DESIGN OF WELDED CONNECTIONS OF COLD-WORKED STAINLESS STEEL RHS MEMBERS

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Abstract

When austenitic stainless steel is cold worked, it undergoes substantial strain hardening leading to significant strength enhancement. Utilisation of the enhanced strength is economic in the case of stainless steel structural applications. However, according to the Eurocodes, the increased strength cannot be utilised without testing, if material is welded after cold working. The tests described in the article show that by certain assumptions, a fillet weld or a full penetration weld does not substantially decrease the strength of tension members, if the design resistance is based on the ultimate tensile strength and the strength of the weld metal is adequate. Based on the tests, the Finnish Constructional Steelwork Association (FCSA) has published a design code for utilisation of cold working in butted RHS joints. This paper presents both the design code and the background tests.

1 INTRODUCTION

The most used stainless steels are austenitic grades with nominal 0.2% proof strengths of 230 - 240 N/mm^2. When the material is cold worked, it undergoes substantial strain hardening leading to significant strength enhancement (Table 1). Material in work hardened condition is delivered as plates, strips, bars and hollow sections.

Current Eurocodes for steel structures do not allow utilisation of the enhanced strength in the work hardened condition. ENV 1993-1-4 [1] states: "*Increased mechanical properties for work hardened conditions shall not be adopted for stainless steels that are work hardened during fabrication, if they are required to be welded or heat treated after cold working, unless it can be demonstrated by testing, that the welding or heat treatment will not reduce the mechanical properties below the values to be adopted".*

Table 1 Nominal values of the yield strength and the ultimate tensile strength for structural stainless steel grades 1.4301 (AISI 304) and 1.4401 (AISI 316).

Nominal strength class	Yield strength 3) (N/mm^2)	Increased ultimate tensile strength (N/mm^2)
ENV 1993-1-4 [1]		
Heat-treated	220 (240 1))	460 (500 1))
C700	350 2)	700
C850	530 2)	850
C1000	750 2)	1000
ANSI/ASCE-8-90 [2]		
Heat-treated	207	571
1/16 hard	276	552 (586 1))
1/4 hard	517	862
1/2 hard	759	1034

1) 1.4401 (AISI 316)
2) According to EN 1088-2 [3]. New draft prEN 10088-2 [4] presents also grades CP350, CP500 and CP700 with increased yield strengths 350, 500 and 700 N/mm^2, respectively. These grades have no limit for ultimate tensile strength.
3) In the case of stainless steels the yield strength is based on 0.2% proof strength.

According to ENV 1993-1-1 [5], the design resistance of a full penetration butt weld should be taken as equal to the design resistance of the weaker of the parts connected, provided that the weld is made with a suitable consumables which will produce all-weld tensile specimens having both the minimum yield strength and minimum tensile strength not less than those specified for the parent metal. The design resistance of fillet weld with transverse loading is determined based on the throat thickness, on the ultimate tensile strength of the weaker part and on the material-dependent correlation factor β. According to ENV 1991-1-4 [1] β should be taken as 1.0 for stainless steels. According to ANSI/ASCE-8-90 [2] the design resistance is always determined based on the weakest part of the welded connection. The resistance of the weakest connected part is based on the ultimate tensile strength of annealed base material and on the ultimate tensile strength of weld material. The principles of the ANSI/ASCE approach are also used in the design code published by FCSA [6].

2 FCSA DESIGN CODE

The basis of the design code [6] is that the design strength of the connection is the minimum of the following resistances:

- resistance of the connected part,
- resistance of the base material in the heat-affected zone and
- resistance of the weld metal.

2.1 Resistance of the connected part

The resistance of the connected part is determined according to ENV 1993-1-1:

$$N_{1,\mathrm{Rd}} = A \cdot f_{y1} / \gamma_{\mathrm{M0}} \,, \tag{1}$$

where A is the cross-sectional area of the connected part, f_{y1} is the increased yield strength of the cold worked material, and partial safety factor γ_{M0} = 1.1.

2.2 Resistance of the base material in the heat-affected zone

The resistance of the base material in the heat-affected zone is determined by

$$N_{2,\mathrm{Rd}} = 0.9 \cdot A \cdot f_{\mathrm{u1}} / \gamma_{\mathrm{Mw}} \,, \tag{2}$$

where A is the cross-sectional area of the connected part, f_{u1} is the increased ultimate tensile strength of the cold worked material, and partial safety factor γ_{Mw} = 1.25.

2.3 Resistance of the weld metal

The resistance of the full penetration butt weld is determined by

$$N_{3,\mathrm{Rd}} = 0.9 \cdot l \cdot t_{\mathrm{w}} \cdot f_{\mathrm{u2}} / \gamma_{\mathrm{Mw}} \tag{3}$$

where l is the length of the weld, t_{w} is the thickness of the weld, f_{u2} is the ultimate tensile strength of the weld metal, and partial safety factor γ_{Mw} = 1.25.

