THE ANALYSIS OF THE OCCURRENCE OF DEFECTS AND DISCONTINUITIES IN THE REW WELD OF DP STEEL AND ALUMINUM ALLOY

A. Đurić [1,*], D. Milčić[2], D. Klobčar[3], B. Marković[1], M. Milčić[2]

[1]University of East Sarajevo, Faculty of Mechanical Engineering, East Sarajevo, RS, B&H
[2]University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
[3]University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia

[*] Corresponding Author. E-mail: aleksija.djuric@ues.rs.ba

Abstract

Resistance element welding (REW) was developed as an alternative technology for joining dissimilar materials that are difficult to weld with RSW (Resistance spot welding) technology. This technology does not require significant modification of existing equipment in a factory, which is its great advantage. This paper analyzes the occurrence of defects and discontinuities in the REW weld of DP steel and aluminum alloy. Analysis of the macrostructure and analysis of the fractography of the joint were used to detect defects and discontinuities. The following defects and discontinuities are observed: Expulsion of aluminum, asymmetrical spot weld nugget and cracks in the weld area.

Keywords: Weld defects, Resistance element welding, DP steel, aluminum alloy

1. Introduction

The structure of dissimilar materials such as DP steel and aluminum has a good perspective for application in the automobile and aerospace industries primarily due to significant weight reduction and good mechanical characteristics [1-3]. A prerequisite for achieving this multi-material structure is to achieve a quality joint between these dissimilar materials. One of the most used technologies in the automotive and aerospace industries is Resistance spot welding (RSW) [4,5]. Due to the different mechanical, physical, and chemical properties of DP steel and aluminum alloy the joining by RSW technology does not provide a quality joint. Resistance element welding (REW) was developed as an alternative technology for joining dissimilar materials [6]. This technology does not require significant modification of existing RSW equipment in a factory, which is its great advantage.

REW is a process that begins with the insertion of steel, called an element, into lightweight material such as aluminum. After the element is inserted into the lightweight material, the procedure of classic resistance spot welding is followed [7]. The REW process is showed on Figure 1.

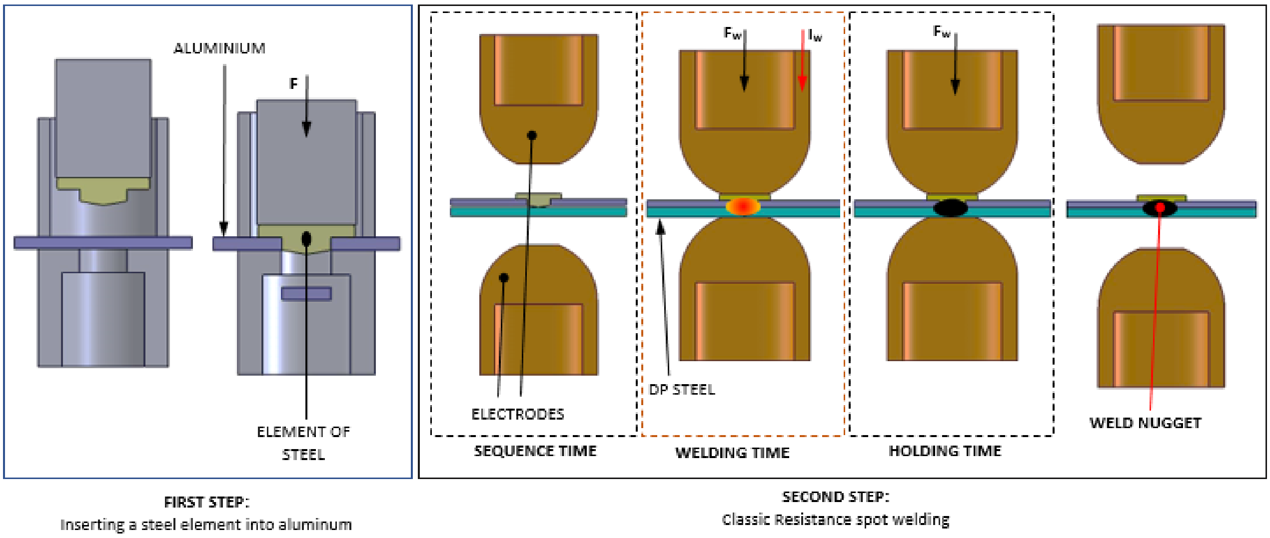

Figure 1. Process of Resistance element welding (REW) [7]

