Stainless Reinforcing Steels

1.0 Introduction

In normal atmospheric exposure conditions, with adequate concrete cover and appropriate detailing, corrosion of reinforcing steel in concrete is not a problem; the concrete provides a protective environment for the reinforcing steel. In certain aggressive environments, or where inadequate cover is provided, corrosion of reinforcing steels can occur, with effects that have been well documented. The problems of maintenance and replacement of corrosion-affected structures are thought to account for a multi-billion dollar problem world-wide.

One solution is to use stainless reinforcing steels, which are inherently resistant to corrosion. Stainless reinforcing steels have the potential to:

- Allow relaxation in design for durability criteria normally used for carbon steel reinforced structures.
- Significantly decrease the inspection and maintenance cost of structures at risk of reinforcement corrosion.
- Extend the design life of structures at risk of reinforcement corrosion.

All of this can lead to cost saving when the whole-life cost of a structure is considered, despite the cost of stainless compared to carbon steel reinforcement.

The use of stainless steel reinforcement is growing significantly in certain parts of the world, notably the Middle East, the Far East, and North America. Although the use of stainless reinforcing steel is at relatively modest levels within the UK, recent reports have demonstrated the potential economic benefits of stainless reinforcing steels when whole life costs are considered. This is leading to growing acceptance. Recent examples of the use of stainless reinforcing steels, both in the UK and worldwide, have been reported, and the use of stainless reinforcement is expected to increase (**Figure 1**).

Stainless Reinforcing Steel in a Nuclear Waste Tank in France

Figure 1 Courtesy of Valbruna UK Ltd

As a response to the market requirement for stainless reinforcing steels, CARES has extended its product certification scheme for reinforcing steels, to cover the particular requirements of this product. The aim is to provide purchasers of CARES approved stainless reinforcing steels with the same level of confidence in specification and purchasing, as has become the established norm in the UK for carbon steel reinforcement.

In the UK, stainless reinforcing steels are specified to BS 6744:2001. The 2001 revision introduced new steel types and grades, and has been aligned as far as possible with the carbon steel standard BS 4449:1997. This standard is the basis of the CARES scheme for stainless reinforcing steels.

2.0 Corrosion of reinforcing steel in concrete

Carbon reinforcing steel is generally passive in terms of corrosion behaviour at the pH levels normally found within concrete (pH = 13). However, corrosion can be accelerated by a number of different chemical processes in certain environmental conditions. The most commonly cited causes of corrosion of reinforcing steel in concrete are:

a) Carbonation of the concrete due to atmospheric attack. The absorption of water and carbon dioxide from the atmosphere into concrete, can cause a lowering of the pH, due to the formation of carbonic acid. Once the pH is sufficiently reduced, corrosion of the reinforcement can occur.

b) Ingress of chloride ions into the concrete. When chloride ions reach a certain threshold level at the steel surface, passivity is broken down, and corrosion of the reinforcing steel proceeds.

Carbonation is normally controlled by the correct provision of concrete cover.

Structures most at risk of chloride attack are those exposed to marine environments or de-icing salts, particularly those parts of the structure experiencing wetting and drying cycles. These may be marine structures exposed to wetting and drying (for example in the inter-tidal or splash zones), or in highway structures or car parks exposed to road de-icing salts.

Stainless steels are generally defined as those having a minimum of 12% chromium present as an alloying constituent. The presence of chromium results in a thin layer of stable chromium oxide forming on the surface of the steel. The oxide layer is passive, and highly resistant to atmospheric corrosion. Moreover, the oxide layer is instantaneously self-healing in oxidising conditions, so that cracks, defects or surface damage do not affect corrosion resistance. Stainless steels retain passivity in concrete at low pH levels, and high chloride concentrations, hence their use in structures at risk of chloride induced corrosion (**Figure 2**).

The Highways Agency's Design Manual For Roads and Bridges document, BA 84/02, provides guidance on the use of stainless reinforcement. This states:

"Correctly specified stainless steel reinforcement should prevent chloride attack for the full design life of any structure."

