BS 6744:2016

BSI Standards Publication

# Stainless steel bars – Reinforcement of concrete – Requirements and test methods

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## Publishing and copyright information



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# Contents

**Summary of pages**

This document comprises a front cover, an inside front cover, pages i to vi, pages 1 to 36, an inside back cover and a back cover.

# Introduction by Lee Brankley, CEO, CARES

BS 6744 is widely specified, both in the UK and internationally. I believe that British Standards remain the choice of informed construction procurement teams because they are performance-based and are developed in partnership with industry.

CARES welcomes the publication by the British Standards Institution of BS 6744:2016, *Stainless steel bars – Reinforcement of concrete – Requirements and test methods*, which was developed by Technical Committee ISE/104 with contributions and support from CARES. Its content forms an essential part of the technical framework used to improve the durability of reinforced concrete structures in chloride containing environments.

I am pleased to introduce BS 6744:2016 and commend its performance-based approach which will make a valuable contribution to the appropriate use of stainless steel reinforcing bar in the UK and internationally.

Developments in the field of the measurement of corrosion resistance and durability guidance have been taken into account during the development of BS 6744:2016. The test method for determining the corrosion resistance of stainless reinforcing steel in chloride contaminated concrete and the guidance on the durability aspects of the corrosion resistance of the reinforcement will be useful tools for engineers.

The 2016 update will help to maintain BS 6744's pre-eminent position in the UK and, more importantly, internationally, as the preferred choice of standard when stainless steel reinforcing is required.

# Foreword

## Publishing information

This British Standard is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 31 May 2016. It was prepared by Technical Committee ISE/104, *Concrete Reinforcing and Pre-Stressing Steels*. A list of organizations represented on this committee can be obtained on request to its secretary.

## Supersession

This British Standard supersedes BS 6744:2001+A2:2009, which is withdrawn.

## Information about this document

Attention is drawn to the fact that compliance with this document might involve the use of patents applied to steel designation 1.4162 (see **3.1.24**). The patent holder agrees to make the material available for production of stainless reinforcing steel bars on reasonable and accessible and non-discriminatory terms. Information on designation 1.4162 may be obtained from: Outokumpu Stainless Ltd, Europa Link, Sheffield, South Yorkshire S9 1TZ.

This standard has been revised so that it can be used in conjunction with BS 8666, *Scheduling, dimensioning, bending and cutting of steel reinforcement for concrete – Specification*, but also to take into account the requirements of Eurocode (EC) 2 (specifically BS EN 1992-1-1 and BS EN 1992-1-2) and the Construction Products Regulations (CPR) [1] with respect to constitutive relationship and durability. It has also been revised to act as the national application standard for BS EN 104031, *Steel for the reinforcement of concrete – Stainless steels* (in preparation).

The decision was taken to remove other uses of steel in concrete, which means that plain bars and grades 200 MPa and ribbed bars above grade 500 MPa are no longer covered by this standard. These products are covered by other standards. This is with the exception of 500 MPa bar and 650 MPa ribbed bar which are now in an informative Annex (Annex I). The standard is open to other strength grades of ribbed bar on the basis that the designers know that these are outside normal UK practice and, once over 600 MPa, outside EC2.

Informative annexes have been prepared to give guidance on durability, magnetic properties, coefficients of thermal expansion, constitutive relationship, welding, performance at elevated temperatures and quality assurance. As far as is possible, the revision has been written to reflect the requirements of BS 4449.

The test method in Annex A is based on the method in BS EN 480-14 adapted by Schönning, Randström and Adair for determining a critical chloride threshold level for stainless steel rebar [2] and that in *Testing for chloride threshold levels of stainless reinforcing bar* [3].

Copyright is claimed on Figure B.1. Copyright holders are Ove Arup & Partners Ltd, 13 Fitzroy Street, London W1T 4BQ.

**Product certification/inspection/testing.** Users of this British Standard are advised to consider the desirability of third-party certification/inspection/testing of product conformity to this British Standard. Appropriate conformity attestation arrangements are described in BS EN ISO/IEC 17065. Users seeking assistance in identifying appropriate conformity assessment bodies or schemes may ask BSI to forward their enquiries to the relevant association.

## Use of this document

It has been assumed in the preparation of this British Standard that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced.

## Presentational conventions

The provisions of this standard are presented in roman (i.e. upright) type. Its requirements are expressed in sentences in which the principal auxiliary verb is "shall".

*Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.*

## Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

**Compliance with a British Standard cannot confer immunity from legal obligations.**

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# 1 Scope

This British Standard specifies requirements and test methods for solid stainless steel bars used for the reinforcement of concrete. It is applicable to ribbed stainless reinforcing steel bars in grade 500.

It is applicable to bars in which the ribs have been formed by the cold working or hot rolling processes.

*NOTE Annex A specifies a test method for determining the corrosion resistance of stainless reinforcing steel in chloride contaminated concrete. Informative annexes give guidance on durability (Annex B), magnetic properties (Annex C), coefficients of thermal expansion (Annex D), constitutive relationship (Annex E), welding (Annex F), performance at elevated temperatures (Annex G) and quality assurance (Annex H).*

This British Standard is not applicable to stainless reinforcing steel bars produced from material whose metallurgical history is not known and fully documented.

It is not applicable to other uses of steel in concrete, such as plain bars and grades 200 MPa and ribbed bars above grade 500 MPa, which are covered by other standards. This is with the exception of 500 MPa bar and 650 MPa ribbed bar which are now in an informative annex (Annex I). The standard is open to other strength grades of ribbed bar on the basis that the designers know that these are outside normal UK practice and, once over 600 MPa, outside BS EN 1992 (EC2).

# 2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS 8666, *Scheduling, dimensioning, bending and cutting of steel reinforcement for concrete – Specification*

BS EN 196-1, *Methods of testing cement – Part 1: Determination of strength*

BS EN 1993-1-2:2005, *Eurocode 3 – Design of steel structures – Part 1-2: General rules – Structural fire design*

BS EN 10088 (all parts), *Stainless steels*

BS EN ISO 148-1, *Metallic materials – Charpy pendulum impact test – Part 1: Test method*

BS EN ISO 3651-2, *Determination of resistance to intergranular corrosion of stainless steels – Part 2: Ferritic, austenitic and ferritic-austenitic (duplex) stainless steels – Corrosion test in media containing sulfuric acid*

BS EN ISO 6892-2, *Metallic materials – Tensile testing – Part 2: Method of test at elevated temperature*

BS EN ISO 15630-1:2010, *Steel for the reinforcement and prestressing of concrete – Test methods – Part 1: Reinforcing bars, wire rod and wire*

# 3 Terms, definitions and symbols

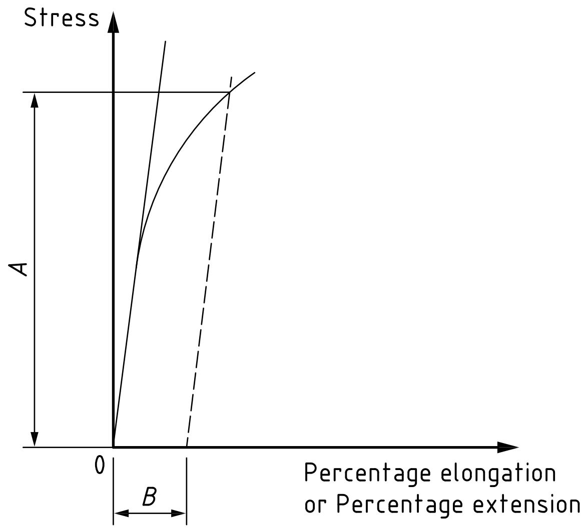
## 3.1 Terms and definitions

For the purposes of this British Standard, the terms, definitions and symbols given in BS EN 10088 (all parts), BS EN ISO 15630-1 and the following apply.

### 3.1.1 0.2% proof strength, $R_{p0.2}$

stress at which a non-proportional extension is equal to 0.2% of the extensometer gauge length (see Figure 1)

Figure 1 **0.2% proof test**




**Key**

*A* Proof strength, non-proportional extension ($R_{p0.2}$ MPa)

*B* Specified percentage non-proportional extension (0.2%)

### 3.1.2 bar

product of ribbed cross section

### 3.1.3 batch

quantity of reinforcing steel processed from an identical heat or cast, diameter or designation, processed in the same production lot under the same process conditions

### 3.1.4 bundle

one coil or a number of lengths bound together

### 3.1.5 cast (heat) analysis

chemical analysis representative of the cast (heat) determined by the steelmaker at their discretion in a manner of their choice

### 3.1.6 characteristic value, $C_v$

value of a material or product property having a prescribed probability of not being attained in a hypothetical unlimited test series

*NOTE This value generally corresponds to a specific fractile of the assumed statistical distribution of the particular property of the material or product.*

**3.1.7 characteristic yield strength, $f_{yk}$**
value of the proof stress, having a prescribed probability of not being attained in a hypothetical unlimited test series the characteristic value of which is the lower limit of the one-sided statistical tolerance interval at which there is a 90% probability (i.e. $1 - \alpha = 0.90$) that 95% ($p = 0.95$) of the values are at or above this lower limit

*NOTE This definition refers to the long-term quality level of production.*

**3.1.8 coil**
continuous hot rolled or cold worked bar in the form of a coil

*NOTE This includes coils welded together to produce a single coiled length.*

**3.1.9 cold worked ribbed stainless reinforcing steel bar**
ribbed bar that has been cold worked

**3.1.10 critical chloride threshold value**
maximum concentration of chlorides by mass of cement that causes no visible pitting corrosion of reinforcement in the test sample

*NOTE Sometimes referred to as "chloride threshold level", "critical chloride content" or "chloride threshold concentration".*

**3.1.11 decoiled product**
reinforcing steel manufactured in coils and subsequently straightened for further processing

**3.1.12 hot rolled ribbed stainless reinforcing steel bar**
ribbed bar that has been hot worked

**3.1.13 length**
piece of nominally straight bar cut to a specified length

**3.1.14 longitudinal rib**
uniform continuous protrusion parallel to the axis of the bar

**3.1.15 manufacturer**
organization that produces stainless reinforcing steel

*NOTE A manufacturer can be a steelmaker, re-roller or a cold worker.*

**3.1.16 maximum value**
value which no test result is permitted to exceed

**3.1.17 minimum value**
value below which no test result is permitted to fall

**3.1.18 nominal cross-sectional area, $A_n$**
cross-sectional area equivalent to the area of a circular plain bar of the same nominal diameter, $d$, i.e.:

$$\frac{\pi d^2}{4}$$

**3.1.19 nominal diameter, $d$**
diameter of a circle with an area equal to the effective cross-sectional area of the bar

