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EFFECTS OF REAL WELDING PARAMETERS OF HIGH-STRENGTH S1100QL STEEL ON HARDNESS AND IMPACT ENERGY PROPERTIES

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The research objective was to test the parameters of real welding of the high-strength micro-alloyed S1100QL steel against the hardness and impact energy. The samples were welded at different welding parameters. Results of measuring the HV10 hardness and of experimental Charpy V-notch test performed at different temperatures are presented in tables and diagrams. This paper presents also the welding parameters, which provides a high quality welded joint without cold cracks.

Key words: weldability, S1100QL, hardness, impact energy, microstructure

INTRODUCTION

High-strength steels are usually fine-grained and micro-alloyed. Fine-grained steels have lower transition temperature than coarse-grained steels, and are not susceptible to fragile fracture. Good weldability is ensured also by a low carbon 0,2 % content (< 0,2 %C and Ce < 0,4). The heat input at welding shall be regulated so that heat-affected zone (HAZ) achieves the same cooling intensity as at normalization.[1] Specific welding technology related to these steels is one of the main problems, so this paper aims to investigate the Metal Active Gas (MAG) welding technology applied to the steel. The steel specificity is its small grain that increases with the heat input, so it is necessary to find the optimum welding parameters in order to assure maintenance of the steel properties.

RESEARCH OBJECTIVE

The authors studied the parameters of real welding of the ultra strong improved S1100QL steel and their effect on hardness and impact energy, with the aim to obtain the weld of acceptable mechanical properties and without cold cracks.

Chemical elements contained in the examined steel are overviewed in the Table 1, and its mechanical properties are presented in the Table 2.

Table 1 **Chemical compositions of S1100QL steel / wt. %**

Base materials	HRN EN 10025-6	Measured values
C	max. 0,20	0,17
Si	max. 0,50	0,25
Mn	max. 1,70	0,88
P	max. 0,02	0,005
S	max. 0,005	0,002
Cr	max. 1,50	0,49
Mo	max. 0,70	0,41
Ni	-	1,28
Nb	-	0,02
V	-	0,02
Co	-	0,03
B	-	0,003

Table 2 **Mechanical properties of S1100QL (HRN EN 10025-6)**

Mat.	Yield strength R_e / MPa	Tensile strength R_m / MPa	Elon-gation A_5 / %	Impact energy K_V / J
HRN EN 10025	min. 1 100	1 200 - 1 500	min. 8	- 40 °C ≥ 30
Mea-sured values	1 120	1 430	12,5	55

PRE-HEATING

In addition to welding, pre-heating of high-strength steel has positive effects on the properties of the welded joints. Pre-heating slows down the cooling of welded joints, which results in structures created in the weld metal (WM) and especially in the heat-affected zone (HAZ) that are less prone to tempering. There are also favorable conditions created for the release of gases from the weld metal, thus reducing the occurrence of porosity and the amount of dissolved gases in WM and HAZ, which is particularly important when referring to hydrogen. Moreover, residual stresses are reduced due

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to the lowering of the temperature gradient. All above-stated positively influences less appearance of cold cracks in the welded joints.

Pre-heating may also have a negative effect on the properties of welded joints, because it may increase the occurrence of hot cracks [2], it can lead to the spread of HAZ, to the spread of the coarse-grain part of HAZ and to the growth of grain in the HAZ, all of which result in deterioration of mechanical properties and toughness in this part of the joint [3]. Pre-heating and maintenance of the inter-pass temperature slow down the preparation of welded constructions and increase the costs of their production. For this reason, steel producers focus on development of new generations of high-strength steels that require lower pre-heating temperatures or no pre-heating at all.

PERFORMED RESEARCH

In order to investigate the effects of welding parameters on hardness and impact energy, there were four butt joints welded on the plates (P_1, P_2, P_3 and P_4) in dimensions 300 x 300 x 12 mm.

Plate edges were processed mechanically in the “V” arrangement, the dimensions of which and the order of welding are presented in the Figure 1.

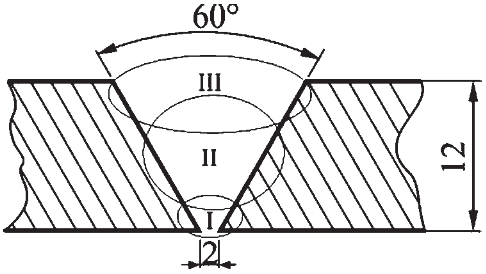

Figure 1 Shape and dimensions of the grove and the order of welding.

