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Evaluation of the Influence of the Welding Current on the Surface Quality of Spot Welds

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ABSTRACT
Welding is a metallurgical process; all aspects of a welding process can be more or less, related to metallurgy of the materials involved in welding,either base metal or electrodes. It is a rapid joining technique extensively used for joining thin assemblies in military and automotive applications. The resistance spot welding process bonds contacting metal surfaces via the heat obtained from resistance to an electrical current flow.Process parameters like welding current, time and pressure are closely controlled to obtain superior weld quality. Welding current is generally considered as a key factor affecting the weld quality. The paper deals with evaluation of welding current as the most important parameter of resistance spot welding on the surface quality of welded steel sheets.Various values of welding current were used in the experiments and consequently the marks of spot welded tips on the welded material surfaces were observed. Hot-dip galvanized steel sheets of H220PD and TRIP RAK 40/70 were used for resistance spot welding.

Keywords: *Resistance spot welding, welding current, surface quality*.

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I. INTRODUCTION

Resistance spot welding (RSW) is one of the oldest of the electric welding processes in use by industry today. In contrast to other welding processes, no filler metal or fluxes are used. This technique is commonly used in automotive industry due to its high efficiency in manufacturing thin metal sheets [1]. For example, one single automobile contains approximately 5000 spot welds; typical vehicle could need 3000-7000 spot welds. The need for lightweight alloys and quality welds becomes a great interest in these industries for achieving improved fuel economy for ground vehicles [2]. Welding is a metallurgical process—all aspects of a welding process can be, more or less, related to metallurgy of the materials involved in welding, either the base metal or the electrodes [3].The RSW process bonds contacting metal surfaces via the heat obtained from resistance to an electrical current flow.The surfaces in contact in the region of current concentration are heated by a low-voltage short-time pulse having a high-amperage current to form a weld nugget. The weldability depends on several parameters but the predominant ones are the physical properties of the constitutive material, the process parameters such as the squeezing force, the duration of the current, and foremost, the contact conditions including both shape and geometry of the electrode active face [4]. After spot welding, important changes occur in mechanical and metallurgical properties of the spot welded areas and heat affected zones. The investigation of these changes is very important for the safety strength of the welded joints [5]. Understanding process parameters, such as weld size, weld indentation, sheet separation and weld residual stresses, will improve the weld quality during fabrications. Quality and performance of the resistance spot welds are very important to the durability and safety design of vehicles.There some other alternative methods of joining, that can replace the resistance spot welding in car body production. In recent years, it is a mechanical joining - especially clinching, clinchriveting and self-piercing riveting that have taken place in automotive industry [6-8]. Three parameters of resistance spot welding in all: pressing force, welding time and mainly welding current have significant effect on the quality of spot welded joints. Influence of the welding current on the surface quality of spot welded materials was observed in the paper.

II. PRINCIPLE OF RESISTANCE SPOT WELDING

Resistance Spot Welding is the process of joining two pieces of metal together by passing current through a relatively small area (spot) while applying pressure for a given amount of time – Fig. 1. When the metal sheets are brought into contact due to the pressure applied by both electrodes, the AC current flows through the sheets with the presence of electrical resistance between the 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 [3].
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. From a metallurgical and mechanical perspective, the process entails a complex interface between the base metal (BM), heat affected zone (HAZ), fusion zone (FZ), phase transformation, material hardening, and material anisotropy [2].

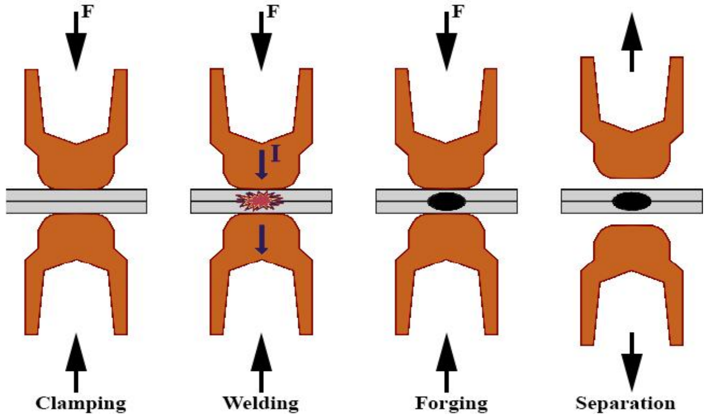

Figure 1: Principle of resistance spot welding

In resistance welding, the heat needed to create the coherence is generated by applying an electric current through the stack-up of sheets between the electrodes. Therefore, 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 weld is obtained by Joule effect.
The general expression of heat generated in an electric circuit is