*NOTE See Clause **5** and Clause **6**.*

**3.1.20 product analysis**
chemical analysis carried out on a sample of the product

**3.1.21 purchaser**
organization that purchases the product for use in reinforced concrete production

**3.1.22 reinforcing steel**
steel product, in bar or coil form, with a circular or practically circular cross section which is suitable for the reinforcement of concrete

**3.1.23 reinforcing steel designation**
indication of chemical composition of steel

*NOTE See Clause* ***8****.*

**3.1.24 reinforcing steel grade**
steel grade defined by its characteristic proof strength

**3.1.25 relative rib area, $f_R$**
area of the projections of all ribs on a plane perpendicular to the longitudinal axis of the wire, bar or rod, divided by the wire length and the nominal circumference

**3.1.26 rib height, $a_{max}$**
distance from the highest point of the rib (transverse or longitudinal) to the surface of the core

*NOTE See BS EN ISO 15630-1.*

**3.1.27 rib spacing, $c$**
distance between the centres of two consecutive transverse ribs, measured parallel to the axis of the bar

*NOTE See BS EN ISO 15630-1.*

**3.1.28 stress ratio, $\sigma_f$**
tensile strength, $R_m$, divided by 0.2% proof strength, $R_{p0.2}$ (see Figure 2)

**3.1.29 supplier**
organization supplying reinforcing steel to an end user

*NOTE The product may be supplied in straight lengths or fabricated in accordance with BS 8666.*

**3.1.30 transverse rib**
rib on the surface of the bar other than a longitudinal rib

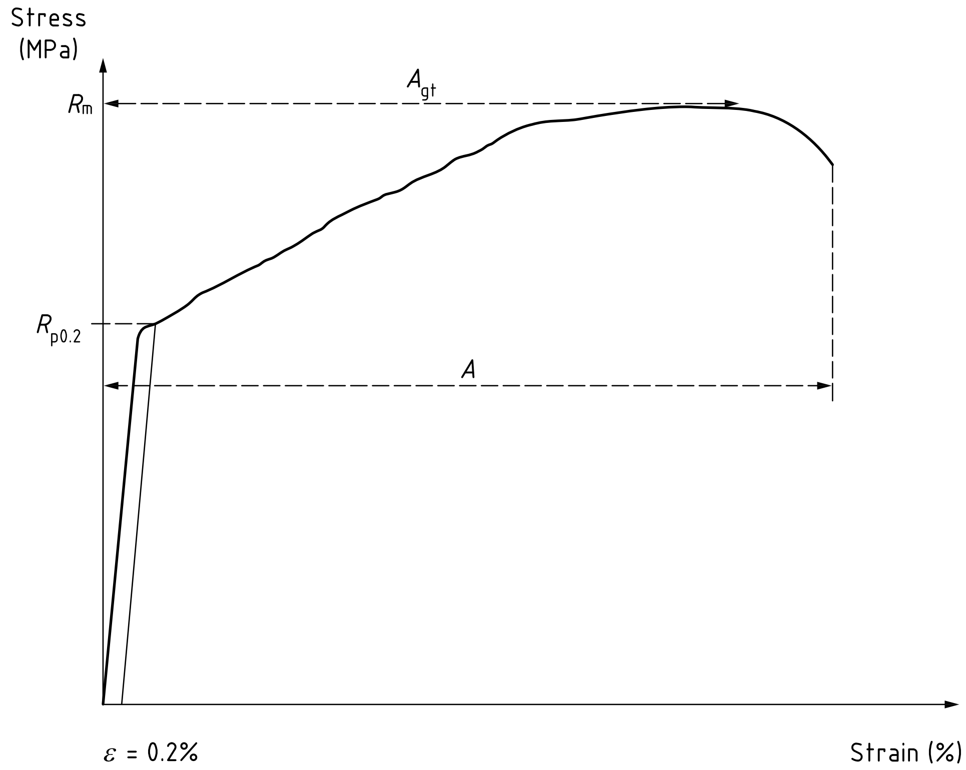
**3.1.31 transverse rib flank inclination, $\alpha$**
angle between the rib flank and the longitudinal axis of the bar

*NOTE See BS EN ISO 15630-1.*

**3.1.32 transverse rib inclination, $\beta$**
angle between the axis of the transverse rib and the longitudinal axis of the bar

*NOTE See BS EN ISO 15630-1.*

Figure 2 **Typical stress-strain curve (relation) for stainless reinforcing**




## 3.2 Symbols

The symbols used in this British Standard are described in Table 1.

Table 1 **Symbols** *(1 of 2)*

| Symbol | Unit | Description |
|---|---|---|
| $A_{gt}$ | – | Percentage total elongation at maximum force |
| $A_n$ | mm | Nominal cross-sectional area of the bar |
| $A_5$ | – | Percentage elongation after fracture using an original gauge length of 5 times the nominal diameter |
| $Cl_{field}$% | % | Theoretical conversion from laboratory test to actual field performance (not covered in this British Standard) |
| $Cl_{test}$% | % | Percentage of chlorides added to the test method the stainless steel reinforcement was exposed to |
| $C_v$ | – | Characteristic value |
| CCTL% | % | Maximum amount of chlorides by mass of cement to which reinforcement can resist pitting |
| $c$ | mm | Transverse rib spacing |
| $D$ | mm | Diameter of cylindrical mortar test block |
| $d$ | mm | Nominal diameter of the bar |
| $E_o$ | GPa | Initial modulus of elasticity |
| $E_s$ | GPa | Modulus of elasticity |
| $E_t$ | GPa | Tangent modulus of elasticity |
| $E_0$ | – | A Ramberg-Osgood fitting parameter resembling the elastic modulus |
| $f_p$ | MPa | Proportional limit |
| $f_R$ | – | Relative rib area |
| $f_t$ | MPa | Tensile strength of carbon steel reinforcement |
| $f_y$ | MPa | Yield strength, 0.2% proof strength |
| $f_{yd}$ | MPa | Design yield strength of reinforcement |
| $f_{yk}$ | MPa | Characteristic yield strength of reinforcement |
| $H$ | mm | Height of cylindrical mortar test block |
| $l$ | mm | Exposed length of the bar in mortar test block (see Annex B) |
| $k$ | – | Acceptability index |
| $L$ | m | Length of bar sample |
| $M_{mR}$ | kg/m | Mass per metre run of bar |
| $M$ | kg | Mass of bar sample |
| $m$ | – | Average of a population of results |
| $N$ | – | Class N values |
| $n$ | – | A Ramberg-Osgood fitting parameter related to the strain hardening |
| $R_m$ | MPa | Tensile strength of stainless steel reinforcement |
| $R_{p0.2}$ | MPa | 0.2% proof strength, non-proportional extension |
| $S$ | – | Standard deviation of a population of results |
| $\alpha$ | ° | Transverse rib flank inclination |
| $\alpha_{max}$ A) | mm | Maximum height of transverse rib |
| $\alpha_{R\text{-}O}$ | – | A Ramberg-Osgood fitting parameter where $\alpha_{R\text{-}O} \approx (0.002*E_0)/\sigma_0$ for stainless reinforcing steel |
| $\beta$ | ° | Transverse rib inclination: angle between the axis of a transverse rib and the bar axis |
| $\varepsilon$ | % | The Ramberg-Osberg modelled strain |
| $\varepsilon_{ud}$ | % | Design strain of reinforcement |
| $\varepsilon_{uk}$ | % | Characteristic strain of reinforcement at maximum load |
| $\gamma_s$ | – | Partial factor for stainless reinforcing steel |
| $\mu_r$ | – | Relative magnetic permeability |
| $\sigma$ | – | The Ramberg-Osgood modelled stress |
| $\sigma_f$ | – | Stress ratio ($R_m/R_{p0.2}$) |

Table 1 **Symbols** *(2 of 2)*

| Symbol | Unit | Description |
|---|---|---|
| $\sigma_{max}$ | – | Specified maximum stress in fatigue test |
| $\sigma_{min}$ | – | Specified minimum stress in fatigue test |
| $\sigma_0$ | – | A Ramberg-Osgood fitting parameter resembling $R_{p0.2}$ |

[A] In some product standards, the symbol *h* is also used for this parameter.

# 4 Designation

**4.1** The stainless reinforcing steel designation numbers used in this British Standard shall be defined in accordance with BS EN 10088.

**4.2** The products covered by this British Standard shall be designated in the following sequence:

a) the description of the product form (e.g. ribbed stainless reinforcing steel bar or ribbed stainless reinforcing steel coil);

b) the number of this British Standard (BS 6744);

c) the nominal dimensions of the product (see Clause **6**);

d) the BS EN 10088 (all parts) steel designation number (see Table 5);

e) the strength grade (see Table 8);

f) the ductility class (see Table 8); and

g) the durability class (see Table B.1).

**EXAMPLE**

In accordance with this British Standard, a ribbed bar with a nominal diameter of 20 mm, a nominal length of 12 000 mm, steel designation number 1.4301, and strength grade 500 ductility and durability is designated thus:

Ribbed bar BS 6744:2016-20×12000-1.4301, B500B.CCTL%.

# 5 Standard diameters

The range of diameters of ribbed stainless reinforcing steel bars shall be from 6 mm to 50 mm.

*NOTE 1 The range of standard diameters is given in Table 2.*

*NOTE 2 Other diameters may be made available on request.*

Table 2 **Standard diameters**

| Grade | Nominal diameters<br>mm |
|---|---|
| 500 | 6, 7, 8, 10, 12, 14, 16, 20, 25, 32, 40, 50 |

# 6 Dimensions, mass and tolerances

## 6.1 Nominal cross-sectional area and mass per metre run

The nominal cross-sectional area and mass per metre run of the bars shall be calculated in accordance with BS EN ISO 15630 using a test sample of length not less than 0.5 m.

The values for the nominal cross-sectional area and nominal mass per metre run, $M_{mR}$, of individual bars shall be in accordance with Table 3.

The tolerances on mass per metre run shall be in accordance with Table 4.

