Researches on the failure modes under tensile forces of the Resistance Spot Welding (RSW) joints

Marius Chirileanu *, Nistoroschi Georgiana* and Eugen Axinte*
*Gheorghe Asachi Technical University of Iasi , Bd. Prof.Mangeron 59 A, Iasi, Romania

ABSTRACT

Resistance spot welding (RSW) is one of the most used methods of joining sheet metals. The RSW process is based on Joule Lenz effect, of the electric current passing trough the (similar or dissimilar) joining metal sheets positioned between the two contact electrodes. At welding process , some important changes occurs in metallurgical and mechanical properties of the welded areas and heat affected zones (HAZ) . The purpose of this work is to highlight the influences of joint materials and welding parameters on the tensile strength and on the failure mode of the joints. By using constant pressure (force) of the electrodes and different values of current and welding time, three types of materials were welded . The welding samples have been subjected to tensile-shear tests and the surfaces of failures were analyzed by scanning electron microscopy (SEM) Some recommendations referring the electing of the optimum welding parameters were formulated..

Keywords: fracture., optimum parameters, spot welding, steel, tensile-shear,

I. INTRODUCTION

Resistance spot welding (RSW) is intensively used in top industries as automotive aerospace because of the relatively low cost of the process. Also RSW have a great adaptability for automation in high-rate production (there are about 5000 spot-welded joint in every car frame. [1] & [2]Usually , the . RSW processes are extensively used for joining low carbon steel components, but ,with some cautions , the stainless steel, aluminium, titanium and copper alloys are also commercially spot welded [1] ,[2] ,[3] and [7] . In [4], [5] and [6] is revealed how by a special small scale RSW method , a Zr-based metal glassy alloy was successfully welded. The RSW process is based on Joule Lenz effect: a great amount of heat is generated by the current and the electrical resistance between the parts to be welded. The heat is developed using a low tension (12 V) and high intensity of the current (>5 kA) [5] and [6].The high temperature developed melts the surfaces and a core of lens shape is formed after cooling . The welding adjustable parameters of the RSW process are : the pressure of the electrodes, the current given by welding machine and the welding time. To calculate the heat released during the welding process, is necessary to know the values of the factors on which that depends: electrical resistance of the conductor, amperage and length of time that current flows. The amount of heat generated Q (J) is calculated with formula (1)

$$Q = I^2 R t \qquad [\text{ joule }] \qquad (1)$$

Where: I= current intensity (A), t= time (s) ; R – electric resistance of joint (Ω) The strength of spot-welds depends on several factors : structure and property of base metals, characteristics and configuration of the welding machine (electrodes geometry , pressure force of the electrodes , current) , size and geometry of the specimens, test conditions [8] Several researches have examined the influence of these factors to predict failure of spot-welds with improved reliability. Kharaman in research paper [1] shows that the effects of parameters interaction regarding the weld diameter and the tensile-shear strength can be analyzed based on mathematical regression models of the welding process. The size of the fusion zone, the electrode penetration and the weld depth are significantly affected by welding current and welding time, [8] In [9] , Yang et al in [8] shows that for tensile-shear strengths the most important factors which affects the failure mode of welded joints are : thickness and length of weld nugget. The failure zone of the structure fulfils the zone with the smallest hardness of the length profile as is revealed by Mukhopadhyay et al in [10]. The paper aims to develop a comparative analysis between characteristics of welded structures of three different materials, the failure manner according to material type, the working parameter and implicitly the zone of failure.

2. THE EXPERIMENTAL SETUP

2.1 Materials

Three types of steels sheets were RS welded : a low carbon steel S235JR, a Zinc (Zn)–coated (galvanized) low carbon steel S235JR and an Austenitic Stainless Steel (grade 304 L).Carbon steel type S235JR is widely used in welding process and has excellent weld ability. [8,9,10,11] The other two types of steels has a high corrosion resistance, which requires some special cautions for preserving materials quality during welding process. The thermal conductibility of austenitic stainless steel is about 50-70% bigger than that of the carbon steels and a lower contact resistance occurs. According with equation (1) higher values of welding parameters - I (kA) or t (s /cycles) are necessary to be used [12, 13] Austenitic stainless steel constitutes the most common and largest stainless steels family [14].The standard austenitic stainless steel weld metals contains austenite and ferrite, similar to an as-cast microstructure [15]. The austenitic stainless steels are used for a very broad range of applications when an excellent combination of strength and corrosion resistance is required [16]. Generally , austenitic stainless steels are easy weld able [16]. When an austenitic stainless steel is welded, its heat affected zone (HAZ) is often sensitized by formation of inter-granular Cr-rich carbides, which deteriorates the corrosion properties of the welded joint. The presence of Delta (ƍ) ferrite has a great contribution in reducing or preventing micro cracks in austenitic stainless steel welds. [17]. All the specimens were prepared with the dimensions according to images in Figure 1 .

