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QUALITY ASSESSMENT OF SINGLE-PASS CORNER STEEL WELDED JOINTS

OCENITEV KVALITETE ENOVARKOVNIH JEKLENIH KOTNIH ZVARNIH SPOJEV

Zdravko Praunseis[1ℜ], Bojan Stergar[1], Iztok Brinovar[1]

Keywords: welded joints, microstructure, cracks, undercut, main frame

Abstract

The aim of this paper is to analyse the quality assessment of single-pass corner steel welded joints. The testing revealed the most burdened welded joints, which were cut out of the work-piece and prepared for metallographic macroscopic and microscopic analysis.

Thus, for all examinations of single-pass corner steel welded joints, the standard test procedures were used to determine the weldability and quality assessment of base materials and welded joints. Additionally, the effects of various welded defects of single-pass weld material on the bearing strength of corner welded joints will be analysed.

Povzetek

Bistvo članka je v analizi kvalitete enovarkovnih jeklenih kotnih zvarnih spojev. Preizkušanje zajema najbolj poškodovane dele zvarnih spojev, iz katerih so bili odvzeti vzorci za mikroskopske in makroskopske analize.

Za določitev varivosti in oceno kvalitete osnovnih materialov in zvarnih spoje so bile v raziskavi enovarkovnih kotnih zvarov uporabljene standardne metode. Ugotovljen je bil vpliv različnih va-

ℜ Corresponding author: Zdravko Praunseis, PhD, Associate Professor, Faculty of Energy Technology, University of Maribor, Tel.: +386 31 743 753, Fax: +386 7 6202 222, Mailing address: Hočevarjev trg 1, Krško, Slovenia, E-mail address: zdravko.praunseis@um.si

[1] Faculty of Energy Technology, University of Maribor, Hočevarjev trg 1, Krško, Slovenia

1 INTRODUCTION

With High-Strength Low-Alloyed Steels (HSLA) and their welded joints, the thermal and strain cycles during welding inevitably bring about metallurgical, mechanical and other heterogeneities. Fig. 1 and Fig. 2 show a summarised illustration of effects of various characteristics on fracture joint performance and/or fracture transition behaviours. Almost all of these factors result in the deterioration of the fracture performance of welded joints, [1,8].

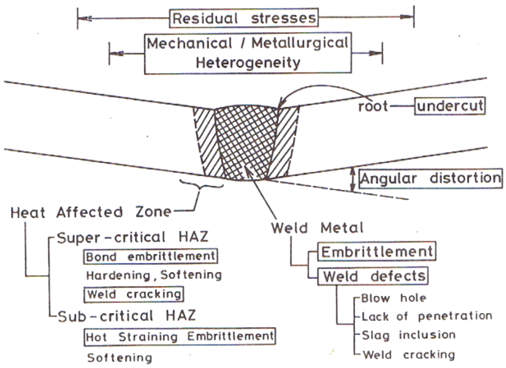


Figure 1: *Mechanical characteristics of energy steel welds*

Microstructures in welded joints of structural steels can be roughly divided as follows with regard to the change of material characteristics: (1) welded metal, (2) fusion line, (3) supercritical heat-affected zone (HAZ), and (4) subcritical HAZ. There are two main controlling factors that dominate the fracture performance of welded joints: factors controlling (a) fracture toughness and (b) deformation behaviour under loading. Although the fracture performance of welds is affected by various factors and their complex combined incidence, the following two controlling factors of brittle fracture strength of welds are essential: (I) the embrittlement in HAZ and the weld metal in the vicinity of pre-existing defects, and (II) inhomogeneity in strength, such as hardening and softening in HAZ and matching between the weld metal and base metal. The various factors control the embrittlement in welds. Mechanical heterogeneity is also a result of the same kind of controlling factors, [6,7]. In particular, as mentioned above, the embrittlement results in problems with the existence of local brittle zones (LBZs) in multi-pass welds.

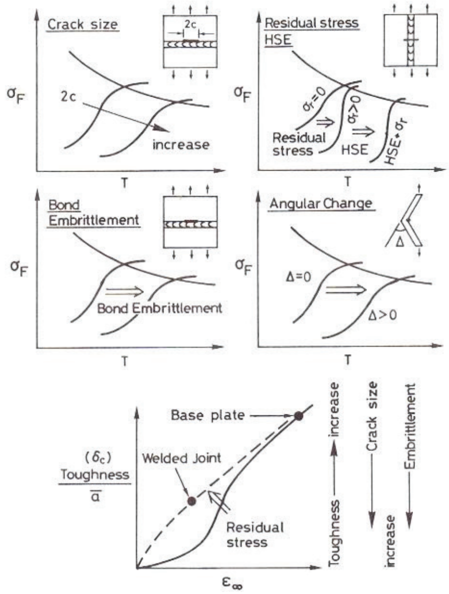


Figure 2: *Summary of various controlling factors on fracture performance of energy steel welds*

2 EXPERIMENTAL PROCEDURE AND DISCUSSION

Examination of single-pass corner welded joints of the main frame is carried out using the following standards methods:

- Surface inspection of welded defects at the single-pass welded joints (EN ISO 5817).

