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DELTASPOT AS AN INNOVATIVE METHOD OF RESISTANCE SPOT WELDING

Resistance spot welding has established itself across a wide range of industries as a cost-effective method for joining steel sheets. In modern vehicle manufacturing in particular, steel sheets of varying strengths, quality and surface treatment need to be joined. One of the problems of resistance spot welding in the automotive industry is the lifetime of welding electrode tips. The new innovative method of resistance spot welding DeltaSpot should solve this problem by using the special process tape between welding electrodes and joining materials. The paper describes the principle of DeltaSpot welding method and evaluates the properties of DeltaSpot joints made by combination of galvanized steel sheets DX51D+Z (a_0 = 0.9 mm) and RA-K 40/70+Z100MBO (a_0 = 0.77 mm). The basic mechanical properties of welded joints were evaluated. Some samples were prepared for metallographic analysis where the influence of the welding parameters on the structure of welded joint was observed. The properties of DeltaSpot joint were compared to the properties of standard resistance spot joints.

Keywords: galvanized steel sheets, resistance spot welding, Delta Spot welding, metallographic analysis

1. Introduction

Resistance spot welding is a joining process for thin metal sheets during which, in contrast to other welding processes, no filler metals or fluxes are used [1]. Instead, pressure exerted by electrodes joins the contacting metal surfaces via heat obtained from resistance to the electrical current flow. Resistance spot welding provides accelerated speed and adaptability for automation in high-volume and high-rate production; however, the technique suffers from inconsistent quality between welds due to the complexity of the process itself and many variables involved in the joining process [2]. Further implementation and improvement of existing process, including weld quality and time improvement, electrode life extension, maintenance cost reduction and development of new techniques for resistance spot welding, will greatly impact on the above noted industries due to the large numbers of spot welds they perform in their manufacturing processes [3, 4].

2. Principle of deltaspot welding

Schematic of standard resistance spot welding method is shown in 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. 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 [1, 5].

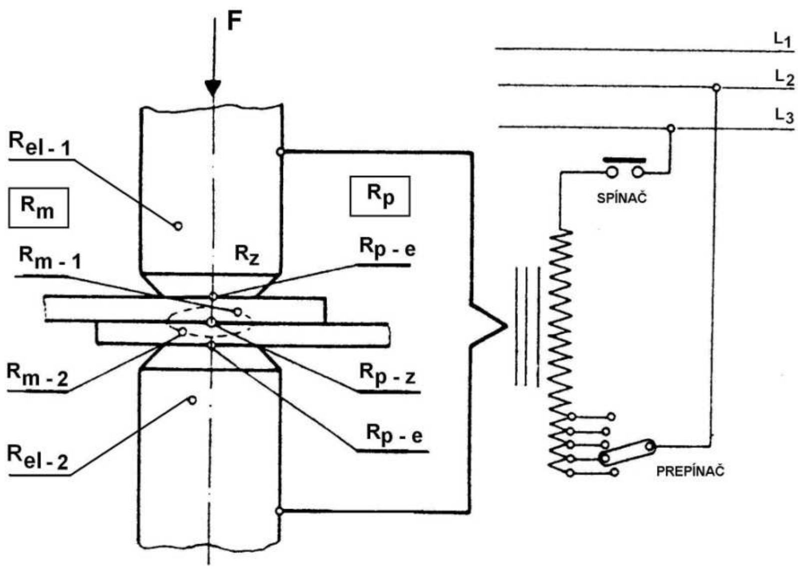

Fig. 1. Scheme of standard resistance spot welding

Figure 1 shows that between two electrodes, a series of electrical resistance exists. The total resistance consists of two parts: the bulk resistance including $R_{el\text{-}1}$ and $R_{el\text{-}2}$ of the electrodes and $R_{m\text{-}1}$ and $R_{m\text{-}2}$ of the material and the contact resistance values $R_{p\text{-}e}$ and $R_{p\text{-}z}$ represent the contact area at electrode to sheet and sheet to sheet interfaces. Bulk resistance is a function of temperature. All metals exhibit a positive temperature coefficient, which means that their bulk resistance increases with temperature. Bulk resistance becomes a factor in longer welds. Contact resistance is a function of the extent to which two surfaces mate intimately or come in contact. Contact resistance is an important factor in the first few milliseconds of a weld [6, 7].

