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INVESTIGATION OF HARDNESS PROFILES AND MICROSTRUCTURE CHANGE IN THE WELD NUGGET AND HAZ OF RESISTANCE SPOT WELDED LOW CARBON STEEL

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ABSTRACT
Metallurgical changes in weld nugget and heat affected zone (HAZ) during resistance spot welding of low carbon steel sheets is very important factor that determines final mechanical properties of welded joint. Thus, effect of spot welding parameters (current, welding time, holding time) on the mechanical and microstructural properties of weld nugget and heat affected zone were analysed in this work. Hardness was measured using Vickers method, while results were presented in the form of hardness distribution over a cross section of weld nugget and HAZ, for different welding parameters. It was observed that hardness in heat affected zone and melting zone is very dependent on welding parameters. Also, tensile tests showed that strength of the joint is very susceptible to welding parameters and thickness of the parent material. Microstructural changes in the weld nugget zone and heat affected zone were examined and analysed for some specific samples.
Key words: Resistance spot welding, low-carbon steel, hardness profile, microstructure

1. INTRODUCTION
Resistance spot welding is a process where heat necessary to melt and formation of weld nugget is generated by virtue of resistance to the flow of electric current through workpieces. Formation and properties of weld nugget and heat affected zone (HAZ) are very dependent on the electrical and thermal properties of the material being welded [1]. Heat generation relies on contact resistance and bulk resistance of the materials. In addition to current, time and electric resistance, electrode force and electrode shape are also the parameters that influences weld quality and contact resistance. Electrode force keeps workpieces together and prevents the molten metal to escape from the contact and, also affect the contact resistance [2]. Resistance spot welding is the most widely used joining technique for the assembly of sheet metal products such as automotive bodies [3,4], domestic appliances, aircraft components, etc . Also, low carbon steel sheets are the group of materials being welded very often. In this regard, effect of spot welding parameters (current, welding time, holding time) on the properties of weld nugget and heat affected zone was studied in this work. Microstructure, strength of the weld, hardness distribution across weld nugget and heat affected zone are experimentaly studied and analysed during investigation.

2. EXPERIMENTAL WORK
2.1. Material and methods
Low carbon steel sheets used for domestic appliances were used in this study. Chemical composition of the material is as follow: C=0,07%, Mn=0,39%, Si=0,007%, P=0,011%, S=0,009%, Al=0,038%, Cu=0,02%, Cr=0,03 % i Ni=0,01%, while mechanical properties are: Rv=291 MPa, Rm=364 MPa, HV1=140. Experimental specimens were cut from hot rolled coils using APH – Abkant Pres Hidrolik. Metallographic examination reveals prevailing ferritic microstructure (Figure 1.)

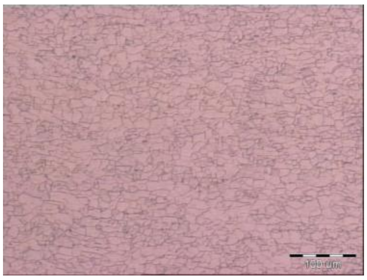


Figure 1. Microstructure of parent material

Experiments were performed using following sheet thicknesses 0,8mm, 1mm, and 2mm. Welding of prepared specimens were done using spot welding machine Tecna 4603N with 48 kVA and maximal current of 11,6 kA .Welding current and time were varied between 4000 – 5700 A, and 0,2 – 0,28 s , respectively. Welding force applied was F=860 N, and force cycle duration was between 0,2 – 0,28 s. Tensile shear tests were performed using ZWICK Machine 30kN. Hardness examination was done using Vikers method.

