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Microstructural and Mechanical Characterization of Spot Welds on AISI 430 ferritic stainless steel sheets

Abstract. *Electric resistance spot welding is a simple and fast process that is widely applied on stainless steel sheets. During this process, a high electric current flows between the electrodes through the pressure parts. By the Joule effect, a nugget of molten solder is formed between the welded parts. In this study, AISI 430 ferritic stainless steel sheets were spot welded by electrical resistance with different welding parameters. The effect of the welding current and the holding time during welding on the microstructure and the mechanical properties of the welded joints have been investigated. Tensile tests and micro hardness measurements were carried out to assess the mechanical properties and the breaking characteristics of the welded joints. The obtained results show that the nugget size, the tensile strength of the welded sheets and the micro hardness distribution depend on the welding parameters. The micro structural study allowed us to explain the transformations produced during welding.*

Streszczenie. *Zgrzewanie punktowe oporem elektrycznym jest prostym i szybkim procesem, który jest szeroko stosowany w przypadku blach ze stali nierdzewnej. Podczas tego procesu pomiędzy elektrodami poprzez części ciśnieniowe przepływa duży prąd elektryczny. Dzięki efektowi Joule'a pomiędzy spawanymi częściami tworzą się bryłki stopionego lutowia. W tym badaniu arkusze ferrytycznej stali nierdzewnej AISI 430 zostały zgrzane punktowo za pomocą opornika elektrycznego przy różnych parametrach spawania. Badano wpływ prądu spawania i czasu przetrzymywania podczas spawania na mikrostrukturę i właściwości mechaniczne złączy spawanych. W celu oceny właściwości mechanicznych i wytrzymałości złączy spawanych przeprowadzono próby rozciągania oraz pomiary mikrotwardości. Uzyskane wyniki pokazują, że wielkość bryłki, wytrzymałość na rozciąganie zgrzewanych blach oraz rozkład mikrotwardości zależą od parametrów zgrzewania. Badania mikrostrukturalne pozwoliły wyjaśnić przemiany powstałe podczas spawania. (**Mikrostrukturalna i mechaniczna charakterystyka zgrzein punktowych na ferrytycznych blachach ze stali nierdzewnej AISI 430**)*

Keywords: Spot Welding, AISI 430 FSS, Microstructure, Micro hardness
Słowa kluczowe: Zgrzewanie punktowe, AISI 430 FSS, Mikrostruktura, Mikrotwardość.

Intreoduction

Resistance spot welding on a flat counter electrode is wedly used in the welding of difficult places such as cabinets or metal boxes or reinforces mentribs, etc.

The device often consists of a downward electrode which presents the work table; the work piece can be placed directly on the table. The surface under the welding point is smooth so that no welding point and no deformation can appear which avoids re-polishing. The AISI 430 ferritic stainless steels (FSS) are the most important in the family of stainless steels because of their good ductility and resistance [1, 2]. The microstructure of ferritic stainless steel changes during spot resistance welding on a flat counter electrode. When the welding cycle is carried out, the solidification of the fused zones produces a very strong bond between the two welded parts. The merged and solidified areas are called weld nuggets and consist of three areas. They are classified into Fusion Zones (FZ), Heat Affected Zones (HAZ), and Base Metal (BM).

Fusion welding is always accompanied by excessive and undesirable grain growth in the Fusion Zone (FZ) and the Heat Affected Zone (HAZ). This leads to the appearance of grains and the precipitation of secondary phases, including components rich in chromium, which contributes to the decrease in toughness and ductility and to reduce the corrosion resistance of steel [3 -4].

The aim of this work is to study the effect of variations in welding current and time on the mechanical and metallurgical properties of welded joints in Ferritic Stainless Steel AISI 430.

Materials and Methods

0.8 mm thick AISI 430 FSS sheets were used as the base metal. The chemical composition of the 430 steel is given in Table 1.

The welding operations were carried out by an RSW machine of PTDN-C-616 type with 80 kVA AC, and 50 Hz. The upper electrode is carried on an articulated arm equipped with a pneumatic jack of 1.8 KN, which ensures the pressure required for welding. The contact at the bottom is made on a copper table 15 mm thick, and not at a point, so the heat dissipates in the worktop. Figure 1 illustrates the assembly used for welding operations.