- Internal inspection of welded defects at the single-pass welded joints through microstructural supervision and measurement of microhardness (ISO 9051:2001, EN ISO 15614-1).

A visual surface inspection of welded defects at the single-pass welded joints demonstrates the presence of undercuts at the cap of the weld joints at marked places of the main frame from joint number 1 to joint number 5, as illustrated in Figures 3, 4 and 5 (see arrows) and Table 1.

The classification of defects (undercuts) in the single-pass corner welded joint is estimated in regard to the EN ISO 5817 standard (Tables 1 and 2).

The depths of the undercuts were measured using a laser depth micrometre and the results are shown in Table 2.

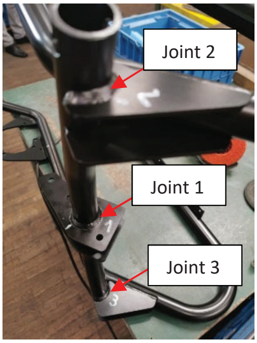


Figure 3: Inspected mark places of the main frame (Joints 1, 2 and 3)

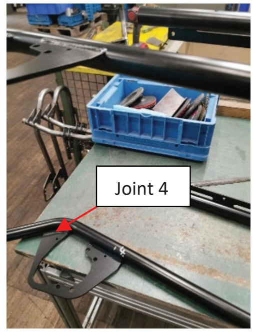


Figure 4: Inspected mark places of the main frame (Joint 4)

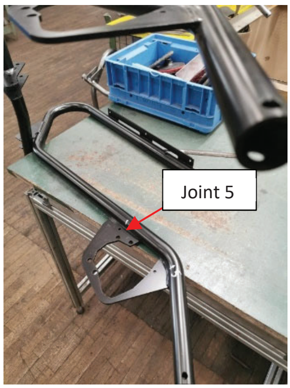
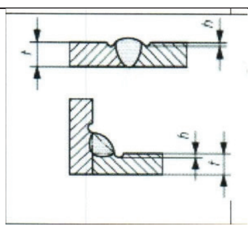


Figure 5: Inspected mark places of the main frame (Joint 5)

Table 1: *EN ISO 5817 standard classification of defects (undercuts) in a single-pass corner welded joint*

Defect sort	**Drawing**	**Weld joint class D**	**Weld joint class C**	**Weld joint class B**
Undercut at the cap of the weld joint.	 Base material thickness, t, from 0.5mm to 3.0mm.	A short undercut length is permitted based on the total length of the weld. h≤ 0.2 t	A short undercut length is permitted based on the total length of the weld. h≤ 0.1 t	An undercut length is not permitted.

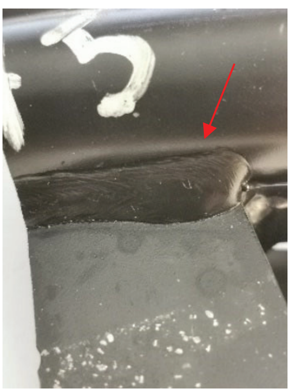
The weld joint class is ordered by the constructor (designer) of the welded structure of the product, based on the estimated and achieved level of the thermal stresses, residual stresses and loading stresses that pertain to the constructed product. The highest level attained of the thermal stresses, residual stresses and loading stresses of a welded structure is typical for weld joint class B, while the lowest level attained of the thermal stresses, residual stresses and loading stresses of a welded structure is typical for weld joint class D. Thus, the main frame product investigated meets the standards of weld joint class D.