*NOTE 1 The values for the nominal mass per metre run are calculated from the values of the nominal cross-sectional area using density values in BS EN 10088 (all parts).*

*NOTE 2 Stainless steel hot rolled bars and coils are subsequently descaled in accordance with Clause **11**. This can lead to a reduction in the mass per metre. Hence, the calculation should be undertaken on a descaled rebar, unless the manufacturer can demonstrate a clear correlation between an as rolled sample and a descaled sample for each diameter tested.*

Table 3 **Nominal cross-sectional area of reinforcing steel and nominal mass per metre run**

| **Nominal size** | **Nominal cross-sectional area** | **Nominal mass per metre run** [A] **Steel designation** | | |
|---|---|---|---|---|
| | | **Standard austenitic** [B] | **Austenitic with Mo addition** [B] | **Austenitic-ferritic (Duplex)** [B] |
| mm | $mm^2$ | kg | kg | kg |
| 6 | 28.3 | 0.224 | 0.226 | 0.221 |
| 7 | 38.5 | 0.304 | 0.308 | 0.300 |
| 8 | 50.3 | 0.397 | 0.402 | 0.392 |
| 10 | 78.5 | 0.620 | 0.628 | 0.612 |
| 12 | 113.1 | 0.893 | 0.905 | 0.882 |
| 14 | 153.9 | 1.216 | 1.231 | 1.200 |
| 16 | 201.1 | 1.589 | 1.609 | 1.569 |
| 20 | 314.2 | 2.482 | 2.514 | 2.451 |
| 25 | 490.9 | 3.878 | 3.927 | 3.829 |
| 32 | 804.2 | 6.353 | 6.434 | 6.266 |
| 40 | 1 256.6 | 9.927 | 10.053 | 9.790 |
| 50 | 1 963.5 | 15.512 | 15.708 | 15.297 |

A) The nominal mass per metre run, $M_{mR}$, is given by the equation: $M_{mR} = M/L$.

B) Example steel designations include: 1.4301 and 1.4311 for standard austenitic; 1.4404, 1.4436 and 1.4429 for austenitic with Mo addition; and 1.4162 and 1.4362 for austenitic-ferritic (Duplex).

Table 4 **Tolerances on mass per metre run**

| **Nominal diameter** mm | **Tolerances on mass per metre run** % |
|---|---|
| 6 | ±9.0 |
| 7 to 12 | ±6.0 |
| over 12 | ±4.5 |

### 6.2 Length

**6.2.1** The nominal length of ribbed stainless reinforcing steel bars shall be agreed at the time of enquiry and order.

**6.2.2** Unless otherwise agreed at the time of enquiry and order, the permissible deviation from the nominal length shall be +100/0 mm or in accordance with BS 8666.

## 7 Steelmaking process

Unless a special steelmaking process is agreed when ordering, the steelmaking process for steels conforming to the applicable part of BS EN 10088 shall be at the discretion of the manufacturer.

## 8 Chemical composition

### 8.1 Cast analysis

The chemical composition of the steel, based on cast analysis, shall be in accordance with Table 5. In cases of dispute, the methods of test specified in the applicable part of BS EN 10088 shall be used.

### 8.2 Product analysis

The maximum deviations in product analysis from the values specified for cast analysis shall be in accordance with those specified in the applicable part of BS EN 10088.

## 9 Surface quality

Steel bars shall be free from defects or other surface contamination which can be shown to adversely affect the corrosion or mechanical properties of the steel, as agreed at the time of enquiry and order.

## 10 Surface geometry

### 10.1 General

Measurement of geometrical characteristics shall be in accordance with BS EN ISO 15630-1.

*NOTE The stainless reinforcing steel products covered by this British Standard are characterized by their surface geometry, which enables them to bond with the concrete.*

Table 5 **Chemical composition (cast analysis)% by mass of typical, commercially available BS EN 10088 stainless reinforcing steel designations**A)

| Steel designation number | C max | Si max | Mn max | S max | Cr max | Ni max | Mo max | Cu max | P max | N max |
|---|---|---|---|---|---|---|---|---|---|---|
| **Alloys used for low magnetic permeability** | | | | | | | | | | |
| 1.4311 | 0.03 | 1.0 | 2.0 | 0.030 | 17.5–19.5 | 8.5–11.5 | – | – | 0.045 | 0.12–0.22 |
| 1.4436 | 0.05 | 1.0 | 2.0 | 0.030 | 16.5–18.5 | 10.5–13.0 | 2.5–3.0 | – | 0.045 | ≤0.11 |
| **Alloys used for corrosion resistance to chloride ingress in concrete**B) | | | | | | | | | | |
| 1.4311 | 0.03 | 1.0 | 2.0 | 0.030 | 17.5–19.5 | 8.5–11.5 | – | – | 0.045 | 0.12–0.22 |
| 1.4162 | 0.04 | 1.0 | 4.0–6.0 | 0.015 | 21.0–22.0 | 1.35–1.70 | 0.10–0.80 | 0.10–0.80 | 0.040 | 0.20–0.25 |
| 1.4362 | 0.03 | 1.0 | 2.0 | 0.015 | 22.0–24.5 | 3.5–5.5 | 0.10–0.60 | 0.10–0.60 | 0.035 | 0.05–0.20 |
| 1.4462 | 0.03 | 1.0 | 2.0 | 0.015 | 21.0–23.0 | 4.5–6.5 | 2.5–3.5 | – | 0.035 | 0.10–0.22 |
| 1.4404 | 0.03 | 1.0 | 2.0 | 0.030 | 16.5–18.5 | 10.0–13.0 | 2.0–2.5 | – | 0.045 | ≤0.11 |
| 1.4429 | 0.05 | 1.0 | 2.0 | 0.030 | 16.5–18.5 | 10.5–13.0 | 2.5–3.0 | – | 0.045 | ≤0.12–0.22 |
| **Alloys used for special applications, e.g. where the steel may be exposed** C) | | | | | | | | | | |
| 1.4501 | 0.03 | 1.0 | 1.0 | 0.015 | 24.0–26.0 | 6.0–8.0 | 3.0–4.0 | – | 0.035 | 0.20–0.30 |
| 1.4529 | 0.02 | 0.50 | 1.0 | 0.010 | 19.0–21.0 | 24.0–26.0 | 6.0–7.0 | 0.50–1.50 | 0.030 | 0.15–0.25 |

A) Table 5 does not provide an exhaustive list of designations.

B) These are the alloys for which the most academic research on chloride resistance is available and which have the most historic use for this application. Refer to manufacturer's certification for CCTL value.

C) Specialist corrosion advice might be required to specify.

## 10.2 Relative rib area

The geometry, the rib distribution and configuration shall be measured in accordance with BS EN ISO 15630-1.

The relative rib area, $f_R$, the rib spacing, $c$, the rib height, $\alpha_{max}$, and the rib inclination, $\beta$, of the transverse ribs, the projection of the transverse rib and the transverse rib flank inclination, $\alpha$, shall be measured according to BS EN ISO 15630-1.

For relative rib area, $f_R$, the rib spacing, $c$, the rib height, $\alpha_{max}$, and the rib inclination, $\beta$, of the transverse ribs shall conform to Table 6 and Table 7.

The relative rib area, $f_R$, shall be regarded as the ruling criterion for the bond performance of ribbed stainless reinforcing steel products.

Table 6 **Minimum relative rib area, $f_{Rmin}$**

| Nominal bar diameter<br>mm | Relative rib area, $f_{Rmin}$ |
|---|---|
| 6 | 0.035 |
| 7 to 12 | 0.040 |
| >12 | 0.056 |

Table 7 **Ranges for the rib parameters**

| Rib height, $\alpha_{max}$ | Rib spacing, $c$ | Rib inclination, $\beta$<br>° |
|---|---|---|
| 0.03*d* to 0.15*d* | 0.4*d* to 1.2*d* | 35 to 75 |

## 10.3 Geometry of rib

### 10.3.1 General

Steel bars shall have rows of parallel transverse ribs (normally 2 or 3), equally distributed around the perimeter with a uniform spacing over the entire length.

*NOTE Longitudinal ribs might be present or not.*

### 10.3.2 Transverse ribs

**10.3.2.1** Transverse ribs shall have a crescent shape and shall merge smoothly into the core of the bar, unless the same product properties can be achieved by other special surface configurations.

**10.3.2.2** The projection of the ribs shall extend over at least 80% of the periphery of the product, which shall be calculated from the nominal diameter and the transverse ribless parameter in accordance with BS EN ISO 15630-1.

**10.3.2.3** The rib flank inclination, $\alpha$, measured in accordance with BS EN ISO 15630-1, shall be greater than or equal to 45° and radiused at the transition to the core of the product (see BS EN ISO 15630-1).

### 10.3.3 Longitudinal ribs

Where longitudinal ribs are present, their height, when measured in accordance with BS EN ISO 15630-1, shall not exceed 0.15*d*.

Minor deviations from the values specified in **10.3.2** shall be permitted provided that the specifications for the relative rib area according to Table 6 are satisfied.

# 11 Conditions of supply

Ribbed stainless steel bar shall be supplied in coil or straight lengths, or fabricated in accordance with BS 8666 in the following conditions:

a) hot rolled and descaled;

b) hot rolled, descaled and decoiled;

c) hot rolled, softened and descaled, and subsequently cold ribbed; and

d) hot rolled, softened and descaled, and subsequently cold ribbed and decoiled.

*NOTE The softening process may be omitted in c) and d), but care is necessary to ensure that the product conforms to the mechanical requirements of this standard and that there is neither a detrimental phase (see **12.12.1**) nor intergranular corrosion (see **12.12.3**).*

# 12 Mechanical and physical properties

## 12.1 Selection of test samples for conformity testing

All units of continuous production shall be tested in accordance with **12.5** to **12.7**. The units of production from which test samples are selected shall be the batch. Test samples shall be selected from each batch at a frequency of one per ten tonnes.

*NOTE Stainless steel samples do not require ageing.*

## 12.2 Test reports

The results of the determination of the product type shall be documented in test reports. All test reports shall be retained by the manufacturer for at least 10 years after the last date of production.

## 12.3 Test certificate

The test certificate shall state:

a) that the products conform to this British Standard, i.e. BS 6744, and have undergone the tests specified in this British Standard at the specified frequency (see **12.1**);

b) the address at which the records of the tests are available for inspection;

c) the cast number, batch reference and cast analysis, including all specified elements in **8.1**;

d) the results of the tensile test, including the effective cross-sectional area;

e) the results of the bend test;

f) the results of Charpy impact test and intergranular corrosion test where applicable;

g) the durability class;

h) for ribbed stainless steel bars, the rolled-on mill bar mark; and

i) the approval number issued by the certifying authority (if applicable).