These resistances change during welding. The electrical resistance of metals increases with increasing temperature. This increase in resistance boosts the generation of heat, causing even more temperature increase. The change in electrical resistance is most dramatic at the contact interface between the work piece parts where the weld nugget is formed. Due to joule heating the temperature at the interface rises until the material melts and the interface breaks down [8].

The defining feature of DeltaSpot is the robot welding gun with running process tape that runs between the electrodes and the sheets being joined. The continuous forwards movement of the process tape results in an uninterrupted process producing constant quality over a number of shifts (Fig. 2). This results in precision in the welding process and high electrode service life. Regular cap cutting of electrodes is no longer necessary. The process tape means that electrodes are effectively protected against wear and deposits from sheet coatings. This means that constant quality and reproducible welding points are assured over multiple production shifts.

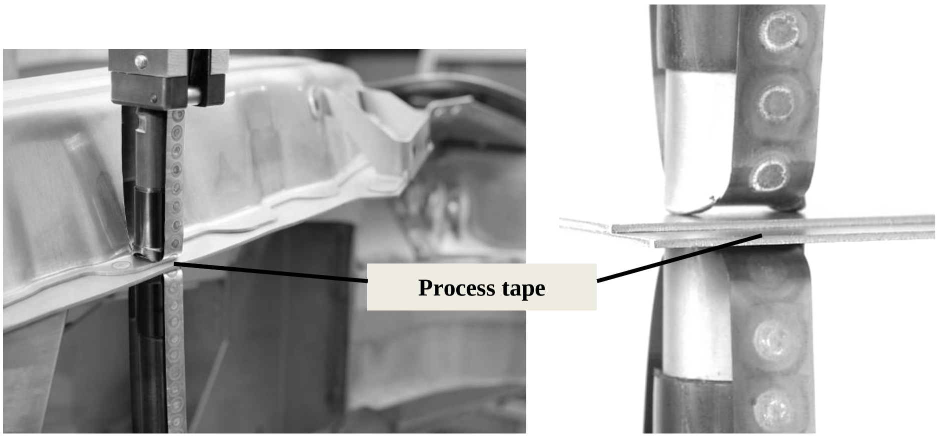

Fig. 2. Process tape of DeltaSpot welding, elaborated based on [9]

The process tape transfers the welding current and, at the same time, protects the contact surfaces of the electrodes from contamination by zinc, aluminium or organic residues. This protection results in a significantly increased service life for electrodes. The process tape provides indirect sheet contact producing a largely spatter-free welding result. It eliminates the otherwise unavoidable rework necessary to meet new quality standards. The process tape needs to be replaced infrequently and this takes little time and effort. In normal use, the process tape produces 7 000 welding points. If every segment of the welding tape is used two or three times, the service life can be extended accordingly [9].

Figure 3 shows DeltaSpot welding and influence of using the process tape on the total resistance. In the comparison with standard resistance spot welding, the bulk resistance $R_{p\text{-}1}$ and $R_{p\text{-}2}$ of the process tape as well as the contact resistance $R_{p\text{-}p}$ between process tape and electrode are taken into the account.

