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The effect of a welding method on the structure of a welded joint

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Abstract

This work explains the influence of a local structural heterogeneity and resulting mechanical heterogeneity in welded joints on the location and nature of welded joint failure. Toughened structural steel S355 with a thickness of 7mm, welded using laser beam or gas metal arc welding (GMAW) was used for the purposes of this analysis. Hardness penetration pattern in welded joint cross-section was defined and mechanical properties of a welded joint in static tensile test (Re, Rm, A_5, Z) were determined. Microstructure and microfractographic tests of fractures were performed.

Key words: *laser beam welding, GMAW, hardness, macrostructure, microstructure*

1. Introduction

Welding methods use heat sources with a different level of energy flux concentration. Particularly difficult to establish are relations between local structural changes and mechanical properties of welded joints. From a practical point of view, these relations have a decisive effect on the weldability of metals, as well as affecting welding technology itself and, ultimately, working properties.

Finding solutions to complex technical problems, dependent on the identification of both physical processes related to welding and its effects within a welded joint and the entire structure is the subject of numerous experimental and theoretical studies [1,3-6,9].

The current knowledge based on the studies of heat-induced structural changes which accompany welding is insufficient to provide an in-depth analysis of the influence of microstructure differences in the vicinity of a welded joint on the mechanical properties [1,3]. According to E. Ratanowski [8,9], the differences of the microstructure within a welded joint area lead to changes of the local stresses and mechanical properties, as well as determining location and nature of welded joint failure.

The aim of this study is to analyse the structure and properties of a welded joint obtained at significantly different values of heat energy concentrations.

2. Material, programme and testing methodology

Toughened structural steel S355 with chemical composition as provided in table 1 was used for the studies.

Table 1. Chemical composition of S355 steel (percent of mass)

C	Si	S	P	Mn	Ni	Cr	Mo	Cu	Ti	Al	Sn	Zn	Mg
0.212	0.403	0.008	0.014	1.416	0.067	0.030	0.009	0.021	0.0	0.053	0.008	0.020	0.049

Mechanical properties of tested steel were defined based on a static tensile test. The properties are as follows: Re=734MPa, Rm=797MPa, A_5=11.2%, Z=42.4%).

Single-run butt welding of test plates with a thickness of 7mm and dimensions of 300x100mm using GMAW or laser beam welding was performed. Transverse macroscopic welded joint microsections etched with Marble reagent were made. Hardness penetration pattern was determined using Vickers HV1 method. Flat quintuple tensile test specimens were cut from the plates. Metallographic nital etched specimens were observed under an optical microscope. Microfractographic analyses of fractures following tensile tests were performed using SEM.

3. Test results

Macrostructure of a welded joint made using GMAW is presented in figure 1, while that of a joint made using laser beam welding in figure 3. Hardness penetration patterns in weld cross-section (figure 2 and 4) were made in each of the areas characteristic of a welded joint (MP-HAZ-SP) halfway through the thickness of the plates.

