST). The various tensile parameters i.e. Elastic deformation to yield point, yield point, plastic deformation, ultimate tensile strength, necking and fracture, are defined in the figure.

Yield strength can be defined in several different ways. Where steels show a so-called "yield effect", as in the example in Figure 1, the standards allow the yield strength to be determined as the upper yield strength. This is the point on the stress-strain curve where the load initially drops; the upper yield point. Alternatively, the yield strength can be defined as the stress at a permanent strain of 0.2% (Figure 1); the 0.2% proof strength. In some steels, for example cold worked steels, no yield effect is observed, the stress-strain plot showing a continuous curve after the linear elastic portion (Figure 2). In these steels, yield strength is always defined as the 0.2% proof strength.

The tensile strength/yield strength ratio (Rm/Re) is a measure of a steel's ability to work harden prior to fracture, and hence is also used as a measure of the ductility of the steel.

The total elongation at maximum force (Agt) is also a measure of a steels ability to deform prior to localised necking, leading to fracture.

In general terms, there is an inverse relationship between strength and ductility. However, this is strongly influenced by the steel manufacturing process route.

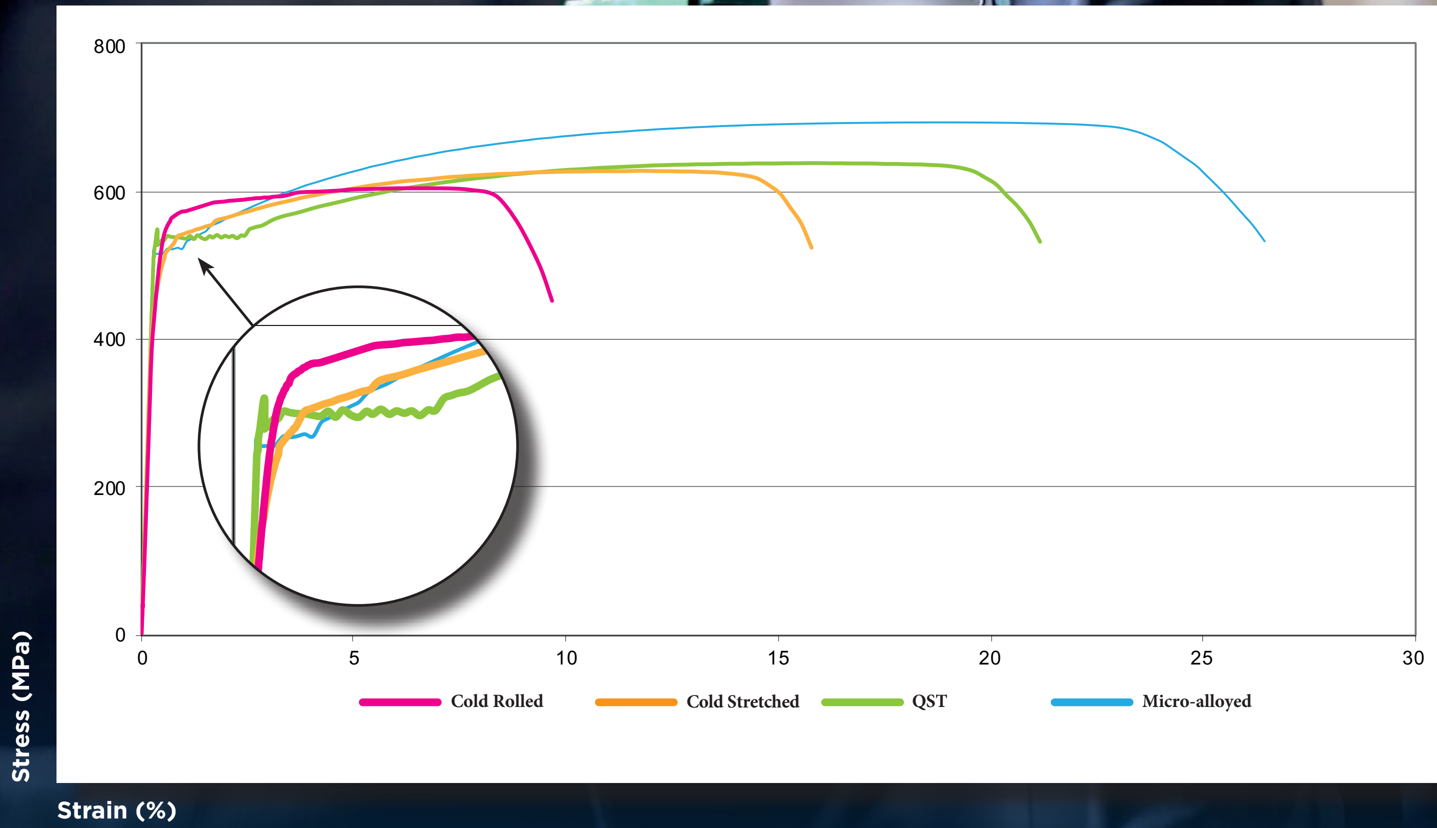


Figure 2. Stress-strain curve of different types of stee. (Figure courtesy of R-Tech Materials)

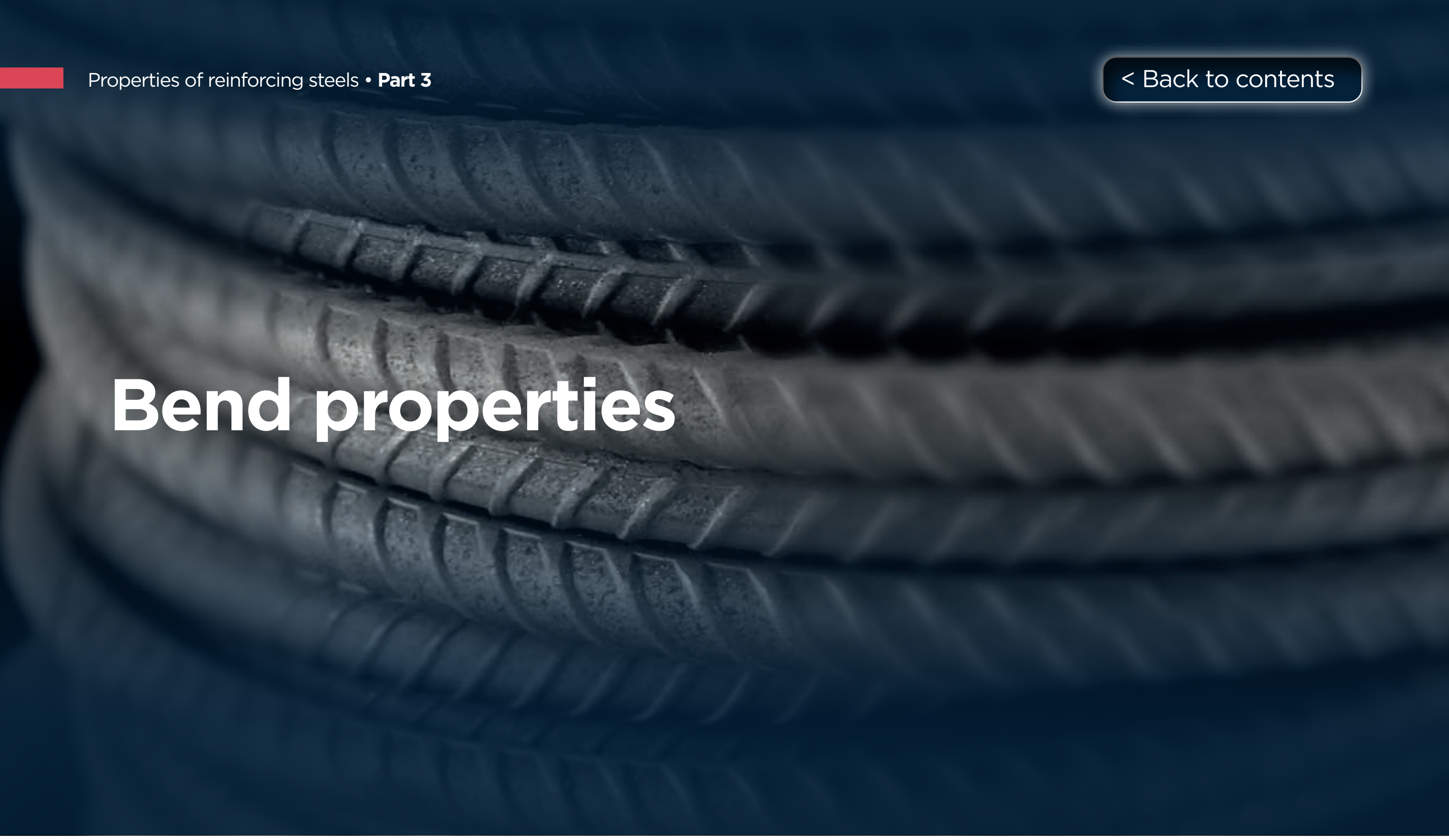
Figure 2 shows the stress-strain curves for four common types of reinforcing steel and demonstrates the differences in tensile behaviour between the different types:

