ANALYSIS OF WELDABILITY OF DUAL-PHASE STEEL SHEETS USED IN CAR BODY PRODUCTION

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Materials used in car body production are joined by resistance spot welding as the dominant method of joining. Significant changes occur in mechanical and metallurgical properties of the weld nugget and heat affected zone during welding process. The research into these changes is very important for estimation of optimal welding parameters to ensure the required quality of welded joints. The paper deals with the problems of weldability of high strength dual-phase steel sheets used in the car body production. Dual-phase steel was developed specifically for automotive industry to benefit from its formability and crash absorption ability in comparison with conventional advanced high-strength steels. Weldability of dual-phase steel is one of the key factors governing its application in automotive industry. The influence of the resistance spot welding parameters, mainly welding current and welding time, on the weld quality was investigated by visual control, static tension test, and structural analysis of the joints and microhardness measurements.

KEYWORDS

resistance spot welding, tension test, metallography, microhardness

1 INTRODUCTION

Resistance spot welding (RSW) is the primary welding process for sheet metal and has been predominantly used in the automotive industry since 1950's, where it serves as a highly productive alternative to other welding methods. RSW is accomplished by passing an electrical current through coincident sheets via electrodes [Zhang 2006, Kaščák 2011]. The heat induced by the electrical current creates a molten nugget. The molten nugget grows until the electrical current ceases, at which point the nugget solidifies to create a bond between the sheets [Wei 2012, Kaščák 2013]. The current requirement for car weight reduction has led to new types of advanced high-strength steels to automobile industry. These steels have been introduced into vehicle designs in an effort to increase the collision energy management and passenger safety, while maintaining or reducing vehicle weight, resulting in fuel economy [Pouranvari 2012]. Dual-phase (DP) steel was developed specially for automotive industry as a high-strength steel with good formability and weldability. The tensile strength typically ranges from 450 to 980 MPa. The DP steel consists of hard martensitic formations dispersed in ferritic matrix; from 70 to 90% of ferrite and from 10 to 30% of martnesite [Hernandez 2010, Kaščák 2013]. Except the above mentioned phases, the structure of DP steel can include small amount of bainite, perlite and residual austenite. Increasing the volume of hard martensite phases increases the strength of steel. The characteristic of as-delivered DP steel is a relatively low yield strength and high initial work hardening resulting in a high n-value. The high n-value provides good protection against local thinning under the forming conditions of drawing and stretching [Farzin 2015]. Dual-phase steels are made by controlled cooling from the austenite phase (hot rolled steels) or from the phase of ferrite and austenite (continuously annealed cold rolled steels or hot-dip coated steels). Some part of austenite is transformed to ferrite and its rapid cooling causes the transformation of residual austenite to martensite. The ferrite phase is soft and continuous and gives the DP steel excellent ductility. During the deformation of the steel, the strain is concentrated in the lower strength ferrite phase surrounding the martensite [Caballero 2006]. The quality spot welded joint is affected by several factors such as welding current, pressing force of welding electrodes, welding time, material of welding electrode tips, thickness and material properties of the joined sheets. Investigation on weld nugget formation provide relevant information about the influence of different welding parameters on the weld properties. The influence of welding parameters of RSW on the properties of spot welds has been studied experimentally to improve the quality of the spot welds. Combination of AHSS steel and HSLA steel in welding was investigated in [Kaščák 2014]. The weldability improvement of dual-phase steels by adjusting electrode force during the spot welding process was investigated by [Xiaoyun 2009]. FEM analysis to evaluate the effects of resistance spot welding parameters on the weld properties of DP steel was verified in [Eshraghi 2014].

This research focused on the evaluation of influence of welding current and welding time on the quality of spot welds of dual-phase steel sheets DP600 used in car body production.

2 MATERIALS AND EXPERIMENTS

The material for the present study was the hot-dip galvanized dual-phase steel sheet DP600 with the thickness of a_0 = 0.9 mm, nominal value of ultimate tensile strength R_m = 623 MPa, yield strength $R_{P0.2}$ = 407 MPa and elongation A_{80} = 23 %. The microstructure of base metal shows the ferrite matrix along with dispersed martensite islands, as shown in Fig.1. The chemical composition of DP600 steel is provided in Tab.1.