Passivity of carbon and stainless reinforcing steel grades in chloride contaminated concrete

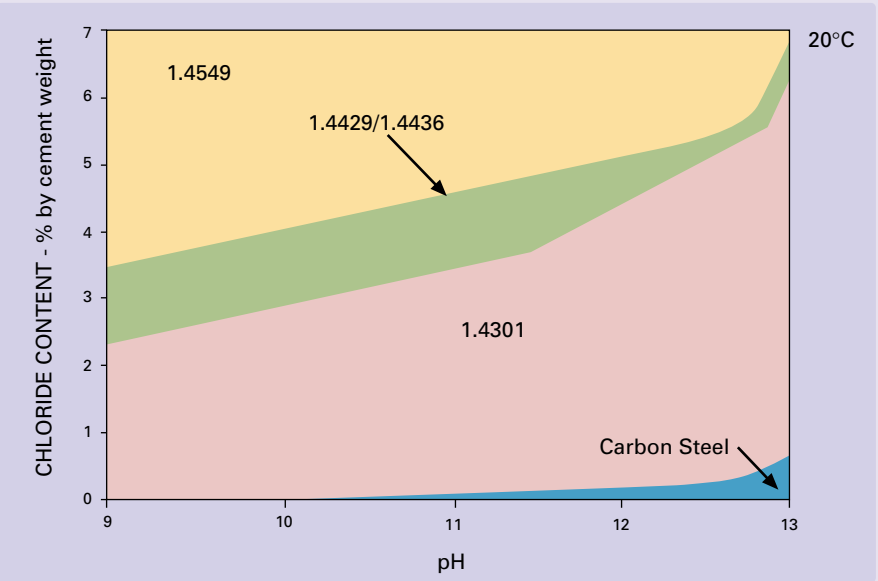

Figure 2

3.0 Stainless reinforcing steels

Within the broad definition of stainless steels, there are many different types available. BS EN 10088-3 lists more than 60 different available alloy compositions. The different steels are grouped by type, according to their metallurgical structure; austenitic, ferritic, martensitic or duplex. Most stainless reinforcing steels are austenitic, with some duplex steels also being used; ferritic and martensitic steels are not normally used for reinforcing applications.

BS 6744:2001 includes six stainless steel designations from BS EN 10088-3, of varying chemical analysis, and corrosion resistance characteristics (**Table 1**).

These steels are austenitic, except for 1.4462 and 1.4501, which are both duplex steels.

Table 1

Stainless steel bar chemical composition (cast analysis) % by mass (from BS 6744:2001)

BS EN 10088-1 Steel Designation	C (max)	Si (max)	Mn (max)	S (max)	Cr (min/max)	Ni (min/max)	Mo (min/max)	P (max)	N (max)
1.4301[a]	0.07	1.0	2.0	0.03	17.0/19.5	8.0/10.5	-	0.045	≤ 0.11
1.4436[a]	0.05	1.0	2.0	0.015	16.5/18.5	10.5/13.0	2.5/3.0	0.045	≤ 0.11
1.4429	0.03	1.0	2.0	0.015	16.5/18.5	11.0/14.0	2.5/3.0	0.045	0.12/0.22
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
1.4501[b]	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[b]	0.02	0.50	1.0	0.010	19.0/21.0	24.0/26.0	6.0/7.0	0.03	0.15/0.25

[a]Nitrogen content of these steels may be increased to 0.22% max.
[b]These designations are available on request but are only required for special applications.

Tensile properties of BS 6744:2001 grades

Grade	0.2% Proof Stress, $R_{p0.2}$ MPa	Stress ratio, $R_m/R_{p0.2}$ (min) (%)	Elongation at fracture, A_5 (min)	Total elongation at maximum force, A_{gt} (min) (%)
200	200	1.10	22	5
500	500	1.10	14	5
650	650	1.10	14	5

Table 2

The most widely used stainless reinforcing steels are 1.4301, 1.4436 and increasingly 1.4462. Steel 1.4301 is a basic austenitic steel, whilst 1.4436 is also austenitic, but with a minimum 2.5% molybdenum addition, for enhanced resistance to pitting corrosion. Steel 1.4462 is a duplex type. Steel 1.4429 is commonly used in North America, but less frequently in Europe. It has high corrosion resistance, and provides superior mechanical properties in large bar sizes. The other two steels in BS 6744 are used for special, highly corrosive applications.