Based on the analysis of the REW process, it can be concluded that REW generally represents RSW welding of two dissimilar steels. It can be expected that most of the defects and discontinuities that appear in the REW weld have been related to the phenomenon of joining two steels with RSW technology. Xiaodong Wan et al [8] analyzed welding defects occurrence and their effects on weld quality in Resistance Spot Welding of AHSS steel. Expulsion and shrinkage void (or solidification crack) occurrence under various welding conditions is detected. Expulsion was checked after the completion of tensile-shear tests. Shrinkage void occurrence was indirectly determined by the significant drop in maximum tensile-shear displacement. This authors also concluded that lower electrode force, larger welding current and longer welding time all contributed to the easier occurrence of welding defects. Rouholah Ashiri et al [9] showed that the following defects and discontinuities may occur during RSW welding of TRIP steel: The high electrode indentation depth, Limited weldable current range and early expulsion and Liquid metal embrittlement (LME) cracks. The authors also demonstrated that the thermophysical properties of the steels have significant impacts on their weldability and susceptibility to the weld defect formation. Dawei Zhao et al [10] were investigated weld defects of spot-welded dual-phase steel. They concluded that failure energy and maximum displacement of the welds with expulsion are smaller than those without an expulsion. Mechanical performances of the welding joints with PF (pullout failure) mode are little affected by shrinkage voids but solidification crack has a more severe effect on the mechanical properties of the welding joints. The RSW joint failure modes of DP steel mainly depended on the weld nugget width at the overlap surface and welding defect [11]. Failure mode of resistance spot welds is a qualitative

measure of mechanical properties [12]. Basically, spot welds can fail in four distinct modes but the most common are IF (interfacial fracture) and PF (pullout failure) mode. An acceptable failure mode is the PF mode, especially in the automotive and aerospace industries.
In recent years, research related to the joining of steel and aluminum alloys using REW technology has become available [7, 13-16]. Seungyeop Baek et al [17] al concluded that the Resistance element welding of SPFC980 steels and AA5052 alloy was successfully done with achieved 9 kN of tensile-shear strengths with excellent failure energies from the welding currents in 6.5 kA–10.5 kA without any common weld defects, e.g., crack, lack of fusion, lack of penetration, undercut, etc. This paper presents the analyzes od the occurrence of defects and discontinuities in the REW (Resistnce element welding) weld of DP 500 steel and aluminum alloy AW5754.

2. Experimental Procedure

In this study 1 mm thick aluminum alloy AW 5754 H22 Al and 1.5 mm thick DP500 steel were used. The auxiliary element was made from Q235 steel. The chemical compositions and basic mechanical properties of these materials are shown in Table 1. The welding specimens were 30 × 100 mm with a 35 mm overlap (Figure 1). The element with a 4 mm diameter was inserted into the aluminum with a force pressure of 300 N. Before welding, industrial alcohol was used to clean the specimens. Welding was carried out using electrode type F1 at the RSW machine manufactured by Kocevar & sinovi.
Welding was repeated four times at each welding parameter, including three specimens prepared for static tensile-shear test and one specimen prepared for metallographic investigation. During the welding process, both the squeeze time and holding time were kept constant at 300 ms. Welding parameters were selected on three levels: welding current (6-8-10 kA), electrode force (2,45-3,68-4,91 kN) and welding time (60-120-180 ms).
The tensile-shear tests were performed at a cross-head speed of 2 mm/min at Beta 50-7/6×14 testing machine. Peak load and Failure energy were measured from the obtained load-displacement curve. This test is used to analyze the effect of weld defects and discontinuities on the tensile-shear mechanical properties and failure mode of the weld. After the test, the fractography of the fracture was done in order to observe the possible defects of weld.

Table 1. Chemical composition and mechanical proprieties of materials used in this study.

