STRUCTURAL DESIGN IN HOT-ROLLED 3CR12 SECTIONS

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Abstract

3CR12 is a corrosion resisting steel that before 2002 was only available in hot-rolled form in relatively simple shapes such as plate and rod. This paper has two aims. Firstly it briefly serves to introduce the new 3CR12 hot-rolled structural sections currently being made available in the local South African market. This is a world first and a welcome addition for the structural designer when structures are to be designed subjected to relatively aggressive corrosive environments such as found at the coast and /or wet abrasive environments or in applications where general corrosive repair is uneconomical. 3CR12 along with its history is briefly described. The second aim of the paper is to describe a current program being conducted to incorporate hot-rolled 3CR12 sections into the current South African code of practice for structural design. Structural steel design in South Africa is usually conducted according to "SABS 0162-1:1993-Limit-states design of hot-rolled steelwork". Currently 3CR12 is not incorporated into this code.

1 INTRODUCTION TO 3CR12 HOT-ROLLED STRUCTURAL SECTIONS

1.1 Introduction

3CR12 is a corrosion resisting steel containing essentially 12 % chromium. It is also specified in EN 10088 as type 1.4003 and is also certified to ASTM A240 UNS S41003. It was originally developed in the early 1980s by Middelburg Steel and Alloys (Pty) Ltd, now Columbus Stainless, as an alternative to coated carbon steels such as galvanized steel. It was developed specifically for use in applications where the steel is to be subjected to wet abrasion or corrosive environments. It is not a stainless steel and should not be regarded as an alternative to the more highly alloyed stainless steels such as AISI 304 and 316 when subjected to severe corrosive environments.
Historically, ferritic stainless and corrosion resisting steels were difficult to weld in thicknesses exceeding approximately 3 mm. This is due to grain growth and the formation of nitride and carbide precipitates at high temperatures in the heat affected zone. This then makes the welds brittle and more susceptible to corrosion than the parent material.
3CR12 was specifically developed to change this having a good weldability up to thicknesses of approximately 30 mm.

Recently Iscor Long Steel Products have started to produce a range of hot-rolled 3CR12 structural sections. Currently flat bar, channels, angles, I.P.E's, round bar and square bar are available in various sizes (see Figure 1). Typically small to medium sized sections are available. Larger sections are built-up. The products are marketed and distributed by Trident Midrand Steel. Columbus Stainless who also provides technical support in the manufacturing holds the rights of 3CR12.

Figure 1 Typical hot-rolled sections now available in 3CR12

1.2 Corrosive properties of 3CR12

The atmospheric corrosion resistance of 3CR12 is in general excellent. It is at least a few orders of magnitude better than mild steel, Corten and zinc, in most atmospheric corrosion environments (see Figure 2). The comparison shows that 3CR12 performs well even in very severe coastal environments such as Durban bluff (hot, humid and industrial coastal venue) and Walvis Bay (arid desert coastal site) in Namibia. In mild inland sites such as the CSIR near Pretoria it is comparable to stainless steels.