4.0 Manufacturing process routes for stainless reinforcing steels

Most stainless steels are made by the electric arc process. This is followed by a secondary refining process, either AOD (Argon Oxygen Decarburising) or VOD (Vacuum Oxygen Decarburising). Steels are continuously cast into blooms or billets, prior to hot rolling.

Stainless reinforcing steels may be hot rolled to achieve their final mechanical properties. This normally requires close control of rolling temperatures. Alternatively they may be hot rolled into coil, followed by a cold rolling operation to achieve the final profile and properties. Stainless steels are supplied in the surface cleaned condition, with rolling scale removed.

Stainless reinforcing steels can be cut, bent and processed in the same way as carbon steel, according to BS 8666 (**Figure 3**).

Bending of Stainless Reinforcing Bar

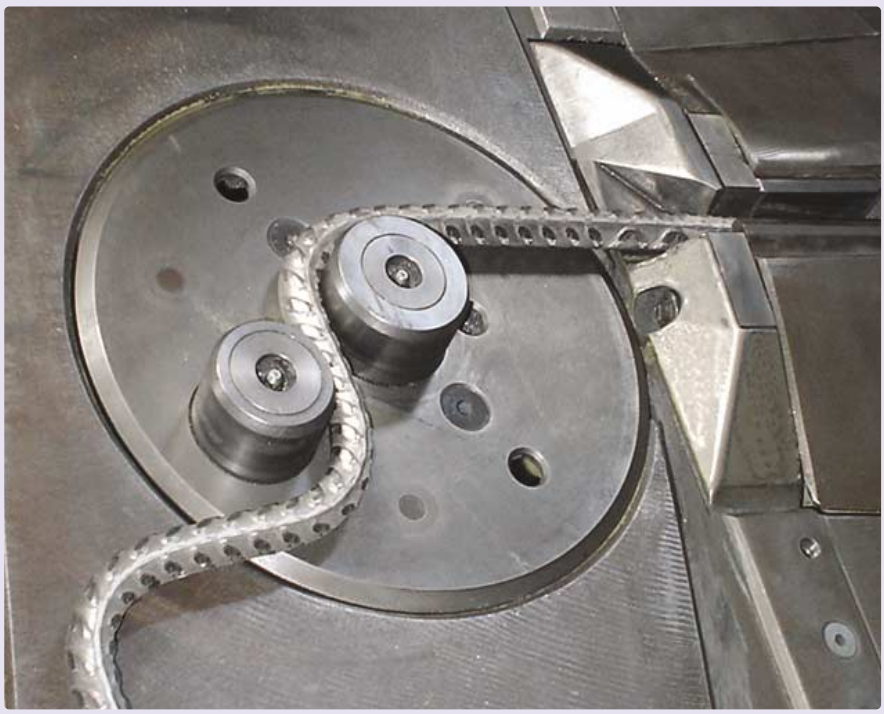

Figure 3 Courtesy of Arminox

5.0 Mechanical properties of stainless reinforcing steels

BS 6744:2001 specifies three grades with different mechanical properties. The term "grade" is often confused with alloy type. In BS 6744, "grade" refers only to the mechanical properties, and not to the chemical composition, which is determined by the steel type (designation). The three mechanical grades may be supplied in any of the steel designations. The three grades specified are given in **Table 2**.

Grade 200 is only available in the plain round section. This is used for dowel bar applications. All grades are potentially available in a ribbed profile, with bond characteristics equivalent to those for type 2 bond in carbon steel reinforcement. The range of grades and designations available in different sizes varies between manufacturers, as does the manufacturing process routes used.

