Properties of Reinforcing Steels

1.0 Introduction

Part 2 of this Guide describes the most common process routes for the manufacture of reinforcing steels. This part (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.

2.0 Codes and Standards

In the UK the technical properties for reinforcing steels has historically stemmed from the requirements of the Codes of Practice:

BS 8110 (Concrete structures)
BS 5400 Part 4 (Concrete bridges)
BS 8007 (Water retaining structures)

Whilst currently superseded by Eurocodes, it is recognised that these particular design codes may be used elsewhere.

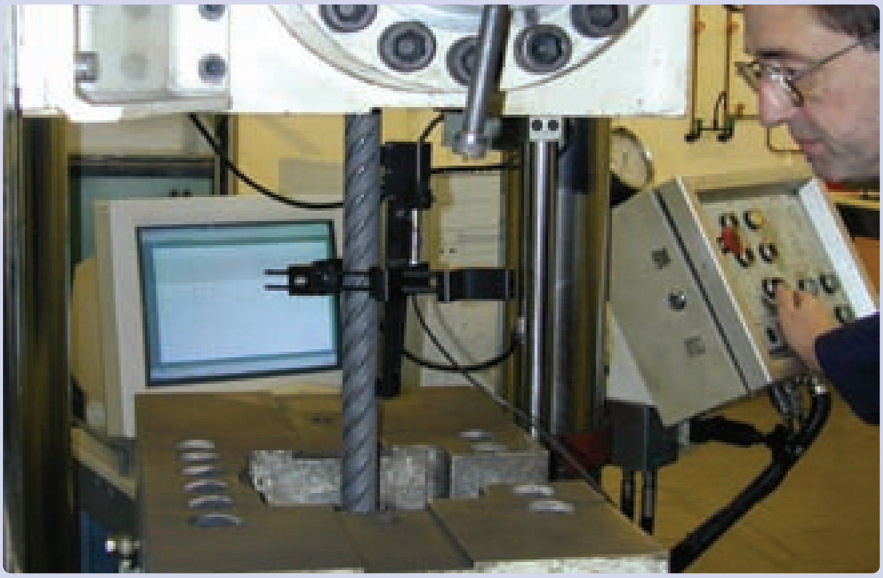
The technical requirements for reinforcement steel in the UK are defined in:

- **BS 4449: 2005** (Carbon steel bars for the reinforcement of concrete)
- **BS 4482: 2005** (Cold reduced wire for the reinforcement of concrete)
- **BS 4483: 2005** (Welded fabric)

Again, these product standards may be used in other countries such as those in the Gulf states, or alternatively close variants may be used, such as in Hong Kong and Singapore.

The UK industry is in the process of undergoing a practical change to Eurocodes, whilst a European product standard for reinforcing steel is yet some way off. This 'design' change is led by Eurocode 2 (EC2); EN 1992-1-1 (General rules and rules for buildings), EN 1992-2 (Reinforced and prestressed concrete bridges) and EN 1992-3 (Liquid retaining and containing structures); together with their UK National Annexes, these have superseded BS 8110, 5400 and 8007 respectively.

Tensile test on reinforcing bar



Courtesy of R-Tech Services

Specified characteristic tensile properties

Standard	Grade/ Class	Yield Stress (N/mm²)	Tensile/Yield Ratio	Elongation A_5 (%)	Elongation A_gt (%)
BS 4449: 1997	460A	460	1.05	12	2.5
BS 4449: 1997	460B	460	1.08	14	5.0
BS 4449: 2005	500A	500	1.05	-	2.5
BS 4449: 2005	500B	500	1.08	-	5.0
BS 4449: 2005	500C	500	1.15 to 1.35	-	7.5

Table 1

Linked to the introduction of the new codes will be the new European Standard for reinforcing steels, EN 10080, although the date of publication of this standard remains uncertain. The British Standards, BS 4449, BS 4482 and BS 4483 remain in practical use and were revised in 2005 in order to align with the requirements of EC2 and the UK National Annex. In revision, these standards fit within the requirements described for reinforcing steel in the relative Eurocodes.

Part 10 of this Guide will cover these changes in more detail, and include their relationship with the Construction Products Regulations and CE marking.