Material	**Chemical composition (%)**									
	C	**Cr**	**Si**	**Mn**	**P**	**Fe**	**S**	**Mg**	Al	Cu
DP 500	0.1	/	0.5	1	0.025	Bal.	0.01	/	0.015	/
AW 5754	/	0.3	0.4	0.4	/	0.3	/	3.6	Bal.	0.1
Q235	0.29	/	0.28	1.03	0.04	Bal.	0.05	/	/	0.2
Mechanical propertis										
	Yield strength $R_{p0,2}$ (MPa)					Tensile strength R_m (MPa)			Elongation A_{80} (min %)	
DP 500	330					550			20	
AW 5754	185					245			15	
Q235	250					475			20	

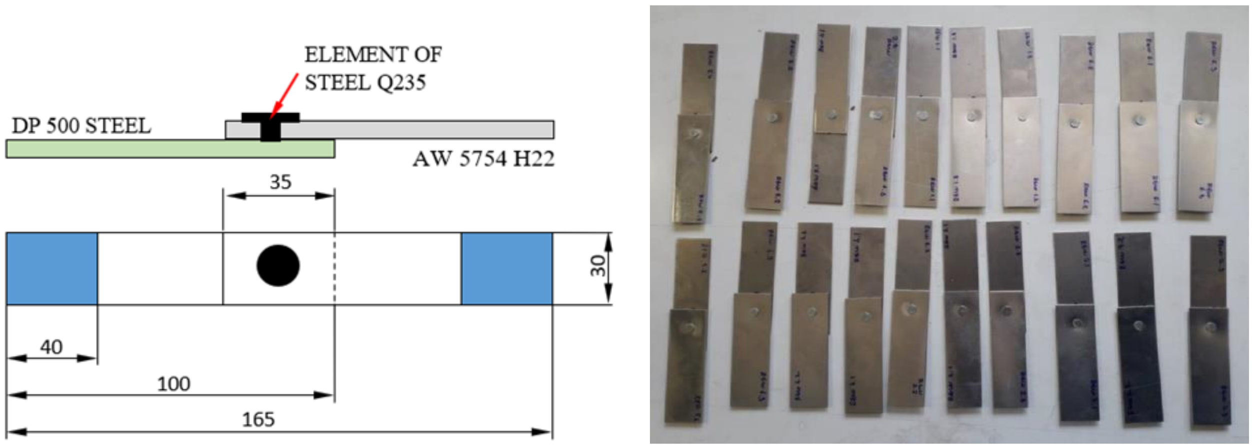

Figure 1. Specimens prepared for tensile-shear test

Metallography analysis was used in order to determine the defects and discontinuities in the REW weld. Macrostructure and Microstructure of joints were observed with a Keyence VHX-6000 microscope. The samples for this analysis were cut from the center of the joints and were ground and polished based on standard metallography procedures. The samples were first etched using 4% nital solution (7 seconds) and then were etched using H2O and HF solution (25 seconds).

3. Results and Discussion

The results obtained from the tensile-shear test show that the considered welding parameters did not greatly affect the value of the peak load, except for the specimen welded with an electrode force of 4.91 kN. The average value of the peak load ranged from 2100 to 2400 N. Opposite to the peak load, the welding parameters have a significant influence on the fracture energy. The highest value of fracture energy was achieved with welding parameters: welding current of 6 kA, electrode force of 3,68 kN and welding time of 60 ms.

In the case of welding with electrode force of 4.91 kN, it can be assumed that due to the high force, the Q235 steel element was pressed into the DP 500steel and thus the aluminum alloy came into contact with the large area with DP500 steel which caused a not a quality joint. Also, all specimens (except the specimens welded with 4.91 kN) fail in the PF mode. The results of tensile-shear testing for some specimens are shown in Figure 2.
Analyzing the fractography from Figure 2 can be concluded that during Resistance element welding of DP steel and aluminum alloy, extrusion of aluminum between DP steel sheet and steel element can occur. Expulsion, which refers to the ejection of molten metal, is a common phenomenon during the resistance spot welding process. It usually occurs at either the electrode/workpiece interface or the faying surface owing to excessive heat input [8]. In this case (REW welding), the expulsion occurs only at the interface of the workpieces (DP steel sheet and steel element). More expulsion was observed by welding with the highest value of current (10 kA) and welding time (180 ms), which confirms that high heat input also in REW welding contributes to the appearance of extrusion of material with a lower heating point. Expulsion may severely affect the weld quality and Figure 2 also show that the failure energy is highest for welding without an expulsion.