It should be noted that the mechanical properties for both Grade 500 and Grade 650 would meet all of the mechanical requirements of BS 4449:1997 Grade 460B. These grades can therefore be substituted for normal carbon steel, without significant design modification.

Guidance on the use of stainless steel reinforcement for different service conditions

Grade in BS EN 10088-1	Service Condition			
	For structures or components with either a long design life, or which are inaccessible for future maintenance	For structures or components exposed to chloride contamination with no relaxation in durability design (eg concrete cover, quality or water proofing treatment requirements)	Reinforcement bridging joints, or penetrating the concrete surface, and also subject to chloride contamination (eg dowel bars or holding down bolts)	Structures subject to chloride contamination where reductions in normal durability requirements are proposed (eg reduced cover, concrete quality or omission of water proofing treatment)
1.4301	1	1	5	3
1.4436	2	2	1	1
1.4429	2	2	1	1
1.4462	2	2	1	1
1.4529	4	4	4	4
1.4501	4	4	4	4

Key

1. Appropriate choice for corrosion resistance and cost
2. Over-specification of corrosion resistance for the application
3. May be suitable in some instances; specialist advice should be obtained
4. Grade suitable for specialist applications, which should only be specified after consultation with corrosion specialists
5. Unsuitable for the application

Table 3

Stainless reinforcing steels are "non-ageing", because of their austenitic structure, and hence there is no requirement to perform a re-bend test. A bend test is included in BS 6744:2001.

The fatigue performance specified for the stainless steels in BS 6744:2001 is the same as for carbon steels in BS 4449:1997. Again this means that stainless steels can easily be substituted into fatigue designs based on carbon steel.

Apart from its corrosion resistant applications, austenitic stainless reinforcing steel can also be used in cryogenic applications, where its toughness at low temperatures is required. In certain special applications, the non-magnetic nature of austenitic stainless can also be advantageous, such as for the reinforcement of structures housing magnetic resonance equipment.

Information on stainless steel reinforcement

Figure 4 Courtesy of BSSA (see ref 16 for contact details)

6.0 Guidance on the use of stainless reinforcing steels

The Highways Agency Design Guide BA 84/02, and BS 6744:2001 both provide guidance on the appropriate specification of stainless reinforcement for particular exposure conditions. **Table 3** summarises the guidance in BS 6744.

It can be seen that for all situations quoted, the use of austenitic designations 1.4301 and 1.4436 are deemed to be adequate. The duplex steel 1.4462 can also be considered suitable in most applications, except those requiring cryogenic or non-magnetic performance.

The most significant barrier to the use of stainless reinforcing steel is the cost. For this reason, stainless steel is normally used selectively in those parts of the structure most at risk of chloride ingress. BA 84/02 provides useful guidance on where stainless reinforcement should be used. A CD ROM provided by the British Stainless Steel Association (BSSA) gives cost models of two common bridge designs using the BA 84/02 guidelines (**Figure 4**).

7.0 The CARES Scheme for manufacturers of stainless reinforcing steel

Based on its extensive experience of assessing manufacturing and fabricating operations for carbon steel reinforcement, CARES has developed a similar scheme for the stainless reinforcing steel sector. Two Quality and Operations Schedules are available, one for manufacturers of stainless reinforcement, and one for processing and supply, CPAS Appendix 16 and 6 respectively.

The schemes provide for:

- Independently verified compliance with the specified standards (BS 6744:2001 and BS 8666).
- Quality management system approval to ISO 9001:2000.
- Approval for the whole process route, from steelmaking, rolling, processing, fabricating to delivery to site.
- Full traceability throughout the supply chain.
- Removing the need for purchasers to have their own testing and inspection regime on site, saving time and cost.

Approval is gained by a manufacturer only after demonstrating that their quality systems meet the requirements of ISO 9001:2000, and the additional product-specific CARES requirements. An extensive programme of witness and independent testing also has to be passed, with independent testing being conducted by UKAS accredited laboratories to ensure integrity and competence.