In the case of a balanced connection, equations (1) - (3) give for the case $l \cdot t_{\mathrm{w}} = A$ that the ultimate tensile strength of base material and weld material divided by the increased yield strength of the cold worked material is 1.26.

The design resistance of the fillet weld with transverse loading is determined by

$$N_{4,\mathrm{Rd}} = 0.9 \cdot \frac{l \cdot a \cdot f_{\mathrm{u2}} / \sqrt{2}}{\gamma_{\mathrm{Mw}}} \,, \tag{4}$$

where l is the length of the weld, a is the throat thickness, f_{u2} is the ultimate tensile strength of the weld metal, and partial safety factor γ_{Mw} = 1.25.

In the case of a balanced connection, equations (1) and (4) give that the throat thickness for a hollow section joint welded around has to be at least 1.79 $(f_{\mathrm{y1}}/f_{\mathrm{u2}})\cdot t$. If for example f_{y1} = 350 N/mm^2 and f_{u2} = 510 N/mm^2, $a = 1.23t$.

3 SCOPE OF APPLICATION

The design guidance published by FCSA [6] is limited to austenitic stainless steels and to connections of rectangular hollow sections (RHS). The butted joint may be made using a groove weld or a spacer plate and fillet weld (Fig. 1). Typical for the joint is that it is only axially loaded.

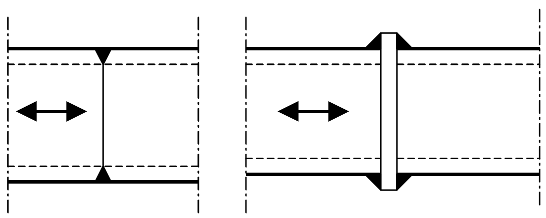


Figure 1 Butted RHS joint with V-groove weld or with a spacer plate and fillet weld.

The applicable stainless steel grades and welding consumables are given in Table 2. The material thickness shall not be more than 8 mm. The highest increased yield strength of the cold worked material (f_{y1}) and increased ultimate tensile strength (f_{u1}) are the minimum values guaranteed by the manufacturer. Regardless of the real material properties given on the mill certificate, the highest design values of f_{y1} and f_{u1} are 350 N/mm^2 and 550 N/mm^2, respectively. Also the design value of ultimate tensile strength of the weld metal (f_{u2}) shall not be higher than f_{u1}. The ultimate tensile strength of the weld metal (f_{u2}) for the applicable steel grades are given in Table 3.

Possible welding procedures are metal arc welding with covered electrode, metal inert gas welding (MIG), metal active gas welding (MAG), MAG welding by flux cored electrodes and tungsten inert gas welding (TIG).

If other steel grades or welding consumables than those given in Table 2 are used, the applicability of the guidance for a full penetration butt weld shall be assured by a transverse tensile test described in EN 895 [7]. For a fillet weld the applicability of the guidance shall be assured by a tensile test for a butted RHS joint with a spacer plate (Fig. 1).

Table 2 Applicable steel grades and welding consumables [8].

Base material		Welding consumables		
Number	**Name**	**Covered electrodes EN 1600 [9]**	**Wires and rods EN 12072 [10]**	**Flux cored electrodes EN 12073 [11]**
1.4301 1.4306 1.4307 1.4318 1.4541	X5CrNi18-10 X2CrNi19-11 X2CrNi18-9 X2CrNiN18-7 X6CrNiTi18-10	E 19 9 E 19 9 L E 19 9 L E 19 9 L E 19 9 Nb	G 19 9 L G 19 9 L G 19 9 L G 19 9 L G 19 9 Nb	T 19 9 L T 19 9 L T 19 9 L T 19 9 L T 19 9 Nb
1.4401 1.4404 1.4571	X5CrNiMo17-12-2 X2CrNiMo17-12-2 X6CrNiMoTi17-12-2	E 19 12 2 E 19 12 3 L E 19 12 3 Nb	G 19 12 3 L G 19 12 3 L G 19 12 3 Nb	T 19 12 3 L T 19 12 3 L T 19 12 3 Nb

Table 3 Mechanical properties of all-weld metal according to EN 1600 [9], EN 12072 [10] and EN 12073 [11].