Table 2: *Measured and estimated values of undercuts in single-pass corner welded joints*

Joint Number	Weld class D	Weld class C
Joint 1 	Base material thickness, t=3mm Permitted undercut depth, h_a=0.6mm Measured undercut depth, h_m=0.2mm h_m=0.2mm≤ h_a=0.6mm Total length of weld, Lw=131mm Total length of undercut, L_u=12mm This equates to 9.1% of the total length of the weld. A short total undercut length (9.1%) is permitted in this length of weld.	Permitted undercut depth: h_a=0.3mm h_m=0.2mm≤ h_a=0.3mm
Joint 2 	Base material thickness, t=3mm Permitted undercut depth, h_a=0.6mm Measured undercut depth, h_m=0.3mm h_m=0.3mm≤ h_a=0.6mm Total length of weld, Lw=94mm Total length of undercut, L_u=11mm This equates to 11.7% of the total length of the weld. A short total undercut length (11.7%) is permitted in this length of weld.	h_m=0.3mm≤ h_a=0.3mm

To be continued

Continuation

Joint 3 	Base material thickness, t=3mm Permitted undercut depth, h_a=0.6mm Measured undercut depth, h_m=0.2mm h_m=0,2mm≤ h_a=0.6mm Total length of weld, Lw=58mm Total length of undercut, L_u=6mm This equates to 10.3% of the total length of the weld. A short total undercut length (10.3%) is permitted in this length of weld.	h_m=0.2mm≤ h_a=0.3mm
Joint 4 	Base material thickness, t=3mm Permitted undercut depth, h_a=0.6mm Measured undercut depth, h_m=0.2mm h_m=0.2mm≤ h_a=0.6mm Total length of weld, Lw=91mm Total length of undercut, L_u=9mm This equates to 9.8% of the total length of the weld. A short total undercut length (9.8%) is permitted in this length of weld.	h_m=0.2mm≤ h_a=0.3mm
Joint 5 	Base material thickness, t=3mm Permitted undercut depth allowed, h_a=0.6mm Measured undercut depth, h_m=0.1mm h_m=0,1mm≤ h_a=0.6mm Total length of weld, Lw=91mm Total length of undercut, L_u=3mm This equates to 3.2% of the total length of the weld. A short total undercut length (3.2%) is permitted in this length of weld.	H_m=0.1mm≤ h_a=0.3mm

A further stage of examinations involved an internal inspection of welded defects at the single-pass corner welded joints through microstructural supervision and measurement of microhardness.

For this purpose, five samples were cut out from the main frame (Figures 3, 4 and 5 (see arrows)) and marked 1 to 5. Metalographical samples were brushed, polished and etched with 5% nital (Figure 6). The etched samples were observed using an optical microscope in order to determine the microstructure and presence of cracks and microcracks and other typical welded defects. Microhardnes measuring (HV 0.1) was performed according to the ISO 9051:2001 standard with the aim of determining the local brittle zones (LBZ) with the highest hardness where cracks may appear.

Figure 6: Metalographical samples used for determination of microstructure and microhardness measurements at the single-pass corner welded joints

The results of the tests to measure the microhardness of weld metal and the HAZ at the single-pass corner welded joints are shown in the final report (Figure 7).

The highest value of 259 HV 0.1 was measured in the HAZ of the single-pass corner welded joints (Figure 7), which is much lower than the maximum permitted microhardness value (340 HV) in the welded joint with a carbon content lower than 0.22%, according to the EN ISO 15614-1 standard.

Microhardness Test Results

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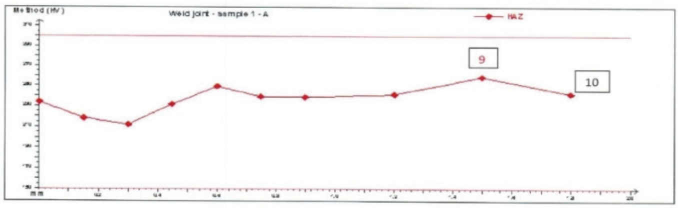
Test Program	Single pass filled Corner weld joint		
Limits for :	Nominal Value	Upper tolerance limit	Lower tolerance limit
WM-FL-HAZ	0,00	300,00	150,00



Number	Hardness value	Conversion	Date	Time	Operator	Comment
HAZ						
1	233,8 HV 0,1	-	3.9.2021	12:53:26	FELABEMI	
2	218,5 HV 0,1	-	3.9.2021	12:53:31	FELABEMI	
3	212,1 HV 0,1	-	3.9.2021	12:53:36	FELABEMI	
4	231,7 HV 0,1	-	3.9.2021	12:53:39	FELABEMI	
5	249,4 HV 0,1	22,0 HRC	3.9.2021	12:53:43	FELABEMI	
6	239,5 HV 0,1	20,3 HRC	3.9.2021	12:53:48	FELABEMI	
7	238,8 HV 0,1	-	3.9.2021	12:53:56	FELABEMI	
8	241,8 HV 0,1	20,7 HRC	3.9.2021	12:54:02	FELABEMI	
9	259,0 HV 0,1	23,8 HRC	3.9.2021	12:54:16	FELABEMI	
10	242,5 HV 0,1	20,9 HRC	3.9.2021	12:54:29	FELABEMI	