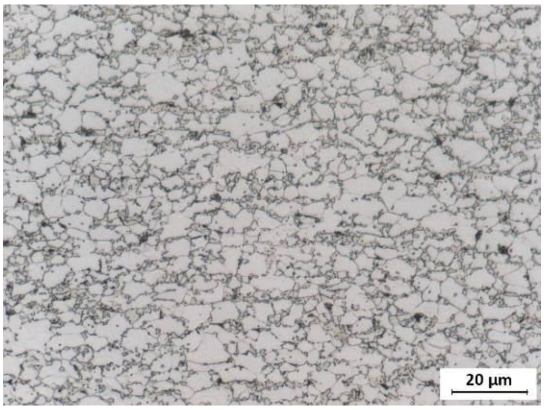

Figure 1. Microstructure of DP600 steel

Table 1. Chemical composition of DP600 steel (wt%)

C	Mn	Si	P	S	Mo	Cr
0.086	1.857	0.022	0.018	0.002	0.178	0.203

Resistance spot welding is the process where materials are joined together by passing current intensity through a relatively small area while applying the pressure for a given amount of time – Fig. 2 [Kascak 2013].

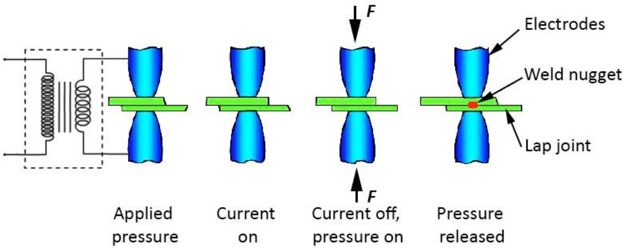

Figure 2. Principle of resistance spot welding

When metal sheets are brought into contact due to the pressure applied by both electrodes, the AC current intensity flows through the sheets with the presence of electrical resistance between the joined sheets. The electrical energy is converted into heat mainly at the faying surface between the sheets being welded. Due to the large and fast increasing rate of welding current used in the process, the temperature increases rapidly and causes the metal sheets to melt at the faying surface. A weld nugget is formed after the solidification of fusion zone and hence two sheets are joined together. Normally, the electrodes are water-cooled to prevent the electrodes from sticking onto the sheet surface [Zhang 2006].

The formation of a welded joint, including the nugget and the heat-affected zone (HAZ), strongly depends on the electrical and thermal properties of the sheet and coating materials. A weld's formation can be linked to the electrical and thermal processes of welding. Controlling the electrical and thermal parameters is a common practice in resistance welding. The general expression of heat generated in an electric circuit can be expressed as

$$Q = I^2Rt \tag{1}$$

where Q is generated heat, I is welding current, R is electrical resistance of the welding circuit and t is welding time the current allowed to flow in the circuit.

The resistance spot welding parameters for dual-phase steel sheets including welding current I, welding time T and pressing force of welding electrodes tips Fz are not normalized. DP steels can be considered as a low carbon steels, so the same welding parameters can be used for welding DP steels for the experiment. As a base for experiment, resistance spot welding parameters given by the International Welding Institute (IIW) were used.

Influence of welding parameters on the quality of welded joints was evaluated on two types of samples. Considering the theory of resistance spot welding [Zhang 2006], welding current (samples A) and welding time (samples B) were changed and pressing force of electrode was constant. The pressing force influences the contact resistance - insufficient pressing force of electrodes leads to insufficient electrical contact. The pressing force also fulfills an important metallurgical role so that prevents a possible expansion of the molten metal from the weld. The parameters of resistance spot welding used for joining of dual-phase steel sheets DP600 are shown in Tab. 2 and Tab. 3.

Table 2. Welding parameters of DP600 steel for samples A

Samples	**Fz [kN]**	**I [kA]**	**T [per.]**
A_5	5.0	***5.0***	20
$A_{5.5}$	5.0	***5.5***	20
A_6	5.0	***6.0***	20
$A_{6.5}$	5.0	***6.5***	20
A_7	5.0	***7.0***	20
$A_{7.5}$	5.0	***7.5***	20

Table 3. Welding parameters of DP600 steel for samples B

Samples	**Fz [kN]**	**I [kA]**	**T [per.]**
B_{20}	5.0	5.0	***20***
B_{25}	5.0	5.0	***25***
B_{30}	5.0	5.0	***30***
B_{35}	5.0	5.0	***35***
B_{40}	5.0	5.0	***40***
B_{45}	5.0	5.0	***45***

Properties of the spot welded joints were evaluated by shear tensile tests, metallographic observation and microhardness test. RSW was performed on the pneumatic spot welding machine BPK20. The welding electrode tips from CuCr with the ø5 mm diameter of working area were used. The values of welding current were monitored during welding process by welding monitor Miyachi MG3 Digital.

