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WELDABILITY INVESTIGATION ON REAL WELDED PLATES OF FINE-GRAINED HIGH-STRENGTH STEEL S960QL

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The paper presents results of impact energy effects on real welded specimens of fine-grained high-strength S960QL steel, and elaborates the dependence of real welded specimen hardness on heat input. Results are obtained through measuring of hardness HV 10 and by experimental Charpy V-notch test. V-notch on test tubes was moved for 0,5 mm from the fusion line in the heat affected zone.

Key words: weldability, S960QL, toughness, impact energy, hardness

INTRODUCTION

High-strength steels have been always considered as a challenge for manufacturers of welded structures and pressure vessels. Savings achieved through lowering of construction mass have proved to be interesting for mobile welded structures, such as rail vehicles, construction machinery and various types of cranes. These advantages are even more visible in mobile pressure vessels, as well as in large stable pressure vessels. Although problems in exploitation of pressure vessels constructed of high-strength steels (stress corrosion cracking and other difficulties) have slowed down the implementation of these steels, their usage, if exempt of aggressive media influences, is still an important technological breakthrough. Cranes in a variety of designs can be taken as an example of structures that would not be possible to build from conventional structural steels because of their dimensions and working capacities. Requirements put on weldability methods are increasing along with the increase of steel strength. Based on previous experiences in production and application of high-strength steel, this paper explains effects of impact energy on the S960QL steel at different distances from the fusion line within heat affected zone (HAZ).

RESEARCH OBJECTIVE

In the HAZ, which normally occupies a relatively narrow area, there are significantly different structures that influence different results of the impact energy. The HAZ can be divided into four different areas in which the material is subjected to various heat impacts, Figure 1.

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In order to assure safety of welded structures in service, especially when exposed to low temperatures, it is necessary to determine the minimum value of impact energy in HAZ as being the most critical area of a weld. Determination of the impact energy minimum value in HAZ is possible only if the V-notch position is precisely determined at a distance from the fusion line, which defines overheated area with the lowest values of impact energy. In practice, minimum value of the impact energy in HAZ is determined according to the HRN EN 875. This standard indicates that the tip of V-notch on the impact energy test tube can be set at a distance of 0,5 to 1,5 mm from the fusion line. This means that the overheated area of HAZ is within that interval. For this investigation it was predicted welding of two plates made of S960QL steel with different welding parameters in order to determine impact energy and hardness of welded joint and predict weldability of this steel. Welding was performed by MAG welding process, which is commonly applied in manufacture of crane components. This semiautomatic welding process has been successfully used for many years as it offers a possibility of making high quality welded constructions with available human and technological resources.

Chemical composition and mechanical properties of tested high strength steel S960QL are presented in the Table 1 and Table 2.

CG - Coarse Grain
FG - Fine Grain PTA - Partial transformed area UA – Untransfor. area

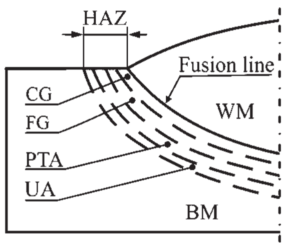

Figure 1 HAZ of single pass weld [1]

Table 1 **Chemical composition of S960QL steel /wt./%**

C	0,17
Si	0,47
Mn	1,42
P	0,008
S	0,003
Cr	0,59
Mo	0,56
Ni	0,79
Nb	0,02
V	0,05
Cu	0,03
Ti	0,01

Table 2 **Mechanical properties of S960QL Steel**

Yield Strength $R_{p0,2}$ / MPa		1 020
Tensile Strength R_m / MPa		1 080
Elongation A_5 / %		16
Contraction Z / %		61,9
Toughness, K_V / J longitudinally	at 0 °C	158
	at - 20 °C	76
	at - 40 °C	58

Figure 2 presents the TTT diagram for S960QL steel.

According to the manufacturer's recommendations for the base material, the Hermann Fliess & Co. Wire ED-FK 1000 (DIN EN ISO 16834-A G89 6 M21 Mn-4Ni2CrMo), diameter f 1,2 mm, combined with protective mixture M 21 – HRN EN 439 (82 % Ar + 18 % CO_2), is applied as a filler material. Chemical composition and mechanical properties of the filler material are shown in the Table 3.