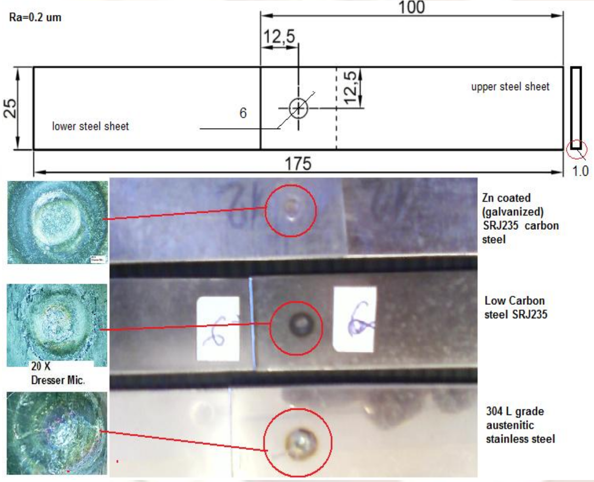


Fig. 1. The dimensions of spot welded specimens,

2.2 The experimental method

Typically, there are three stages in RSW processes : in the first stage, the electrodes are brought together against the metal and pressure is applied before the current is turned on. Next stage, the current is turned on and is maintained a time (cycles) This is followed by the third stage, or hold time in which the current is turned off but the electrodes are still pressed on the weld joint .

The hold time forges the metal while it is cooling (figure 2, adapted from Kharaman)

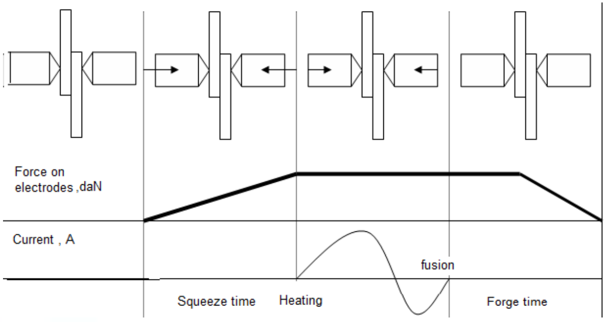


Fig. 2 Typical RSW process (adapted from [1])

It were studied the effects of two main parameters of the process (current and welding time) on tensile-shear resistance of weld samples. The failure modes were also studied and commented. During the welding process the electrodes force was maintained constant at 1.7 KN (see Table 1)

Table 1. The welding parameters

Welding on (cycles)	Electrode force [KN]	Electrode Pressure [bar]	Weld current , [KA]
5 6 7	1.7	6	5 6 7

In order to evaluate the weld quality of joined materials, the strength of welded joint was also determined. Structures employing spot weld are usually designed so that the welds are loaded in shear when the parts are exposed to tension or compression loading. In some cases, he welds may be loaded in tension, where the loading direction is perpendicularly to the plane of the joint or a combination of tension and shear [1]

In experimental setup were used three values for welding time, 5 , 6 and 7 cycles, and the welding currents was 5, 6 and 7 kA. The welded samples were subjected to tensile shear tests on the Universal Testing Machine WDW-50. During these tests ,a maximum force of 15 kN was required After the tests were identified the three types of breaking failure, each with a special feature: *(1) interfacial ; (2) pullout ; (3) tearing.* In the present work, optical examination of samples was carried out using a *Vega Tescan Scanning Electron Microscope (SEM)* . The dedicated software was used to obtain the microstructure images of broken welded joints. .

3. RESULTS AND DISCUSSIONS

In Figure 3 is presented a interfacial sample, in which the nucleus formed gave the structure of the tensile test. Tensile resistance grows depending on the heat released at welding zoneAt a lower heat is observed a breaking failure type *Interfacial* , where the tracks are not very well connected through the welding joint. The amount of heat released during the welding process depends on entrance parameters, time and current.