The load-bearing capacities Fmax of the spot welded joints were measured according to standard STN 05 1122 - Welding: Tensile test on spot - and complete penetration welds. The static tensile test was carried out on the testing machine with the loading speed of 8 mm/min. Dimensions of the samples given by above mentioned standard are shown in Fig. 3. The microhardness test HV 0.1 was performed with the load of 15 seconds according to STN EN 1043-2 standard to evaluate the particular zones of spot weld.

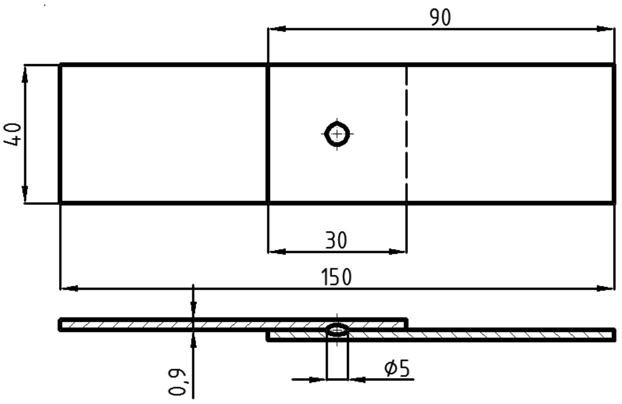

Figure 3. Dimensions of sample for tensile test

3 RESULTS AND DISCUSSION

Within all observed parameter of resistance spot welding, only the fusion welded joints were created. Increasing the values of welding current led to increasing of visibility of indentations of welding electrode tips on the surface of joined materials, as shown in Fig. 4. During the creation of spot weld between two galvanized steel sheets, zinc is melted and extruded from the weld. The annular area is then created which surrounds the weld.

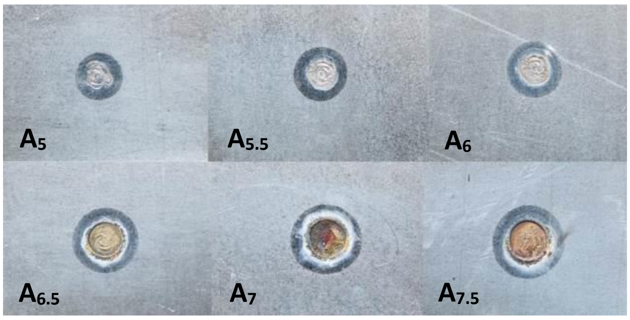

Figure 4. Indentations of electrode tips on samples A

The samples $A_{6.5}$, A_7 and $A_{7.5}$ show the brass layer in the place under welding electrode tips. The brass layer is created after switching on the welding current where the zinc from the surface of joined materials starts to melt and diffuse into copper welding electrodes.

The brass layers of on the surfaces of welded samples B were not changed significantly with increasing the values of welding time, in comparison with samples A – Fig. 5. However, the dimension of annular area is increasing with the increasing of welding time.

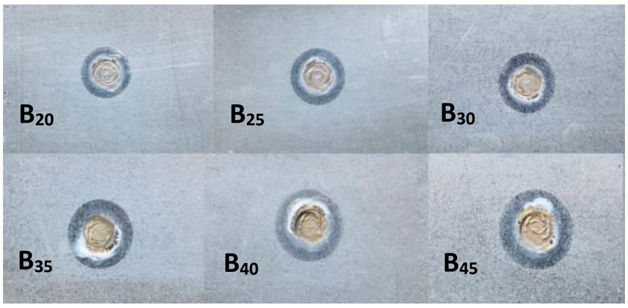

Figure 5. Indentations of electrode tips on samples B

Tensile tests were executed on the samples in order to characterise the static behaviour of the joints and to estimate load-bearing capacity of the spot weld. The values of load-bearing capacity of spot welded joints of samples A ranged from 8.650 N to 12.530 N. Fig. 6 shows the load-displacement curves of samples A. The form of the curves indicates capacity for deformation. Increasing the values of the welding current caused an increase in load-bearing capacity Fmax up to the value of 12.530 N in the samples welded with I = 7 kA. Further increase of welding current to I = 7.5 kA led to significant decrease in carrying capacity of the welded joint.