Welding of the butt joints was performed by MAG procedure with a device for automatic welding. Welding was done in the direction of sheet rolling, with the “V” preparation of the welding grove. Filler material was a full wire Union X 96 (EN ISO 16834-A, 2012.), Ø1,2 mm, produced by Böhler Welding Austria GmbH. The content of chemical elements and the mechanical properties of the filler material are overviewed in the Table 3.

Table 3. **Chemical content and mechanical properties of the filler material [4]**

<table>
<tr><th rowspan="2">Filler mat.</th><th colspan="6">Chemical composition in mass / %</th></tr>
<tr><th>C</th><th>Si</th><th>Mn</th><th>Ni</th><th>Cr</th><th>Mo</th></tr>
<tr><td>Union X 96</td><td>0,12</td><td>0,80</td><td>1,90</td><td>2,35</td><td>0,45</td><td>0,55</td></tr>
<tr><td colspan="7">Mechanical properties at standard room temperature</td></tr>
<tr><td colspan="2">$R_{p0,2}$ / MPa</td><td colspan="2">R_m / MPa</td><td>A_5 / %</td><td colspan="2">K_V / J - 50°C</td></tr>
<tr><td colspan="2">≥ 930</td><td colspan="2">≥ 980</td><td>≥ 14</td><td colspan="2">≥ 50</td></tr>
</table>

The protective gas was a mixture of 82 % Ar and 18 % CO_2 (M21) (HRN EN 14610).

The plates were cut into segments of 57 x 12 x 12 mm by water jet. Those segments were used to prepare tubes for testing of hardness and impact energy.

RESEARCH RESULTS

Welding parameters

The Table 4 shows the pre-heating temperatures (T_0), current (I), voltage (U) and weld pass speed (v) at all four weld joints, as well as the corresponding amount of heat Q.

Table 4 **Parameters of welding of butt joints on the plates P_1, P_2, P_3 and P_4.**

		T_0 / °C	I / A	U / V	v_z / cm/min	Q / kJ/mm
P_1	root	100	170	21	15	1,14
	filling	20	250	26	32	0,98
P_2	root	100	170	21	15	1,14
	filling	100	230	24	30	0,83
P_3	root	100	170	21	15	1,14
	filling	20	245	25	25	1,17
P_4	root	100	170	21	15	1,14
	filling	100	212	24	24	1,02

Testing of hardness and impact energy

The Figure 2 presents division of locations on the real-welded samples at which the hardness was measured.

Diagrams below in the Figures 3 and 4 overview the values of hardness after real welding.

Results of impact energy at the temperatures of 20, - 20, - 40 and - 60 °C are presented in the Figure 5.

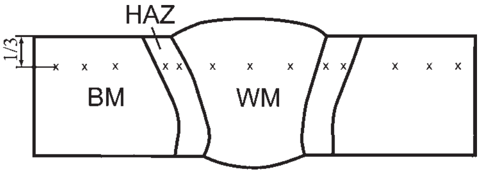

Figure 2 Positions for measuring of hardness on the real-welded samples

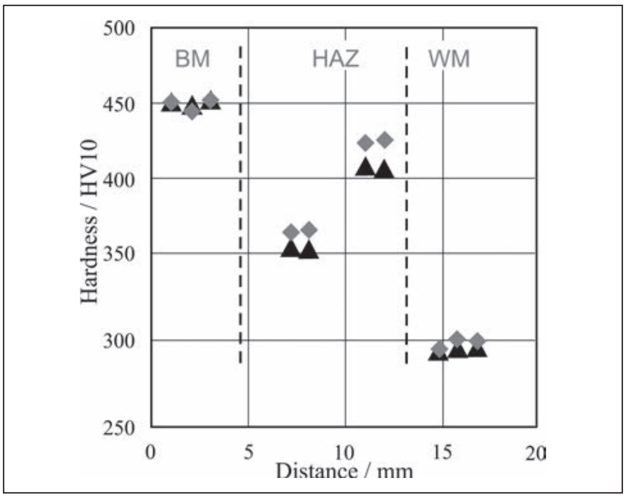

Figure 3 Diagram of hardness values in dependence of the distance for the samples P_1 (▲) and P_2 (◆).