3.0 Properties

The main performance characteristics required of reinforcing steels may be categorised as follows:

- Tensile strength, including yield strength and elongation
- Bend/rebend
- Fatigue
- Bond
- Weldability (chemical composition)

3.1 Tensile properties

Table 1 shows the specified characteristic tensile properties which are currently specified in BS 4449. It should be noted that the 1997 and 2005 revisions of BS4449 are referenced, as both are still in use globally, although it seems that the use of BS4449:2005 is increasing. In BS4449:1997, the Yield Strength is specified as both a minimum, and a characteristic value, whilst in BS4449:2005, this 'characteristics' applies both to the properties of Yield Strength and Elongation. In the case of manufacturing, this means that the manufacturer must demonstrate long-term statistical compliance, as well as achieving the required test results on each individual batch.

It is also worth noting that BS4449 and BS4482 describe ductility in terms of two parameters; the tensile strength to yield strength ratio (R_m/R_e), and the elongation, (BS4449:1997 - both at fracture (A_5) and at maximum load (A_gt) and BS4449;2005 only at maximum load (A_gt.) The symbols used in EC2 for these properties are f_t/f_y and ϵ_u respectively.

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 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 (R_m/R_e) 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.

Uniform elongation (A_gt) is also a measure of a steels ability to deform prior to fracture. It should be noted that in the European design codes and also the draft European product standard, uniform elongation replaces elongation to fracture (A_5), which has been the measure of ductility in British Standards to date. A_gt is deemed to be a more appropriate design characteristic.