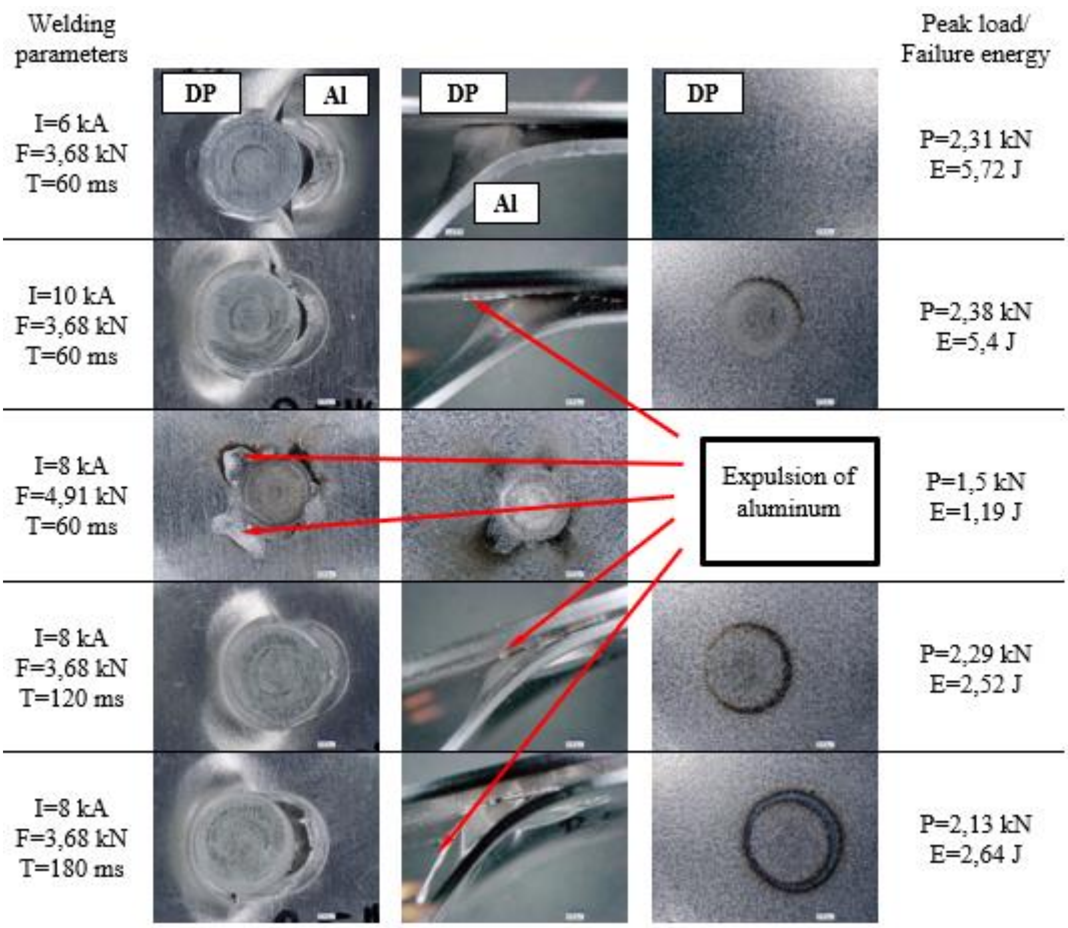

Figure 2. The results of tensile-shear testing

The Macrostructure of the REW joint of DP500 steel and aluminum alloy AW 5754 for some welding parameters is shown in Figure 3. The defects observed during the macrostructure analysis are (1) the occurrence of the IMC layer, (2) Shrinkage void and (3) asymmetrical spot weld nugget.
The Fe-Al intermetallic compound is primarily formed due to the extremely low solid solubility of iron in aluminum. The IMC layer is very brittle, and its presence in the joint significantly reduces the mechanical properties of the joint. In some samples, during the preparation for metallographic testing, the brittle IMĆ layer was torn, which manifested as a hole in the macrostructure.
Vijeesh Vijayan et al [18] explained the reason for the formation of Shrinkage void in their study: "Dendrites growing axially (in electrode direction) will experience a higher cooling rate and would grow faster than the dendrites growing in the direction of interface/bulk. As a result, the axially growing dendrites obstruct the interdendritic feeding during the final stages of solidification owing to dendrite coherency. The coherency causes an acute shortage in liquid feeding to the nugget center; this shortage along with metal contraction is believed to cause large pores in the nugget known as shrinkage void (cavity)". Shrinkage voids formation is strongly dependent also on carbon equivalent. A higher carbon equivalent results in more shrinkage voids in spot welds [19]. From Figure 3 it can be seen that high heat input (welding with a current of 10 kA) significantly contributes to the formation of shrinkage voids.