3. RESULTS AND DISCUSSION

Tensile shear tests results and welding parameters are presented in the table 1. Statistical analysis showed that the most influential factor is current. It can be seen that maximal strength was obtained using the highest values of the current and the welding time. Increasing of the current from 4000A to 5700A resulted in increased strength for about 15%. Higher the heat input caused the growing of weld nugget, which resulted in improved strength of the joint. Also, it can be seen that strength of the weld is very dependent of sheet thickness. Increasing of sheet thickness from 0,8 mm to 1 mm resulted in very significant change in weld strength for almost 30% (Figure 2), which is very important data to consider during sheet selection phase. All specimens failed in the area which belongs to the heat affected zone, where weld nugget was pulled out from the sheet (Figure 3). This kind of failure belongs to pullout failure mode according to [5].

Tabele 1. Tensile shear tests results and welding parameters

R.br.	I_z	t_z	$t_1 = t_4$	Fm (kN) 0,8mm	Fm (kN) 1mm
1	4000	0,2	0,2	3,49	4,46
2	5700	0,2	0,2	4,04	5,08
3	4000	0,28	0,2	3,48	4,51
4	5700	0,28	0,2	4,21	5,30
5	4000	0,2	0,28	3,64	4,54
6	5700	0,2	0,28	4,11	4,94
7	4000	0,28	0,28	3,61	4,83
8	5700	0,28	0,28	4,02	5,33
9	4850	0,24	0,24	3,63	4,99
10	4850	0,24	0,24	3,79	5,00
11	4850	0,24	0,24	3,66	4,90
12	4850	0,24	0,24	3,77	4,92

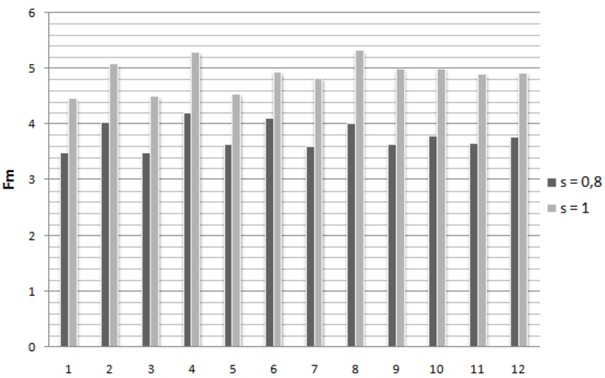


Figure 2. Weld strength for thicknesses 0,8mm and 1mm.

Figure 3. Failure of the weld

Weld nugget geometry analysis showed that increasing of the current from 4000- 5700 A caused raising of the average weld nugget diameter from 3,03 mm to 3,59 mm. Also, extension of the welding time affects the nugget geometry in the very similar way as the welding current, while variations of holding time caused insignificant variation of the weld nugget diameter. Taking into account all aforementioned, it can be concluded that increasing of the weld nugget diameter using the higher heat input has a very important influence on mechanical properties of the welds.

Increasing of thickness of material required the higher heat input in order to attain welding. Thus, intensified heat dissipation from welding zone and reduced resistivity was compensated by increased welding time. In this regard, prolongation of welding time from 0,65 to 0,9 s, for thickness of 2 mm, resulted in the growth of weld nugget diameter for about 25 %, (I=4000 A).
Hardness investigation showed that heat affected zone and melting zone has a very high hardness compared to parent material. Phase transformation, as a consequence of high cooling rate and generation of bainite, martensite and pearlite, caused strengthening of material in melting zone and the heat affected zone. It is very important to notice that hardness values do not depend only on welding parameters, but also on distance from the weld nugget center. Changes in microstructure and grain size in different zones of weld nugget and HAZ have shaped the hardness profiles. It can be seen that higher welding heat input results in increased hardness values. Increasing of current, as the most influential factor, from 4000 to 5700A causes raising of average hardness for about 14%, taking into account the hardness of melting zone and heat affected zone (Figure 4).