$$Q = I^2.R.t \tag{1}$$

where Q is heat, I is current, R is electrical resistance of the circuit, and t is time the current is allowed to flow in the circuit. When the current or resistance is not constant, integrating the above expression will result in the heat generated in a time interval t [9].
For resistance welding, the heat generation at all locations in a weldment, rather than the total heat generated, is more relevant, as heating is not and should not be uniform in the weldment. In addition, the heating rate is more important than the total heat, as how fast the heat is applied during welding determines the temperature history and, in turn, the microstructure [10].

III. EXPERIMENTS

The following galvanized steel sheets were used for experiments: microalloyed steel HSLA H220PD with the thickness of 0.8 mm and, advanced high strength steel TRIP 40/70-Z100MBO with the thickness of 0.77 mm. Their basic mechanical properties and chemical composition are shown in Table 1 and Table 2 respectively.

Table 1: Basic mechanical properties of used materials

Material	**$Rp_{0.2}$ [MPa]**	**Rm [MPa]**	**A_{80} [%]**
H220PD	238	382	36
TRIP40/70	450	766	26

Table 2: Chemical composition (in [%] of wt) of used materials

Material	**C**	**Mn**	**Si**	**P**	**S**	**Al**	**Cu**	**Ni**
H220PD	0.012	0.435	0.119	0.057	0.002	0.041	0.040	0.013
TRIP40/70	0.204	1.683	0.198	0.018	0.003	1.731	0.028	0.018
Material	**Cr**	**Ti**	**V**	**Nb**	**Mo**	**Co**		
H220PD	0.046	0.033	0.012	0.052	0.009	0.047		
TRIP40/70	0.055	0.009	0.004	0.004	0.008	0.007		

The following samples of the material combinations for the resistance spot welding were joined:
- *Samples A*: H220PD + H220PD
- *Samples B*: H220PD + TRIP40/70
- *Samples C*: TRIP40/70 + TRIP40/70

The samples with dimensions of 40 x 90 mm and 30 mm lapping according to STN 05 1122 standard were used for the experiments (Fig. 2). The tensile testResistance spot welding was carried out in laboratory conditions on a pneumatic spot welding-machine BPK 20 made by VTS ELEKTRO Bratislava, as shown in scheme in Fig. 3. CuCr welding electrodes were used according to ON 42 3039.71 standard. The diameter of working area of the electrode was d = ø5 mm. The parameters of resistance spot welding (Fz – pressing force of electrodes, T – welding time and I – welding current) with marked tested samples are shown in Table 3. The samples were prepared by cutting against the direction of sheet rolling. The surfaces of the samples were degreased in concentrated CH3COCH3. Five values of welding current were used for each welded sample (Table 3, welding current I). The carrying capacities of the spot welded joints Fmax were measured according to standard STN 05 1122 - Welding: Tensile test on spot - and complete penetration welds. The test was carried out on the testing machine TIRAtest 2300 with the loading speed of 8 mm/min.