Weld material	Yield strength N/mm^2	Ultimate tensile strength N/mm^2
E 19 9 E/G/T 19 9 L E/G/T 19 9 Nb	350 320 350	550 510 550
E 19 12 2 E/G/T 19 12 3 L E/G/T 19 12 3 Nb	350 320 350	550 510 550

4 VERIFICATION BY TESTING

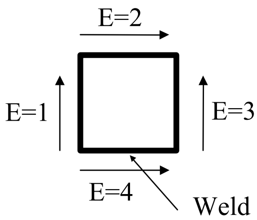
4.1 Test programme

The test programme consists of tensile tests for specimens, which were welded by the consumables given in Table 4. In all, 17 full-scale tension tests for butted RHS joints and 40 transverse small-scale tensile tests according to EN 876 [12] were performed. The full-scale specimens were butted RHS joints with a V-groove weld or with a spacer plate and fillet weld (Fig. 1). Test pieces for small-scale tests were taken from the faces of the RHS joint with a V-groove weld. The tests of RHS joints with a spacer plate had different throat thicknesses. The small case specimens were taken from the faces opposite and adjacent to the face with the manufacturing weld of the section (see small icon in Table 4). Mainly the connections were tested in the welded stage, but from some of the small-scale specimens, the excess metal was removed by machining. Also tensile tests for heat treated RHS material and all weld material were performed. Then the test specimens were annealed for 2 - 6 minutes (depending on the thickness) at temperature of 1150°C. Tensile test pieces for all-weld metal samples were prepared according to EN 1597-1 [13]. In addition, some hardness tests over the weld were made from the microsections. The material grade of the test specimens was 1.4301 and the strength of the material was increased by cold working. The rectangular hollow sections were manufactured by Stalatube Oy.

Table 4 Summary of the test programme. Numbers of letters in the test name ‘ABCDE’ identify the test. The nominal dimensions of the RHS cross-sections were 120x80x6 (B = 1), 30x30x2 (B = 2), 80x80x3 (B = 3) and 150x150x6 (B = 5).

	Full-scale tests A = 1				**Small-scale tests A = 2**				**Hardness A = 3**	
ID of RHS cross section, B =	1	2	3	5	1	2	3	5	3	5
Base material (D = 0)										
- RHS (C = 0)	X	X	X	X	X	X	X	X		
- annealed RHS (C = 1)					X	X	X	X		
V-groove (C = 2) with filler										
- OK 63.20 (D = 1)	X	X	X	X	X	X	X	X	X	X
- OK 16.32 (D = 2)	X				X					
- OK 67.20 (D = 3)				X				X		X
- OK 67.50 (D = 4)				X				X		X
V-groove, weld machined (C = 3)										
- OK 63.20 (D = 1)								X		
- OK 16.32 (D = 2)										
- OK 67.20 (D = 3)								X		
- OK 67.50 (D = 4)								X		
Spacer plate, *a* = 1.3t (C = 4)										
- OK 63.20 (D = 1)	X	X	X	X						X
Spacer plate, *a* = 1.0t (C = 5)										
- OK 63.20 (D = 1)				X						
Spacer plate, *a* = 1.6t (C = 6)										
- OK 63.20 (D = 1)				X						X

Weld metal, tensile tests:
1. OK 63.20/test piece according to EN 1597-1
2. OK 67.20/ test piece according to EN 1597-1
3. OK 67.50/ test piece according to EN 1597-1
4. OK 63.20, RHS 150x150x6, *a* = 1.6 mm, face E=3
5. OK 63.20, RHS 150x150x6, *a* = 1.6 mm, face E=4



Welding work on the RHS joints was carried out in the horizontal position, as shown in Fig. 1. Weldings on faces E = 2 and E = 4 were downhand weldings and weldings on faces E = 1 and E = 3 were upward weldings in the vertical position except for test specimens welded by MIG (OK16.32 in Table 4), in which case faces E = 1 and E = 3 were downward weldings [14].

The filler metal OK 63.20 corresponds to steel grade 1.4401 (Table 5). The electrode is developed especially for position welding of pipes. OK Autrod 16.32 is the corresponding welding wire for MIG welding. OK 67.20 is a welding electrode, which is highly alloyed with Cr and Ni and is used, for example, for welding of dissimilar metal joints. OK 16.32 and 67.50 were chosen because of their higher strength.

Table 5 Typical mechanical properties of all-weld metal according to the manufacturer [15].

Trade name by Esab Oy	**Alloy symbol EN 1600 (1997) EN 12072 (1999)**	**Yield strength N/mm^2**	**Ultimate tensile strength N/mm^2**
OK 63.20	E 19 12 3 L R 11	480	580
OK Autrod 16.32	G 19 12 3 L SI	440	620
OK 67.20	E 23 12 2 L R 11	480	640
OK 67.50	E 22 9 3 N L R 32	645	800

4.2 Results of hardness tests

An example of the hardness of a V-groove joint is shown in Fig. 2. Because the joint is welded upwards in the vertical position, the heat input is quite high (1 - 2 kJ/mm). The cold-worked material then softens in the heat-affected zone. In the middle of the material, the width of the softened zone of base material is roughly the plate thickness. However, the decrease in hardness does not prove the decrease in ultimate tensile strength, because during loading the softened zone is strain-hardening again before the joint finally breaks. Also the triaxial stress state in the softened zone can increase the ultimate tensile strength of the joint, if the softened zone is clearly narrower than the plate thickness [16].