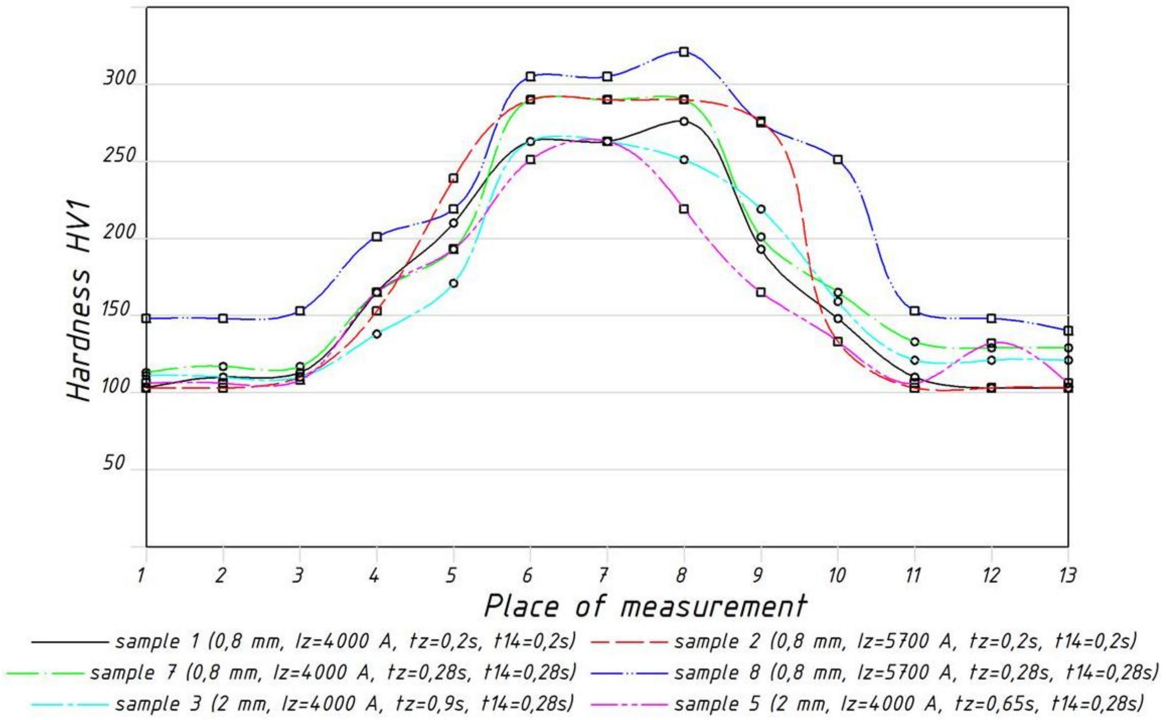
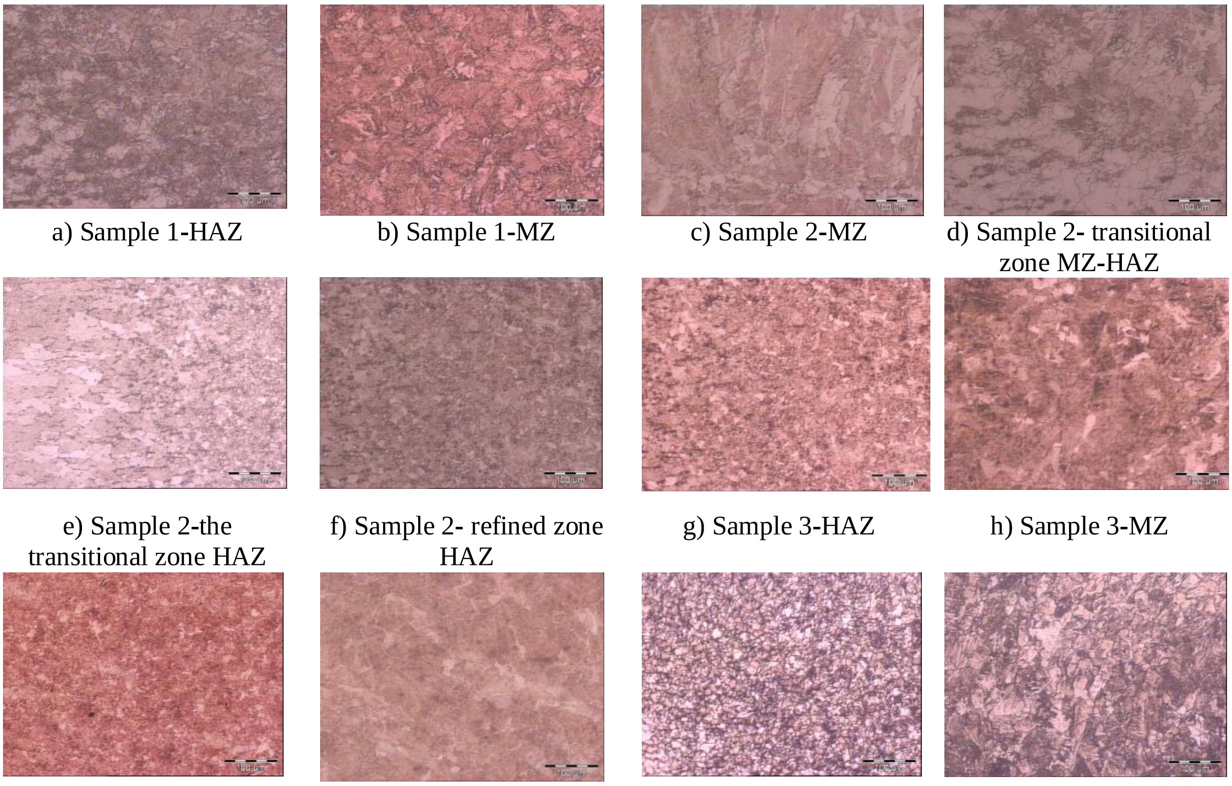