Table 3 **Chemical composition and mechanical properties of filler material ED-FK 1 000**

Chemical composition / %					
C	Si	Mn	Ni	Cr	Mo
0,09	0,80	1,80	2,20	0,31	0,55
Mechanical properties					
R_m / MPa		$R_{p0,2}$ /MPa		A_5 / %	KV / J
≥ 940		≥ 885		≥ 14	≥ 47 (- 60)

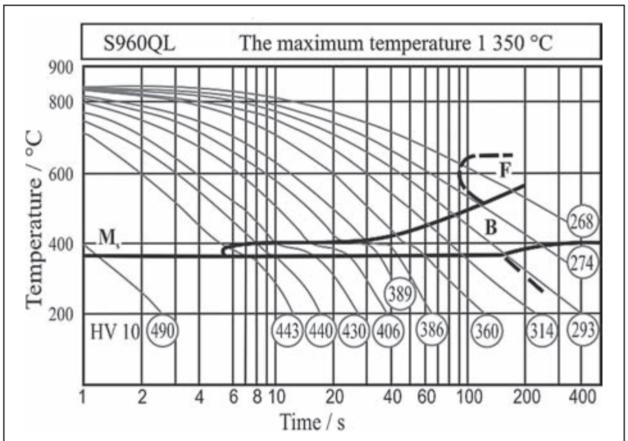

Figure 2 TTT diagram for S960QL steel [3]

Two 20 mm thick plates, dimension 150 x 150 mm, were joined by automatic MAG welding process. Preheating temperature was 150 °C, weld grove was „1/2 V". Welding parameters for test plates are given in the Table 4.

Table 4 **Welding parameters for test plates**

Plate	Welding parameters				
	I / A	U / V	v_z / cm/min	E_{ef} / J/mm	$E_{av.}$ / J/mm
P_1	130	18	21	568	570
	235	24	50	575	
P_2	128	17	13	835	859
	240	24	34	865	

Where:

E_{av}, E_{ef} … Average and Effective heat input / J/mm
v_z … Welding speed / cm/min
I … Arc welding current /A
U … Arc welding voltage / V

RESEARCH RESULTS

Welded plates are used for preparation of Charpy V-notch test. According to HRN EN 50115, there are 44 test tubes prepared, of which 32 test tubes are used for testing of HAZ area, and 12 for testing of the impact energy on the weld. Prior to test tubes preparation, there was the process of specimens preparation in order to detect HAZ area, weld and fusion line. Preparation was performed with 5 % HNO_3. After preparation, areas of HAZ and fusion line in specimens were exactly determined. Specimens were used for test tubes to measure impact energy. Position of V-notch in HAZ in relation to fusion line was changed for 0,5 mm, as presented in the Figure 3.

Each moving of the V-notch tip for 0,5 mm was done by an electronic milling machine. Impact energy was measured at four different positions within HAZ with respect to fusion line. Obtained results of measuring are overviewed in the Table 5.

Research results referring to impact energy as depending on the movement from the fusion line and mean value of effective input energy are presented on

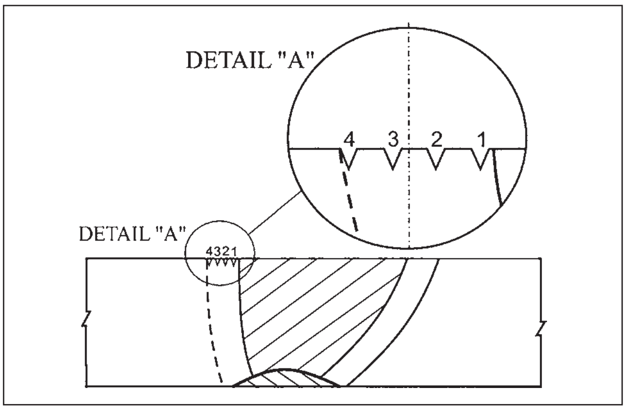

Figure 3 Position of V-notch in HAZ in relation to fusion line (V-notch position from the fusion line: 1 – 0,5 mm; 2 - 1,0 mm; 3 - 1,5 mm and 4 - 2,0 mm)

Table 5 **Results of impact energy measurements**

Average heat input / J/mm	Distance from the fusion line			
	0,50	1,0	1,5	2,0
E_{av} = 570	70	75	180	155
	72	77	180	155
	70	72	177	160
E_{av} = 859	121	135	180	160
	125	131	180	158
	120	130	185	163