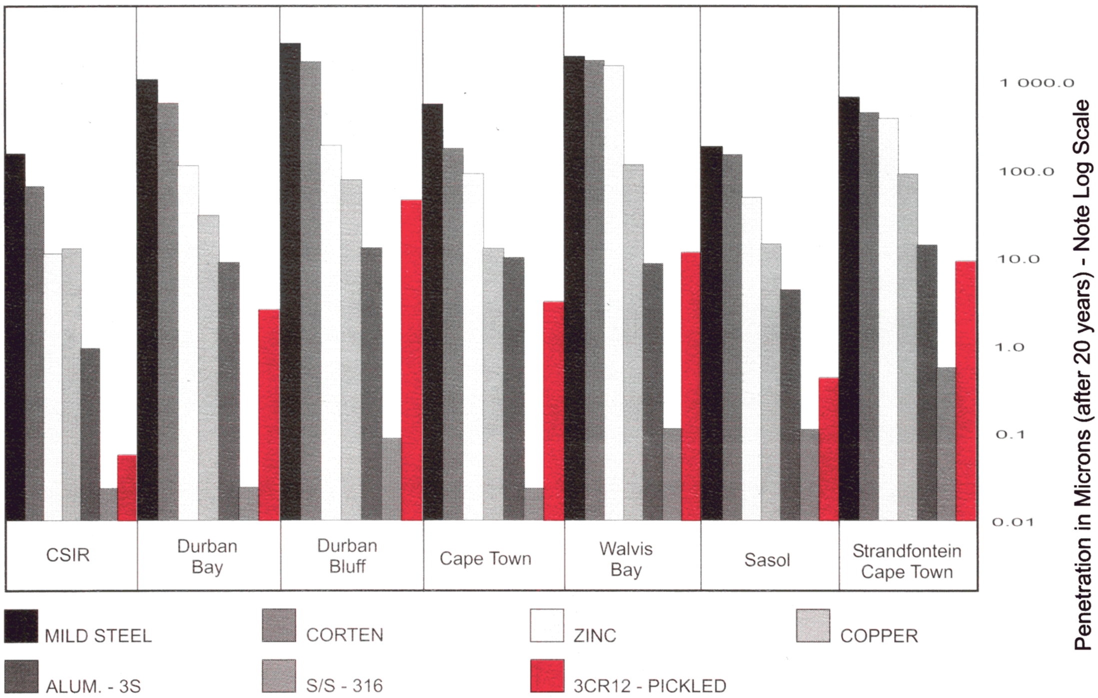

Figure 2 Comparison of seven metal types exposed to various corrosion sites after 20 years exposure.

1.3 Use of 3CR12 in structural applications

Although 3CR12 as a construction material is not new, 3CR12 hot-rolled structural sections are. Historically, the structural use of 3CR12 was limited to plate and sheet material. Structural elements were either cold formed or built-up by welding. This limitation led to the development of a code of practice for thin-walled stainless steel members first published in 1997 (SABS 0162-4:1997). 3CR12 was incorporated into this code of practice.

Some preliminary hot-rolled sections were rolled during the middle 1990's and investigated by Prof van den Berg and his colleagues at the Chromium Steels Research Group at Rand Afrikaans University [4,5]. I sections (203×203 and 152×152) and an angle section (70×70×8) were rolled with Columbus Stainless produced material by Iscor Long Steel Products. Subsequent structural evaluation of these sections was promising. The angle section particularly showed great promise but unfortunately heat treatment problems with the few I sections produced ruled these out as representative samples.

2 CURRENT PROGRAM TO INCLUDE 3CR12 INTO CURRENT SOUTH AFRICAN CODE OF PRACTICE

2.1 Hot-rolled steelwork

Hot rolled steelwork design in South Africa is normally conducted according to the SABS 0162-1:1993 code of practice. It is based largely on the Canadian code (CAN/CSA-S16.1-M89). It provides rules and requirements for the design, fabrication and erection of steel structures based on the limit states design philosophy. It is therefore only natural that the 3CR12 hot-rolled sections are tested and evaluated for compliance and inclusion into this code of practice. The immediate benefits are that the sections then immediately become more competitive to their normal structural steel counterparts because they are not seen as unknown quantities when it comes to structural behaviour.

SABS 1431 specifies weldable structural steels. SABS 0162-1:1993 has provisions for "special structural steels" not described in SABS 1431 that may be used if approved by the Engineer provided that such specifications lay down the required chemical composition and mechanical properties and:

(a) the specified yield strength shall not exceed 700 MPa
(b) the ratio of minimum tensile strength to yield strength be at least 1.2
(c) the elongation shall not be less than 15 %
(d) "Approval shall be based on published specifications that establish the properties, characteristics and suitability of the material or product to the extend and in a manner of those covered in the listed standard." Unfortunately not enough data in this regard exists for 3CR12 hot-rolled sections.

This places the onus squarely on the Engineer if non standard materials or products are used. A responsibility he may be loath to take.

2.2 Structural design philosophy

Structural design in South Africa is based on the so-called Limit States Design (LSD) philosophy. This basically states that a structural element (beam, column ect.) is deemed acceptable if the following design criterion is met:

Design resistance of a structural element > Design load action imposed on the element

$$R_d > Q_d$$

The two entities above are defined in different codes of practice. The standard code of practice for obtaining a design resistance is given in SABS 0162-1:1993 and is applicable to steel structures only whereas the design load is obtained from SABS 0160:1989 and is applicable to structures in general.