Once approval has been granted, it is maintained by regular surveillance audits conducted by CARES specialist assessors. At these inspections, the system is audited, and random checks are made on product quality, by both witness and independent testing.

Approval is gained by a processor after demonstrating that their quality management system meets the requirements of ISO 9001:2000 and the product-specific CARES requirements. Regular surveillance visits include both quality system audits and verification of cutting and bending capability.

7.1 The CARES Scheme-verified compliance

The CARES scheme for stainless reinforcing steel, through its combination of auditing and independent testing throughout the supply chain, ensures compliance of stainless reinforcing steels with the specified requirements.

When using CARES approved fabricators, specifiers can be confident that all steel supplied will be from CARES approved manufacturers. The product can be used without the need for further product testing. Where CARES approved fabricators are not specified, the onus is on the purchaser to verify compliance, which may require inspection and testing involving both significant cost and potential site delays.

8.0 Specification of CARES approved stainless reinforcing steel

The May 2001 amendment of the Highways Agency specification for highway works requires stainless reinforcing steels to be purchased from a firm holding a valid CARES (or fully equivalent) certificate of approval.

Section 4 of the Highways Agency Design Guide BA 84/02 states that it is the intention to modify the "Specification for Highway Works" to ensure stainless steel reinforcement suppliers will hold a valid CARES certificate of approval.

Suggested wording for inclusion in specification documents is as follows:

"Only firms that have achieved certification to CARES Construction Products and Associated Services Scheme Appendix 6, (or equivalent) shall be permitted to bid or undertake contracts to supply stainless reinforcing steel."

Stainless reinforcing steel offers designers the possibility of producing durable structures with inherent resistance to reinforcement corrosion. The CARES scheme for stainless reinforcing steels offers purchasers the confidence that the product has been produced and tested in accordance with the specification.

9.0 References

1. "Corrosion of reinforcement in concrete construction" **Crane, Ellis Horwood 1983**

2. "Mechanisms of corrosion of steel in concrete" **B Borgard, C Warren, S Somayaji, R Heidersbach** in "Corrosion Rates of Steel in Concrete" **N S Berke, V Chaker, D Whiting eds ASTM STP 1065 1990**

3. "Guidance on the use of stainless steel reinforcement" **Concrete Society Technical Report 51, 1998**

4. "The use of stainless steel reinforcement in bridges" **Report and Cost Analysis Tool British Stainless Steel Association CD ROM, 2003**

5. "Success for stainless steel- durable reinforced concrete bridges" **Concrete March 2003 David Cochrane**

6. "Welsh engineers design durable bridges" **Concrete June 2003 Edward James**

7. **BRITISH STANDARDS INSTITUTION. BS 6744:2001** "Stainless steel bars for the reinforcement of and use in concrete-Requirements and test methods"

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

9. **UK CARES** "Construction Products and Associated Services Scheme- Appendix 16- Quality and operations assessment schedule for stainless steel bar and coil for the reinforcement of concrete including inspection and testing"

10. "Behaviour of stainless steels in concrete" Pedeferri published in "Repair and rehabilitation of reinforced structures: the state of the art." **Ed Selva Araya, W F et al American Society of Civil Engineers 1998 pp 192-206**

11. **Highways Agency Design Manual for Roads and Bridges Part 15 BA 84/02**

12. **BRITISH STANDARDS INSTITUTION. BS EN 10088-3:1995** "Stainless Steels-Part 3; Technical delivery conditions for semi-finished products, bars, rods and sections for general purposes

13. **BRITISH STANDARDS INSTITUTION. BS 8666:2000** "Specification for scheduling, dimensioning, bending and cutting of steel reinforcement for concrete

14. **UK CARES** "Construction Products and Associated Services Scheme- Appendix 6- Quality and operations assessment schedule for the processing and/or supply of stainless steel products for the reinforcement and use in concrete"

15. **HIGHWAYS AGENCY Specification** For Highway Works

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