Table 3: Parameters of resistance spot welding (Fz-pressing force, T-welding time and I-welding current)

Samples	Fz [kN]	T [per.]	I [kA]
A	3	12	4 / 5 / 6 / 7 / 8
B	3	12	5 / 6 / 7 / 8 / 9
C	5	14	4 / 5 / 6 / 7 / 8

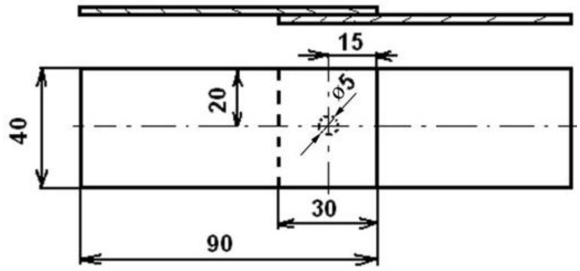

Figure 2: Dimension of the welded samples

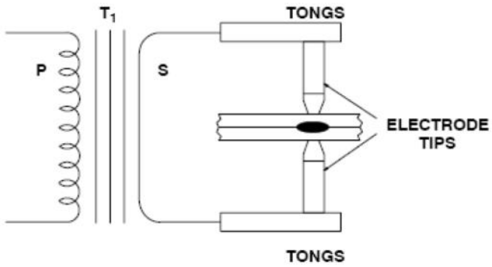

Figure 3: Scheme of resistance spot welding machine

The amount of weld current is controlled by two things: first, the setting of the transformer tap switch determines the maximum amount of weld current available; second, the percent of current control determines the percent of the available current to be used for making the weld. Low percent current settings are not normally recommended as this may impair the quality of the weld [3].
The weld current should be kept as low as possible. When determining the current to be used, the current is gradually increased until weld spatter occurs between the metal sheets [10].

IV. RESULTS

The indentations formed by resistance spot welding electrode tips are shown in Fig. 4 – Fig. 6. Changing the values of welding current influenced the welding electrode indentations on the surfaces of welded materials. The most obvious indentations were observed on the surfaces of samples prepared with the parameters of maximum value of welding current and the least obvious indentations were on the surfaces of both welded steels prepared with the minimum value of welding current of all observed samples. The zinc layer was definitely destroyed under welding tips in value of welding current of I = 6 kA, as shown in Fig. 7.

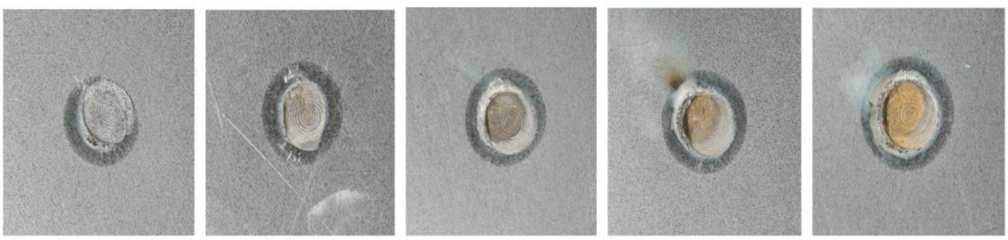

Figure 4: Welding electrodes indentations of Samples A (H220PD + H220PD): a) I=4kA, b) I=5kA, c) I=6kA, d) I= 7kA, e) I=8kA

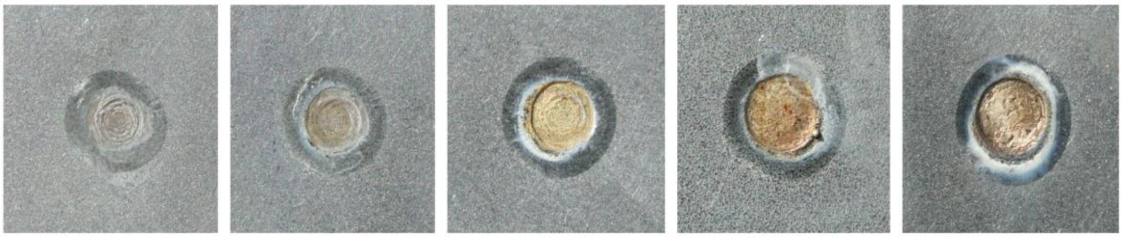

Figure 5: Welding electrodes indentations of Samples B (H220PD + TRIP40/70): a) I=5kA, b) I=6kA, c) I=7kA, d) I= 8kA, e) I=9kA

Figure 6: Welding electrodes indentations of Samples C (TRIP40/70 + TRIP40/70): a) I=4kA, b) I=5kA, c) I=6kA, d) I= 7kA, e) I=8kA