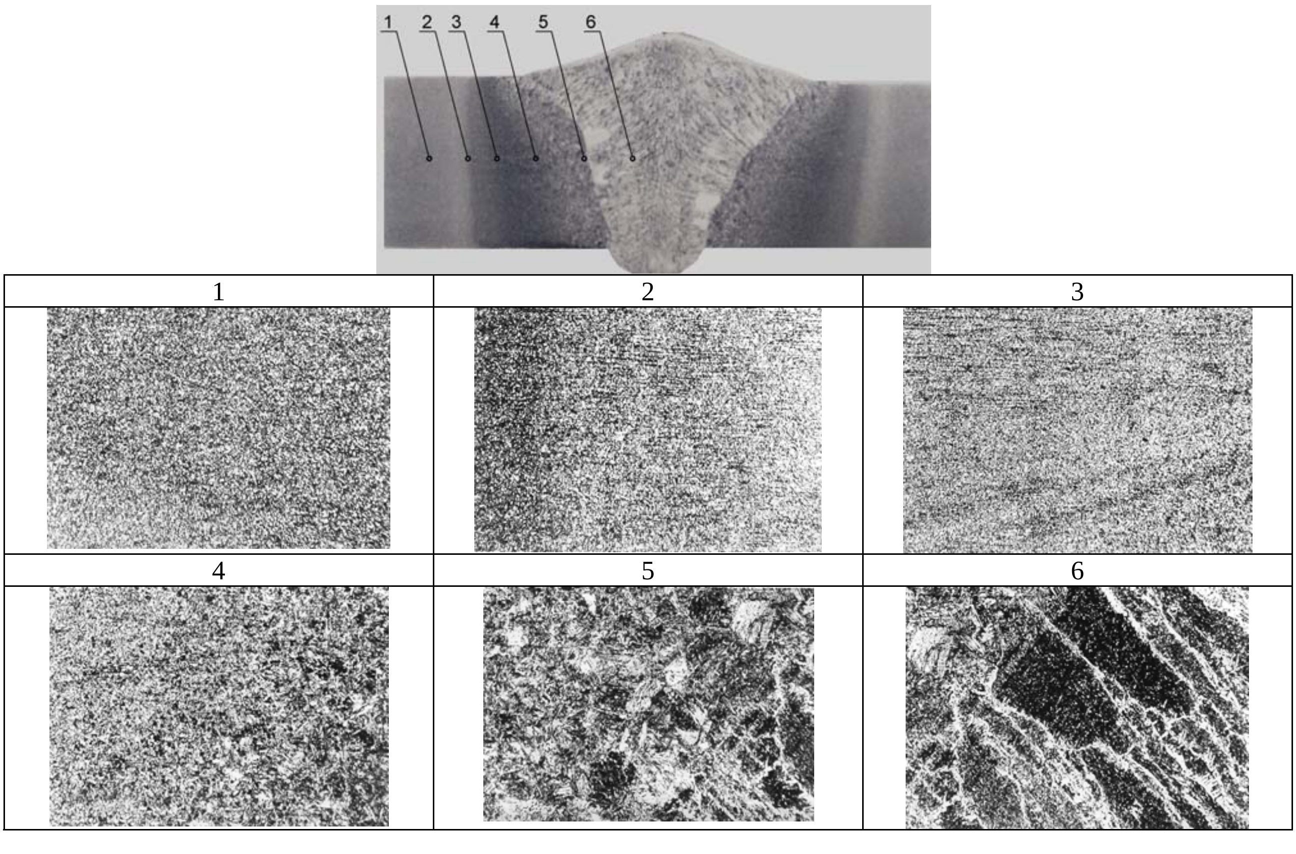

Figure 1. Macrostructure of a joint welded using GMAW, magnified 4x times. Microstructure of numbered areas, 70x times magnified, nital etched

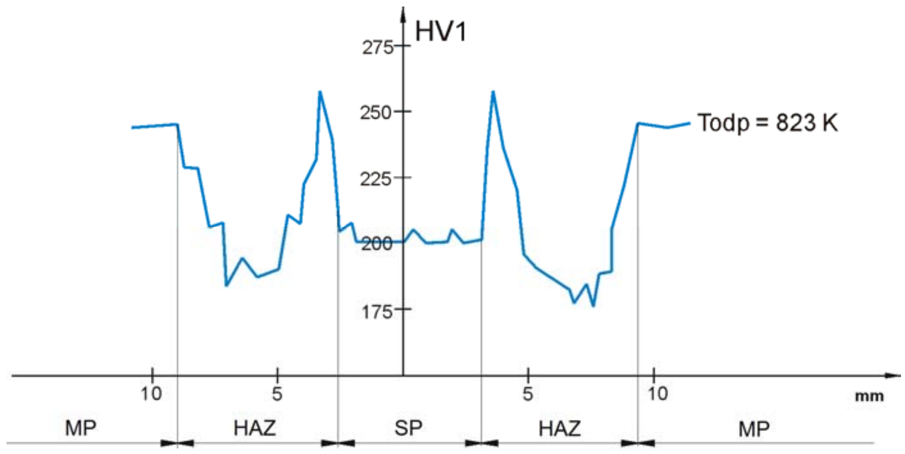

Figure 2. Hardness penetration pattern in cross-section of a joint welded using GMAW