Tab 1.The chemical composition of AISI 430 (wt.%).

Cr	Ni	Mn	C	Si	S	Fe
17.5	0.141	0.769	0.12	0.471	0.01	Bal.

Various welding variables were used to obtain different sizes of welding nuggets. At the beginning, we carried out welding tests on control samples to have the best working parameters without bad welding and without expulsion. The main experimental parameters used in this work, are indicated in table 2. The upper electrode was kept unchanged during all the tests, and it is of (RWMA) type, class 2 with a 45 ° truncated cone and a diameter 4 mm front [5]

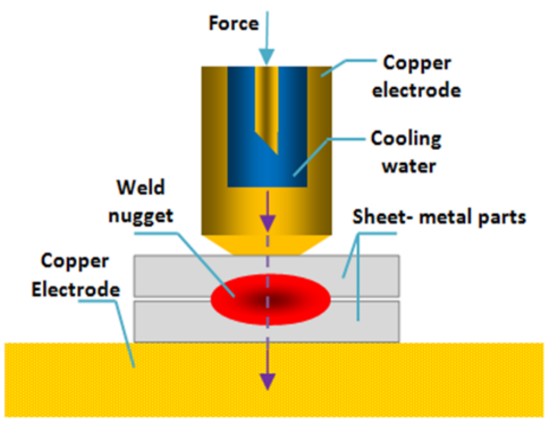

Fig 1. RSW welding on flat counter-electrode

Tab 2. Parameters for welding similar AISI 430 FSS

Weld schedule	Exp. N°	Current (KA)	Time (cycle)	Force (KN)	Electrode Tip (mm)
(a)	1	6.0	15	1.8	4
	2	6.4			
(b)	3	6.0	20		
	4	6.4			
(c)	5	6.0	25		
	6	6.4			

The welded samples were cut by EDM in the center of the weld nugget, then placed in a hard resin, polished and etched to observe the weld microstructures. To have the microstructures of the three zones of the nugget, we carried out a chemical attack according to standard ASTM E407-07 [6].

The microstructure and morphology of the different areas of the welds that appears during the welding cycle were observed using a LEICA DMLM metallurgical microscope optical microscope. Micro hardness tests were used to evaluate the hardness profile on the transverse face of the nugget in the vertical direction, by applying a load of 100 g for 15 s on a Mutotoyu VH2 Vickers micro hardness tester. Tensile shear test samples were prepared according to JIS Z 3136 [7]. Figure 2 shows the dimensions of the samples used in the tensile test. The tensile tests were carried out on a ZWICK / ROELLZ 050 machine. The values considered in this work present the average of five tests

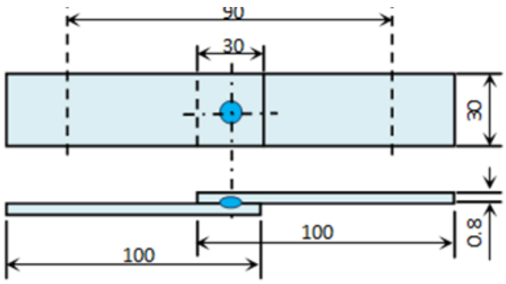

Fig 2. Dimensions of samples used in the tensile tests

Results and discussion
Microstructures

In the welding of Ferritic stainless steels (FSS), the thermal conductivity and the melting point are identical, and the nugget formed is often symmetrical when thermal energy is applied to the tips of the electrodes. The weld sections of the spot resistance welded joints undergo a temperature gradient indicating the metallurgical changes which occur during the formation of a weld. The typical microstructure of these welds reveals three large distinct microstructural zones: the Base Metal (BM), the Heat Affected Zone (HAZ) and the Molten Zone (FZ) Figure. 3a.