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

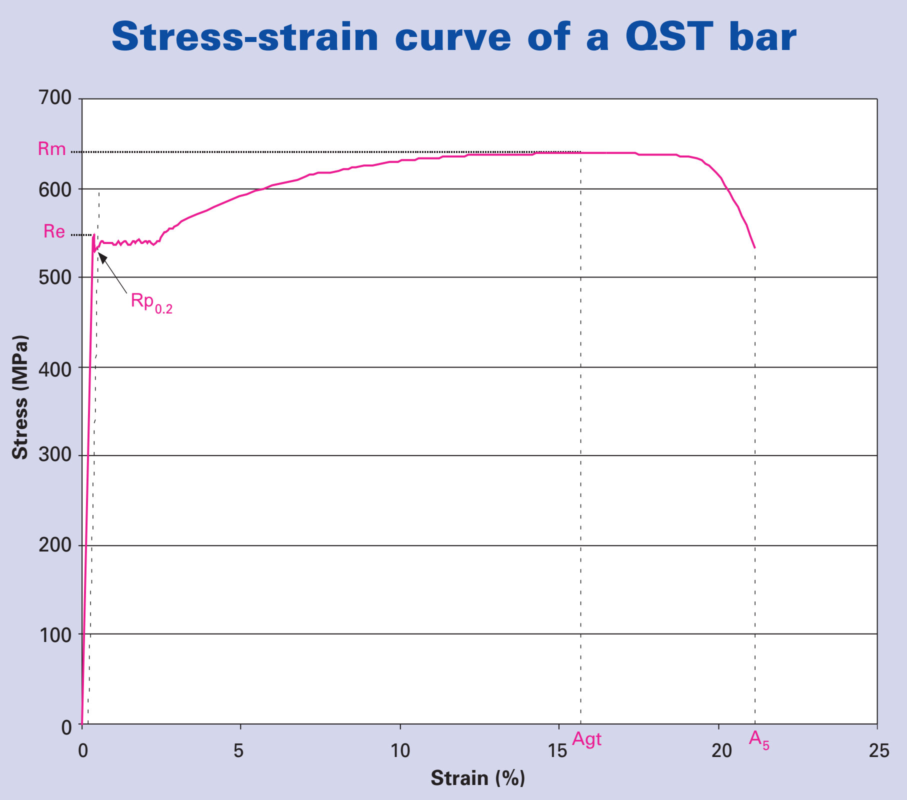


Figure 1 Courtesy of R-Tech Services

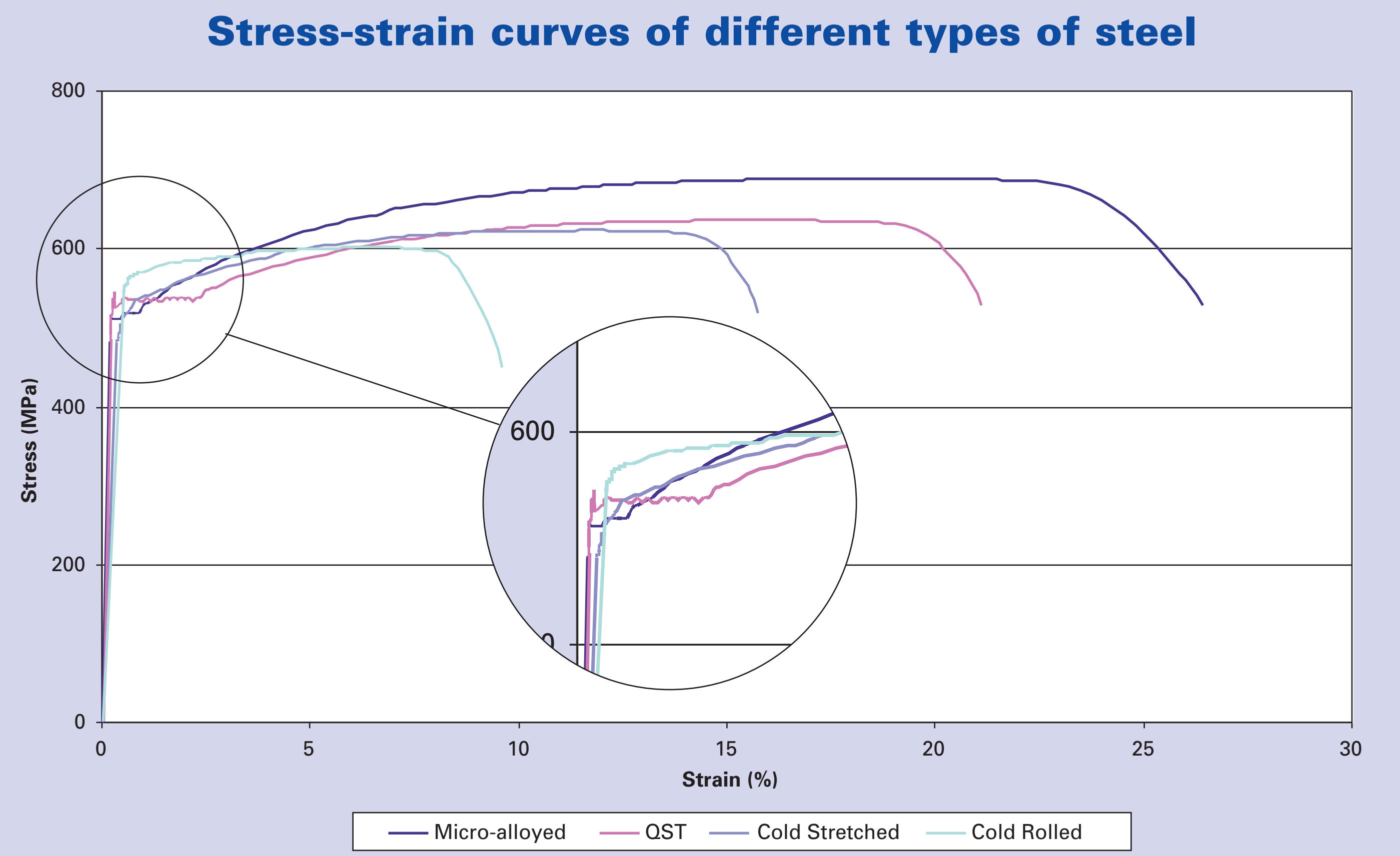


Figure 2 Courtesy of R-Tech Services

- Micro-alloy. This is characterised by having a high work hardening rate, and a high level of elongation. The R_m/R_e figure is particularly high for these steels, and they have a relatively high level of ductility. The curve shows a discontinuous yielding behaviour. Micro-alloy steels would normally be Grade B or Grade C ductility as defined in BS4449:2005.

- 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 R_m/R_e. QST steels would also normally be classed as Grade B or Grade C ductility, depending on the details of the process route.

- Cold stretched. Because of the cold work present, this material shows continuous yielding behaviour; there is no defined yield point. The work hardening capacity is generally lower than in the micro-alloy and QST steels. The A_gt figure in particular is generally lower. These steels would normally meet Grade B ductility.

- Cold-rolled steel. Because of the amount of deformation in the manufacturing 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.

3.2 Bend properties

Most reinforcing steel will require bending, before it is installed into a concrete structure. Because they are relatively high strength steels, and because the ribs on the bar surface act as stress concentrators, reinforcing steels may fracture on bending if the radius of bend is too tight. Both BS 4449:1997 and BS4449:2005 specify minimum mandrel diameters for bending of high yield reinforcement. These are as follows:

Bar Diameter (mm)	Minimum Mandrel Diameter (mm)
≤ 16	5d (1997), 4d (2005)
> 16	7d (both 1997 and 2005)

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.

BS 4449:1997 includes a re-bend test, in which the steel is bent 45° around a specified mandrel, aged at 100°C for an hour, and then bent back by 23°, whilst BS4449:2005 requires bending to 90° and back by 45° after ageing. 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.