Fig. 3 Interfacial fracture in galvanized steel core

In the stainless steel samples , the amount of heat was not sufficient to form a welding type pullout or tearing. Instead, the resistance of these samples at tensile-shear tests was bigger than that of the other two materials. The breaking failure was produced through shearing the welding joint between samples (Figure 4).

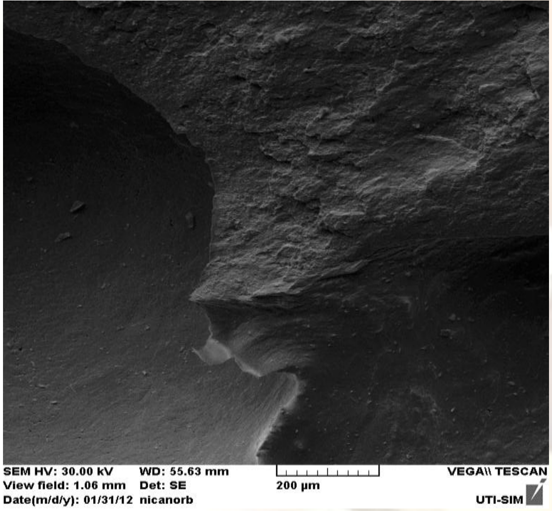


Fig. 4 Interfacial fracture in 304 L stainless steel core

The thickness of specimens subjected to tensile tests influences the rupture manner . During the tensile test, , at lower specimens thickness (less than 1 mm) , the joined specimens exhibit a bending phenomenon in the core zone. This bending phenomenon changes the distribution of forces inside the joint and another mode of breaking failure occurs. (Figure 5)

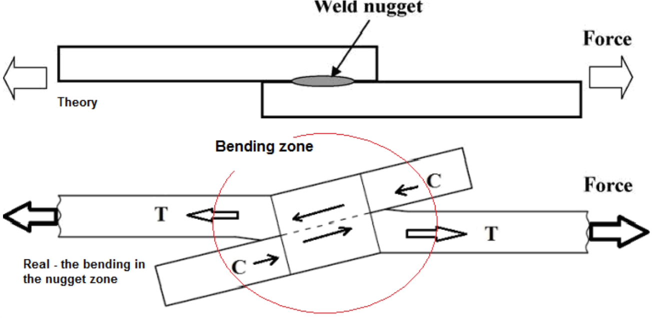


Fig. 5 Sample subjected to tensile-shear

Once the values of time and current parameters were fixed at highest levels, the heat generation was more pronounced and the nucleus structure well defined. This led to a better resistance of the welded joints. Once the values of time and current parameters were fixed at highest levels, the heat generated was more pronounced and the nugget structure is well defined. This led to a better resistance of the welded joint. In this case the knotting rupture occurs. The knotting rupture consists on an extraction point on one of the parts due to significant changes occurring in the material and near the nugget . On the upper surface of the residual nugget can be observed the footprint left by the electrode. At the galvanized steel sample, because the zinc coating, the contact resistance was reduced and a splash of material occurred. After the tensile tests ,it was observed that a part of welding nugget remained on the lower layer (figure 6) It was also observed a displacement of the nugget due to the forces involved in the tensile test.