To obtain an acceptable structural element the relationship above needs to be tested for two different limit states as follows:

(a) The ultimate limit state which concerns safety and has to do with the maximum load bearing capacity of the structural element.
(b) The serviceability limit state which concerns restriction of normal use and occupancy and durability because of effects such as excessive deflections and camber, dynamics effects, fatigue and permanent deformation.

In both limit states the design resistance of the element in question stays the same whereas different load cases are applied according to SABS 0160:1989.

2.3 Scope of work to be conducted for structural evaluation

Currently an experimental program is being conducted by the Chromium Steels Research Group (Prof P van der Merwe as chairman) at the Rand Afrikaans University to evaluate the structural behaviour of 3CR12 hot-rolled sections. The main aim of the project is to evaluate the structural behaviour of the sections experimentally and then to make recommendations for possible inclusion into the current code of practice. The work to be conducted for structural evaluation of sections manufactured from a new material would typically necessitate evaluation of the following:

Part 1 - Mechanical properties of material

- Development of Experimental stress-strain curves for hot-rolled 3CR12 sections
- Statistical analysis of mill tests
- Representative values for mechanical properties based on comprehensive experimental and statistical study
- Design values for mechanical properties based on minimum requirements
- Analytical models for normal stress - normal strain curves
- Analytical models for shear stress - shear strain curves

- Secant modulus
- Tangent modulus
- Shear modulus
- Plasticity reduction factors

Part 2 - Behaviour and design of structural members
Tension members

1. Flexural members
   - Beams laterally supported
   - Lateral-torsional buckling
   - Plate girders
2. Compression members
   - Elastic buckling
   - Inelastic buckling
   - Torsional-flexural buckling
   - Local buckling of elements of member sections
3. Beam-column members
4. Connections
   - Bolted connections
   - Welded connections
5. Composite steel-concrete construction

A technical committee has been appointed to oversee the various evaluations and consists of various members from academia and industry. Currently the committee is made up of the following members:

Prof PC Pretorius (RAU University) Chairman
Prof AR Kemp (University of the Witwatersrand)
Dr G van den Berg (consultant)
AG Ballack (consultant)
Dr J Mahachi (CSIR)
Prof RF Laubscher (RAU University)
D Slater (SASSDA)

The procedure for structural evaluation and incorporation into the current code of practice in the South African context would then comprise the following:

1. Appointment of representative technical committee
2. Material evaluation
3. Structural evaluation
   - Compressive members
   - Flexural members
4. Connection evaluation
   - Bolted connections
   - Welded connections
5. Technical committee evaluates results
6. Technical committee makes a recommendation to the SABS committee that oversees SABS 0162-1:1993 for possible inclusion and method of inclusion.

3 EXPERIMENTAL PROGRAM

The experimental project is broken up into two main parts, i.e. material and structural evaluation.

3.1 Material evaluation

3CR12 is not a new material which implies that much work [1,4,5] has all ready been done on its mechanical properties but further work is needed for the hot-rolled sections.

Part 1 consists of experimentally testing a statistically significant amount of specimen machined from a relevant number of sections. Tensile and compressive testing needs to be done along the rolling direction as well as transverse to it. Stub column tests are also conducted to investigate the overall material behaviour of the various sections. The following sections are currently being investigated in detail:

Channel: 100×50, 127×63, 160×65
Angle: 50×50×3, 70×70×6, 90×90×8
IPE: 100×55

Mill data is also to be investigated. Typical results as obtained for the 90×90×8 angle are presented and Table 1.

Table 1 Typical mechanical properties as obtained for the 90×90×8 angle. The values are averages for at least 5 tests. The tensile and compressive data are for the longitudinal direction only.