The hardness of the weld made by OK 67.20 and OK 67.50 exceeds that of the weld made by OK 63.20. The difference is especially noticeable in the mid-layer of the plate where, due to the lower heat input, the dilution of filler metal is less than in the top layer. However, the difference in hardness is lower than it could be as predicted from the values given in Table 5. The reason for the relatively low hardness is that when austenitic base material is welded by duplex filler metal (OK 67.50), the percentage of deltaferrite is only 20, which is only slightly more than if filler metal OK 67.20 were used. Therefore it can be concluded that because of the dilution the ultimate tensile strength of the joint can be less than predicted by the mechanical properties of all-weld metal. The dilution of filler metal does not of course occur if duplex base material is welded by duplex filler metal.

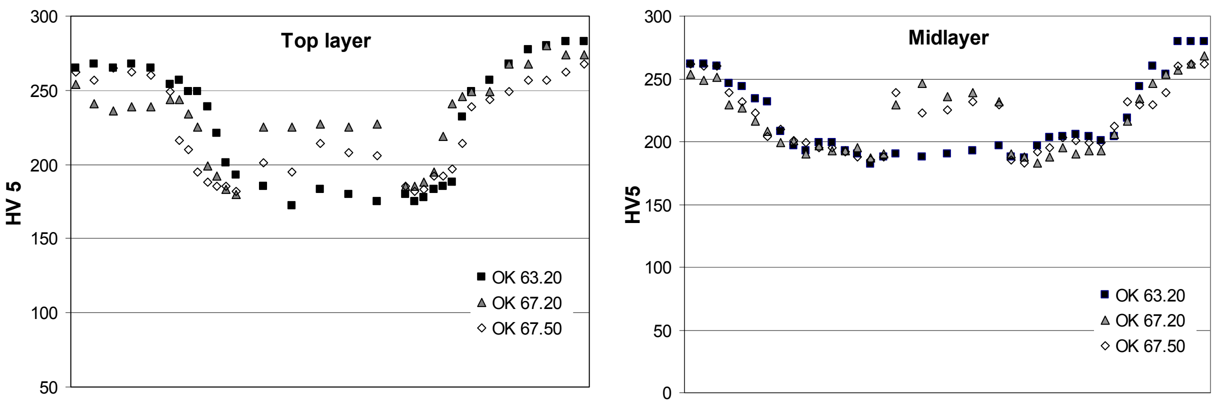


Figure 2 Measured hardness over the weld [14]. Full penetration V groove weld of RHS 150x150x6, face E = 1 (ID ‘ABCDE’ is 35211, 35231 and 35241). The measurement points are shown in Fig. 3.

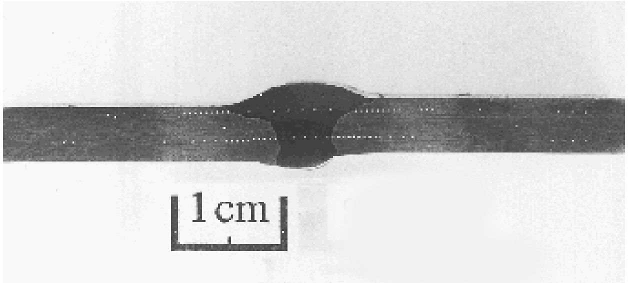


Figure 3 Points of hardness measurements in the middle and top layers of a full penetration butt weld [14]. RHS 150x150x6, face E = 1, filler metal OK 63.20.

4.3 Result of small scale tensile tests

Figures 4 and 5 show the results of small-scale tensile tests [17]. In the case of specimens not broken at the weld material (symbol M or F), the tensile strength of welded test piece is 0.90 - 1.11 times the tensile strength of the base material and 1.13 - 1.40 times the tensile strength of the heat treated base material. The comparison based on the tensile strength of cold worked material seems to result in smaller variance than the comparison to annealed material.

The asterisks in Fig. 5 represent the measured tensile strengths of all-weld metal samples. The tensile tests were performed according to EN 895 [7]. In the case of specimens broken at the weld (symbol W), the strength of specimens welded by OK 63.20 corresponds best to the tensile strength of all-weld metal. Then the ratio of the tensile strengths of welded joint and weld metal is 1.11 - 1.13 for the untreated joint and 1.02 for the machined joint. The corresponding ratios for specimens welded by OK 67.20 are (1.05 - 1.12) and (0.96 - 1.00). For specimens welded by duplex filler material OK 67.50 the ratios are only (0.85 - 0.88) and (0.70 - 0.84). The reason for the low values is the mixing of the filler and base materials, which results in changes to the microstructure of the weld metal. Therefore the high strength of filler metal does not usually result in equal strength in the welded joint if the composition of the weld metal and base material are different.