Figure 4. Hardness distribution in weld nugget and HAZ [6]

During cooling, formation of microstructure is mainly dependent on cooling conditions. High cooling rates, which follows resistance spot welding, causes formation of martensite and bainite in the melting zone and HAZ (Figure 5). These phases explains sudden increase in hardness. In addition to microstructure changes, heat affected zone experienced grain size changes in accordance with the distance from melting region and the peak temperature experianced during welding. Microstructure examination was presented in the figure 5. The zones next to the melting region, which were subjected to higher temperature experienced intensified grain growth. Figures 5c, 5d, 5e, 5f presents microstructure in differents zones of sample 2, starting from melting zone (MZ) 5c, trough graing growth zone 5d, transition to grain refinement zone 5e and refined zone. In addition to aforementioned, phases Widmanstatten and grain boundary ferrite appear in the weld nugget zone (Figure 5).



a) Sample 1-HAZ b) Sample 1-MZ c) Sample 2-MZ d) Sample 2- transitional zone MZ-HAZ

e) Sample 2-the transitional zone HAZ f) Sample 2- refined zone HAZ g) Sample 3-HAZ h) Sample 3-MZ

i) Sample 5-HAZ j) Sample 5-Melting zone k) Sample 7- HAZ l) Sample 7- MZ

Figure 5. Microstructure of the weld nugget and heat affected zone[6] (Samples designated as in Figure 4)

4. CONCLUSION

Quality of resistance spot welded of analysed material is very susceptible to welding parameters and material thickness. The most influential parameter is welding current, followed by welding time, while holding time did not affect so intensive. Increasing of welding current improves weld strength for about 15%, while small variation of thickness changed strength for approximately 30%. Phase transformations that took place during high cooling rate of melting zone and heat affected zone caused formation of hard phases that increased hardness up to 300HV1. Also, increasing of heat input affected weld nugget dimensions and hardness of HAZ and melting zone. It was found that raising of welding current resulted in average hardness increasing for about 14%. Increasing material thickness to 2 mm required raising the heat input to succesfully weld. In this regard, prolongation of welding time from 0,65 to 0,9s resulted in weld nugget diametar raising for about 25%.

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