*NOTE Users of this British Standard are advised to consider the desirability of product certification against the requirements of this British Standard and the appropriate standard in the BS EN ISO 9001 series by an accredited third-party certification body (see also Annex H).*

## 12.4 Retests

If any test sample fails to meet the stress ratio, proof strength, percentage elongation after fracture, $A_5$, percentage total elongation at maximum force, $A_{gt}$, or bend test requirements (see **12.6**), two additional test samples shall be taken from different bars of the same batch and subjected to the test(s) which the original sample failed. If both additional test samples pass the test(s), the batch from which they were taken shall be deemed to conform to this British Standard. If either of the samples fails, the batch shall be deemed not to conform to this British Standard.

## 12.5 Tensile properties

### 12.5.1 0.2% proof strength, $R_{p0.2}$

When test samples selected and prepared in accordance with BS EN ISO 15630-1:2010, Clause **4**, are tested in accordance with BS EN ISO 15630-1:2010, **5.3**, the 0.2% proof strength shall be as specified in Table 8.

For routine testing the 0.2% proof strength shall be considered a minimum value. For determination of long-term quality level, the values given in Table 8 shall be for the characteristic yield strength, $f_{yk}$ (see **3.1.7**).

### 12.5.2 Tensile strength, $R_m$

When test samples selected and prepared in accordance with BS EN ISO 15630-1:2010, Clause **4**, are tested in accordance with BS EN ISO 15630-1:2010, **5.3**, the tensile strength shall be as specified in Table 8.

### 12.5.3 Stress ratio, $\sigma_f$

When test samples selected and prepared in accordance with BS EN ISO 15630-1:2010, Clause **4**, are tested in accordance with BS EN ISO 15630-1:2010, **5.3**, the stress ratio shall be as specified in Table 8.

### 12.5.4 Elongation at maximum force

When test samples selected and prepared in accordance with BS EN ISO 15630-1:2010, Clause **4**, are tested in accordance with BS EN ISO 15630-1:2010, **5.3**, the percentage total elongation at maximum force, $A_{gt}$, shall be as specified in Table 8.

If the total elongation at maximum force, $A_{gt}$, is below the minimum value specified in Table 8, this shall not be the cause for non-conformity with this subclause, provided the minimum percentage elongation after fracture is met (see **12.5.5**).

For elongation values, the test results shall be regarded as valid, irrespective of the position of fracture, provided that the minimum percentage elongation after fracture, $A_5$, specified in Table 8 has been obtained.

### 12.5.5 Percentage elongation after fracture, $A_5$

When test samples selected and prepared in accordance with BS EN ISO 15630-1:2010, Clause **4**, are tested in accordance with BS EN ISO 15630-1:2010, **5.3**, the percentage elongation after fracture shall be as specified in Table 8.

Table 8 **Strength and ductility properties**

| **Property** | | **Strength class** |
|---|---|---|
| | | B500 |
| Characteristic yield strength $f_{yk}$ (MPa) | | 500 |
| Fatigue stress range (MPa) for N ≥5 × $10^6$ cycles with a stress ratio, $\sigma_{min}/\sigma_{max}$ = 0.2 | **Nominal bar size diameter (mm)** | |
| | ≤16 | 200 |
| | >16 ≤20 | 185 |
| | >20 ≤25 | 170 |
| | >25 ≤32 | 160 |
| | >32 ≤50 | 150 |
| | | **Ductility class B** |
| Minimum value of stress ratio | | ≥1.08 |
| Percentage total elongation at maximum force, $A_{gt}$ | | ≥5.0 |
| Percentage elongation after fracture, $A_5$ | | ≥14% |

*NOTE BS EN 10080 refers to a yield strength, $R_e$, which relates to the characteristic, minimum and maximum values based on the long-term quality level of production. In contrast, $f_{yk}$ is the characteristic yield strength based on only that reinforcement used in a particular structure. There is no direct relationship between $f_{yk}$ and the characteristic $R_e$. However, the methods of evaluation and verification of yield strength given in BS EN 10080 provide a sufficient check for obtaining $f_{yk}$.*

## 12.6 Bendability

When test samples selected and prepared in accordance with BS EN ISO 15630-1:2010, Clause **4**, are subjected to the bend test in BS EN ISO 15630-1:2010, Clause **6**, being bent through 180° round a former of maximum diameter given in Table 9, they shall show no visible sign of fracture or irregular bending deformation.

Table 9 **Bend test formers**

| **Nominal diameter of the bar**<br>mm | **Maximum diameter of former, *d*** |
|---|---|
| ≤16 | 4 |
| >16 | 7 |

## 12.7 Bonding strength (surface geometry)

Surface geometry parameters shall be determined in accordance with BS EN ISO 15630-1:2010, Clause **11**.

## 12.8 Fatigue characteristics

The fatigue characteristics of ribbed stainless reinforcing steel bars shall be verified every five years or after 1 000 tonnes are produced for each diameter and designation manufactured, whichever occurs sooner.

Test samples shall be selected and prepared in accordance with BS EN ISO 15630-1:2010, Clause **4**, and subjected to type testing in accordance with BS EN ISO 15630-1:2010, Clause **8**, to determine the characteristics of a particular geometric shape and designation. When subjected to 5 × $10^6$ cycles of stress at a stress ratio, $\sigma_{min}/\sigma_{max}$ of 0.2 and a frequency not exceeding 120 Hz, the test samples shall show no visible sign of fracture.

## 12.9 Strength at elevated temperature (tensile strength)

The strength at elevated temperature shall be determined in accordance with BS EN ISO 6892-2.

## 12.10 Chemical composition and durability

The chemical composition shall be determined in accordance with the test certificate issued with the material.

When 10 test specimens are tested in accordance with Annex A, for at least 9 of the specimens the maximum current density shall not exceed 80 MA/m$^2$ and there shall be no indication of corrosion attack determined by the visual inspection.

*NOTE In the event of stainless reinforcing steel being specified primarily for the purposes of the corrosion resistance then durability in specific environment is defined as the characteristic to resist corrosion as explained in Annex B.*

## 12.11 Weldability

The chemical composition shall be determined in accordance with the applicable part of BS EN 10088.

*NOTE Highways England* Specification for Highway Works *[4], Clause 1714, does not currently permit welding of stainless steel reinforcement.*

## 12.12 Additional test requirements

### 12.12.1 General

BS EN 10088 steel designations 1.4162, 1.4362, 1.4462 and 1.4501 shall undergo further testing in accordance with **12.12.3** to ensure the absence of detrimental metallurgical phases in the finished condition. The results shall be quoted on the test certificate.

### 12.12.2 Charpy impact test

Three impact tests shall be performed for each batch. When impact testing is carried out in accordance with BS EN ISO 148-1 on test pieces with a V-notch, the average values obtained from three test pieces shall conform to BS EN 10088 (all parts) for the appropriate grade designation.

*NOTE Charpy impact tests should only be performed on bar diameters 16 mm and above.*

### 12.12.3 Intergranular corrosion test

The resistance to intergranular corrosion shall be tested for all alloy designations in accordance with BS EN ISO 3651-2, at a frequency of one test per batch.

# 13 Product identification

## 13.1 Product marking

Ribbed stainless reinforcing steel bars shall be identified by rolled-on legible marks on the surface at intervals not greater than 1.5 m to identify the manufacturer.

## 13.2 Product labelling

Each bundle of bar, or each coil, shall have a label attached containing the following information:

a) reference to this British Standard, i.e. BS 6744:2016 [1)];

b) reinforcing steel designation;

c) diameter;

d) strength grade;

e) ductility class;

f) durability class (see Table B.1);

g) cast number;

h) batch reference; and

i) name of the manufacturer.

[1)] Marking BS 6744:2016 on or in relation to a product represents a manufacturer's declaration of conformity, i.e. a claim by or on behalf of the manufacturer that the product meets the requirements of the standard. The accuracy of the claim is solely the claimant's responsibility. Such a declaration is not to be confused with third party certification of conformity, which might also be desirable.

# Annex A (normative) Test method for determining the corrosion resistance of stainless reinforcing steel in chloride contaminated concrete

*COMMENTARY ON ANNEX A*

*This test method has been adapted from BS EN 480-14.*

## A.1 Principle

The corrosion behaviour is evaluated for a set of 10 bars of a specific designation of stainless reinforcing steel embedded in a standardized mortar with a predefined amount of mixed-in chlorides (expressed as percentage by mass of cement, $Cl_{test}$%).

## A.2 Materials

### A.2.1 Ribbed stainless reinforcing steel

Carry out the tests on commercially-produced ribbed stainless reinforcing steel bars in the as-received condition, unless otherwise specified. Document the surface conditions of the rebar and the nominal diameter of the bars, *d* (mm).

### A.2.2 Mortar

Mix a standard mortar with a Portland cement (type CEM I 52.5R according to BS EN 197-1) and a water/cement ratio of 0.5, using European CEN standard sand with a maximum size of 2 mm. Mix batches of mortar made of 1 350 g of sand, 450 g of Portland cement and 225 g of distilled water in accordance with BS EN 196-1. Add chlorides to each batch by dissolving sodium NaCl in the mixing water, having first calculated the amount of salt (expressed in grams) to be dissolved in order to achieve the necessary amount of chloride ions ($Cl_{test}$% by mass of cement).

### A.2.3 Specimens

Prepare 10 cylindrical mortar specimens of diameter *D* (mm) and height *H* (mm) (see Figure A.1). In order to prevent leaching of chloride at the depth of the bars during the test, choose the diameter, *D*, to provide a concrete cover thickness of at least 25 mm, i.e. $D \geq d + 2 \times 25$ (mm). *H* should be (100 ±20) mm.

Embed a ribbed bar of stainless reinforcing steel (100 ±20) mm long and with diameter, *D*, along the axis of each specimen, as shown in Figure A.1. Apply an electrical contact to one end of each bar (e.g. by using a rivet) and then properly mask both ends of each bar in order to electrically insulate the cut surfaces and the electrical contact. Prevent crevice corrosion underneath the coating by, for example, a thin layer of styrene-butadiene rubber modified cement mortar in contact with the steel, coated with an insulating polymeric material after hardening or lacomite.

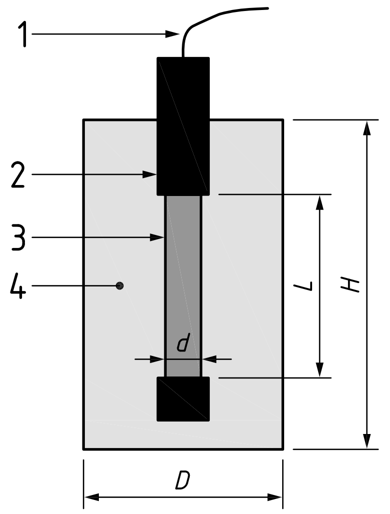
The exposed length of the bars shall be at least 60 mm. Degrease the exposed surface with acetone before casting.