The 0.2% proof strength of the faces of the sections was 370 - 650 N/mm^2 and the tensile strength was 640 - 845 N/mm^2. After annealing the 0.2% proof strength decreased to 200 - 225 N/mm^2 and the tensile strength to 545 - 605 N/mm^2, which agrees with the values given in Table 1 for heat-treated grade 1.4301. The tensile strengths measured from all-weld metal samples were 620 N/mm^2 (OK63.20), 682 N/mm^2 (OK67.20) and 867 N/mm^2 (OK 67.50). They agree well with the typical values given by the manufacturer (Table 5). The samples were taken from the batches used in welding of the specimens.

Figure 6 gives the measured elongation, when the stress level is 50% of the measured ultimate tensile strength of the base material. The stress level corresponds to the maximum stress at the serviceability limit state (SLS), when the load factor is 1.5 and the design resistance is determined by equations (2) and (3). The measured elongations are very small at SLS.

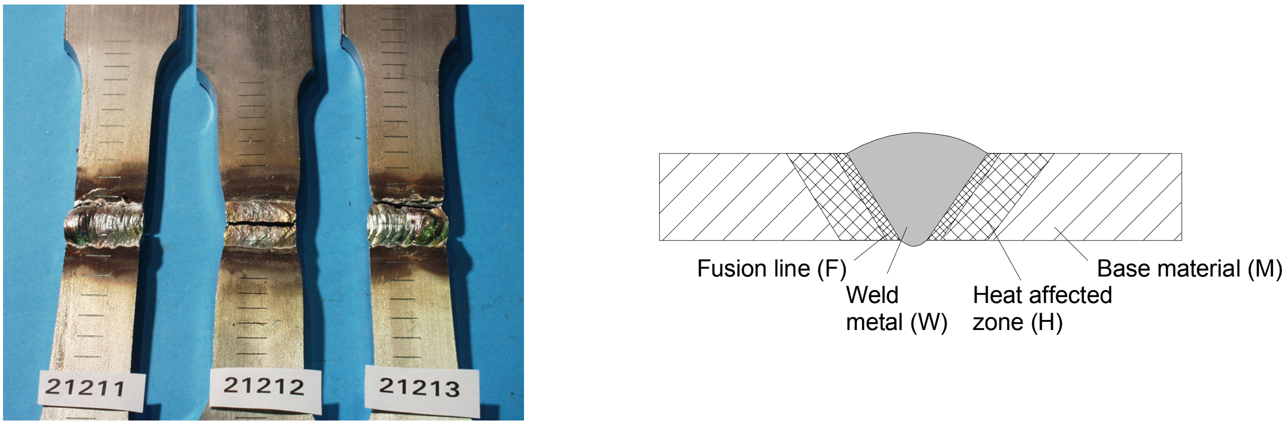


Figure 4 Fractures in the weld metal and at the fusion line (left) and scheme of the zones of a welded butt joint (right) [17].

