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Properties and Structure of Resistance Short-Circuit Welded Joints in TMCP Steel S700MC

Abstract: The article presents tests concerning the structure and properties of resistance short-circuit welded joints made of 10 mm thick high yield point steel S700MC. The tests revealed the significant effect of a welding thermal cycle leading to less favourable mechanical and plastic properties of the joints. The welding process led to a decrease in tensile strength from 820 MPa (base material strength) to 660 MPa in the joint area. The welded area hardness decreased to 215 HV₁, whereas that of the base material amounted to 290 HV₁. The hardness in the HAZ area amounted to approximately 235 HV₁. The welding process also resulted in a significant decrease in plastic properties. The toughness of the steel dropped from 50 J/cm² (testing temperature being 30°C) to approximately 6 J/cm² in the weld line, approximately 8 J/cm² in the area between the weld and the HAZ and to approximately 11 J/cm² in the HAZ area.

Keywords: Steel S700MC, resistance short-circuit welded joints

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Introduction

The process of resistance welding is characterised by many characteristics connected with the variable field of temperatures as well as with widely variable physical and mechanical properties of materials subjected to welding. The nature of the formation of the heat affected zone (HAZ) influenced by the welding thermal cycle leads to the formation of highly diversified structures. The welding thermal cycle, i.e. changes in temperatures of points of the joint in time, includes changes in temperature affected by the flow of heat at every point of given volume and involves results of the above-named changes. The type of a thermal cycle affecting a given material and the HAZ influences

structural and mechanical properties. The control over the heat flow dynamics results from the appropriate performance of welding processes. The momentary cooling rate is variable and changes along with decreasing temperature. The time of cooling restricted within the temperature range of 800 to 500°C ($t_{8/5}$) is usually adopted as the parameter characterising the conditions of cooling. Consequently, types of structural transformations and resultant HAZ properties depend on the maximum thermal cycle temperature and on cooling time $t_{8/5}$. An increase in the maximum temperature is accompanied by the increased austenite superheating degree, the growth of austenite grains and the amount of precipitates dissolved in

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austenite, slowing down transformation γ - α during cooling and shifting it towards lower temperature. The presence of vanadium, titanium and niobium in the base material leads to the formation a fine-grained structure triggered by the presence of fine titanium nitride precipitates as well as vanadium and niobium carbonitrides restraining the growth of austenite grains. Welding can disturb the course of the above-named processes, leading to the uncontrolled precipitation of the MX type phases. In addition, the excessively high content of nitrogen in the base material combined with the insufficient content of elements bonding free nitrogen (aluminium, and particularly titanium) can result in aging, adversely affecting the weldability of steel.

Individual Research

The tests aimed to identify the structure and properties of resistance short-circuit welded joints made of 10 mm thick high yield point steel S700MC as well as to assess the effect of the welding thermal cycle on the mechanical and plastic properties of the joints. The chemical

composition and the mechanical properties of the test steel are presented in Table 1. The structure of steel S700MC is presented in Figure 1.

Welding Process

The tests involved a resistance short-circuit welded joint made of steel S700MC (10 × 10 mm) using a ZDZ-7 welding machine (Fig. 2). Preliminary welding tests were used to adjust welding parameters (welding current, upsetting force, current flow time, welded element extension and shortening allowance) enabling the obtainment of joints satisfying the criteria of visual tests.