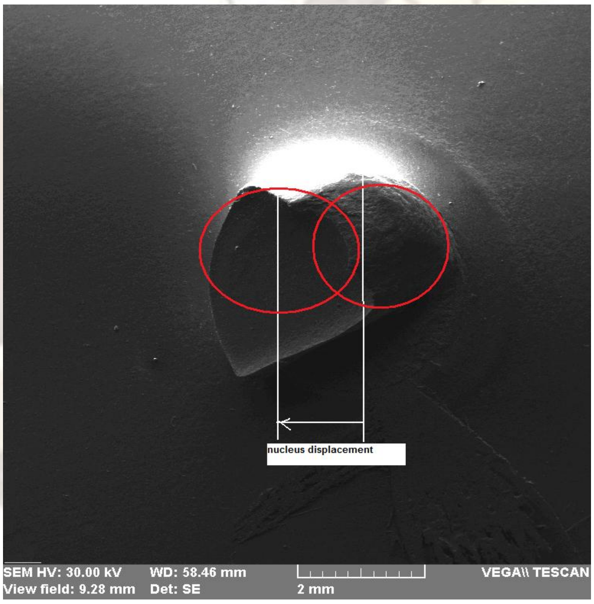


Fig. 6 Pullout failure mode of S235JR steel

Figure 7 represents the breaking failure tearing type. Appropriate parameters ensure a nucleus with a resistant structure. Shear failure do not appeared in nucleus but into the surrounding material. On the figure we can note the characteristic RSW area: electrode mark, HAZ and semi-finished product. The welded samples on which we meet this type of breaking failure are considered being at the best quality of the three types of breaking failure.

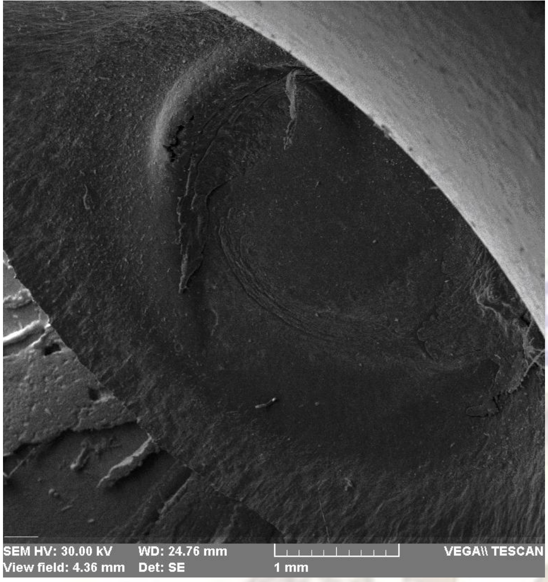
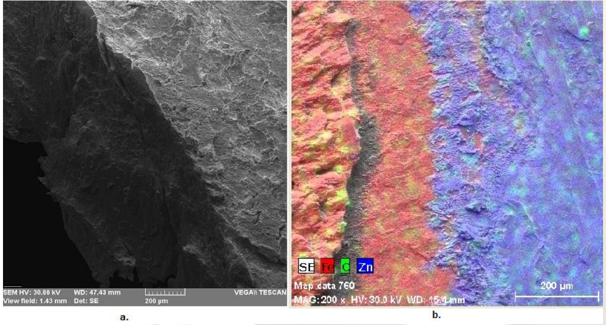


Fig. 7 Tearing failure mode of S235JR steel

In Figure 8 we notice a shearing edge of the base material, in our case galvanized steel, phenomenon occurred after traction-shear test. It was also observed phenomenon of migration of coating material (Zn) beyond the margins of the weld nugget .



a. b.

Fig. 8 Failure mode of galvanized steel
a. shearing edge of the base material b. migration of Zn beyond the margins of the weld nugget

4. CONCLUSION

Generally, the most important factors that influences the weld quality are surface quality (roughness) , strength and ductility of welded materials, weld nugget size, weld penetration, sheet separation surface , and internal discontinuities. Surface appearance of the welded specimens is shown in Fig.1. Normally, the visual appearance of a RSW nugget is round or oval with a relatively smooth surface. Stainless steel samples measurements shows that at a current of 5 kA, the tensile strength is almost the same for all cycles of time that were used. The tensile strength grows significantly at a higher current used . The biggest tensile strength was obtained at a current of 7 kA combined with a time of 7 cycles. .The tests results shows that the best resistance for the studied stainless steel samples were obtained at the biggest values of current and time used. Is observed that the influence of current parameter has the biggest importance regarding the tensile strength of stainless steel RSW joints .In the case of S235JR steel RSW joints and of the galvanized S235JR steel RSW joints it was observed the crucial influence of the welding time (cycles) . The best results were obtained using 5 welding cycles. Also, the highest tensile strength of welding joint of S235JR steel was obtained using a current of 6 kA. At galvanized S235JR steel highest tensile strength of welding joint was obtained at 5 cycles and a current of 7 kA.

ACKNOWLEDGEMENT

The research was realized with the support of POSDRU CUANTUMDOC “Doctoral studies for european performances in research and inovation” ID79407- project funded by the European Social Found and Romanian Government.

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