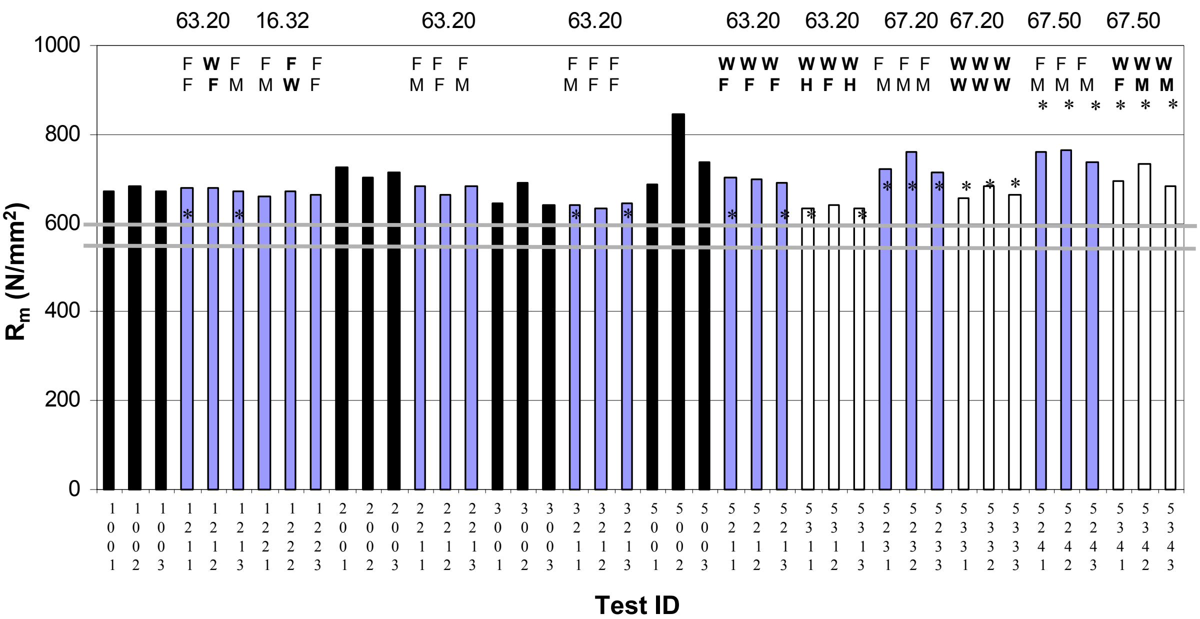


Figure 5 Ultimate tensile strengths of small-scale specimens [17]. The filler metal and location of fracture (both on the weld and root side of the joint) are shown at the top of the figure (symbols are given in Table 5 and Fig. 4). The test ID 'BCDE' is based on Table 4. The horizontal lines represent the range of measured ultimate tensile strengths of annealed base material and the asterisks the measured tensile strengths of all-weld metal.

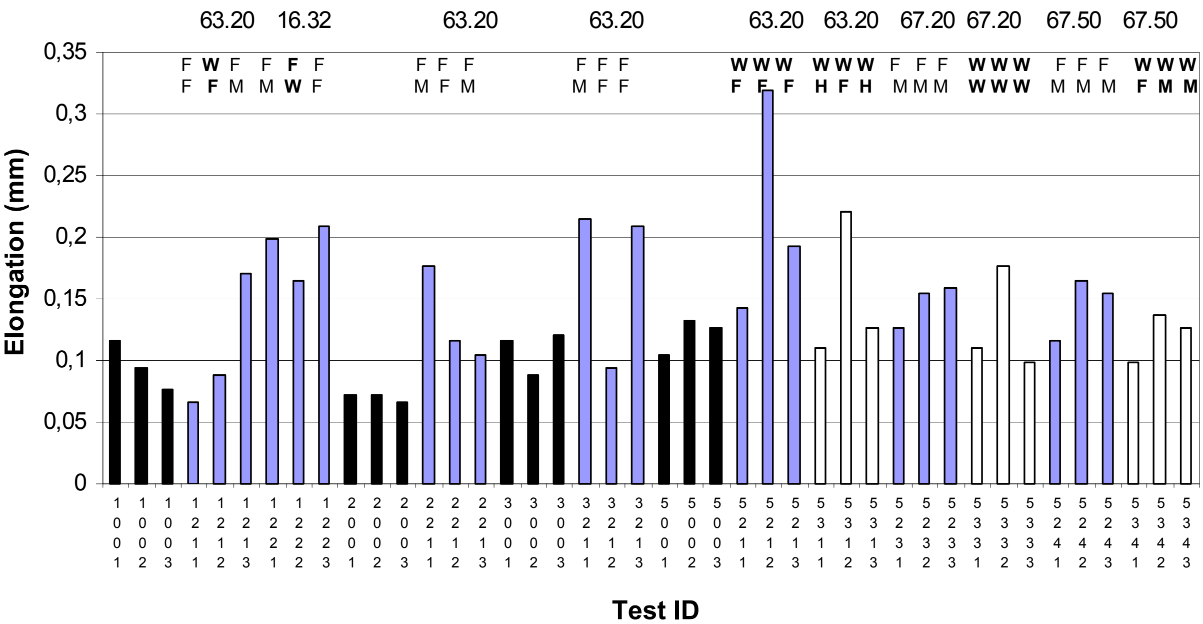


Figure 6 Elongation measured by extensometer gauge length 55 mm, when the stress level is 50% of the measured ultimate tensile strength of the base material [17]. The test ID 'BCDE' is based on Table 4.

4.4 Results of full scale tensile tests

The results of full-scale tensile tests are shown in Figure 7. Butted RHS joints with V-groove welds were broken at the outer surface at the fusion line or in the weld metal (symbol F or W), and at the inner surface at the fusion line or heat affected zone (symbols F or H) (Fig. 8). Butted RHS joints with a spacer plate and fillet weld were broken either at the weld metal or the heat affected zone near the weld toe. In the case of specimens not broken at the weld metal (symbol M or F), the tensile strength of welded test piece was 0.88 - 0.92 times the tensile strength of the base material. If the results are compared with the tensile strength of heat treated base material, the ratio is 1.03 - 1.32. Also in this test series, the comparison based on the tensile strength of cold worked material results in smaller variance than the comparison with the annealed material.