Expulsion is a common phenomenon in resistance spot welding.Its influence the strength of a weld. In general, expulsion can happen either from the contact interface between electrodes and sheets or from the sheet faying interface. Expulsion is often associated with other discontinuities, such as excessive internal porosity due to loss of liquid metal. Most welds with expulsion can be identified by visual inspection of the spot weld, through the characteristic traces of ejected liquid metal at the electrode-sheet interface which requires a peeling action in order to reveal the expulsion trace. Steel welds tend to have a sharp thin layer of ejected and rapidly solidified metal (Fig. 6e).

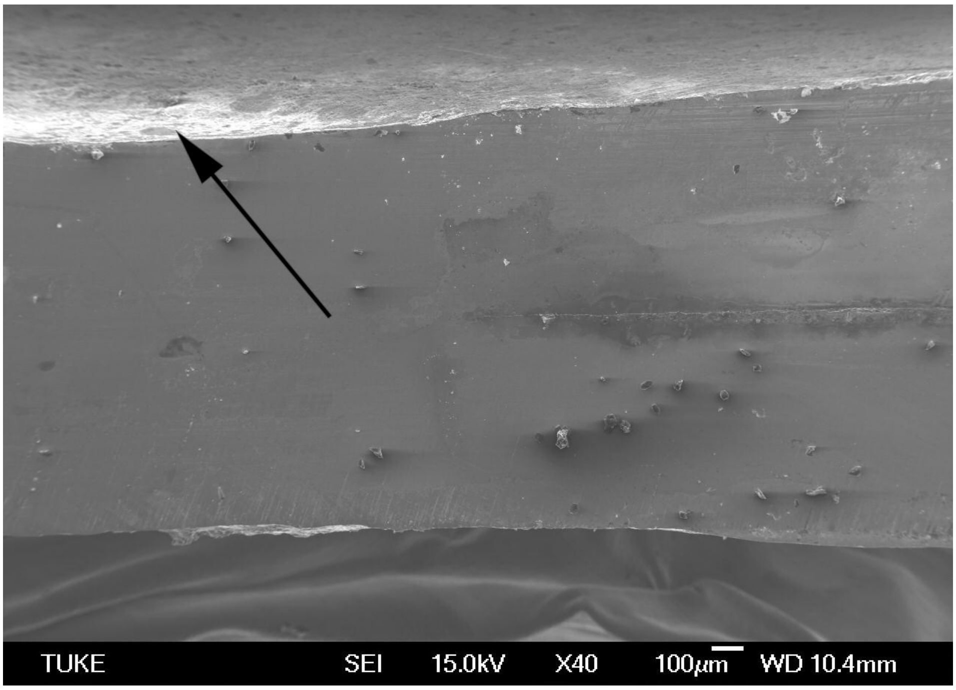

Figure 7: Indentation of welding electrode tip in sample B (I=6kA)

There is no trace of expulsion for some welds such as the ejected and solidified metal around a weld. Therefore, it is difficult to identify the expulsion without metallographic examination. However, employing commonly used sensing devices, such as displacement measurement between electrodes, the occurrence and even magnitude of an expulsion can be accurately recorded.

In samples A (H220PD + H220PD) and C (TRIP40/70 + TRIP40/70) which were welded with the highest value of welding current (I = 8kA), a surface cracking due to liquid metal embrittlement (LME) was observed. LME occurs when molten (zinc in the case of hot-dipped galvanized steels) attacks the susceptible steels. It may happen in low-carbon steels, stainless steels or advanced high-strength steels.
The key factors contributing to LME cracking in coated steel welding are electrode misalignment, excessive heat input, excessive electrode wear, and insufficient electrode cooling [3].
The coupling of zinc (from the coating) and copper (from the electrode) may promote LME cracking near the surface of a weld. The cracks initiate in the solid phase mainly at grain boundaries that are attacked, in such as the heat affected zone, which is in direct contact with the electrodes and has sufficiently high temperature for Zn to melt during welding. The thermal stresses during solidification are essential to break the embrittled structure. LME cracks do not have a significant effect on the static performance of a spot weld.