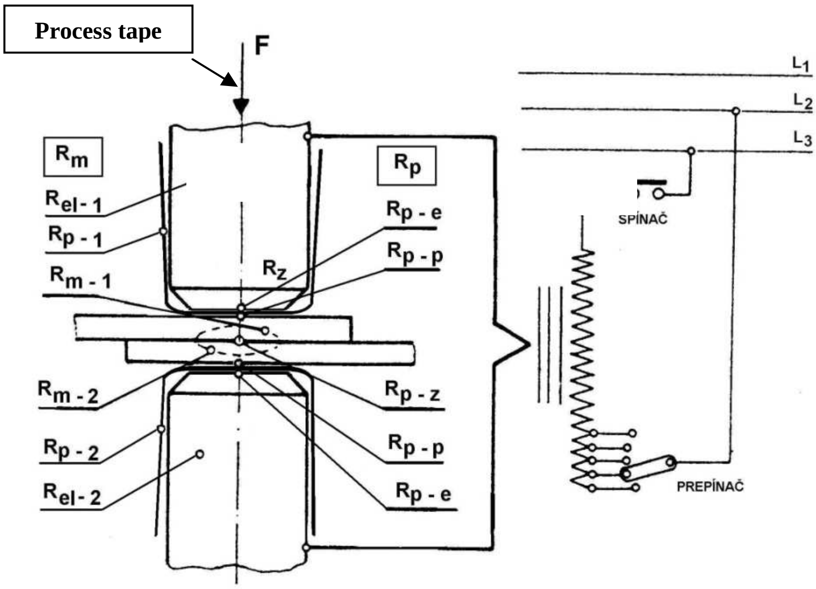

Fig. 3. Scheme of DeltaSpot welding using process tape

The process tape transfers the welding current and, at the same time, protects the contact surfaces of the electrodes from contamination by zinc, aluminium or organic residues. This protection results in a significantly increased service life for electrodes. The process tape provides indirect sheet contact producing a largely spatter-free welding result. It eliminates the otherwise unavoidable rework necessary to meet new quality standards. The process tape needs to be replaced infrequently and this takes little time and effort. In normal use, the process tape produces 7 000 welding points. If every segment of the welding tape is used two or three times, the service life can be extended accordingly.

3. Material and experiment

Double-sided hot-dip galvanized steel sheets RA-K 40/70+Z100MBO of 0.77 mm thickness made by Voestalpine Austria, and DX51D + Z (EN 10142/2000) of 0.9 mm thickness made by U.S.Steel Košice were used for the experiments. Average thicknesses of zinc coatings measured by contact thickness gauge Quanix were as follows:

- RA-K 40/70+Z100MBO – 18.2 μm,
- DX51D + Z (EN 10142/2000) – 16.8 μm.

The basic mechanical properties of the observed materials declared by the producers and their chemical compositions are shown in Table 1 and 2.

The samples with dimensions of 40 x 92 mm and 32 mm lapping according to DIN 50 124 standard were used for the experiments (Fig. 4). Six samples were prepared for every combination of sheets.

Table 1. Basic mechanical properties of used steels

Material	$R_{p0.2}$ [MPa]	R_m [MPa]	A_{80} [%]	n_{90}
RA-K40/70	450	766	26	0.278
DX51D+Z	≥ 140	270-500	≥ 22	*

* – not specified by producer

Table 2. Chemical composition [wt %] of used steel sheets

Material	C	Mn	Si	P	S	Al	Cu	Ni	Cr
RA-K40/70	0.204	1.683	0.198	0.018	0.003	1.731	0.028	0.018	0.055
DX51D	0.64	0.178	0.007	0.016	0.002	0.120	0.041	0.02	0.023
	Ti	**V**	**Nb**	**Mo**	**Zr**				
RA-K40/70	0.009	0.004	0.004	0.008	0.007				
DX51D	0.002	-	-	-	-				

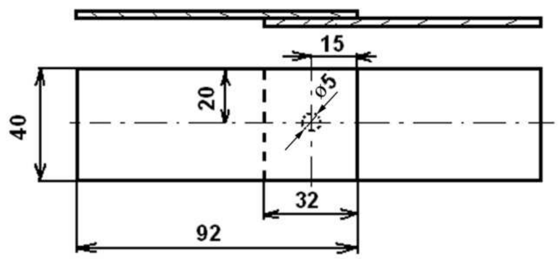

Fig. 4. Dimensions of samples for the tensile test and principle of clinching

The samples with the DeltaSpot welds were made in the affiliated company of Fronius in Austria. Standard resistance spot welding was carried out with the pneumatic spot welding-machine BPK 20 of VTS ELEKTRO Bratislava producer. CuCr welding electrodes were used for welding, according to ON 42 3039.71 standard. The diameter of working area of the electrodes was 5 mm.