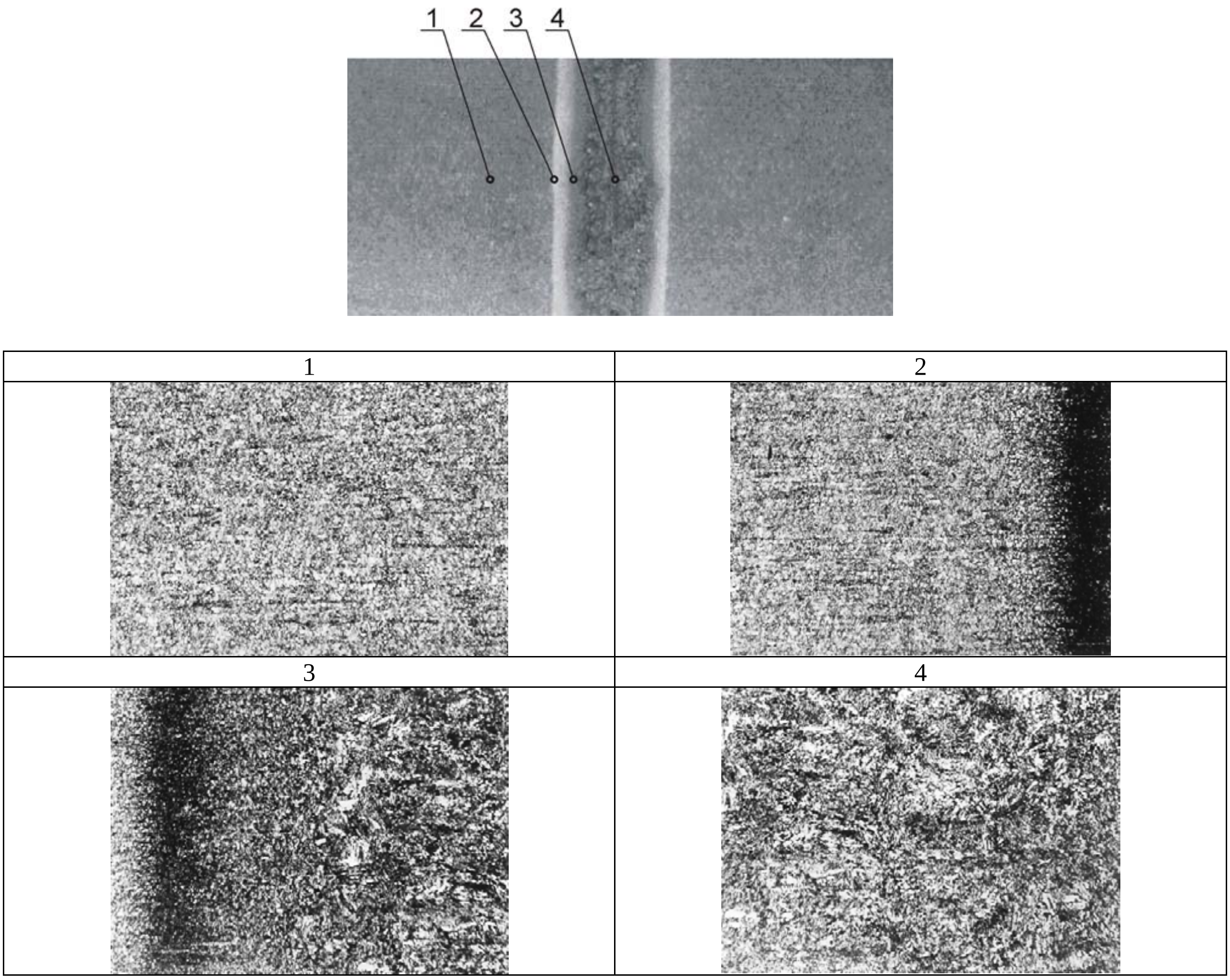

Figure 3. Macrostructure of a laser beam welded joint, magnified 6x times. Microstructure of numbered areas, 70x times magnified, nital etched