Prepare cylindrical moulds (made of plastic or steel) in a way that the steel bars can be fixed vertically along their axis. The fixing system shall be such that the cover depth, *c*, is in the range of ±2 mm with respect to the nominal value.

Fill the mould with the test mortar and compact the mortar to prevent segregation and an excessive amount of entrapped air, using a vibrating table or manual tamping with a rod.

After casting, cure specimens in the mould, maintaining a temperature of (23 ±2) °C and relative humidity >95%. After 24 h, de-mould the specimens and immerse each of them for 6 days in a cell of a capacity of approx. 1 L, filled with a saturated solution of $Ca(OH)_2$ until the time for testing.

Figure A.1 **Geometry of the specimens**




**Key**

| | | | |
|---|---|---|---|
| 1 | Electrical connection | 3 | Stainless steel bar |
| 2 | Insulating coating | 4 | Mortar |

## A.2.4 Test procedure

At the end of curing, carry out electrochemical testing in the same cells where the specimens were cured (do not replace the test solution), in order to prevent further leaching of chlorides from the mortar. Introduce in each cell:

a) a reference electrode, which can be either a saturated calomel electrode (SCE) or silver/silver chloride electrodes; and

b) a counter-electrode in the cell, which is either a platinum electrode, a thin sheet of stainless steel (e.g. BS EN 10088, type X2CrNi19-11) or activated titanium with an area large enough to give a cathodic current of 10 MA.

Record the free corrosion potential of all the steel bars, then carry out a potentiostatic polarization test by polarizing all the bars at +200 mV versus SCE for 24 h. Monitor the polarization current (with step intervals of 10 min or less) using either a zero-resistance ammeter or an ohmic drop on a shunt resistor placed on the wire connected to the counter-electrode.

## A.2.5 Test results

For all test specimens, calculate the maximum current density between 1 h and 24 h as $MA/m^2$ using the calculated area of the rebar (working electrode) in contact with mortar for the period where the potential has been applied.

At the end of the test, break the specimens to visually inspect the steel surface and detect the presence of corrosion attacks. To facilitate removal of mortar remains from the specimens, the stainless reinforcing steel rebar can be immersed in 15 weight% $H_3PO_4$.

Consider specimens that show the following characteristics as non-valid for the final evaluation and repeat the test until a set of 10 valid tested specimens is available:

a) crevice corrosion attack in the masked area; or

b) evidence of corrosion attack as a result of voids caused by poor compaction or due to segregation or any other experimental procedure non-compliance.

In the event of one failure and one contradictory occurrence, that is visible pitting corrosion and current density less than 80 MA/m$^2$ or a current greater than 80 MA/m$^2$ and no visible pitting corrosion, test a further batch of 5 samples.

### A.2.6 Test report

Record the following in the test report:

a) the designation of the stainless reinforcing steel, the producer and the nominal diameter of the tested bars;

b) the description of the surface condition of the tested bars and, possibly, photographic documentation;

c) the percentage of chlorides admixed to the testing mortar, $Cl_{test}$%;

d) the composition of the testing mortar;

e) the type of counter electrode;

f) the procedure of casting and curing of the specimen;

g) details of the geometry of the specimens and, specifically, *D*, *H* and the exposed length of the bars, *l*;

h) the corrosion potential of each specimen at the end of the curing period;

i) a plot with the monitoring of the current density in each specimen during the 24 h potentiostatic polarization;

j) the maximum current density measured in each specimen between 1 h and 24 h of potentiostatic polarization; and

k) the photographic documentation of each bar showing corrosion attacks.

## Annex B (informative) Guidance on durability

### B.1 General

The durability of a reinforced concrete structure depends on the quality and thickness of the concrete cover, but also the resistance to corrosion of the steel reinforcement. In fact, the corrosion resistance of the reinforcement is dependent upon the properties of the concrete in resisting the ingress of carbon dioxide (carbonation-induced corrosion), the ingress of chlorides (chloride-induced corrosion), but also the corrosion resistance of the reinforcement itself. This annex deals only with the durability aspects of corrosion resistance of the reinforcement.

The corrosion-induced damage to the structure can be either or both the spalling of the concrete as a result of the bursting forces of the expansive corrosion products or loss of cross-sectional area of the reinforcement, weakening the structure. EC2 makes provision for the use of stainless reinforcing steel and potential relaxation of concrete durability measures, but gives no specific guidance. BS EN 206, which supersedes BS EN 206-1 referred to in EC2, provides a prescriptive guidance for the prevention of the corrosion of carbon steel reinforcement, but only deals with the durability aspects of the concrete and overlooks the potential of increased corrosion resistance of the reinforcement, as in the case of stainless reinforcing steel, as part of the overall durability solution.

In the prescriptive approach the scale of the environmental threat, e.g. surface chloride content, the durability measure, e.g. the chloride diffusion coefficient of the concrete, and the resistance of the reinforcement to corrosion, e.g. critical chloride threshold level (CCTL), are not visible. Therefore, prevention of reinforcement corrosion is currently dealt with in a prescriptive manner, although corrosion is regarded as the major reason for premature failure of reinforced concrete structures. In this approach, the service life is not stated. In performance-based approaches, conversely, design for durability is carried out on the basis of a specific design service life and defined limit states (e.g. corrosion initiation, concrete cracking).

A "state-of-the-art" durability guidance is the fib *Model Code for Service Life Design* [5] which adopts a performance approach to the solution for both carbonation-induced corrosion and chloride-induced corrosion. The approach to the latter requires the supplier to meet the CCTL value required from the durability calculation carried out. Due to the numerous types of ribbed stainless reinforcing steel bars now available and possible changes in the corrosion resistance as a function of chemical composition, microstructure, surface finishing, etc., a test method for the comparison of the corrosion resistance among different types of stainless reinforcing steel is required.

This annex deals with the limitations of existing ribbed stainless reinforcing steel rebar standards and gives guidance to facilitate the use of "state-of-the-art" performance methods beyond providing a method to test stainless reinforcing steel rebar under pre-fixed $Cl_{test}$%. Whilst durability of reinforced concrete structures is only dependent in part on the resistance to reinforcement corrosion, the other parameters are dealt with in a performance manner.

## B.2 Terminology

Durability of reinforced concrete is determined by the type and quality of the concrete used and the corrosion resistance of the reinforcement. The high alkalinity of the concrete ensures that the carbon steel reinforcement is passive and protects it from further corrosion. However, this passivation can fail either by the long-term carbonation of the concrete, lowering the alkalinity and rendering the carbon steel prone to further corrosion, or by the ingress of chlorides to a point at which they break the passive layer and initiate corrosion. The concentration of chlorides required to defeat the passive layer is referred to as the CCTL.

In the fib Model Code [5], carbon steel reinforcement in structures exposed to the atmosphere is assumed to have a minimum CCTL value of 0.2% chlorides by mass of cement. The value of stainless reinforcing steel is far higher and dependent upon alloy designation and the surface finish. CCTL values are also dependent upon the temperature of the concrete structure and the pH of the concrete throughout the design life.

## B.3 Prescriptive guidance

EC2 deals with the durability of reinforced concrete by reference to BS EN 206-1. BS EN 206, which has superseded BS EN 206-1, tabulates the exposure conditions causing the durability issues and the measures that can be taken to ensure durability, i.e. cement type, water-cement (w/c) ratio, and concrete cover to reinforcement. Provision is made to allow the reduction of concrete cover when stainless reinforcing steel is used, but not the other factors of cement type and w/c ratio, and is not included in the tables. The durability tables in BS EN 206 therefore specify the measures to be taken to prevent the initiation of corrosion of carbon steel reinforcement as opposed to the relaxed allowance of cement type, w/c ratio and concrete cover if stainless reinforcing steel is used.

Both BS 6744 and the French stainless reinforcing steel rebar standard, XP A 35-014, contain guidance tables on stainless alloy designation choice for given exposure conditions. Highways England also has an advice note [6] with guidance on alloy selection and where to use stainless reinforcing steel within the structure. However, neither of these documents indicate the actual exposure, e.g. chloride concentration, that the alloy needs to resist. Table B.1 reflects best prescriptive advice available without taking a full performance route.

## B.4 Performance guidance

### B.4.1 General

Performance durability design methods are given in the fib *Model Code for Service Design Life* [5] for both carbonation-induced corrosion and chloride-induced corrosion. In both cases the methods replace the prescriptive guidance given in EC2.

### B.4.2 Performance guidance for carbonation induced corrosion.

As an example, Concrete Society Technical Report 61 (CS TR61) [7] carries a spreadsheet tool named CARBUFF [2)] to aid the calculation of carbonation. If the concrete is deemed to be carbonated at rebar depth at design life then stainless reinforcing steel rebar is a replacement option.

*NOTE With performance-based design methods, the designer is being guided only to replace the carbon steel rebar where it will be affected by the corrosion mechanism in the structure and not all of the reinforcement. As per Table B.1, any stainless reinforcing steel alloy in BS EN 10088 can be used as stainless reinforcing steel and will not corrode in carbonated concrete in the absence of any other aggressive elements.*

2) This information is given for the convenience of users of this standard and does not constitute an endorsement by BSI of this product.

Table B.1 **Prescriptive guidance advice**

| **Level class** | **Exposure conditions** | **Risk** | **Advice** | **Recommended steel designation** |
|---|---|---|---|---|
| CR I | Very long-life structures not exposed to chlorides.<br>Described as XC conditions in EC2 but outside the time scope of the advice. | Carbonation of the concrete is almost certain and corrosion will be initiated on the carbon steel reinforcement. | The chromium rich oxide covering on stainless reinforcing steel ensures passivity of the reinforcement without any other aggressive elements. | Any stainless reinforcing steel designation in BS EN 10088 (all parts). |
| CR II<br>(levels defined by numbers correspondent to chloride content) | Exposure to chlorides from de-icing salts or marine conditions.<br>Described as XD and XS conditions respectively in EC2. | 1) an intended working life of greater than 60 years is required; and/or<br>2) the chloride exposure conditions are significantly more severe than those covered within codes and standards; and/or<br>3) the consequences of reinforcement corrosion are high; and/or<br>4) conditions for construction and/or maintenance are particularly difficult. | | If a performance method is appropriate to calculate the required corrosion resistance for a given chloride concentration at rebar depth and design life, specify an alloy with a required minimum $Cl_{test}$% by mass of cement and refer to manufacturer's certification. [A)] |
| CR III | The reinforcement is designed to be partly exposed to chloride attack, e.g. exposed bars in roads subject to de-icing salts or marine structures. | Rapid corrosion of the reinforcing bar at the exposed section and loss of cross-sectional area, causing structural failure. | | Use a highly alloyed stainless reinforcing steel designation: 1.4501<br>1.4529<br>*NOTE Specialist advice should be obtained.* |

[A)] In the fib Model Code [5], carbon steel reinforcement in structures exposed to the atmosphere is often assumed to have a minimum CCTL value of 0.2% chlorides by mass of cement.