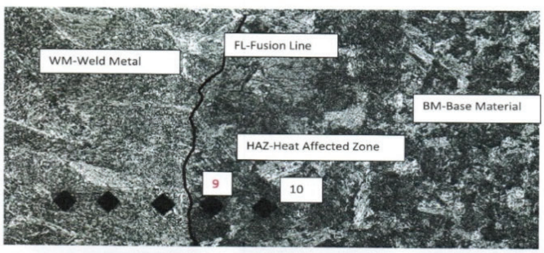


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Figure 7: Microhardness test results of the weld metal and HAZ at the single-pass corner welded joints

Carbon equivalents for theorethical prediction of microcracks and weldability of single-pass corner welded joints are calculated according to the EN 1011-2 standard using the equation (2.1), in regard to the real chemical composition of the base material (steel tube and steel plate) and weld metal of the single-pass corner welded joints, measured using an X-ray fluorescence spectrometer XRF (Thermo Scientific Niton XL3t GOLDD+), as illustrated in Table 3.

$$\mathrm{Ceq} = \mathrm{C} + \frac{\mathrm{Mn}}{6} + \frac{\mathrm{C_r} + \mathrm{M_o} + \mathrm{V}}{5} + \frac{\mathrm{N_i} + \mathrm{C_u}}{15} \tag{2.1}$$

Table 3: *Real chemical composition of base material (steel tube and steel plate) and weld metal of single-pass corner welded joint, measured using an X-ray fluorescence spectrometer XRF (Thermo Scientific Niton XL3t GOLDD+) and values of calculated C_{eq} according to the EN 1011-2 standard:*

Chemical Composition (%)	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	V
Steel tube	0.169	0.201	1.354	0.129	0.038	-	-	-	-	0.021
Steel plate	0.081	0.006	0.732	0.011	0.002	0.018	0.007	0.003	0.006	
Consumable VAC 65	0.078	1.110	1.564	0.020	0.025	0.002				
Weld metal (WM)	0.101	0.184	1.421	0.010	0.029	0.009	0.001	0.002	0.005	0.019
Carbon equivalent (C_{eq})	$C_{eqBM\ (tube)}$ = 0.398	$C_{eqBM\ (plate)}$ = 0.208	C_{eqWM} = 0.343							

The values of the calculated carbon equivalent (C_{eq}) predict the following appearance of microcracks in single-pass corner welded joints:

If $C_{eqBM\ (tube)} = 0.398 > C_{eqWM} = 0.343$, cold microcracks may appear in the base material.

If $C_{eqBM\ (plate)} = 0.208 < C_{eqWM} = 0.343$, cold microcracks may appear in weld metal.

In the event that the calculated $C_{eqBM\ (tube)} = 0.398$ and $C_{eqWM} = 0.343$ is lower than 0.40, this value guarantees very good weldability of the base material steel plate and tube used for welding of the main frame.

Due to the possibilty of the appearance of cold microcracks in weld metal and base material, an investigation into the microstructure of single-pass corner welded joints was carried out using an optical microscope (Figures 8, 9, 10, 11, 12 and 13).

Cracks and microcracks in combination with undercut can be very dangerous for the safe operation of single-pass corner welded joints, due to the concentration of stress that can appear around the profile of undercuts, thus a further investigation into the microstructure of single-pass corner welded joints is required.

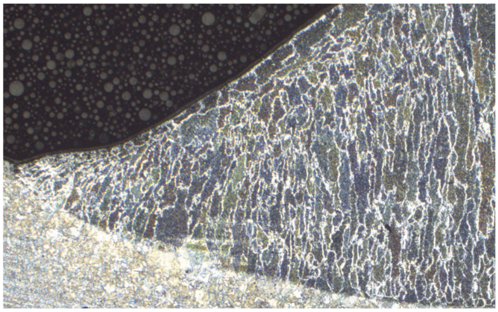

Figure 8: Microstructure without the presence of cracks in the weld metal, and the HAZ of a single-pass corner welded joint (sample 1, joint 1), mag(50x).