The parameters of both methods of resistance spot welding (Table 3) were determined according to the recommended welding parameters by IIW – International Institute of Welding, adapted to welding machines, technology of DeltaSpot – process tape occurrence and its possibilities. The welding parameters for standard resistance spot welding were optimized and published in [10, 11].

Table 3. Spot welding parameters of both welding methods

Parameters / Methods	*Fz* [kN]	*I* [kA]	*t* [periods]
Standard RSW	4	6	12
DeltaSpot RSW	3	11	20

Fz – welding pressing force, *I* – welding current, *t* – welding time (RSW – resistance spot welding)

The peak load and the failure energy were extracted from the load displacement curve. Failure mode was determined from the failed samples. Samples for metallographic examination were prepared using standard metallography procedure with metallographical scratch patterns prepared according to ISO 6507-1 and ISO 6507-2 standards on Olympus TH 4-200 microscope. The samples were etched in 3% solution of HNO3 [12]. Optical microscopy was used to examine the sample microstructures.

4. Results

The measured values of carrying capacities F_{max} of resistance spot welded joints of both methods are shown in Table 4. Tensile tests were executed under displacement control conditions on the specimen configurations in order to characterise the static behaviour of the joints and to estimate the ultimate tensile strength. The maximum shearing load was the most significant value obtained from the „load-displacement" curves (Fig. 5). The form of the curves indicates the behaviour of the joints under loading, especially capacity for deformation.

The carrying capacities of DeltaSpot welds and standard spot welds are almost of the same values. Differences between methods were observed in the marks of welding tips (Fig. 6). The obvious marks of welding tips with the typical layer of brass were observed on the surfaces of samples made by standard spot welding in comparison to DeltaSpot welded samples. The standard brass layer was created by diffusion process of Cu in electrodes and Zn in surface coatings of joined steels and has significant effect on the lifetime of welding tips [13].

Table 4. Measured values of carrying capacities F_{max} of resistance spot welded joints

Sample no	F_{max} [N] of Standard RSW	F_{max} [N] of DeltaSpot RSW
1	7310	7420
2	7402	7635
3	7513	7610
4	6974	7419
5	7074	7590