### B.4.3 Performance guidance for chloride-induced corrosion

The transport mechanisms for chloride ingress into the reinforced structure are capillary, diffusion, wick and permeation. This subclause only deals with diffusion caused by chloride concentration gradient between the notional surface chloride content and that at rebar depth. Allowances are made in some models for the first transport method of capillary action which creates the notional surface chloride concentration, but the available models generally deal with chloride ingress by diffusion and use a Fick's Second law solution to predict chloride concentration at reinforcement depth at design life. These commercially available models, known as "predictive models", have been in widespread use for some time now to specify durability for the reasons stated in Table B.1 (see Figure B.1 for an example). Two examples of models are Life-365 [3)] (First version 2000 second in 2008) [8] and AGEDDCA[3)] from CS TR61 (2004) [7]. Both models produce a chloride content at depth and design life prediction for a given cement type, w/c ratio and a known notional surface chloride content. CS TR61 (2004) [7] refers to diffusion coefficients collected on real concretes in service and calculates an ageing factor for the concrete. There is an important difference between the two models as Life 365 [8] ceases the aging factor of the concrete at 25 years, whereas AGEDDCA continues using it for the design life of the structure which gives a very different answer.

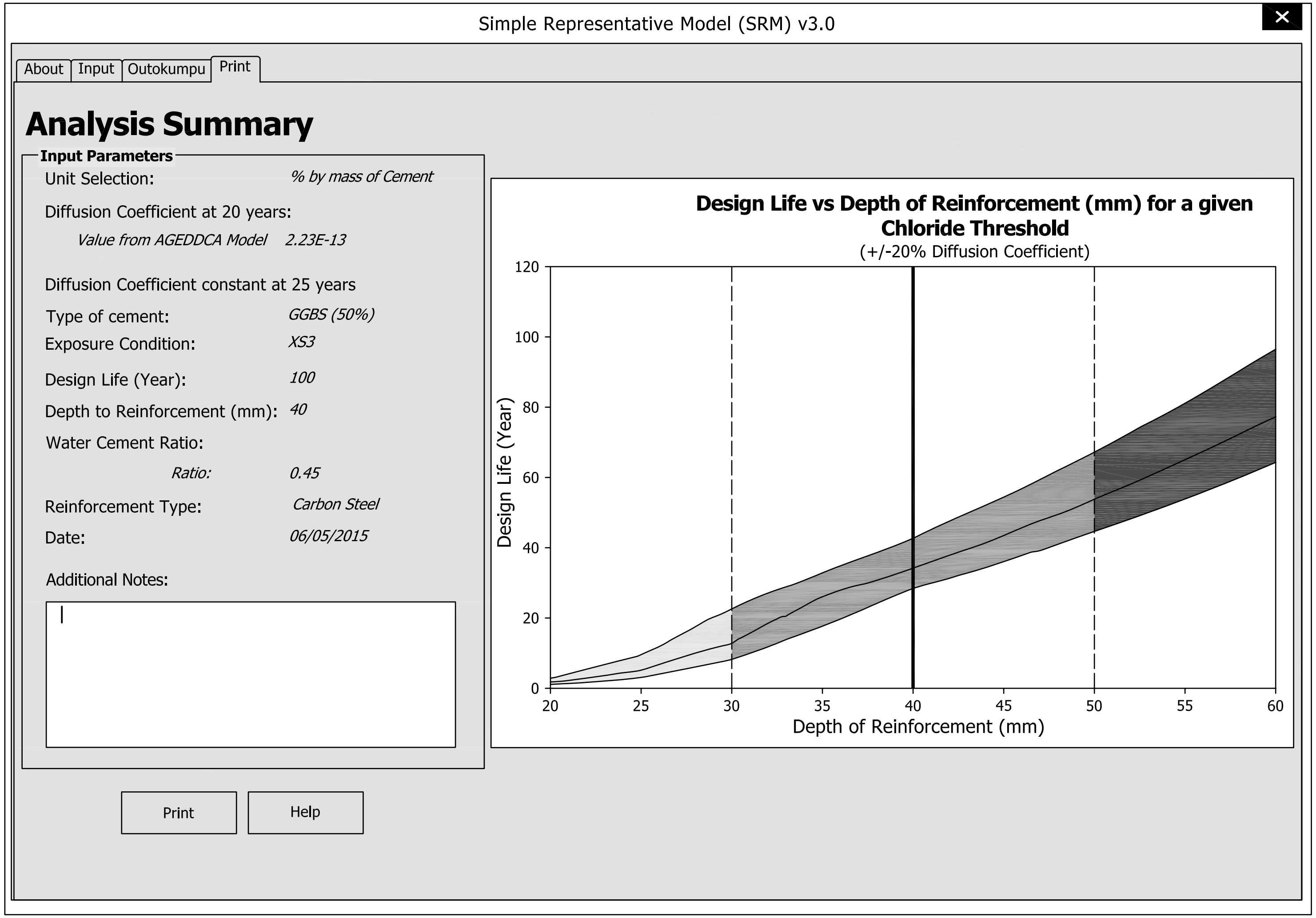
The fib Model Code [5] method requires the designer to have an average diffusion coefficient for the life of the structure. It is outside the scope of this standard to give advice on the use of these models, but Annex A gives a test method to verify the corrosion resistance of a manufacturer-produced stainless reinforcing steel alloy to a pre-fixed $Cl_{test}$%.

### B.4.4 Performance guidance for chloride induced corrosion in carbonated concrete

The corrosion resistance of both carbon steel and stainless reinforcing steel is highly influenced by the pH of the concrete and is lowered in carbonated concrete. However, as the transport mechanisms of carbon dioxide and chlorides need opposite conditions, this is unlikely to happen. The test method in Annex A therefore only considers non-carbonated concrete conditions. It should be noted that BS EN 1993-1-4:2006+A1:2015, *Supplementary rules for stainless steels*, gives corrosion and material selection guidance in Annex A "Selection of materials and durability", which should not be applied to the use of stainless reinforcing steel bar in concrete, as it is only for atmospheric corrosion resistance and not for corrosion resistance in high pH environments.

3) This information is given for the convenience of users of this standard and does not constitute an endorsement by BSI of this product.

Figure B.1 **Example predictive model indicating where carbon steel reinforcement can be replaced by stainless steel reinforcement for a given chloride surface content, design life and reinforcement depth**




SOURCE: *Stainless Steel Reinforcement: The use of predictive models in specifying selective use of stainless steel reinforcement* [9].

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## B.5 Adaptations and limitations

The fib Model Code [5] also takes into consideration capillary action, by introducing a convective zone and shifting the chloride profile.

The fib model requires a diffusion coefficient to be measured using a standardized laboratory test.

Conversely, it does not provide any test for the chloride threshold:

a) test methods and corrective factors are proposed to model the chloride penetration;

b) test methods are not proposed for chloride threshold;

c) an evaluation is required for the chloride threshold in the case of stainless reinforcing steel rebar;

d) the proposed procedure allows comparison of the behaviour of different types of stainless reinforcing steel by means of $Cl_{test}$%; and

e) by using specific corrective factors (which are outside the scope of this British Standard) to take into account the role of factors described here, $Cl_{test}$% can be converted in $Cl_{field}$%.

In principle it could be possible to find appropriate corrective parameters to adapt the measured value of $Cl_{test}$% in order to estimate a value for the chloride threshold to be used in performance-based design models. This should take into account:

1) the actual concrete characteristics, e.g. the type of binder (which influences, for instance, the pH of the pore solution and chloride binding), w/c ratio, compaction and curing;

2) the environmental conditions of exposure, with regard to temperature (increase in temperature decreases the chloride threshold) and moisture (moisture of concrete determines the electrochemical potential of steel and thus the chloride threshold);

3) possible carbonation associated with chloride penetration (when concrete carbonates at the depth of the bars, the chloride threshold decreases); and

4) the actual surface condition of the stainless reinforcing steel used at the construction site (if different from that of the tested bars).

Presently, it is not possible to define such corrective parameters and further research is required. The test procedure in Annex A could also be used as a quality control procedure, e.g. in order to assess that the stainless reinforcing steel delivered at the construction site conforms to the $Cl_{test}$% considered in the design stage.

# Annex C (informative) Guidance on magnetic properties

Austenitic stainless reinforcing steels are generally considered to be non-magnetic in the hot rolled condition. However, after cold working some magnetic permeability will be evident. Conversely, austenitic-ferritic (Duplex) stainless reinforcing steels (1.4162, 1.4362, 1.4462 and 1.4501) are considered to be magnetic.

Relative magnetic permeability, $\mu_r$, is defined as the ratio of the magnetic flux density produced in the material relative to that produced in free space by the same magnetizing force. Therefore, the lowest achievable relative magnetic permeability is 1.

The relative magnetic permeability for stainless reinforcing steel decreases in the designation in the order 1.4301 > 1.4311 > 1.4404 > 1.4429 > 1.4529. However, as noted earlier, the magnetic permeability is directly affected by the manufacturing route. Therefore, where low magnetic permeability is of importance ($\mu_r \approx 1.005$), the purchaser should agree the specific supply condition and chemical composition with the manufacturer at the time of order.

## Annex D (informative) Guidance on coefficients of thermal expansion

The coefficient of thermal expansion of austenitic stainless reinforcing steels is greater than that of either carbon steel reinforcement or concrete. Table D.1 provides comparative thermal coefficient of expansion data.