Both issues of BS 4449 limit the nitrogen content of reinforcing steels to 0.012%, in order to restrict strain ageing. The only exception to this is for micro-alloyed steels, where nitrogen is combined with vanadium 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 be preferred. Cold rolled steels are generally of lower ductility however and hence BS8666 effectively limits the use of this type of steel to diameters to sizes12mm diameter and below.

BS4449 is performance based, but all 'usual' (see Part 1) process routes for reinforcing steels can result in steel which meets the specified requirements for bend and/or re-bend, provided that the manufacturer exercises suitable care with his rolling process and equipment.

3.3 Fatigue properties

Both issues of BS 4449 specify a fatigue test regime, which is designed to be compatible with the UK bridge design code, BS 5400. The test requirement for these standards is to survive 5 million stress cycles, at stress conditions that depend on the size of the bar. 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 the period of time as specified in the product standard.

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.

Photograph of a bar which failed in fatigue

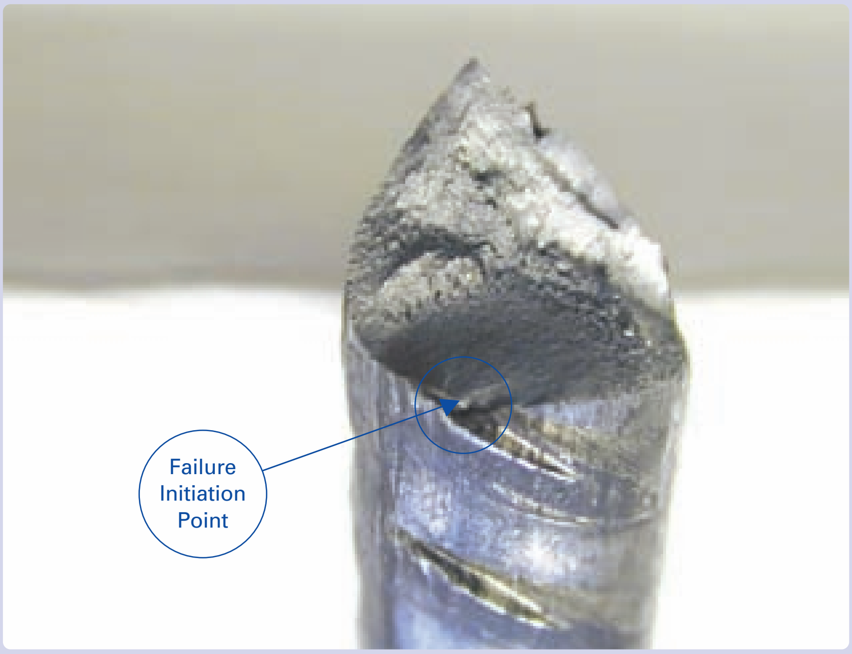


Figure 3 Failure initiated at base of transverse rib

Drawing of a CEB/RILEM beam test specimen

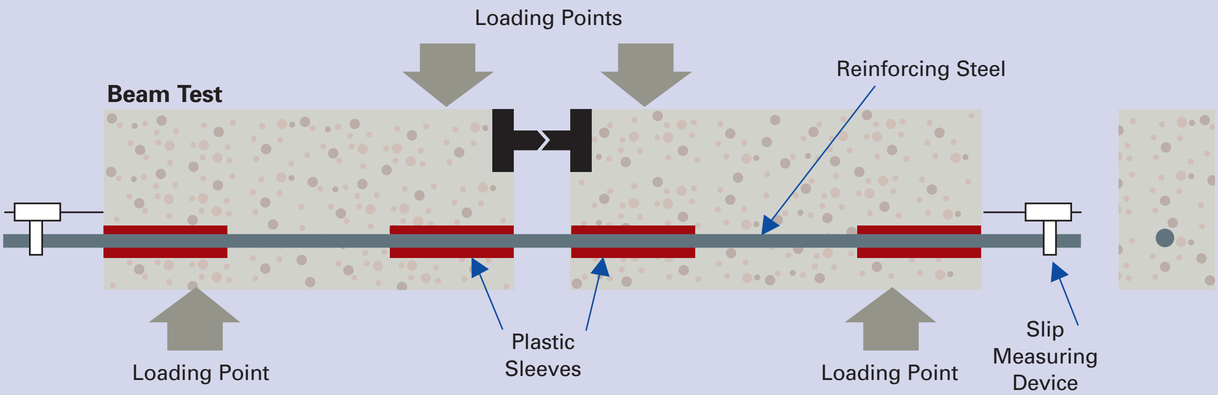


Figure 4

3.4 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 is to define bond principally in terms of the rib area. This is a measure of the rib area in a unit length perpendicular to the axis of the bar. As a secondary option, 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 for a particular rib geometry. BS4449:1997 and BS4482:1985 specify a pull-out test, whereas the 2005 revisions of both standards specify a beam test in line with EC2 Annex C. Both tests are based on earlier CEB/RILEM test methods (see **Figure 4**). It should be noted that the beam test is much more complex and expensive.