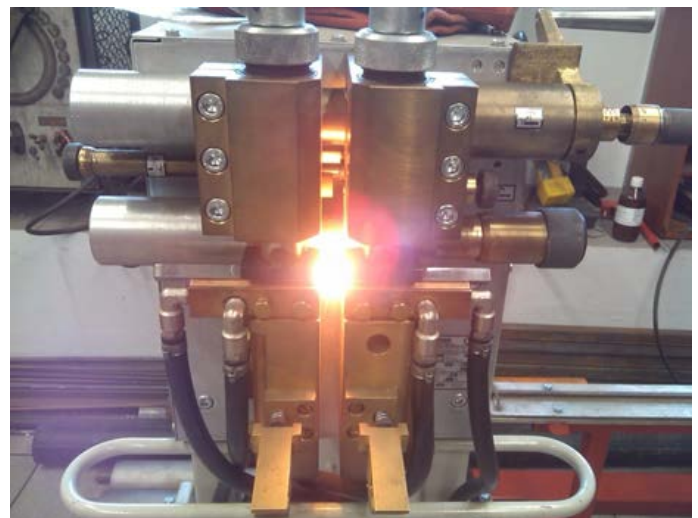


Fig. 2. Welding process

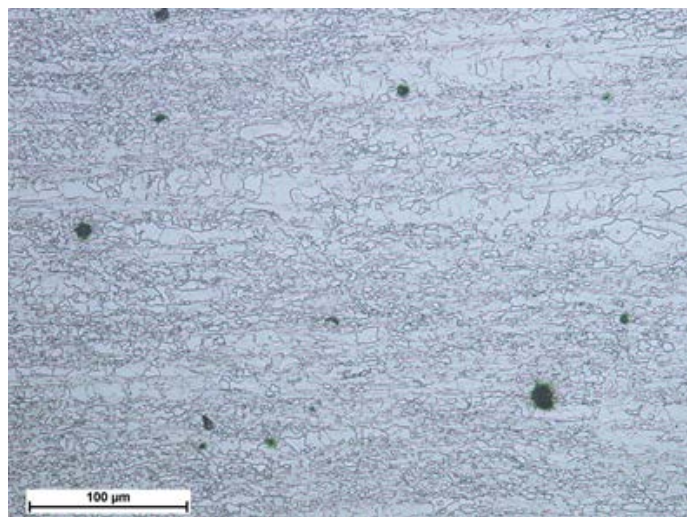


Fig. 1. Bainitic-ferritic structure of steel S700MC

Tests of Welded Joints

The test joints were subjected to visual tests followed by destructive tests. To perform the above-named tests, the previously welded joints were subjected to gridding aimed to remove the excess material formed during upsetting. The scope included the following destructive tests:

- tensile tests performed in accordance with PN-EN ISO 6892-1:2010 using a ZWICK/ROELL Z 330RED testing machine,

Table 1. Chemical composition of 10 mm thick steel S700MC

Chemical element content, %											
C	Mn	Si	S	P	Al	Nb	Ti	V	N*	Ce**	
0.056	1.68	0.16	0.005	0.01	0.027	0.044	0.12	0.006	72	0.33	

* - N: content in ppm; nitrogen determined using the high-temperature extraction method

** Ce - carbon equivalent

- bend tests performed in accordance with PN-EN ISO 5173:2010 using a ZWICK/ROELL Z 330RED testing machine provided with an additional module for bend tests involving the use of a bending mandrel having a diameter of 30 mm; the distance between rollers was set at 60 mm. To identify the position of the weld axis, the specimens were etched using Adler's reagent;
- impact strength tests performed in accordance with PN-EN ISO 148-1:2010 using the V-notch, a ZWICK/ROELL RKP 450 impact testing machine; the tests were conducted at a temperature of -30°C. The tests were performed in the weld line (specimen designation: A), in the area between the weld and the HAZ (designation: B) and in the HAZ (designation: C). Before the test, the specimens were etched using Adler's reagent;
- macroscopic metallographic tests performed using an Olympus SZX9 stereoscopic light microscope. Before the tests, the specimens were etched using Adler's reagent;
- microscopic metallographic tests performed using a NIKON ECLIPSE MA100 light microscope. Before the tests, the specimens were etched using Nital;
- Vickers hardness test performed in accordance with PN-EN ISO 9015-1 using a WILSON WOLPERT 430 tester. The hardness measurements were performed along three measurement lines, two millimetres from the lower and upper surface of the specimen and inside the specimen.

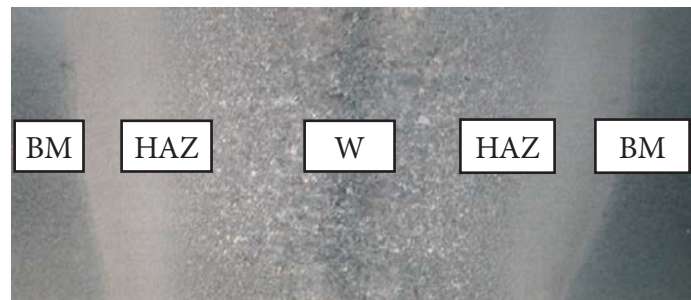


Fig. 3. Macrostructure of the welded joint made of steel S700MC

presence of cracks, porosity or incomplete fusions. The macroscopic metallographic tests did not reveal the presence of welding imperfections in the weld and HAZ areas (Fig. 3).