Compared with the predicted values, the results of full-scale tests are on average slightly weaker than the results with small-scale specimens, for which the ratio of measured/predicted resistance is 0.90 - 1.11. The results are also slightly weaker than those in earlier test series for butted RHS joints [19], which included 15 full-scale tensile tests for RHS joints with V-groove weld and 12 tests for joints with a spacer plate and fillet weld. Then the range and average values of the ratio of measured/predicted resistance were 0.85 - 1.03 and 0.95 for V-groove joint, and 0.90 - 1.16 and 0.97 for fillet weld joints, respectively. However, the results are not exactly comparable, because the comparison was earlier based on the average tensile strength of the face materials of the sections whereas here the comparison is based on the tensile strength of the full section. However, all the ratios are clearly higher than the value 0.9/1.25 = 0.72, which is the ratio of the measured and predicted resistance, when the safety factors in equation (2) are included.

The comparisons to resistance of weld metal are inaccurate because of the small number of full-scale test specimens, of which the ultimate tensile strength of the weld material was known, broke at the weld metal. All of them were welded by OK 63.20. The values of the ratio measured/predicted were 1.02 and 1.13 (2 tests) for V-groove joints, and 0.80 - 0.96 (4 tests) for fillet weld joints, respectively. All these values are higher than the value 0.9/1.25 = 0.72, which is the ratio of the measured and predicted resistance, when the safety factors are included in equations (3) and (4). Equation (3) seems to be slightly safer than equation (4).

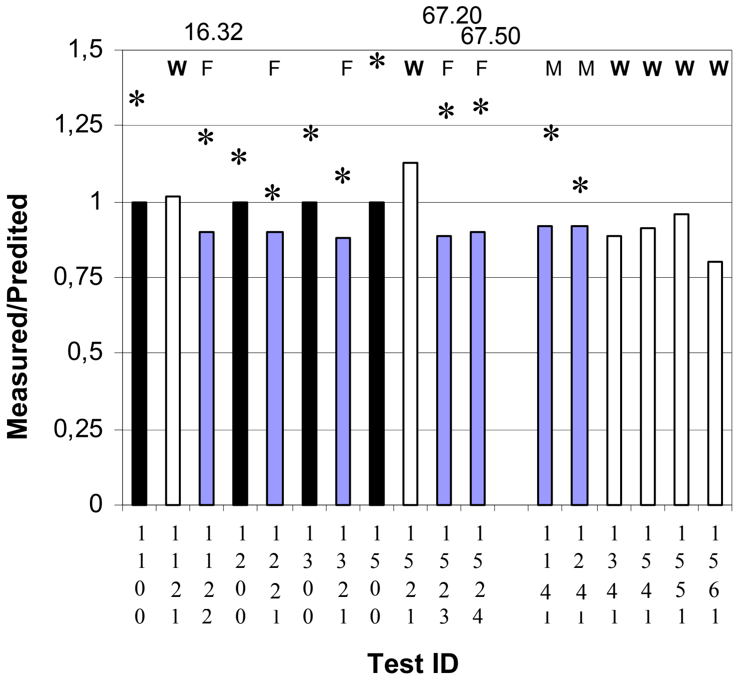


Figure 7 Measured resistances divided by predicted resistances [18]. The left group represents joints with a V-groove weld and the right group joints with a spacer plate and fillet weld. The filler metal which is different from OK 63.20, and the fracture location on the weld side of the joint are shown at the top of the figure (symbols given in Table 5 and Fig. 4). The test ID 'ABCD' is based on Table 4. The asterisks represent the ratios if the comparison is made based on the tensile strength of annealed base material.

Figure 8 Fractures of butted RHS joints with V-groove weld (left) and with a spacer plate and fillet weld (right) [18].

4.5 Statistical evaluation of the test results

The statistical evaluation of the test results is based on the strength model given in equations (1) - (4) except that the factor 0.9 and partial safety factor 1.25 are taken as unity. The calculated resistances are determined by the dimensions and throat thicknesses measured from the test specimens. Because the statistics (mean values and coefficients of variation) of the geometrical properties were not available for cold worked stainless steel members, the comparison is based on the values given in ANSI/ASCE standard [2]. There the coefficient of variation is 0.10 for the cross-sectional area of the section, 0.15 for the throat thickness of the weld and 0.05 for the tensile strength of the weld. Respectively, the ratio of mean-to-nominal value is 1.0 for the dimensions and 1.1 for the tensile strengths.

The calculation of partial safety factor γ_R is based on ENV 1993-1-1/A2 Z [20]. The coefficient γ_R in Table 6 takes into account only the coefficient of variation. The mean values are taken into account in coefficient γ_R^*. Based on the mean values 1.0 and 1.1 described above, the final partial safety factor $\gamma_R^* = \gamma_R/b/1.0/1.1$, where b is the mean value of the ratios of experimental and calculated strengths.