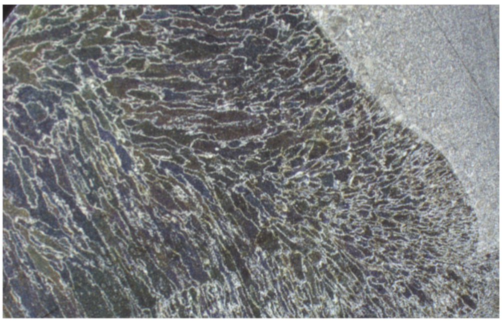

Figure 9: Microstructure without the presence of cracks in the weld metal, and the HAZ of a single-pass corner welded joint (sample 2, joint 2), mag(50x).

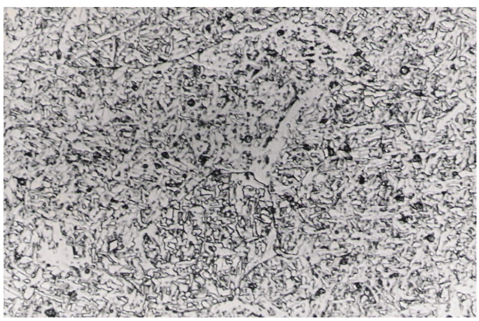

Figure 10: Ferritic-perlitic microstructure without the presence of cracks in the weld metal of a single-pass corner welded joint (sample 3, joint 3), mag(100x).

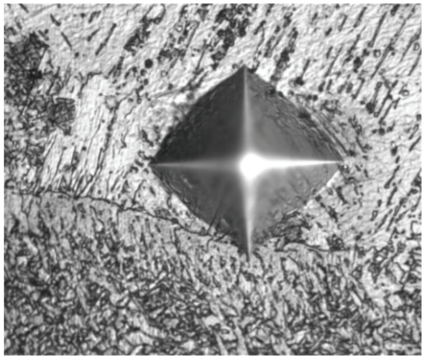

Figure 11 : Bainitic-martenzite coarse grain microstructure at the point where the highest level of microhardness (259 HV) was measured, without the presence of cracks of the HAZ of a single-pass corner welded joint (sample 3, joint 3), mag(200x).

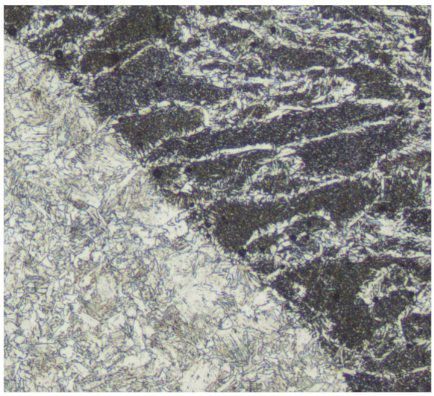

Figure 12: Microstructure without the presence of cracks in the weld metal, and the HAZ of a single-pass corner welded joint (sample 4, joint 2), mag(75x).

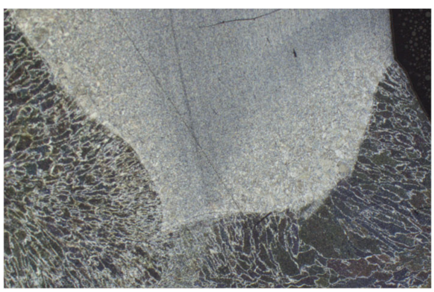

Figure 13: Microstructure without the presence of cracks in the weld metal, and the HAZ of a single-pass corner welded joint (sample 5, joint 5), mag(50x).

The investigations in the microstructure of single-pass corner welded joints confirmed that in all single-pass welded joints, weld metal and the HAZs, cracks and microcracks did not appear due to the proper selection of base materials, consumables and welding technology.

3 CONCLUSIONS

This examination of single-pass corner welded joints of the main frame resulted in the following conclusions:

1. Classification of defects (undercuts) in single-pass corner welded joints was estimated based on the EN ISO 5817 standard, which permitted existing undercuts in real single-pass corner welded joints in the case of weld joint class D and weld joint class C.

2. The highest value of 259 HV 0.1 was measured in the coarse grain heat-affected zone (CG HAZ) at the single-pass corner welded joints (Figure 7), which is much lower than the maximum permitted microhardness value (340 HV) in the welded joint with a carbon content lower than 0.22%, according to the EN ISO 15614-1 standard. This value of 259 HV 0.1 guarantees that dangerous cracks, microcracks or any other typical welded defects do not form in single-pass corner welded joints.

3. The investigations into the microstructure of single-pass corner welded joints confirmed that in all single-pass welded joints, weld metal and HAZs, cracks and microcracks, as well as other typical welded defects, did not appear due to the proper selection of base material, consumables and welding technology.

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