The microscopic metallographic tests revealed the coarse-grained ferritic-bainitic structure of the weld. The size of grains was considerably smaller in the HAZ, which could be attributed to heat emitted during resistance welding (Fig. 4).

The analysis of the destructive test results concerning the welded joints revealed the significant effect of the welding thermal cycle on the mechanical and plastic properties of the joints. The welding process led to a decrease in tensile strength to approximately 660 MPa (in relation to that of the base material amounting

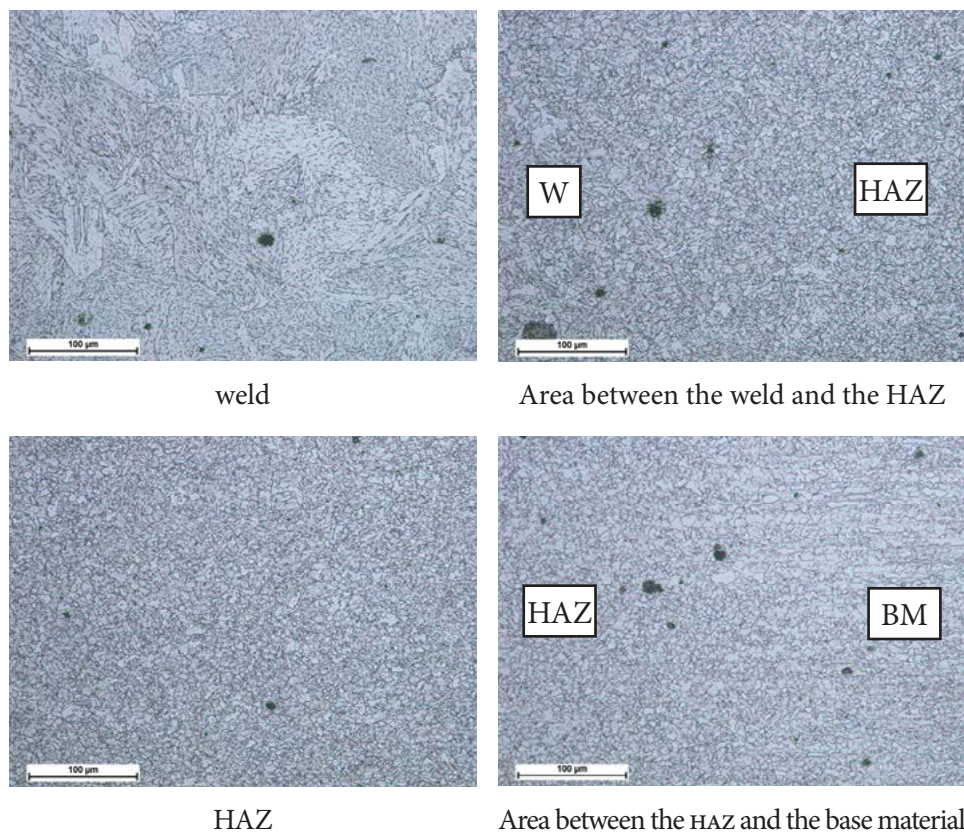


Fig. 4. Microstructure of the welded joint made of steel S700MC

Analysis of Test Results

The visual tests of the welded joints did not reveal the

to 820 MPa). The rupture took place in the weld, where the structural notch was formed. The above-named reduction of tensile strength was related to the loss of properties obtained by steel S700MC in the thermomechanical control process. The bend test resulted in the obtainment of a bend angle of 180°, yet with visible cracks in the welding area. The hardness tests (performed at a temperature of -30°C) using the Charpy impact testing machine revealed a very significant decrease in the plastic properties of the welded joints made of steel S700MC in comparison with the toughness values concerning the base material. The lowest value was observed in the weld line and amounted to approximately 6 J/cm². Along with an increase in the distance from the weld line, toughness increased slightly reaching approximately 8 J/cm² in the area between the weld and the HAZ and to approximately 11 J/cm² in the HAZ (Fig. 5). Each area of the welded joint contained brittle fractures (Fig. 6). The hardness tests revealed a significant decrease in the hardness of the fusion line (215 HV1) in relation to that of the base

material (290 HV1). The hardness in the HAZ area amounted to 235 HV1 (Fig. 7).