- Micro-alloyed. This is characterised by having a high work hardening rate, and a high level of elongation. The Rm/Re figure is particularly high for these steels, and they have a relatively high level of ductility. Micro-alloy steels would normally be Grade B or Grade C ductility as defined in BS 4449:2005.

- Quench and Self Temper (QST). The stress-strain curve has a similar shape to the micro-alloy steel. The steel has slightly lower levels of elongation and Rm/Re. QST steels would also normally be classed as Grade B or Grade C ductility, depending on the details of the process route.

- Cold stretched. Due to the degree of cold working this material shows continuous yielding behaviour; there is no defined yield point. The work hardening capacity is generally lower than in micro-alloy and QST steels. The Agt results in particular are generally lower. These steels would normally meet Grade B ductility.

- Cold-rolled steel. As a result of the amount of deformation in the cold rolling process, this material also shows continuous yielding behaviour. The ductility is lower than in the above steels, and this type is generally certified to Grade A ductility.



Bend properties

Most reinforcing steel will require bending during fabrication. Since they are relatively high strength steels, and because the ribs on the bar surface act as stress concentrators, reinforcing steels could be liable to fracture on bending if the radius of the bend is too tight. For this reason, the standard for cutting and bending (BS 8666:2020)[11] specifies minimum bending radii for different bar diameters.

In some reinforcing steel standards, a bend test is included, the purpose of which is to demonstrate that bends can be made around a diameter smaller than that specified in fabrication. Examples of standards which retain this type of bend test are ASTM A706/A706M-22a, where 180° bend tests are specified around mandrels with diameter varying from 3d to 10d, depending on strength grade and size (d) of the bar. In SS 560, the bend test is 180° around mandrels of 3d (for sizes up to 16mm), or 6d (for sizes above 16mm). After bending, the sample is examined by eye to ascertain whether any cracking has occurred. If present, this will generally be along the base of any transverse ribs, and would constitute a test failure.

Another approach to measuring bend performance is to specify a rebend test. This is a different type of test and as well as assessing bend performance also serves to assess the steel's susceptibility to strain ageing. In the BS 4449:2005 rebend test, the steel is bent 90˚ around a specified mandrel diameter, aged at 100˚C for an hour, and then bend back by at least 20˚. The sample is then examined for any signs of cracking. This test is designed to measure the effect of strain ageing on the steel.

Strain ageing is an embrittlement effect, which occurs after cold deformation, by the diffusion of nitrogen in the steel. BS 4449:2005 limits the nitrogen content of reinforcing steels to 0.012% (cast analysis), in order to restrict strain ageing. The only exception to this is for micro-alloyed steels, where nitrogen is combined with vanadium (V) for strengthening. In the combined form, nitrogen does not have a strain ageing effect.

Bending characteristics of a particular reinforcing steel will be a function of both the mechanical characteristics of the steel, and the bar profile. Micro-alloy steels generally require higher bending loads, due to their increased work hardening rate.

Consistency of bar shape is required for consistent bending performance. The dimensional tolerances achieved with cold rolling are better than for hot rolling, so that for demanding bending operations in small diameters, this process route can sometimes be preferred.

The risk of fracture on bending is increased as the temperature is decreased, because these steels have decreasing toughness at lower temperatures. Hence design codes specify minimum bending temperatures for safe operation.

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Figure 3. Photograph of a bar which failed in Fatigue. (Photograph courtesy of R-Tech Materials)

Fatigue properties

BS 4449:2005 specifies a fatigue test regime, which was designed to be compatible with the previous UK bridge design code, BS 5400-2:2006[12]. The fatigue test requirement is to survive 5 million stress cycles, at stress conditions that depend on the size of the bar, recognising that as bar size increases, fatigue performance decreases. Due to the nature of fatigue tests, these are performed as type tests, and not on a batch basis. The CARES scheme provides for samples of each approved bar and coil type to be independently tested at the Initial Assessment stage and thereafter at approximate six-monthly intervals, to ensure that the full range of sizes produced by a manufacturer is covered over a five-year period as specified in the product standard.

