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DESIGN RESISTANCE OF STAINLESS-STEEL FILLET WELDS

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Abstract: *Welded joint strength depends on the correlation factor β_w, which should be taken 1.0 for all stainless-steel families (according to Eurocode 3 (EN 1993-1-4, 2006)). The aim of this study is to investigate the strength and failure mode of the welded stainless-steel joints to determine the value of the correlation factor β_w for austenitic grade EN 1.4301 based on experiments. The experiments investigation consists of tensile tests of two plates (15 mm thick) connected by four longitudinal fillet welds. The load was applied parallel to the weld causing only shear stress in the fillet weld. Every specimen was tested to investigate the strength, strain and failure mode.*

Keywords: Correlation factor, stainless steel, fillet weld.

1. Introduction

Stainless steel structures are increasingly used in the building industry due to their corrosion resistance, aesthetic appearance, and other favorable properties. It is load bearing material which combines good mechanical properties with excellent corrosion performance, superior ductility and strain hardening characteristic. In fact, the corrosion resistance is the ability of the steel to form a thin, compact, impermeable, and renewable passivating layer on the surface, which gives these steel grades the resistance to electrochemical corrosion in oxidation environment. This layer is caused by chromium addition (it is necessary for the steel to contain at least 10.5% of the chromium alloy).

Furthermore, both open and hollow cross-sections are made of stainless steel, nevertheless, those sections are mostly welded. Hence, it is important to investigate the weldability and strength of welded connection. Various studies show that most of the stainless-steel grades have very good weldability by almost all commonly used welding methods (Mathers, 2019).

This paper is focused on the load-bearing capacity of the stainless-steel welded joints. The aim of this work is to determine the value of the correlation coefficient based on experiments and existing analytical formulae.

2. Research on the strength of fillet welds

The weldability of high-alloy stainless steels depends on their structure, which is related to the chemical composition. Most stainless steels are materials with very good weldability, but it is necessary to choose the welding method and the procedure correctly regarding their structure. The choice of additional materials and protection of the welding also plays a major role. Generally speaking, the additional material should have the same or very similar chemical composition as the basic material.

It is important to mention that the main disadvantage of the austenitic stainless steel is susceptibility to intergranular corrosion, which might lead to hot-cracking (in the case of increasing contents of elements

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S, P, Si, Ti, Nb in the structure). It occurs owning the degradation of grain boundaries by Cr. (Ogawa & Tsunetomi, 1982) (Whillock & Dunnett, 2004). However, several methods have been used to prevent or minimalize the intergranular corrosion of austenitic stainless steel. For instance, welding without preheating (maximal thermal input up to 15 kJ/cm and interpass temperature up to 150°C, i.e. reduce the heat input as much as possible) or adding strong stabilizing elements such as niobium or titanium in the stainless steel.

According to valid Eurocode 3 Design of steel joints (EN 1993-1-8, 2005) the predicted resistance of the fillet weld is sufficient in Formula 1 and 2 are both satisfied.

$$\sigma_{w,Ed} = \sqrt{\sigma_{\perp}^2 + 3 \cdot (\tau_{\perp}^2 + \tau_{II}^2)} \leq \frac{f_u}{\beta_w \cdot \gamma_{M2}} \tag{1}$$

$$\sigma_{\perp} \leq \frac{0.9 \cdot f_u}{\gamma_{M2}} \tag{2}$$

where: f_u is the ultimate tensile strength of the weaker part of the two base metals; β_w is the correlation factor; $\sigma_{\perp}$ is the normal stress perpendicular to the weld throat plane; $\tau_{\perp}$ is the shear stress perpendicular to the weld throat axis; τ_{II} is the shear stress parallel to the weld throat axis; γ_{M2} is the partial safety factor for the connection resistance.

As can be seen from Formula 1, the fillet weld capacity is affected by correlation factor β_w. In practice, the calculation procedure for stainless steel weld capacity is almost the same as for carbon steel, namely the von Mises stress in the weld (see Formula 1) comparison with the ultimate design resistance. Correlation factor β_w for carbon steel vary between 0.8 and 1.0 depending on the steel grade (see Tab. 1), for stainless steels grades should be assumed as 1.0. In the work "Experimental Study of the Strength of Stainless Steel Fillet Welds" (Fortan, Dejans, Debruyne, & Rossi, 2018) was proved that the average overdesign of welded stainless steel joints is 27% for transverse welds and 12% for longitudinal welds. It follows, that the existing design rules need to be updated and improved.

Tab. 1 : Comparison of strengths and correlation factors of materials

Steel grade		S235[1)]	S355[1)]	1.4301[2)]
f_y	[MPa]	235	355	210
f_u	[MPa]	360	490	520
β_w	[-]	0.8	0.9	1
$f_u/(\beta_w \cdot \gamma_{M2})$	[MPa]	360	436	416

According to Eurocode: [1)] (EN 1993-1-8, 2005); [2)] (EN 1993-1-4, 2006)

Also, a series of experimental studies on the strength of welded joints in stainless steel constructions (Yang, et al., 2017) was carried out on samples of round bars. Six tests with transverse weld and five samples with longitudinal weld were performed to determine the capacity of the welds, mode and the angle of failure. Tensile and bending resistance of the weld provided by the TIG method was examined (Rao & Deivanathan, 2014). The influence of the TIG method on austenitic steel joints was described in (Niagaj, 2006).