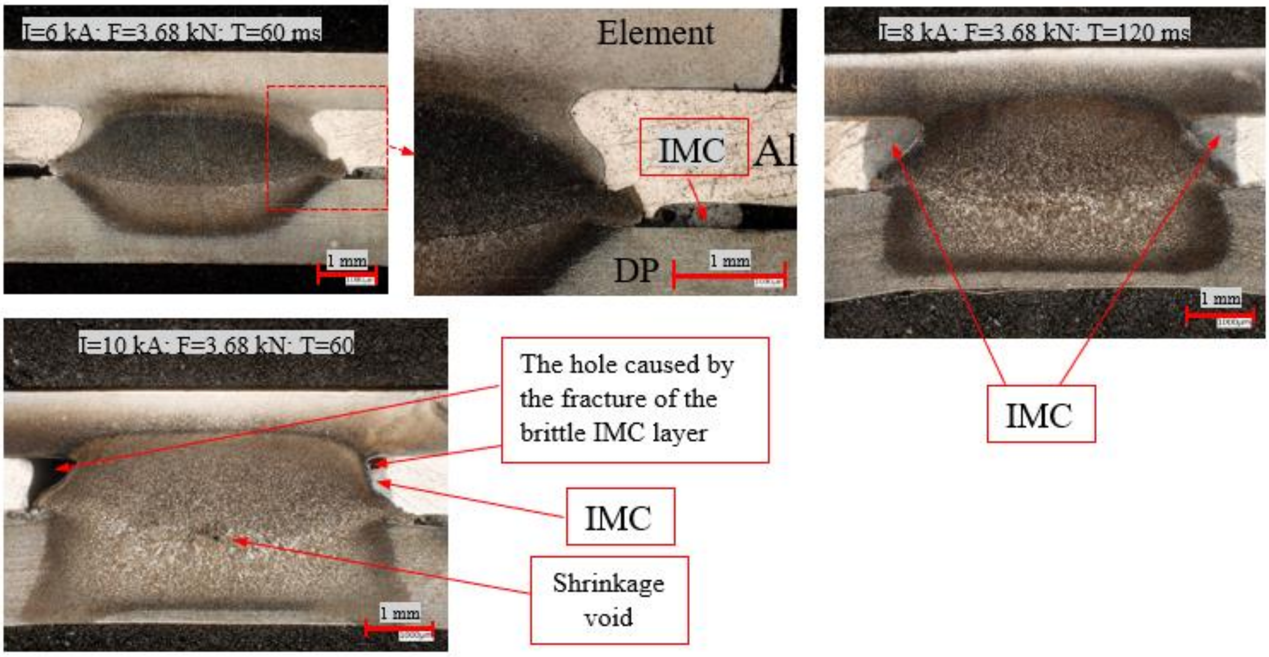

Figure 3. The Macrostructure of the REW joint of DP500 steel and aluminum alloy AW 5754

The macrostructure weld shows asymmetrical nuggets formation for all welding parameters. The larger part of the nugget is in the Q235 steel element. This formation of the asymmetrical nuggets can be attributed to the differences in electrical resistivity and thermal conductivity. The occurrence of defects and discontinuities in the weld does not have a significant effect on the peak load as well as a failure mode.

5. Conclusions

This paper analyzed the occurrence of defects and discontinuities in the REW (Resistance element welding) weld of DP500 steel and aluminum alloy AW5754. Analysis of the macrostructure and analysis of the fractography of the joint were used to detect defects and discontinuities. The following conclusions were reached:

1. Between the DP steel sheet and steel element, the extrusion of aluminum is occurred. More expulsion was observed by welding with the high value of current (10 kA) and welding time (180 ms), which confirms that high heat input also in REW welding contributes to the appearance of extrusion of material with a lower heating point.
2. The defects observed during the macrostructure analysis are (1) the occurrence of the IMC layer, (2) Shrinkage void and (3) asymmetrical spot weld nugget. The Fe-Al intermetallic compound is primarily formed due to the extremely low solid solubility of iron in aluminum. Shrinkage voids are formed due to high carbon equivalent and high heat input. This formation of the asymmetrical nuggets can be attributed to the differences in electrical resistivity and thermal conductivity.
3. The occurrence of defects and discontinuities does not have a significant effect on the peak load as well as the failure mode for the REW weld presented in this study.

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