In Europe, the practice has been to use a 2 million cycle fatigue test, but at higher stress levels than required in BS 4449:2005, particularly for larger bar sizes. The National Annex to EC2 currently specifies fatigue testing to the regime in BS 4449:2005, and this remains the UK practice. The CS2:2012 standard includes fatigue test requirements which are identical to those in BS 4449:2005, whilst those in SS 560 have the BS 4449:2005 stress conditions, but with a specified endurance of 2 million cycles.

In reinforcing steels, fatigue properties are governed primarily by the stress concentration developed at the root of the ribs (Figure 3) and any bar failures normally initiate from such points. As such, this is more a function of the care exercised by the manufacturer in producing the ribs, than of a particular process route. Any excessive rib damage resulting from bending or de-coiling can create a problem with respect to fatigue.

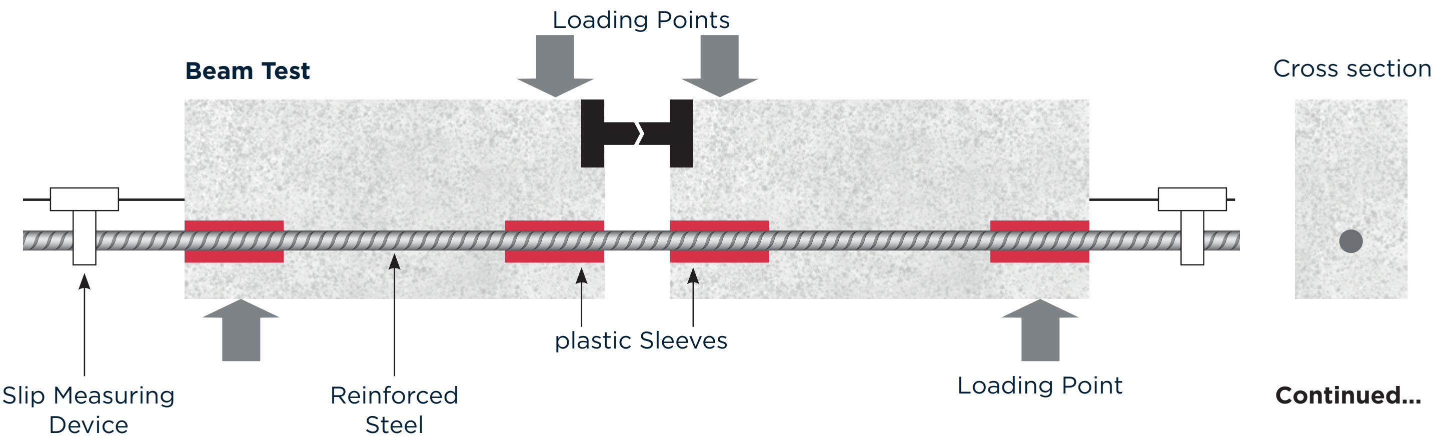
Bond properties

Unlike the other performance characteristics, bond is really a composite characteristic of the steel in a particular concrete. Reinforcing steel standards specify bond performance by either measurement of rib geometry or by standardised bond tests.

The approach used in BS 4449:2005 and most other product standards is to define bond principally in terms of the relative rib area. This is a measure of the rib area in a unit length perpendicular to the axis of the bar. As an alternative, manufacturers may use a bond test to establish satisfactory bond performance, if the rib geometry requirements are not met. The bond test is a one-off type test series for a particular rib geometry. In BS 4449:2005, the bond test is based on the RILEM Recommendation RC5 beam test method (see Figure 4), and this was also included as an option in BS EN 10080:2005, and was referenced in EC2 Annex C. It should be noted that the beam test is relatively complex and expensive, and for this reason these tests are seldom performed.

Since bond is a function of the surface geometry, it is not related to any particular manufacturing process. For cold rolling, manufacturers generally try to minimise the amount of deformation, in order to maintain reasonable ductility. This means that rib heights are generally lower than on equivalent hot rolled steels. In relation to this process therefore, manufacturers may use the bond test option to establish satisfactory bond performance. For approved manufacturers, CARES oversees the bond tests, which are performed at independent UKAS or other accredited laboratories. From these tests, requirements for the ongoing control of rib dimensions are established for use within the manufacturer's quality management system, to ensure that the steels continue to meet the specified bond performance.