Stub column			**Tensile test**					**Compression test**		
E (GPa)	$F_y^{0.2}$ (MPa)	$F_p^{0.01}$ (MPa)	E (GPa)	$F_y^{0.2}$ (MPa)	$F_p^{0.01}$ (MPa)	F_t (MPa)	Elon-gation	E (GPa)	$F_y^{0.2}$ (MPa)	$F_p^{0.01}$ (MPa)
215.8	357	335	204.8	306.7	280.7	478	36.9	204.75	325.0	298.5

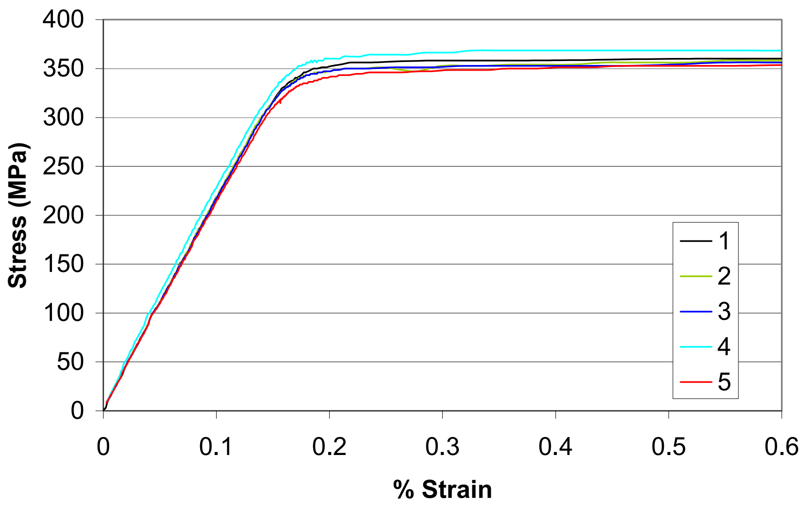

Figure 3 Typical Stress-strain curves for the 90×90×8 angle. Stub column tests.

3.2 Structural evaluation

Only limited data is available [1,4,5] for one or two of the issues that need to be evaluated to make a well-informed design recommendation concerning the structural behaviour of hot-rolled 3CR12 structural sections.

The main aim of part 2 is to determine whether SABS 0162-1:1993 is applicable to the 3CR12 hot-rolled sections. It will also form the basis of recommendations of how these sections are to be incorporated into the code. The following sections are currently being evaluated:

IPE 100×55
Channels 140×60 and 152×76
Angles 70×70×6 and 90×90×8

The members need to be evaluated as axial compression and bending members.

Compression testing

Compressive testing consists of testing different sections as columns of different slenderness ratio's. Double and single symmetric sections are tested. The tests are duplicated for carbon steel sections (300WA) to act as a control group.

Columns of different heights are placed between two specially prepared end fixtures. The end fixtures consist of specially prepared plates mounted on steel balls to allow for free rotation. Translation of the end plates are made possible by set screws on the end fixtures to allow for accurate alignment of the test specimen to obtain a centroid aligned test (see figure 4).

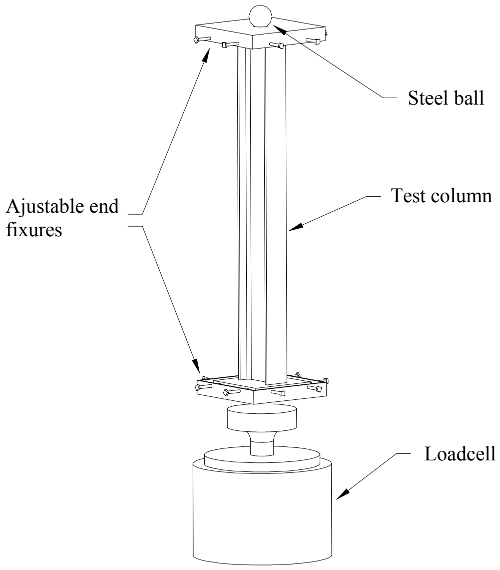

Figure 4 Compression testing

Flexural testing

The flexural testing consists of loading a beam in such a way as to induce a bending moment between two supports. The worst case being when a constant bending moment is induced between the two supports by moments at each support.

The test beam is loaded in a four-point load configuration. The beam is simply supported at two central points. Moments are induced at these supports by applying a load to the ends of the beam. This induces a constant moment between the two supports. At the supports the beam is free to rotate in the plan view but is fixed for lateral rotation as well as translation. The two end points are once again fixed against lateral rotation and lateral displacement but free to move vertically (see Figure 5). The tests are also again duplicated for carbon steel sections to act as a control group.