3. Experimental Investigation

3.1. Welding Process and Procedure

For the experiments carried out for this work, chromium-nickel austenitic steel (AISI 304 or EN 1.4301) has been chosen, which contains 17-19% Cr, 8-10.5% Ni and less than 0.08% C. Generally speaking, that is the most common stainless steel grade widely used in chemical, medical, gastronomy, machinery industry as well as in civil engineering. This material is particularly convenient for building structures due to its excellent material properties, such as being non-magnetic; having high strength, high ductility and improved corrosion resistance (in such surroundings as water, weak alkalis, weak acids, and the city's atmosphere), and excellent forming properties.

For purpose of this study, samples were welded manually (see Fig. 1) using the TIG method (i.e. Method 141 according to Standard (EN ISO 4063, 2001)) with the additional material OK AUTROD 316LSi on diameter of 1 mm, which has the most suitable chemical composition of the resulting metal for the following experiments, as it can be seen in Tab. 2.

Tab. 2 : Chemical composition of welding material (http://www.esab.cz, 2019)

Mn [%]	Mo [%]	Cu [%]	C [%]	Si [%]	Ni [%]	Cr [%]
1.8	2.6	0.12	0.01	0.9	12.2	18.4

Tab. 3 : Mechanical properties in tensile (http://www.esab.cz, 2019)

Tensile strength R_m [MPa]	Yield strength R_e [MPa]	Extension A [%]
440 - 560	340 - 440	26 - 37

Fig. 1 Stainless steel plates welded by the TIG method (left), typical failure mode (right).

3.2. **Test Programme**

In the course of the work, 5 tensile welding tests of stainless-steel plates (1.4301 grade) will be performed. Each sample consists of two plates (of size 250x140mm, 15 mm thick) connected by four longitudinal filler welds of 3 mm throat thickness and 50 mm length. As was mentioned, welding is done manually using the TIG method with the OK AUTOD 316LSi additional material from ESAB (http://www.esab.cz, 2019). The specimens were bolted to jigs designed for this purpose (see Fig. 2). The tests were performed in a tensile device with a maximum capacity of 300 kN (predicted strength according to Eurocode 3 (EN 1993-1-4, 2006) of the welded connection is $F_{pred} = 144.107\ kN$). The load was applied quasi-statically with speed 0.462.mm/min. The specimens were loaded by axial force causing the shear stress parallel to the weld throat axis.

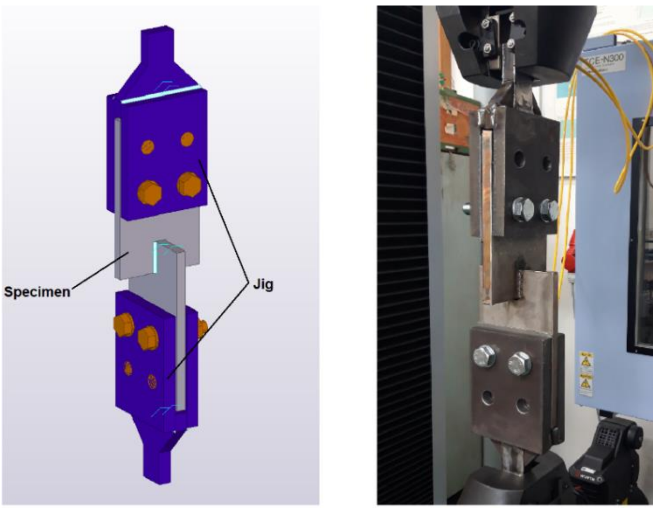

Fig. 2 : The test setup

The results of the experiments are shown in Tab. 4. By measuring the weld throat over the whole length of the weld, the average volume is considered in the evaluation of the strength. For purpose of evaluation, the partial safety factor γ_{M2} was taken as 1.0. Besides, the ultimate strength of the base material ($f_u = 599$ MPa) was determined from three coupons, which were cut in the same direction as welded specimen were tested in tension.

Tab. 4 : Overview of the test results

Name	a_w	l_w	A_w	F_{exp}	β_w	F_{exp}/F_{pred}
	[mm]	[mm]	[mm^2]	[N]	[-]	[-]
CS01	3.0648	48.21	591.1	247 972.90	0.824	1.721
CS02	2.5842	47.72	493.3	228 714.30	0.745	1.587
CS03	3.1222	47.86	597.7	247 972.90	0.833	1.721
CS05	3.2933	49.875	657.0	265 910.30	0.854	1.845
CS06	3.1304	49.13625	615.3	256 310.80	0.830	1.779

4. Conclusion

The correlation factor has an important influence on the designed capacity of the stainless steel welded joints. The resulting correlation factor is $\beta_w = 0.904$, which was determined statistically based on 5 tests. For those specimens, an average experimental-to-predicted strength ratio 1.73. Based on investigation herein, it can be said that the relevant approach in Eurocode (EN 1993-1-4, 2006) leads to slightly conservative design of welded stainless steel joints.

5. Acknowledgement

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