Figure 4. Drawing of a RILEM Recommendation RC5 beam test specimen.



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Welding of reinforcing steel – 'Weldability'

In recent years, there has been a significant increase in the use of welding to produce reinforcement cages, in place of the conventional wire tying. The ability of a steel to produce satisfactory welds will depend on a whole range of factors, including the welding process employed, the equipment used and also the competence of the welder. Weldability is considered to be an extremely important property of reinforcing steels, hence the inclusion of the word "weldable" into many of the reinforcing steel standards.

For reinforcing steel, it is common to define weldability in terms of the chemistry of the steel, and in particular a carbon equivalent value (CEV). This is a composite chemical analysis parameter, defined as follows:

CEV = %C + %Mn/6 + %(Cr+Mo+V)/5 + %(Cu+Ni)/15

This CEV parameter is a way of defining a steel's hardenability, i.e. the ease with which it forms hard, brittle structures when subject to a particular heating and cooling cycle. The higher the CEV, the higher the hardenability, and the less weldable a steel is considered to be.

CEV is adopted in BS 4449:2005 and in BS 8548:2017 "Guidance for arc welding of reinforcing steels"[13] in order to describe weldability. BS 8548:2017 is itself based on BS EN ISO 17660:2006 Parts 1[14] and 2[15], and seeks to translate the requirements of the ISO standards in a way which is compatible with UK welding practice. Table 2 shows typical CEV levels for the different common steel process routes. It can be seen that the CEV of steels produced by the micro-alloying or cold stretching processes routes are generally higher than for the QST or cold rolling routes, and it is a requirement of BS 8548:2017 that weld procedures apply only to the steel process route for which they were tested.

Table 2. Typical analysis of steels from different process routes

Process	Product	C	Mn	Si	V	CEV
QST	Bar/Coil	0.15-0.20	0.60-1.00	0.15-0.30	-	0.30-0.35
Microalloy	Bar/Coil	0.15-0.20	1.10-1.30	0.15-0.30	0.05-0.10	0.40-0.50
Cold Stretched	Coil	0.18-0.22	1.10-1.30	0.15-0.30	-	0.40-0.50
Cold Rolled	Coil	0.05-0.10	0.50-1.00	0.10-0.20	-	0.20-0.30

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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' quality 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 (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.

CARES

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 EN 1992-1-1:2004+A1:2014 "Eurocode 2: Design of concrete structures" Part 1.1 "General rules and rules for buildings" British Standards Institution London

[2]BS EN 10080:2005 "Steel for the reinforcement of concrete. Weldable reinforcing steel. General" British Standards Institution London

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

[4]BS 4482:2005+A1:2007 Amendment 1 "Steel wire for the reinforcement of concrete products – Specification" 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]Hong Kong Construction Standard CS2 "CS2:2012 Steel reinforcing bars for the reinforcement of concrete". The Government of Hong Kong Special Administrative Region.

[7]Singapore Standard SS 560:2016 "Specification of steel for the reinforcement of concrete- Weldable reinforcing steel – Bar, Coil and Decoiled Product". Singapore Standards Council

[8]International Standard ISO 6935-2:2015 "Steel for the reinforcement of concrete – Part 2-Ribbed Bars" International Standardisation Organisation Geneva

[9]ASTM Standard A615/A615M-22 "Standard Specification for Deformed and Plain Carbon Steel Bars for concrete reinforcement". ASTM International

[10]ASTM Standard A706/A706M-22a "Standard Specification for Deformed and Plain Low-Alloy Steel Bars for Concrete Reinforcement". ASTM International

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

[12]BS 5400-2:2006 (Withdrawn) "Steel, concrete and composite bridges – Specification for loads" British Standards Institution London

[13]BS 8548:2017 "Guidance for arc welding of reinforcing steels" British Standards Institution London

[14]BS EN ISO 17660-1:2006 "Welding – Welding of reinforcing steel – Non-load bearing welded joints" British Standards Institution London

[15]BS EN ISO 17660-2:2006 "Welding – Welding of reinforcing steel – Load bearing welded joints" British Standards Institution London

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