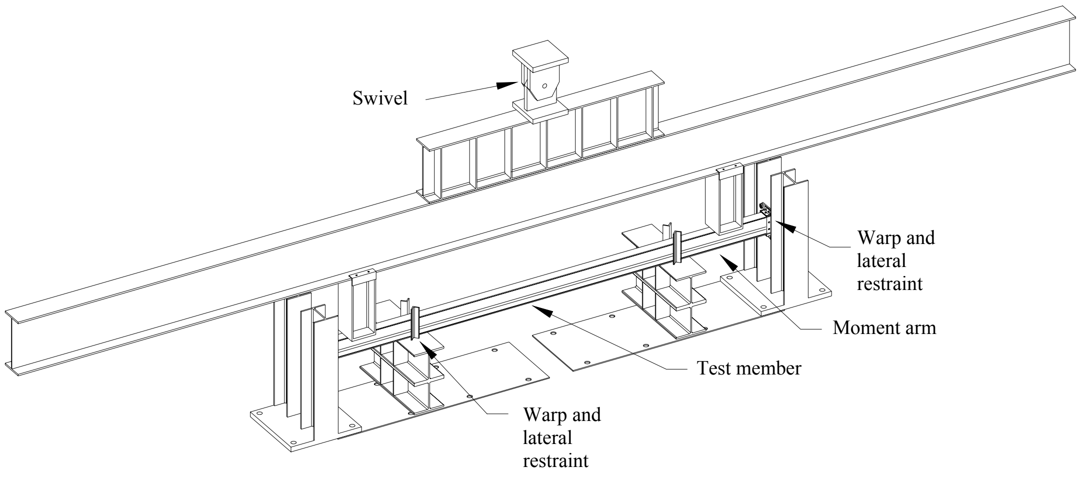

Figure 5 Flexural testing

3.2. Connector testing

Welded connector testing

Design of 3CR12 hot-rolled welded connections are currently under investigation. Various different weld geometry's are experimentally evaluated and then compared to code of practice requirements and specification. Hot-rolled flat bar are used as base material. Weld geometries that typically needs to be investigated are presented in Figure 6.

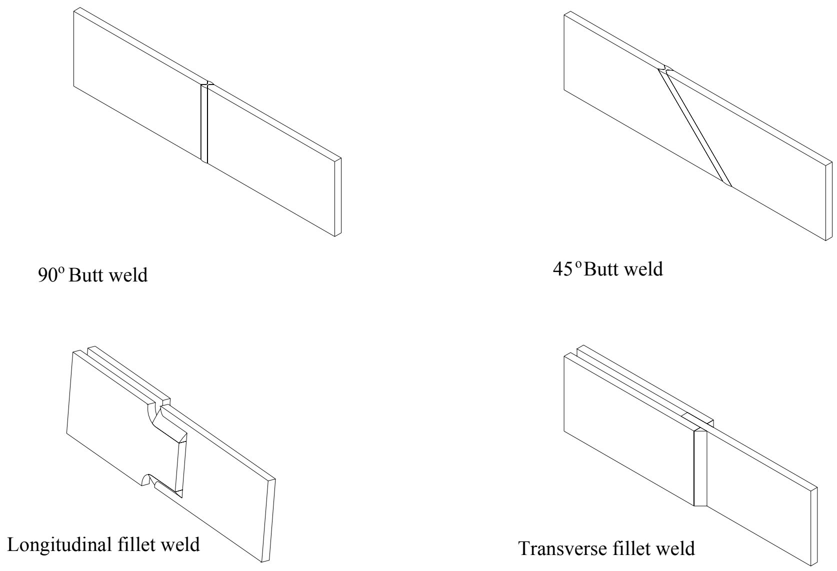

Figure 6 Typical weld geometries that need to be evaluated

Bolted connector testing

Design of hot-rolled 3CR12 bolted connectors is also currently under investigation. The typical joints that need to be investigated to gain an understanding of its behaviour are depicted in Figure 7.