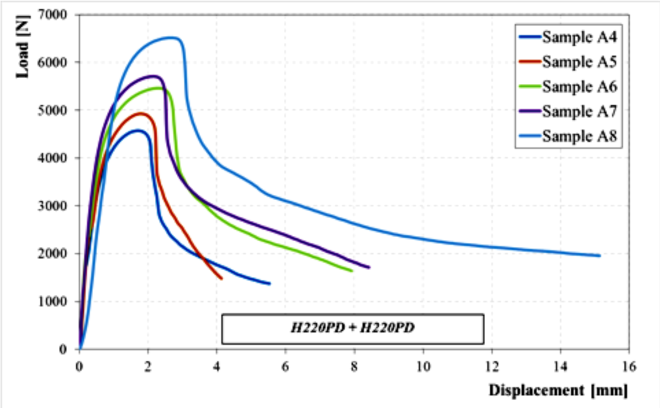

Figure 8: Load-displacement curves of samples A

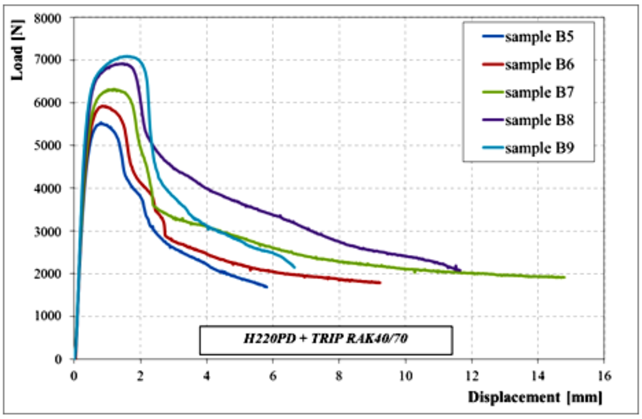

Figure 9: Load-displacement curves of samples B

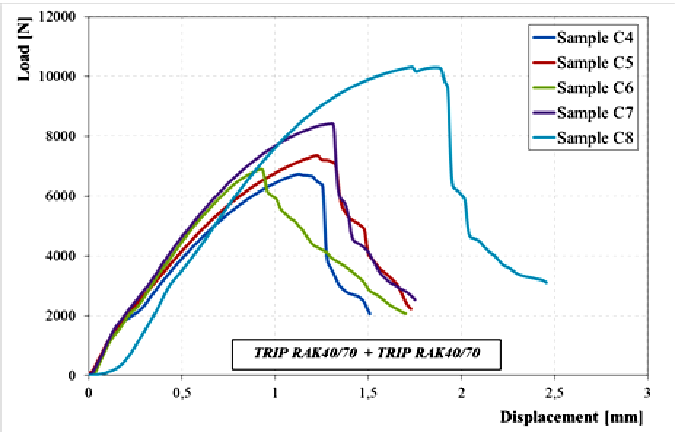

Figure 10: Load-displacement curves of samples C

Load-displacement curves of all tested samples from tensile test are shown in Fig. 8-10. Tensile tests were executed under displacement control conditions on the sample configurations in order to characterize the static behavior of the joints. Increased values of the welding current *I* caused an increase in load-bearing capacity in all tested samples.

V. CONCLUSION

The paper describes the influence of welding current on the surface quality of joined materials such as advanced high strength steels TRIP 40/70 and high-strength low-alloy steel H220PD.

The samples prepared with various values of welding current and indentations formed by electrode tips were observed. The experiments show that the welding current has a determining influence on the weld joint. When using the welding current of the lowest value, weld joint was of high quality, fusible and without defects, but the weld nugget had smaller dimensions with inexpressive indentations of electrodes tips. Increasing the values of welding current influenced the welding electrode indentations on the surfaces of welded materials in all observed samples as well as the load-bearing capacities of the joints. Welding current of the highest values caused expulsion of the metal from the contact interface between electrodes and welded sheets or surface cracking due to liquid metal embrittlement.

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