Table D.1 **Comparative thermal coefficient of expansion data**

| British Standard steel designation | Coefficient of thermal expansion × $10^{-6}$ (20 °C to 100 °C) |
|---|---|
| BS 4449, grade 500 (carbon steel) | 12 |
| 1.4162 | 13 |
| 1.4362 | 13 |
| 1.4462 | 13 |
| 1.4301 | 16 |
| 1.4404 | 16 |
| 1.4311 | 16 |
| 1.4429 | 16 |

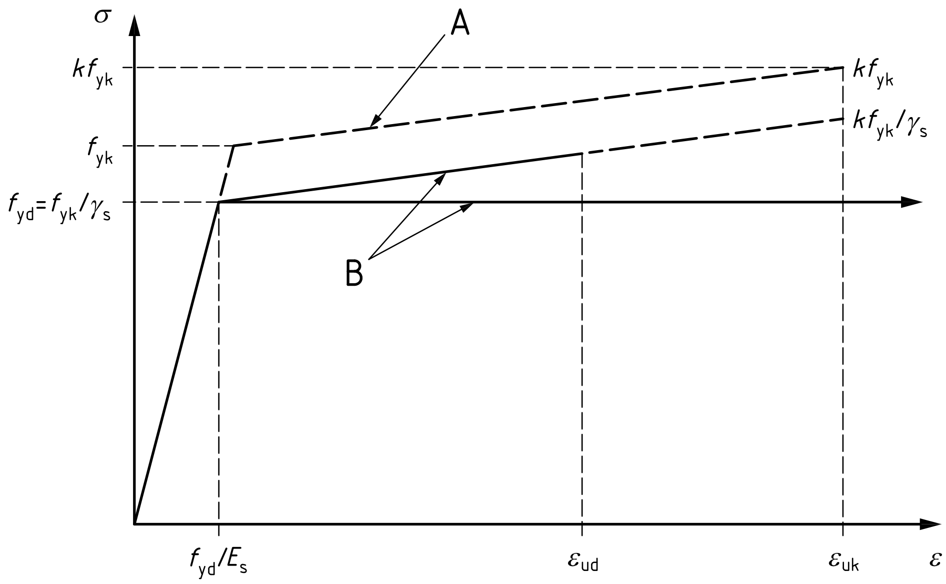
## Annex E (normative) Design guidance: constitutive relationship

### E.1 Background

The idealized stress, the strain curve shown in Figure E.1 from BS EN 1992-1-1:2004+A1:2014 (Figure 3.8), which uses a Young's modulus ($E_s$) of 200 GPa, might not always be applicable in some design applications of stainless reinforcing steel because of a different constitutive relationship to that of carbon steel.

Figure E.1 **Idealized design curve from BS EN 1992-1-1:2004+A1:2014**




**Key**

*A* Idealized

*B* Design

*k* $(f_t/f_y)_k$

EC2 gives the Young's modulus of carbon steel reinforcement as 200 GPa.

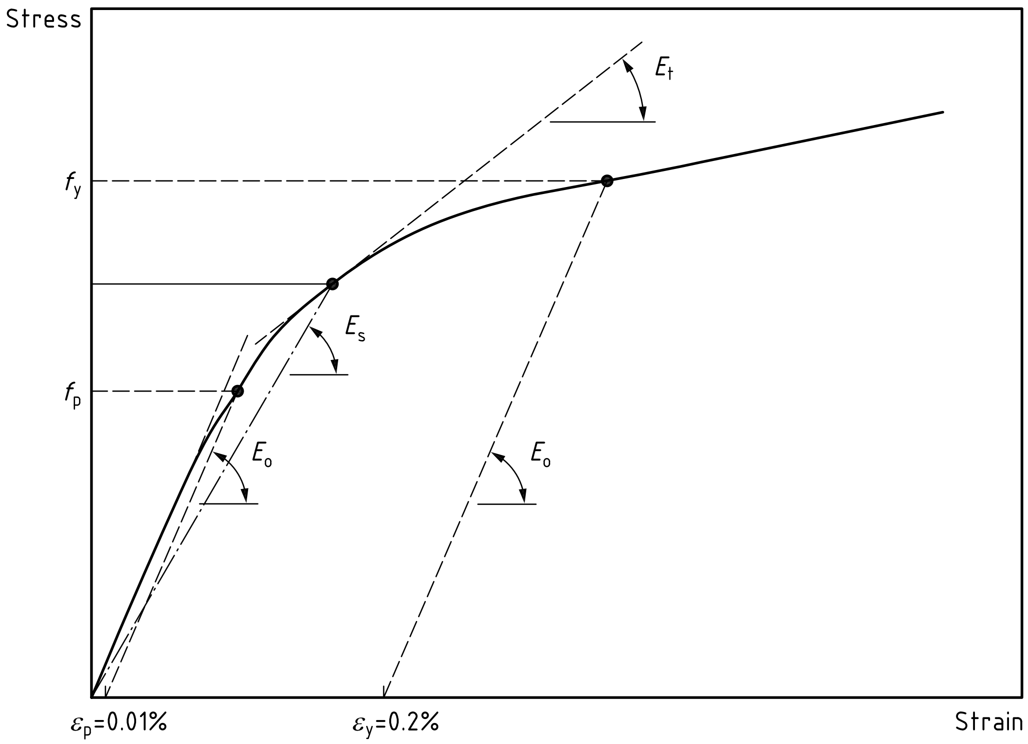
BS EN 10088 (all parts) gives different values for different designations of stainless reinforcing steel (Table E.1).

Table E.1 **Young's modulus for stainless reinforcing steel**

| Stainless family | Young's modulus |
|---|---|
| Austenitic-ferritic corrosion resistant stainless reinforcing steels | 200 GPa |
| Austenitic corrosion resistant stainless reinforcing steels | 190 to 200 GPa |

EC3 (BS EN 1993) gives calculations based on the secant modulus of the stainless reinforcing steel, $E_s$, as shown in Figure E.2.

Figure E.2 **The constitutive law of stainless reinforcing steel**




**Key**

$E_o$ is the initial modulus of elasticity

$E_t$ is the tangent modulus

$E_s$ is the secant modulus

$f_y$ is the yield strength = 0.2% proof strength

$f_p$ is the proportional limit

## E.2 Steps for using the full properties of higher strength and ductility of stainless reinforcing steel

When using the full properties of higher strength and ductility of stainless reinforcing steel the following steps should be taken.

a) Use the Ramberg-Osgood expression for the constitutive law of stainless reinforcing steel formula as follows:

$$\varepsilon = \frac{\sigma_0}{E_0} + \alpha_{\text{R-O}} \frac{\sigma_0}{E_0} \left( \frac{\sigma}{\sigma_0} \right)^n$$

where:

$\varepsilon$ is the modelled strain (%);

$\sigma_0$ is a fitting parameter resembling $R_{p0.2}$;

$E_0$ is a fitting parameter resembling elastic modulus;

$\alpha_{\text{R-O}}$ is a fittting parameter, where $\alpha_{\text{R-O}} \approx (0.002 \times E_0)/\sigma_0$ for stainless reinforcing steel;

$\sigma$ is the modelled stress in megapascals (MPa);

$n$ is a fitting parameter related to the strain hardening.

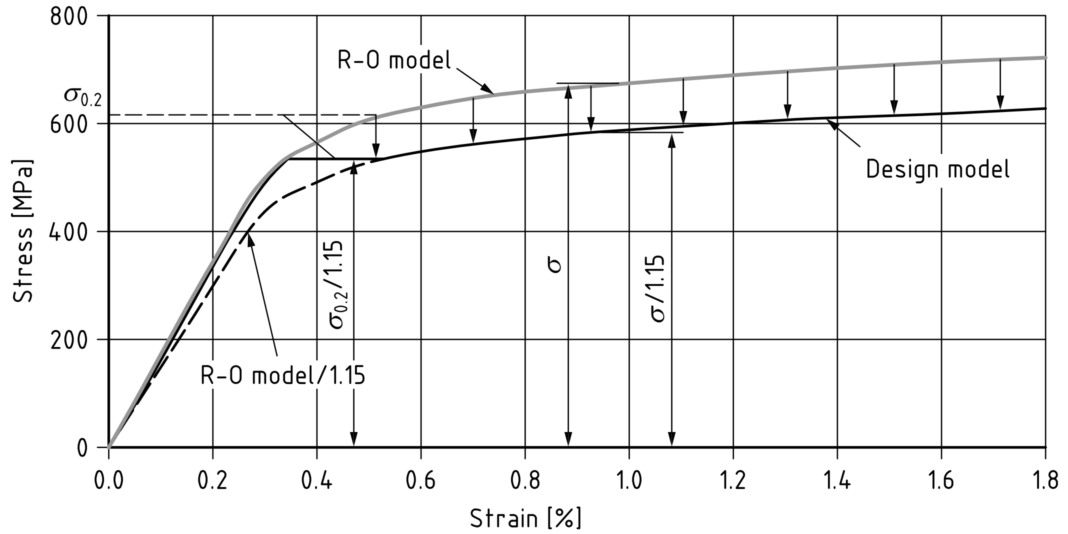
 

b) Use Ramberg-Osgood parameters $E_0$, $\alpha_{R\text{-}O}$, $\sigma_0$ and $n$ from measured curves available from the manufacturer.

*NOTE These values should be specific and from the finished product identified as having been hot rolled or cold rolled as cold working will affect the values. The values should be obtained from the manufacturer. The values in EC3 are not applicable.*

c) Determine the design curve from the measured values in accordance with the example in Figure E.3.

Figure E.3 **Example of design model for stainless reinforcing steel**




**Annex F (informative)**

# Guidance on welding

## F.1 Austenitic stainless reinforcing steel

The austenitic stainless reinforcing steels listed in Table 5, 1.4311, 1.4404 and 1.4429, can be welded with all methods normally used for welding stainless reinforcing steels and are not sensitive to cracking or grain growth during welding.

If the welding is carried out with filler material, austenitic stainless reinforcing steel with a corresponding designed matching composition should be used.

## F.2 Duplex stainless reinforcing steel

The austenitic-ferritic stainless reinforcing steels listed in Table 5, 1.4162 and 1.4362, have good weldability. Welding with fillers, with a composition specifically designed for these stainless reinforcing steels, leads to higher ductility in the weld metal compared to autogenous welding. High ferrite in the weld metal is the reason for the reduction in ductility for these autogenous welds.

## F.3 Welding stainless reinforcing steels to carbon steels

The best result when joining stainless reinforcing steels to carbon steels is obtained when over-alloyed fillers such as 23Cr12Ni are used.

### F.4 Handling and processing

When handling stainless reinforcing steel bars it is advisable to avoid direct contact with carbon steel. Stainless reinforcing steel bars should not be stacked together with carbon steel bars. To restore the corrosion resistance after welding, or contamination after contact with carbon steel, the stainless reinforcing steel should be cleaned before use to remove welding slag, spatter, weld tint (weld oxides) and contamination from carbon steel. Recommended methods include brushing with a stainless steel brush, shot blasting, hot water pressure cleaning and/or chemical pickling. When considering chemical cleaning, local safety regulations need to be followed.

Stainless reinforcing steel in the descaled condition should be straightened, cut and bent, and processed in any other way on equipment used solely for the processing of stainless reinforcing steel in order to avoid embedded contamination.