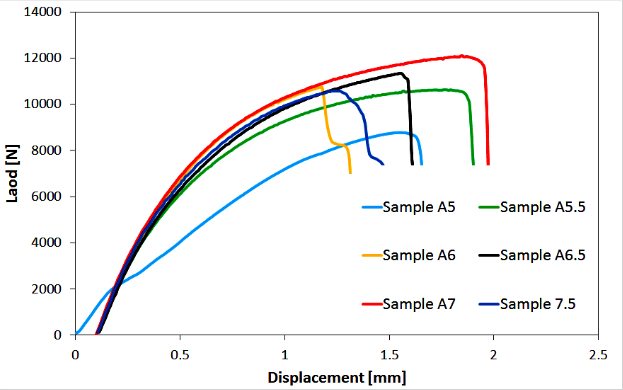

Figure 6. Load-displacement curves of samples A after tensile test

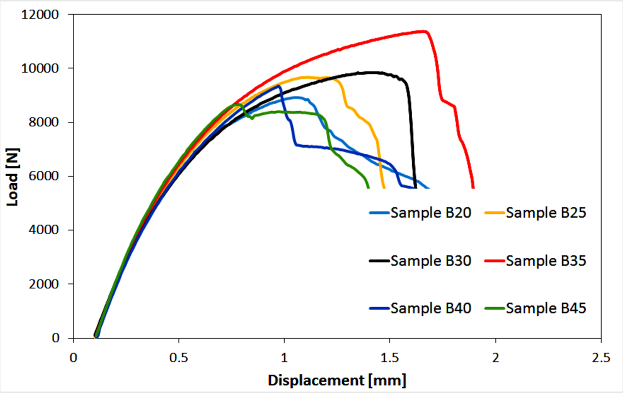

Figure 7. Load-displacement curves of samples B after tensile test

The load-displacement curves of samples B are presented in Fig. 7. The values of load-bearing capacity of spot welded joints of samples B ranged from 8.920 N to 11.370 N. Increasing the values of the welding time caused an increase in load-bearing capacity Fmax up to the value of 11.370 N in the samples welded with T = 35 periods. Further increase of welding time to T = 40 periods as well as T = 45periods caused decreasing in carrying capacity of the welded joint.

The metallographic observation of the spot welded joints confirmed the formation of fusion welds with characteristic areas of base material (BM), heat affected zone (HAZ) and weld metal (WM) in all tested samples. Fig. 8 presents the microstructures of samples A_5, A_6, A_7 and $A_{7.5}$. The size of weld nugget increased with increasing the value of welding current, which correspond to the measured values of load-bearing capacity. The smallest weld nugget with the large void was observed in the sample A_5 (Fig. 8a), welded with the lowest value of welding current I = 5kA. The void was created in consequence of the metal shrinkage during cooling of the weld. Further increase of weld current to I = 6 kA led to creation of typical dendritic growth of weld metal the weld without any voids, but with the small amount of pores in the weld nugget - Fig. 8b. The largest weld nugget formed at the value of the welding current I = 7 kA is shown in Fig. 8c. The pores were observed in the heat affected zone of the weld but with no significant impact on the performance of the weld. Numerous pores in the weld nugget and cracks in the heat affected zone were observed in sample $A_{7.5}$, which was made with the highest value of welding current I = 7.5 kA. The occurrence of pores and cracks led to decreased carrying capacity of welded joints.