In ENV 1993-1-1/A2 Z the requirement is $\gamma_R^* = 1.25$ for strength models, which are based on the ultimate tensile strength. Based on the results shown in Table 6, the requirement is principally fulfilled, although the factor 0.9 in equations (1) - (4) is unity. The major exception is the last series, which includes the full-scale joints broken in the weld metal [18]. The low number of tests and quite high coefficient of variation results in high γ_R^*. Because no more test results are available, for the present the use of factor 0.9 in equations (1) - (4) is justified.

Table 6 Statistical values and partial safety factors determined for test series [21]. Partial safety factors are shown based both on the cross-sectional area of the section ($V_A = 0.05$) and on the throat thickness of the weld ($V_A = 0.15$).

	Strength model			**Partial safety factor**			
	Number of tests	**Mean value**	**Coeff. of variation**	**$V_A = 0.05$**		**$V_A = 0.15$**	
Reference	N	b	V_σ	γ_R	γ_R^*	γ_R	γ_R^*
Huhtala et al. (2001) 1)	15	0.95	0.06	1.22	1.17	1.29	1.23
Huhtala et al. (2001) 2)	27	0.98	0.10	1.27	1.18	1.32	1.22
Talja (2002) 3)	16	0.98	0.05	1.20	1.11	1.27	1.18
Talja (2002) 4)	14	1.00	0.12	1.35	1.22	1.40	1.27
Huhtala (2002) 3)	7	0.90	0.02	1.16	1.17	1.24	1.25
Huhtala (2002) 4)	6 (∞)	0.95 (0.95)	0.12 (0.12)	1.6 (1.3)	1.5 (1.25)	1.6 (1.35)	1.5 (1.30)

1) Includes only V-groove joints
2) Includes all V-groove joints and fillet weld joints not broken in the weld metal
3) Includes all joints not broken in the weld metal
4) Includes all joints broken at weld metal. Values in brackets are valid only, if N were large

5 CONCLUSIONS AND FURTHER RESEARCH NEEDS

The paper describes tests and design rules for welded connections of cold worked stainless steel RHS members. The validity of the rules is verified by tests for butted RHS joints, which are made by a V-groove weld or by a spacer plate and fillet weld (Figs. 1 and 8).

The main results are:

1. When the fracture occurs in the heat-affected zone of the RHS joint, the use of increased ultimate tensile strength in the prediction model, results in the best fit to experimental resistances. The use of ultimate tensile strength of annealed material (as proposed in ANSI/ASCE standard) results in larger scattering.

2. When the fracture occurs in the weld material, the use of ultimate tensile strength of the weld metal in the prediction model, results in the best fit to the experimental resistances, if the filler metal and base material are compatible. If incompatible filler metal is used, e.g. duplex metal for welding of austenitic grades, the dilution decreases the ultimate tensile strength of the filler metal.

3. Based on short-term tests, ultimate tensile strengths of about f_u = 700 N/mm^2 could be applicable in determining of the resistance of the joint in the heat-affected zone. Then, based on equations (1) and (2), even values of f_y = 540 N/mm^2 of cold-worked steel could be utilised in design. However, utilisation is for the present limited to f_y = 350 N/mm^2 and f_u = 550 N/mm^2. Use of these values results in design stress levels already applied in ANSI/ASCE-based design [2]. The lack of information concerning room temperature creep of weld materials, the low number of tests for fillet weld joints and the relatively low ultimate tensile strength of filler metals limit the use of higher strengths of cold worked materials.

The following research topics are important for developing the design rules and generally for the utilisation of cold worked materials in welded joints:

1. Long-term tests of welded joints. Some tests indicate that if the stress level in heat-treated condition of austenitic stainless steel is higher than 0.7 f_y, room temperature creep may occur [22]. The tests should reveal whether local creep (both in the weld material and in the heat-affected zone) has an effect on the tensile strength of the joint or on the long-term deformations at the serviceability limit state.

2. Tests for fillet weld joints. For optimising the throat thickness and for statistical evaluation of the strength model more data are necessary. Also accurate statistical data of throat thickness are necessary for statistical evaluation.

3. Increasing the ultimate tensile strength of weld metal. The strength can possibly be increased by optimising the filler metal so that the tensile strength remains high also after dilution. The tensile strength of weld material may also be increased by the use of filler metals, that are strongly strain hardening. The weld may also be mechanically strain-hardened.

4. Extending the applicability of the design rules to other joint and product forms, such as shear connections and lap joints, joints between RHS brace and chord members etc. Also the possibilities to utilise the results in process pipes and vessels should be surveyed.

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