## Annex G (normative) Performance at elevated temperatures

For N values for performance retention at elevated temperatures the relevant designation shall be selected from BS EN 1993-1-2:2005, Table C.1.

## Annex H (informative) Quality assurance

### H.1 Long-term quality

#### H.1.1 Consistency of production

To determine the production consistency of the manufacturer, the long-term quality level should be regularly assessed. However, no conclusion regarding product conformity to this British Standard can be made on the basis of this assessment.

#### H.1.2 Determination of the long-term quality level

##### H.1.2.1 Extent of testing

The 0.2% proof stress results obtained on all casts for each size should be collated every six months. The results should be used to determine the long-term quality level.

##### H.1.2.2 Evaluation

The average proof stress, *m*, should satisfy the following:

$$m \geq c_v - k\sigma$$

where:

$c_v$ is the characteristic yield strength, in megapascals (MPa);

$k$ is the acceptability index (see Table H.1); and

$\sigma$ is the standard deviation of the population.

Table H.1 **Acceptability index, *k*, as a function of the number of test results, *n*, for a reliable failure rate of 5% (pass = 0.95) at a probability of 90% (1 – α = 0.90)**

| *n* | *k* | *n* | *k* |
|---|---|---|---|
| 5 | 3.40 | 30 | 2.08 |
| 6 | 3.09 | 40 | 2.01 |
| 7 | 2.89 | 50 | 1.97 |
| 8 | 2.75 | 60 | 1.93 |
| 9 | 2.65 | 70 | 1.90 |
| 10 | 2.57 | 80 | 1.89 |
| 11 | 2.50 | 90 | 1.87 |
| 12 | 2.45 | 100 | 1.86 |
| 13 | 2.40 | 150 | 1.82 |
| 14 | 2.36 | 200 | 1.79 |
| 15 | 2.33 | 250 | 1.78 |
| 16 | 2.30 | 300 | 1.77 |
| 17 | 2.27 | 400 | 1.75 |
| 18 | 2.25 | 500 | 1.74 |
| 19 | 2.23 | 1 000 | 1.71 |
| 20 | 2.21 | ∞ | 1.64 |

## H.2 Acceptance testing

### H.2.1 General

The production consistency of the manufacturer, and the long-term quality level, may be determined by more extensive acceptance testing on each batch. Sampling should be carried out at the manufacturer's works or in the stockholder's storage facility. Testing should be carried out at a suitably certified laboratory.

### H.2.2 Extent of sampling and testing

For a product which is not subject to continuous third-party approval the following process should apply.

For testing purposes, the batch should be divided into test units, each with a maximum mass of 10 t. Each test unit should comprise products of the same reinforcing steel grade and nominal diameter from the same batch. The manufacturer should certify that all products in the test unit originate from the same batch.

Test samples should be taken from each test unit as follows:

a) 15 samples or (if appropriate) 60 samples (see **H.2.4**) from different bars, for testing in accordance with **H.2.3**a) and **H.2.3**b);

b) two test samples from different bars, for testing in accordance with **H.2.3**c).

The test samples should be prepared in accordance with BS EN ISO 15630-1.

### H.2.3 Properties to be tested

Samples selected in accordance with **H.2.2** should be tested for the following:

a) inspection by variables:

1) tensile strength $R_m$;

2) 0.2% proof stress $R_{p0.2}$;

3) percentage total elongation at maximum force, $A_{gt}$;

b) inspection by attributes:
   1) deviations from the nominal cross section;
   2) surface geometry;
   3) bend test;
c) chemical composition according to product analysis of all elements listed in Clause **9** to be analysed;
d) fatigue properties: for ribbed stainless reinforcing steel bars, the fatigue properties should be determined for each size and defined bar shape in the batch.

The test procedures should be as described in BS EN ISO 15630-1.

## H.2.4 Evaluation of results

### H.2.4.1 Inspection by variables

Inspection by variables should be carried out as follows.

a) The following should be determined for the characteristic value when testing for the properties listed in **H.2.3**a):
   1) all individual values for characteristic value, $C_v$, for the 15 test samples;
   2) the mean value of 15 test results for the characteristic strength, $m_{15}$;
   3) the standard deviation of 15 test results, $S_{15}$.

   The test unit can be deemed to conform to this British Standard if all individual values of $R_m/R_{p0.2}$, the elongation after fracture, $A$, and percentage total elongation at maximum load, $A_{gt}$, exceed the values in Table 8 and the following condition is fulfilled by the characteristic strength, but see also b):

   $$m_{15} - (2.33 \times S_{15}) \geq C_v$$

b) If the condition for the characteristic strength given in a) is not fulfilled, a secondary calculation (the acceptability index $k$) should be made, where:

   $$k = \frac{m_{15} - c_v}{S_{15}}$$

   If $k \geq 2$, testing should continue. 45 further test samples should be taken and tested from different bars in the test unit, so that 60 test results are available.

   The test unit can be deemed to conform to this British Standard if all individual values of $R_m/R_{p0.2}$, the elongation after fracture, $A$, and percentage total elongation at maximum load, $A_{gt}$, exceed the values in Table 8 and the following condition is fulfilled by the characteristic yield strength (1.93 is the value for the acceptability index, $k$, for 60 test results in accordance with Table H.1):

   $$m_{60} - (1.93 \times S_{60}) \geq C_v$$

#### H.2.4.2 Inspection by attributes

Inspection by attributes should be carried out as follows. When testing for the properties listed in **H.2.3**b), either:

a) all the results determined on the 15 test samples should conform to this British Standard; or

b) if a maximum of two of the 15 results do not conform to this British Standard, 45 further test samples should be taken and tested from different bars in the test unit, making 60 results available.

   The unit can be deemed to conform to this British Standard if not more than two of the 60 test samples fail the test.

### H.3 Corrosion testing

**H.3.1** Following initial type testing, the treatment conditions to achieve the corrosion resistance obtained should be incorporated in the procedures manual and become part of the quality assurance scheme.

**H.3.2** Testing thereafter should be every 500 t or annually, whichever occurs first.

## Annex I (informative) High-strength bars

Products in previous editions of BS 6744 that did not conform to BS EN 104031, currently in preparation, or the current editions of BS 4449 and EC2 have been removed, with the exception of strength grade 500 MPa bar which is included in Highways England's specification [4] or as specified by the specifier to BS EN 10088.

BS 6744:2001+A2:2009 included ribbed bar to Grade 650 MPa which has been deleted from this revision as this is outside the scope of BS EN 1992-1-1:2004+A1:2014 and its UK National Annex. However, stainless steel reinforcement can offer higher strength than 500 MPa provided the designer recognizes the constitutive relationship. This risk is dealt with in Annex E.

If the designer specifies a strength grade outside of Table 8 then all the other requirements of this standard are applicable to the material with the exception of Table 8.

# Bibliography


**Standards publications**

For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS 4449, *Steel for the reinforcement of concrete – Weldable reinforcing steel – Bar, coil and decoiled product – Specification*

BS EN 197-1, *Cement – Part 1: Composition, specifications and conformity criteria for common cements*

BS EN 206, *Concrete – Specification, performance, production and conformity*

BS EN 206-1, *Concrete – Part 1: Specification, performance, production and conformity* [4)]

BS EN 480-14, *Admixtures for concrete, mortar and grout – Test methods – Part 14: Determination of the effect on corrosion susceptibility of reinforcing steel by potentiostatic electro-chemical test*

BS EN 1992-1-1:2004+A1:2014, *Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings*

BS EN 1992-1-2, *Eurocode 2: Design of concrete structures – Part 1-2: General rules – Structural fire design*

BS EN 1993, *Eurocode 3: Design of steel structures*

BS EN 1993-1-4:2006+A1:2015, *Eurocode 3: Design of steel structures – Part 1.4: General rules – Supplementary rules for stainless steels*

BS EN 10080, *Steel for the reinforcement of concrete – Weldable reinforcing steel – General*

BS EN 104031, *Steel for the reinforcement of concrete – Stainless steels* [5)]

BS EN ISO/IEC 17065, *Conformity assessment – Requirements for bodies certifying products, processes and services*

NA to BS EN 1992-1-2:2004, *UK National Annex to Eurocode 2 – Design of concrete structures – Part 1-2: General rules – Structural fire design*

XP A 35-014, *Reinforcing steels – Stainless steel bars, wire rod and wire*

**Other publications**

[1] EUROPEAN COMMUNITIES. Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC. OJ L 88, 4.4.2011, p. 5–43. Luxembourg: Office for Official Publications of the European Communities.

[2] EUROCORR. *Adaption of EN 480-14:2006 as a test method for determining a critical chloride threshold level for stainless steel rebar*. M. Schönning, S. Randström and M. Adair. EUROCORR.

[3] EUROCORR. *Testing for chloride threshold levels of stainless reinforcing bar*. S. Randström, M. Adair and M. Schönning. *18th International Corrosion Congress 2011 Paper 250*. EUROCORR


4) Withdrawn.

5) In preparation.

[4] HIGHWAYS ENGLAND. *Manual of Contract Documents for Highway Works. Volume 1: Specification for highway works.* [6)]

[5] INTERNATION FEDERATION FOR STRUCTURAL CONCRETE (fib). fib Bulletin No. 34: *Model Code for Service Life Design*. Lausanne: fib, 2006.

[6] HIGHWAYS ENGLAND, SCOTTISH EXECUTIVE DEVELOPMENT DEPARTMENT, THE NATIONAL ASSEMBLY FOR WALES and THE DEPARTMENT FOR REGIONAL DEVELOPMENT NORTHERN IRELAND. *Design Manual for Roads and Bridges.* Interim Advice Note IAN 124/11, *Use of Eurocodes for the design of highway structures*, 2011. [7)]

[7] CONCRETE SOCIETY. Technical Report 61: *Enhancing reinforced concrete durability: Guidance on selecting measures for minimising the risk of corrosion of reinforcement in concrete*. Camberley: Concrete Society, 2004.

[8] Life 365 Service Life Prediction Model™ (Version 1 2000; Version 2 2008).

[9] ARUP MATERIALS CONSULTING. *Stainless Steel Reinforcement: The use of predictive models in specifying selective use of stainless steel reinforcement*. London: Ove Arup & Partners Ltd, 2009.

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6) http://www.standardsforhighways.co.uk/ha/standards/mchw/vol1/pdfs/series_1700.pdf [Last accessed: 20 April 2016].

7) http://www.standardsforhighways.co.uk/ha/standards/ians/pdfs/ian124.pdf [Last accessed: 20 April 2016].

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