Summary

Steel S700MC was characterised by the considerably defected bainitic-ferritic structure. A very low carbon content of 0.05%, primarily bounded by titanium and niobium, resulted in the decreased contribution of carbon to steel hardening and reduced its effect during phase and structural transformations. The analysis of the short-circuit butt welded joints made of steel S700MC revealed the possibility of making welding imperfection-free joints. However, welding process decreased the mechanical and plastic properties of the areas subjected to welding. The heat input during welding as well as the structural strain in the weld area resulted in the loss of properties obtained through the thermomechanical control process. The toughness of the steel dropped to approximately 6 J/cm² in the weld line, approximately 8 J/cm² in the area between the weld and the HAZ and to approximately 11 J/cm² in the HAZ. The decrease

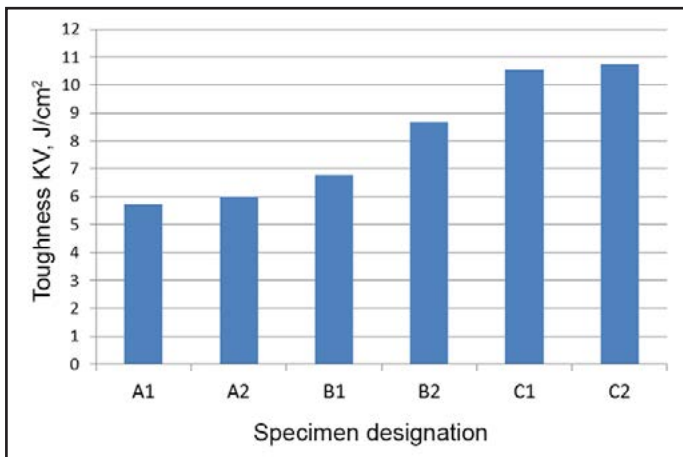


Fig. 5. Toughness of the welded joint made of steel S700MC

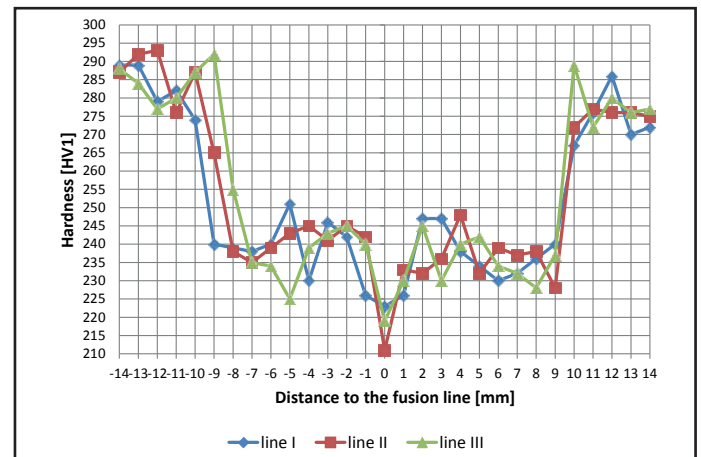


Fig. 7. Hardness distribution in the welded joint made of steel S700MC



Specimen fracture in the welding area



Specimen fracture in the area between the weld and the HAZ



Specimen fracture in the HAZ

Fig. 6. Fractures after the impact strength test

in toughness in the welding area could be attributed to structural changes as well as to the uncontrolled precipitation of the MX type phases. The tensile strength of the joint decreased (in relation to that of the base material) from 820 MPa to 660 MPa. The welded area hardness decreased to 215 HV₁, whereas that of the base material amounted to 290 HV₁. The hardness in the HAZ area amounted to approximately 235 HV₁.

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