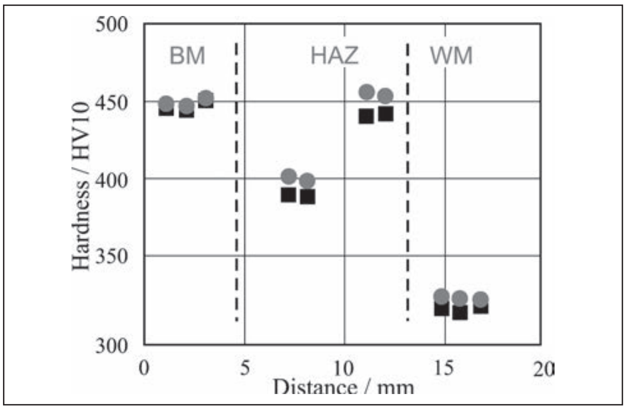

Figure 4 Diagram of hardness values in dependence of the distance for the samples P_3 (●) and P_4 (■).

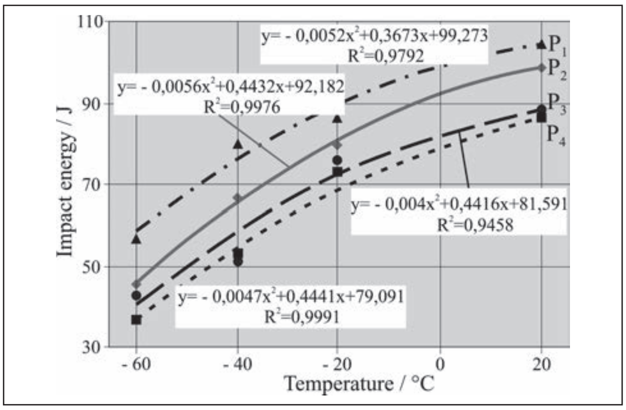

Figure 5 Dependence of the impact energy of real welded samples on the testing temperature.

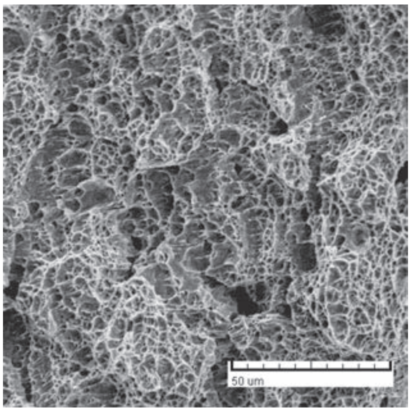

Figure 6 Base metal, temperature of testing 20°C. Impact energy 120 J.

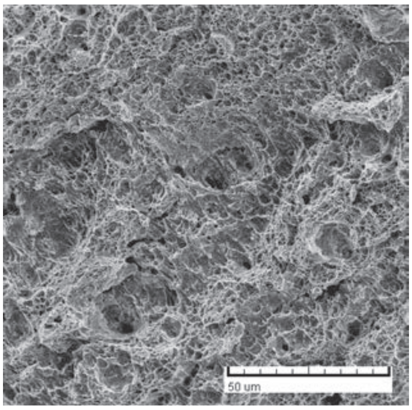

Figure 7 HAZ (preheated), temperature of testing 20°C. Impact energy 98 J.

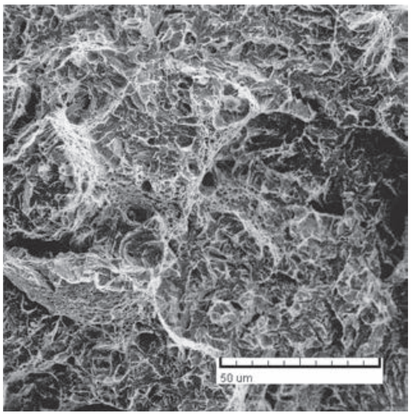

Figure 8 HAZ (without preheating), temperature of testing - 60 °C. Impact energy 33 J.

It shows that the impact energy is lower at lower testing temperatures, which is expected.

Microstructure of the S1100QL steel were tested on the SEM and presented in the Figures 6 - 8.

The microstructure is needle-like low-carbon martensite, the size of the primary austenitic grain is finer than 7.

CONCLUSION

When welding the S1100QL steel, it is necessary to control and apply selected welding parameters, because even a slight deviation can have negative effect on the quality of the welded joint.[5] The lowest values of impact energy at real-welded samples were obtained at the temperature of - 60 °C and were related to the slackened martensite grain, which was caused by hardness ranging from 380 to 430 HV. The results of testing the hardness, impact energy and microstructures showed that the pre-heating temperature, the inter-pass temperature and the heat input resulted in satisfactory hardness and microstructure in the HAZ of butt joint of S1100QL steel, when welding with the welding parameters applied on the P_4 sample plate.

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