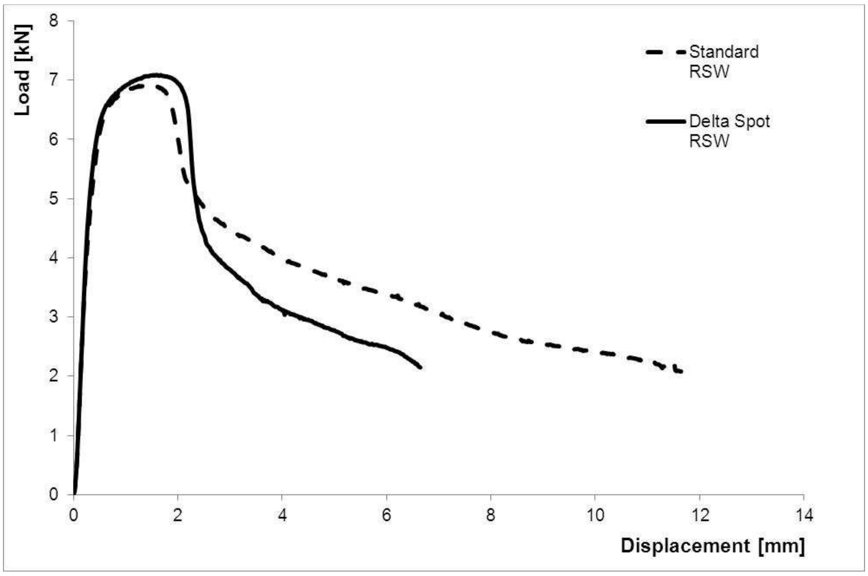

Fig. 5. Load-displacement curves of spot welded joints after tensile test

Only one type of the joint occurs in both methods of resistance spot welding – fusion welded joint, where the weld nugget was pull-out from RA-K steel sheet (Fig. 7). The macrostructures of welded joints of both methods are shown in Fig. 8. There are no significant differences between the samples; typical shape of spot welds was observed. The metallographic analysis confirmed formation of fusion welded joints with characteristic areas of weld metal, heat affected zone and base material (Fig. 9a). The base material of DX51D consists of a fine-grained ferrite-perlite structure. The microstructure of the RA-K steel base material consists of a fine-grained multi-phase structure with dominant ferrite component, bainite and retained austenite segregated on boundaries of ferrite grains. The macrostructures of a weld joint show a characteristic dendrite structure typical for resistance spot welds. The microscopic observation of macrostructures of the welds shows no pores and cavities occurring in the weld metal. Figure 9b shows microstructure of DeltaSpot sample in the middle of weld nugget. The microstructure of weld metal consists of mostly fine-grained martensite arranged in typical lamellar formations. Such lamellar formations prevent the austenite from transformation; therefore the retained austenite occurs in the microstructure. Besides martensite, also ferrite and both forms of bainite occur in the microstructure of weld metal.

a) b)

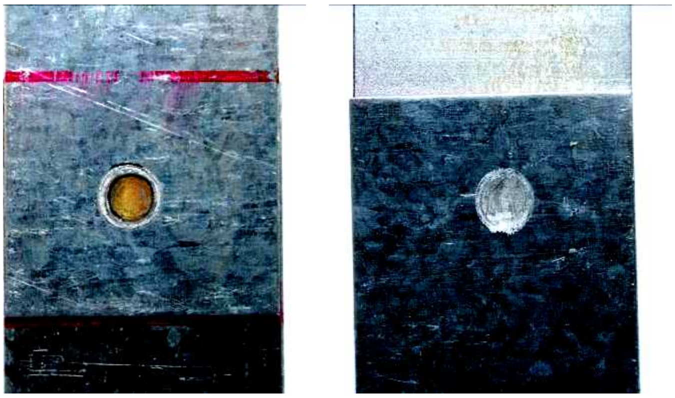

Fig. 6. Marks of welding tips: a) standard RSW, b) DeltaSpot RSW

a) b)

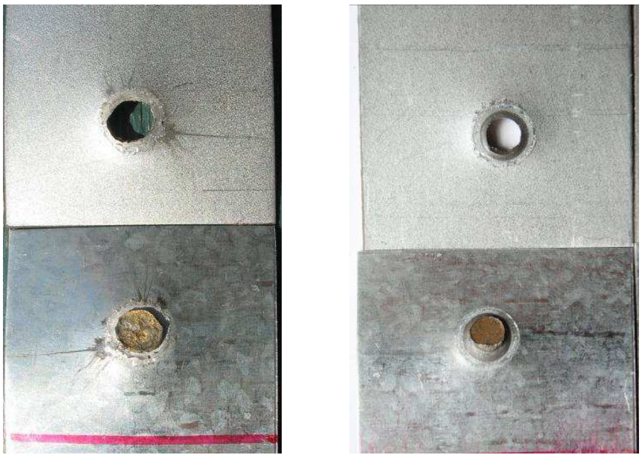

Fig. 7. Welded samples after tensile test: a) standard RSW, b) DeltaSpot RSW

a) b)

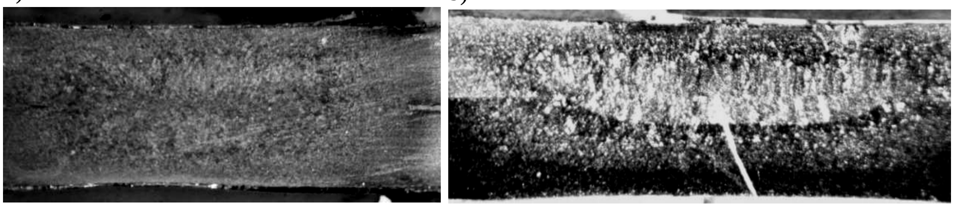

Fig. 8. Macrostructure of welded joints: a) standard RSW, b) DeltaSpot RSW

a) b)