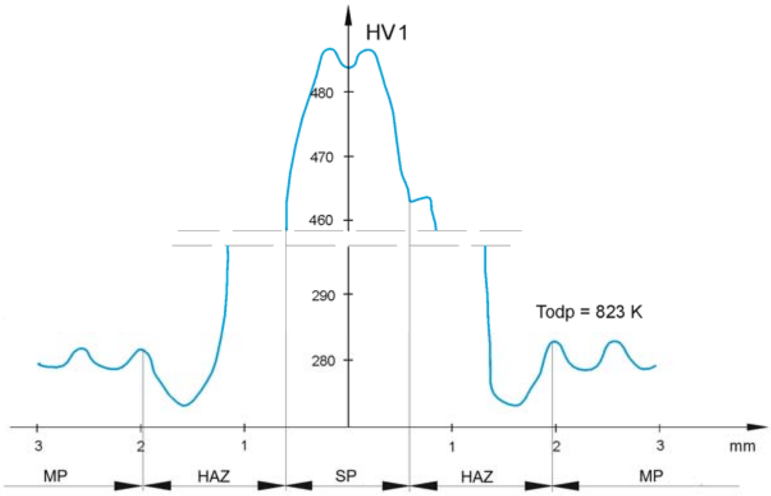

Figure 4. Hardness penetration pattern in a laser beam welded joint cross-section

Strength properties of welded joints are presented in table 2. Measurement results were given confidence interval at coefficient 1-α = 0.95.

Table 2. Results of welded joints static tensile test

Welding method	$\mathbf{Re_{śr}}$, MPa	$\mathbf{Rm_{śr}}$, MPa	$\mathbf{A_{5śr}}$, %	$\mathbf{Z_{śr}}$ %
GMAW	480.6 ± 31.8	686.0 ± 11.8	12.88 ± 1.27	38.98 ± 6.33
Laser beam welding	737.4 ± 8.7	793.2 ± 4.1	11.34 ± 0.72	42.77 ± 1.97

Joints made using GMAW were destroyed in the areas with reduced hardness, i.e. in the joint area or in the heat-affected zone. Laser beam welded joints become destroyed only in base metal.

As a rule, joints made using GMAW become destroyed in the areas with reduced hardness, i.e. in the joint area or in the heat-affected zone. Reduced hardness in these areas results from the microstructure that occurs there. The microstructure of an SP weld with a hardness of ca. 200HV consists of coarse-grained, column ferrite and pearlite. The narrow heat-affected zones with increased hardness adjoining the welded joint have a fine pearlite structure. During the heating, these areas had an austenitic structure. The relatively high speed of heat penetration into the inside of the material causes austenite to be converted into dense pearlite with a hardness of 255HV. The subsequent area of reduced hardness (fig. 2) results from the conversion of austenite under conditions of lower cooling and tempering speed (temperature belowAr_1).

In the case of laser beam welding, energy concentration within a small area of a welded joint and a very large gradient of temperature causes non-diffusive transformation to occur, which results in obtaining a maximum hardness of 490HV (fig. 4). The joint is destroyed as a consequence of tensile test only in base metal.

Morphological characteristics of the fracture surfaces in specimens depend on the location of a fracture (base metal, heat-affected zone and weld). This is closely connected with the type and quantity of structures present there.

In the case of GMAW, fractures most often run along the border of the heat-affected zone – base material or in the weld. The occurrence of a coarse-grained ferritic and pearlitic structure in these areas determines largely the nature of fractures which can be classified as transcrystalline ductile and fissile with ductile being predominant.

Laser welded specimens were destroyed in base metal. The fracture is mainly transcrystalline and ductile with small fissile fracture presence (fig. 7).