Since bond is a function of the surface geometry, it is not related to any particular manufacturing process. For cold rolling, manufacturers will generally try to minimise the amount of deformation, in order to maintain reasonable ductility. This means that rib heights are often 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 accredited laboratories. From these tests, requirements for the ongoing control of rib dimensions are established for use within the manufacturer's quality system, to ensure that the steels continue to meet the specified bond performance.

4.0 Weldability

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. This is dealt with more comprehensively in Part 6 of this Guide. In any case, Weldability is considered to be an extremely important property of reinforcing steels.

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 analytical 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.

CEV is adopted in both revisions of BS4449 and also in the British Welding standard, BS 7123, to define weldability. **Table 2** shows typical CEV levels for the different common 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, so that the influence of different steel process routes on welding performance should always be taken into account when approving weld procedures.

5.0 CARES Approval.

As part of the scheme for reinforcing steel, CARES implements various procedures to ensure that approved manufacturers produce steel according to the performance requirements of the standard. These are as follows:

- Initial approval. CARES accounts for the process route employed. Before any process used by a manufacturer is approved, CARES conducts an extensive series of witness and independent tests across the size range. Testing includes tensile properties, bend/rebend, geometry and chemical analysis. Fatigue type testing is also performed across the size range.
- Review of process control parameters to ensure consistency of production operations.

Typical analysis of steels from different process routes

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

Table 2

- Surveillance. Every six months, CARES samples at random from a manufacturer's production, and again conducts witness and independent tests. The system is designed to cover all products, process routes and sizes. A set of independent fatigue tests is also performed, generally at each surveillance audit.

- Long term quality level. CARES monitors the statistics of test results produced by a manufacturer to ensure that the long term characteristic requirements are being met.

- Non-conforming material. CARES regulations ensure that any non-conforming material is disposed of by the manufacturer, and does not reach the supply chain.

- Complaint resolution. CARES monitors any complaints raised against a manufacturer's quality by their customers. CARES ensures that any non-conforming material is properly disposed of, and the causes of non-conformity are investigated and corrected.

Both revisions of BS 4449 have 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 approved 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.

6.0 References

1. **BRITISH STANDARDS INSTITUTION. BS 4449:1997** "Carbon steel bars for the reinforcement of concrete".

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3. **BRITISH STANDARDS INSTITUTION. BS 4482:1985** "Cold reduced steel wire for the reinforcement of concrete".

4. **BRITISH STANDARDS INSTITUTION. BS 4482:2005** Steel wire for the reinforcement of concrete products - Specification.

5 **BRITISH STANDARDS INSTITUTION. BS 4483:1998** "Steel fabric for the reinforcement of concrete".

6. **BRITISH STANDARDS INSTITUTION. BS 4483:2005** Steel fabric for the reinforcement of concrete - Specification.

7. **BRITISH STANDARDS INSTITUTION. BS 8110:Part 1:1997** "Structural use of concrete. Code of practice for design and construction".

8. **BRITISH STANDARDS INSTITUTION. BS 5400:Part 4:1990** "Steel, concrete and composite bridges. Code of practice for design of concrete bridges".

9. **CEN. EN 1992-1-1 "Eurocode 2: Design of concrete structures-Part 1:** General rules and rules for buildings".

10. **CEN. EN 1992-2 "Eurocode 2: Design of concrete structures-Part 1:** Concrete bridges - Design and detailing rules.

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12. **CEN. EN10080** "Steel for the reinforcement of concrete-weldable reinforcing steel-General".

13. **Concrete June 2003 pp 8-10.** "Reinforcing Steels: processes and properties" Tony Franks, R-Tech Services.

14. **The CARES Guide to Reinforcing Steels: Part 2.** Manufacturing Process Routes for Reinforcing Steels.

15. **The CARES Guide to Reinforcing Steels: Part 6.** Welding and Pre-Fabrication.

16. **BRITISH STANDARDS INSTITUTION. BS 7123:1989** "Specification for metal arc welding of steel for concrete reinforcement".

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