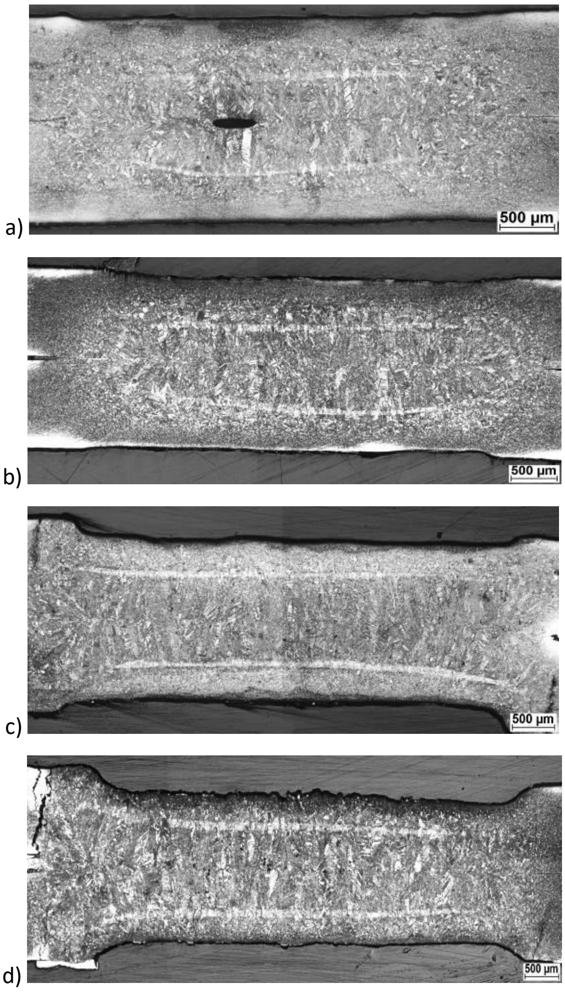

Figure 8. Microstructure of spot welded joints: a) sample A_5, b) sample A_6, c) sample A_7 and d) sample $A_{7.5}$

Hot cracks observed in HAZ of sample $A_{7.5}$ is shown in Fig. 9. This is derived from the fact that large stress concentration occurs in the HAZ, rather than in the weld nugget.

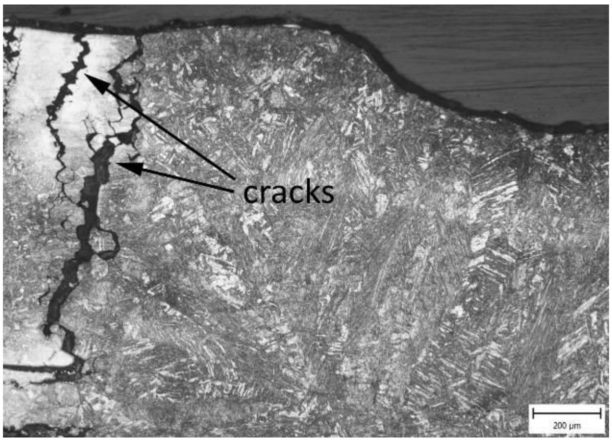

Figure 9. Hot cracks in the heat affected zone in sample $A_{7.5}$

Fig. 10 presents the microstructures of samples B_{20}, B_{35} and B_{45}. The size of weld nugget increased with increasing the value of welding time, which correspond to the measured values of load-bearing capacity. The lowest value of welding time T = 20 periods led to formation of smallest size of weld nugget (Fig. 10a) of all observed samples B. No crack, voids or pores occurred in the weld. The increasing the welding time causes formation of pores, mainly in the weld nugget (Fig. 10b), but with no negative impact on the load-bearing capacity of the weld. However, further increasing of values of welding time led to formation of coarse grain structure of the weld metal and large amount of pores, cavities in the heat affected zone (Fig. 10c) and cracks near the material surface which causes significant decreasing of the load-bearing capacity of the welds. The crack filled with the brass layer is shown in Fig. 11. This is related to the temperature distribution and the expansion of the nugget during welding.

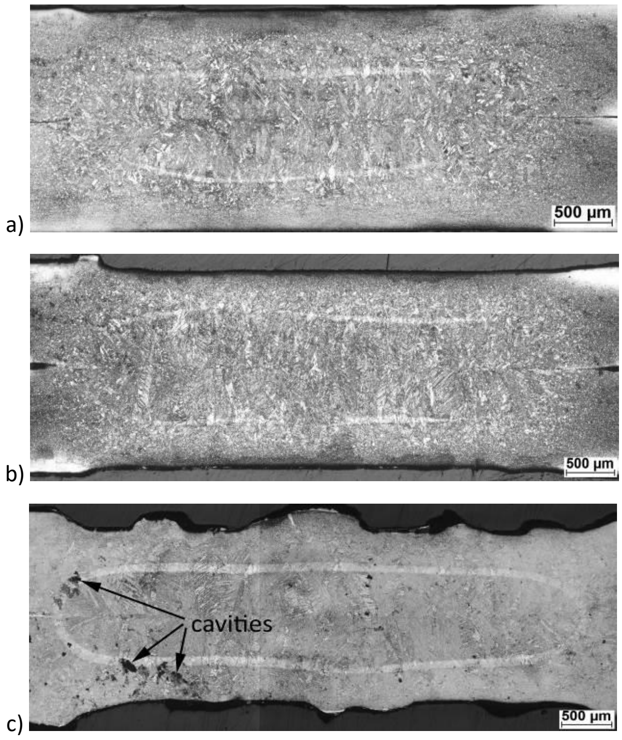

Figure 10. Microstructure of spot welded joints: a) sample B_{20}, b) sample B_{35} and c) sample B_{45}