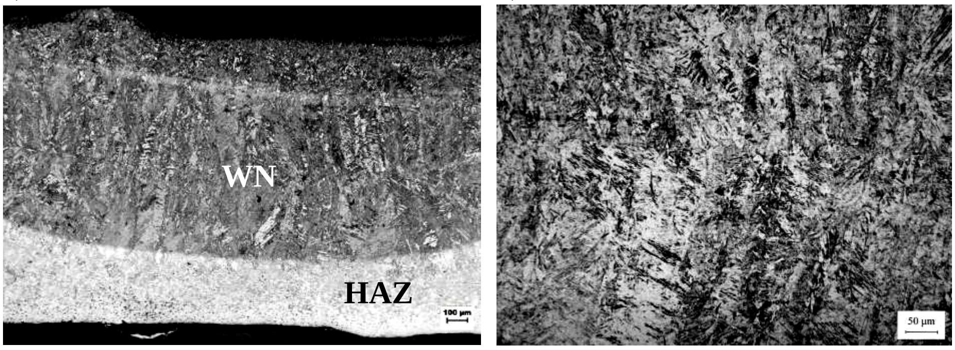

Fig. 9. Microstructure of DeltaSpot weld: a) weld nugget (WN) and heat affected zone (HAZ), b) weld nugget

5. Conclusions

Nowadays, the requirement for automobile weight reduction has brought many new types of advanced high-strength steels (AHSS) to automobile industry. A recent research in Europe showed that the use of AHSS could significantly reduce the weight of automobile (about 25%). Resistance spot welding has great importance to automobile industry for it accomplishes about 90% of car body assembly. The paper evaluated the properties of joints made by new innovative method of resistance spot welding known as DeltaSpot. The advanced high strength steel RA-K 40/70+Z100MBO (a_0 = 0.77 mm) and the drawing grade steel DX51D+Z (a_0 = 0.9 mm) were used for experiments. On the basis of the conducted experiment, the following conclusions can be formed:

1. Only fusion welded joints occur in the samples made by DeltaSpot welding with characteristic areas of weld metal, heat affected zone and base material.
2. No crack or failures were observed in the microstructures of welded joints.
3. The using of the process tape causes that electrodes are effectively protected against wear and deposits from the sheet coatings.

4. The carrying capacities of DeltaSpot welds were on the same values as the carrying capacities of standard resistance spot welding.

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DELTASPOT JAKO INNOWACYJNA METODA PUNKTOWEGO ZGRZEWANIA OPOROWEGO

S t r e s z c z e n i e

Zgrzewanie oporowe punktowe znalazło różnorodne zastosowanie w wielu obszarach przemysłu jako ekonomicznie efektywna metoda łączenia blach. Potrzeba łączenia blach stalowych o różnej wytrzymałości, jakości i obróbce powierzchni występuje we współczesnym przemyśle samochodowym. Jednym z problemów punktowego zgrzewania oporowego w przemyśle samochodowym jest żywotność końcówek elektrod zgrzewających. Innowacyjna metoda punktowego zgrzewania oporowego DeltaSpot rozwiązuje ten problem przez zastosowanie specjalnej taśmy pomiędzy elektrodami zgrzewającymi a łączonymi materiałami. Artykuł zawiera opis zasady zgrzewania DeltaSpot oraz ocenę właściwości połączeń zgrzewanych metodą DeltaSpot złożonych z blach stalowych ocynkowanych DX51D+Z (a_0 = 0,9 mm) i RA-K 40/70+Z100MBO (a_0 = = 0,77 mm). Określono podstawowe właściwości mechaniczne połączeń zgrzewanych. Część próbek była poddana analizie metalograficznej w celu określenia wpływu parametrów zgrzewania na strukturę połączenia zgrzewanego. Właściwości połączeń DeltaSpot zostały porównane z właściwościami połączeń wykonanych tradycyjną metodą punktowego zgrzewania oporowego.

Słowa kluczowe: blachy stalowa z powłoką galwaniczną, zgrzewanie oporowe, zgrzewanie DeltaSpot, badania metalograficzne

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