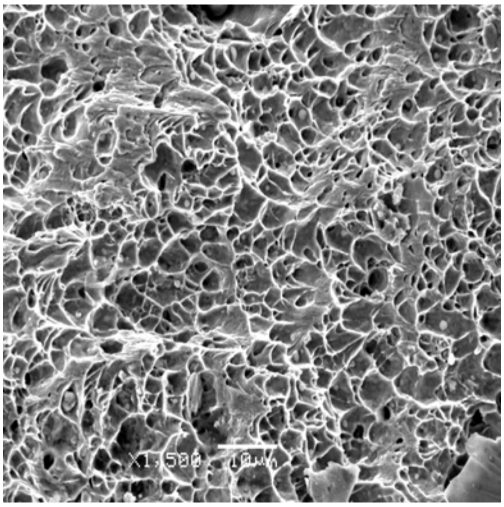

Figure 5. Microfractography of a joint welded using GMAW, fracture in the heat-affected zone, 1500x times magnified

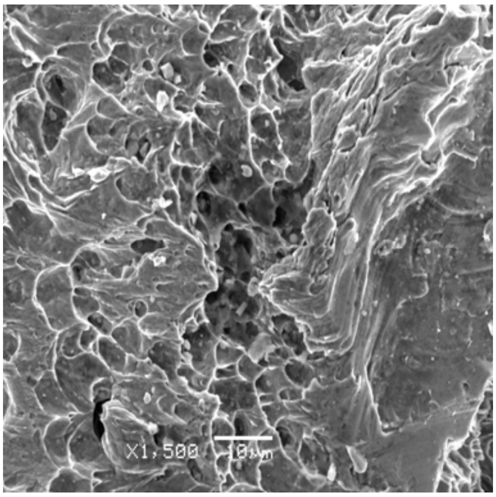

Figure 6. Microfractography of a joint welded using GMAW, fracture in the weld, 1500x times magnified

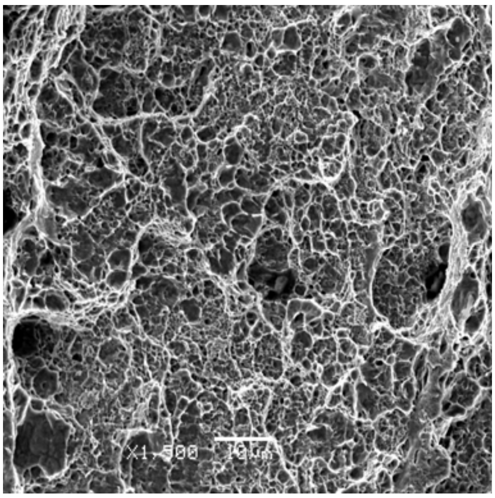

Figure 7. Microfractography of a laser welded joint, fracture in the base metal, 1500x times magnified

Experimental studies enabled the widths of areas with different hardness to be determined. The outcome of the experimental tests was input data for MES numeric calculations [4]. The basis for determination of the areas with a varied microstructure was the value of maximum temperature and time $t_{8/5}$, which was determined based on the temperature isotherms running through any given cross-section point. With time values $t_{8/5}$ as a function of a distance from the weld axis, it was possible to set the width of respective zones using CTPc-S graphs [2,7]. The widths of the zones established based on MES and experiments, both for GMAW and laser beam welding demonstrated good compliance.

4. Conclusions

A joint welded using GMAW becomes destroyed in areas with reduced hardness compared to base metal, i.e. in the weld area or in the heat-affected zone, whereas in the case of laser beam welded joints the failure is located only in base metal.

Fracture in GMA welded joints is combined, transcrystalline fissile with some ductile characteristics. Fracture in laser welded joints is transcrystalline and ductile with small fissile fracture present.

The strength of a GMA welded joint is substantially reduced compared to that made using laser beam welding. Worth noting is also much higher scatter of results around the average in the case of GMAW compared to laser beam welding.

Further tests should be focused on determining parameters of joint crack resistance.

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