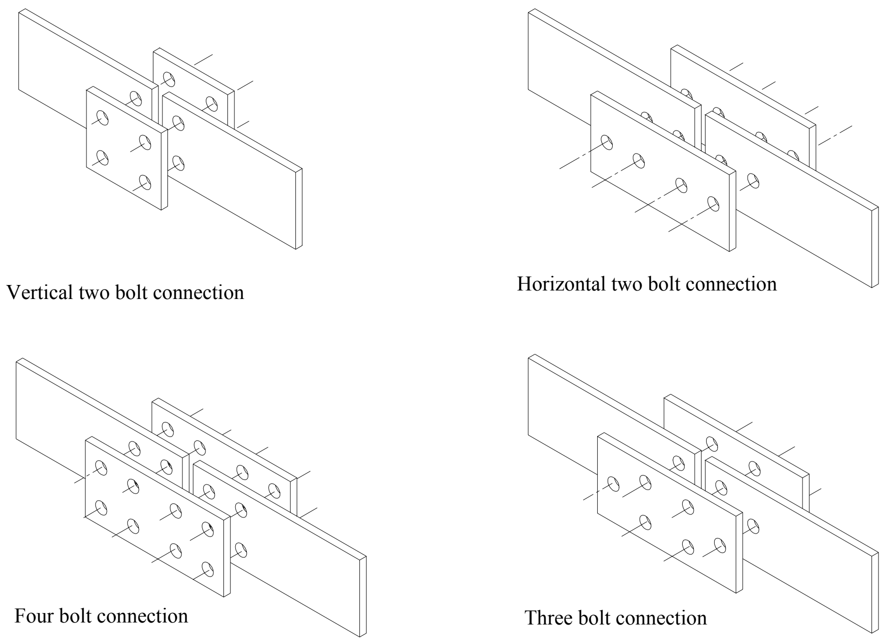

Figure 7 Typical weld geometries that need to be evaluated

Reinforcing bar testing
8, 16 and 32 mm reinforcing bar are also being evaluated to determine its mechanical properties and the bonding length. Preliminary bonding length results for the 8 mm bar are presented in Figure 8. Preliminary results indicate that the critical embedded depth is approximately 20 diameters.

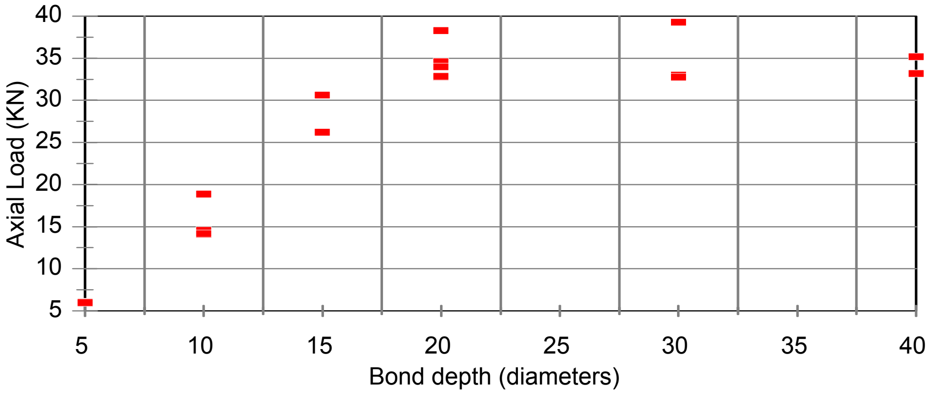

Figure 8 Results of bond length tests conducted on 8 mm 3CR12 reinforcing bar.

4 CONCLUSION

This paper briefly introduced the new 3CR12 hot-rolled structural sections that are currently being produced in South Africa. These sections offer a marked increase in corrosion resistant properties when compared to carbon steels but are available in general engineering sections normally only associated with the former.

Because 3CR12 is known to behave similarly to stainless steels, incorporation into any current design code of practice is not a simple exercise. An experimental programme to evaluate its structural behaviour is needed. Aspects such as material properties, axial behaviour, flexural behaviour and connection behaviour need to be assessed before any recommendation regarding the incorporation of the material into a current code of practice can be considered. This work needs to be conducted under the supervision of an impartial technical committee. The different aspects that will typically need to be investigated to adequately quantify a section made from new materials are listed and briefly discussed.

It is envisaged that under the leadership of the technical committee that a written recommendation will be submitted to the relevant committee for SABS 0162-1 for evaluation either for inclusion into the relevant code of practice or as may be suggested by the technical committee. The work is still ongoing.

5 REFERENCES

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