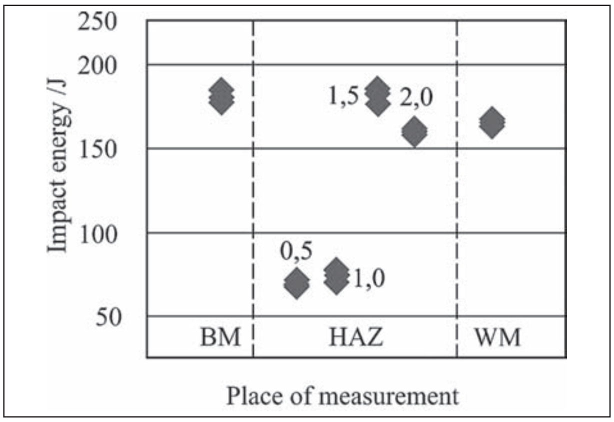

Figure 4 Results of testing the impact energy for mean value E_{ef} = 570 J/mm

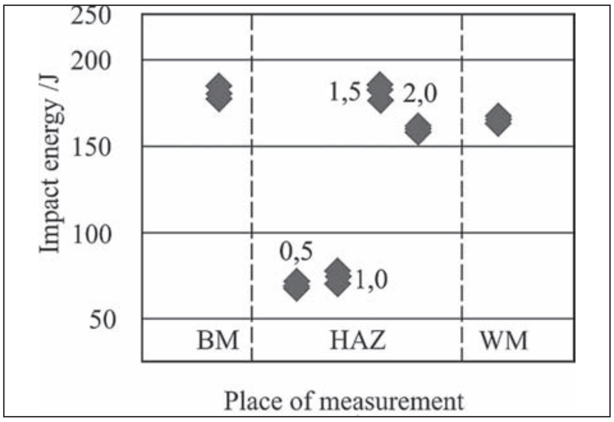

Figure 5 Results of testing the impact energy for mean value E_{ef} = 860 J/mm

Figures 4 and 5. Along with marking of toughness in HAZ, there is also the distance from the fusion line marked (0,5, 1,0, 1,5 and 2,0 mm). The testing was performed at a room temperature.

Specimens were also tested for hardness HV10 according to HRN EN 9015-1 at two positions, as shown in the Figure 6.

Results of hardness measuring are overviewed in the Figure 7.

It can be concluded that hardness in HAZ was increased for 110 HV in relation to hardness of base material at first measurement. In the second measuring, hardness in HAZ was slightly increased in relation to hardness of base material, because the hardness was lowered through application of upper welds. The hardness was also reduced in the weld metal if compared to the base material.

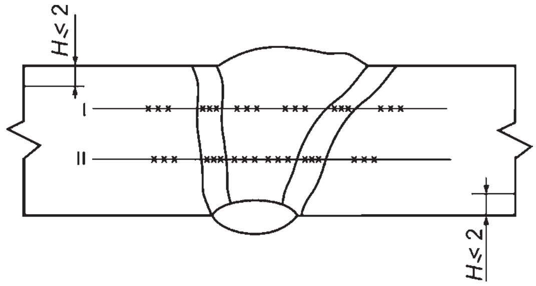

Figure 6 Positions for measuring of hardness in real welded joint

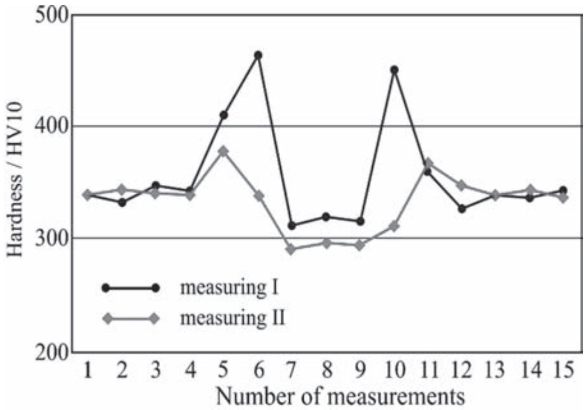

Figure 7 Dependence of hardness HV10 on measurement positions

CONCLUSION

Technology of welding the S960QL steel is based on controlled energy input during welding (pre-heating, temperature between passes, heat input generated by the electric arc, reheating) and on strict application of defined procedure, all with the aim to avoid cold cracks and other errors in manufacture, and to achieve required properties of welded joint. Insufficient heat input usually affects the increase of welded joint strength and hardness, which, along with residual stresses and presence of hydrogen in the weld, can cause cracks, reduce deformability and increase the tendency to brittle fracture [4].

The highest value of impact energy is related to 1,5 mm and 2,0 mm long distances from the fusion line. Values of the impact energy at a distance from the fusion line of 0,5 mm and 1,0 mm were approximately equal, and for two and a half times lower than the impact energy in specimens made at 1,5 mm distance from the fusion line, which is also conditioned by hardness higher than 400 HV 10 (Figure 7).

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Note: Responsible translator: Martina Šuto, University of Osijek, Croatia