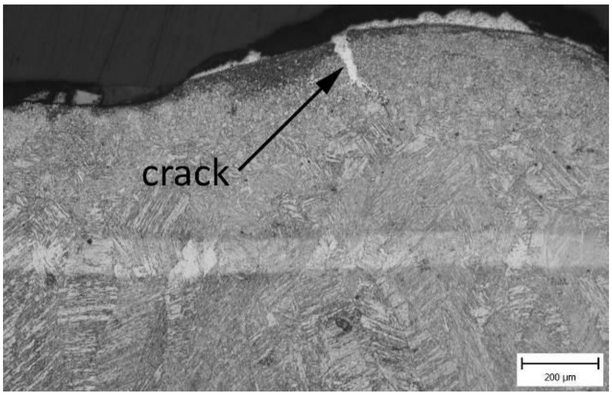

Figure 11. Crack in the weld of sample B_{45}

The changes of the microhardness values in the areas of resistance spot weld are shown in Fig. 12. The highest values were measured in the weld metal. Increasing the observed parameters of welding current does not cause the significant changes of microhardness in the spot weld.

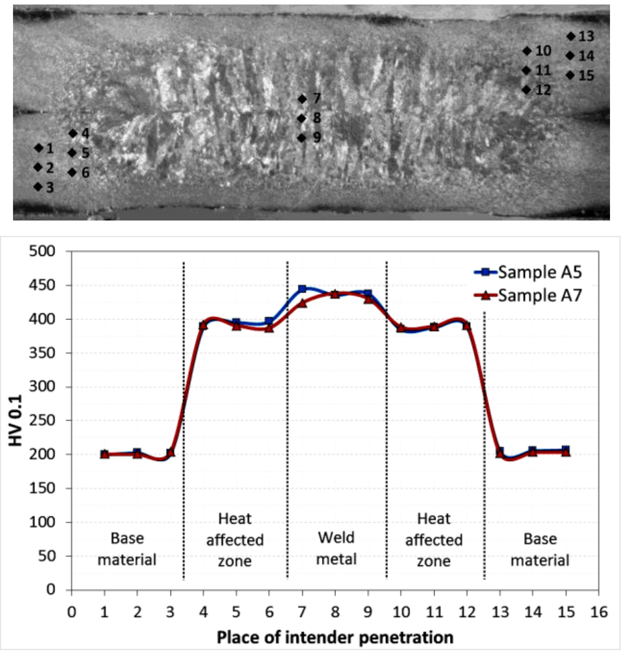

Figure 12. Measuring points and values of microhardness of samples A

4 CONCLUSIONS

Car producers are seeking the ways to satisfy the customer demands concerning the fuel efficiency of cars by reducing the car weight and enhancing the occupant safety. These demands lead to utilize the materials of good formability, weldability or joinability. Dual-phase steel can meet all of these requirements. Resistance spot welding as one of the oldest joining methods of thin-walled sheet metal constructions is used for joining the DP steels. This technique is commonly used because of its high performance when joining thin steel sheets. However, it is important to understand the spot welding behaviour of dual-phase steels.

The influence of the welding current and welding time on the weld quality of DP600 steel sheets was investigated in this study. Only the fusion weld joints occurred in case of all observed parameters of resistance spot welding.

In the samples in which the welding current was changed, the highest value of load-bearing capacity of the weld was measured in the samples A_7 made with the value of welding current 7 kA. Increased values of the welding current resulted in an increase in load-bearing capacity, except for samples made with the maximum welding current of 7.5 kA. In these samples, pores and cracks were observed which led to a significant negative influence on the load-bearing capacity of the welded joints. When using the lowest value of welding current 5 kA, weld joint was fusible with a void in the middle of the joint, but the weld nugget had smaller dimensions and low values of load-bearing capacity Fmax. Welding current of 7.5 kA is not suitable for the examined steel sheets due to the occurrence of pores in the weld metal and cracks in the heat affected zone.

The increasing of welding time caused increasing the values of load bearing capacity until T = 35 periods. Further increasing of welding time led to decreasing of the values of load-bearing capacity because large amount of pores, cavities and cracks occurred in the spot weld.

The resistance spot welding of dual-phase steel sheets requires consistent optimization of welding parameters whereas the appropriate welding parameters are only in a very narrow field.

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