The microstructure of the Base Metal (BM) is mainly composed of a ferritic phase with entirely fine grain, with an average size of about 5 to 10 µm (figure 3b), and characterized by vast fine precipitates of marten site grain boundaries. Depending on the temperature distribution (Figure 3d), the HAZ can be divided into:

❖ A coarse-grained heat affected area (CGHAZ), which is located in the areas immediately adjacent to the melted area. This zone is characterized by a significant growth of the equiaxed ferrite grains without precipitates, with a size between 200 and 300 µm.

❖ And a fine-grained heat affected zone (FGHAZ), bordering the BM zone [8]. This zone is relatively coarser than the BM zone, mainly composed of a ferritic phase with chromium carbide precipitates in the form of dispersed islands.

Likewise, the Fused zone (FZ) can be presented in two distinct regions in the weld nugget as shown in Figure 3e: the internal fusion zone having a fine dendritic morphology and the external fusion zone having a coarse dendritic morphology.

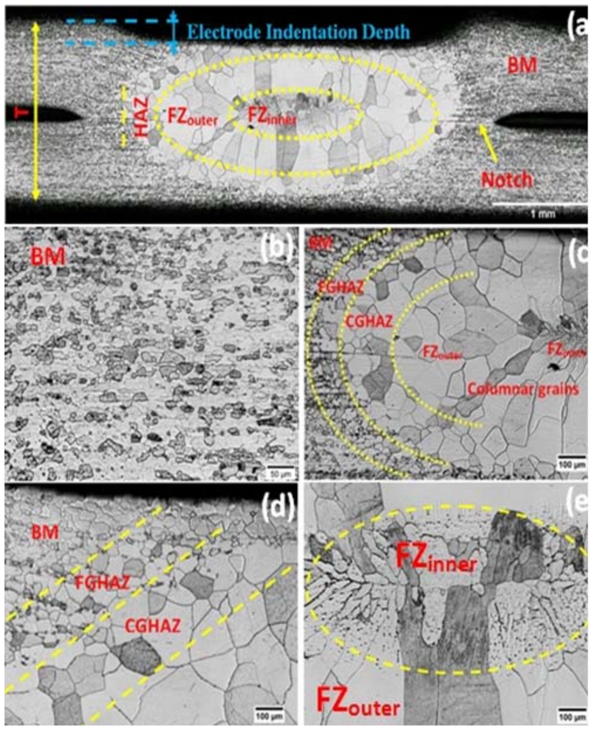

Fig 3. a) typical macro graphy of resistance spot welding; b) Base metal; c) gradient three zones HAZ, FZ and BM ; d) CGHAZ and FGHAZ ; e) ZF inner and outer

Micro hardness

The micro hardness profiles of the welded samples with a welding current of 6.0 and 6.4 kA and welding times of 15 to 25 cycles are presented in Figure 4. The obtained values confirm the structural modification during the welding process, where the current plays a key role in the development of micro hardness during welding processes by RSW.

According to Figure 4, we can advance the following remarks and observations:

❖ The micro hardness of different zones (FZ, HAZ and BM) obtained by 6.0 KA current are larger than those obtained by 6.4 KA current whatever the number of cycles. This allows us to say that the welding current does not have a great influence on the microstructure transformations of the welded zone. According to Pouranvari [9], as time and temperature increase, the cooling rate also increases, which leads to microstructures with higher micro-hardness.

❖ The shape of the micro hardness profiles as a function of the welding current and the number of cycles makes it possible to say that the micro hardness of the welding increases when the number of cycles increases.

❖ In all cases the micro hardness of the Melted Zone (FZ) is larger than the Heat Affected Zone (HAZ) and the Base Metal (BM). Indeed, the hardness of each zone depends on its structure and on the grainsize of this structure [10]. Figure 4c shows a hardness of 155 HV in the Base Metal (BM), followed by a hardness of around 250 HV for the Fine Grain Heat Affected Zone (FGHAZ). Then a slight drop in hardness which corresponds to the Coarse Grain Heat

Affected Zone (FGHAZ) and which is justified by the enlargement of grains during cooling. The fluctuation of the micro hardness values in this Heat Affected Zone is justified by the presence of precipitation of chromium carbides during the thermal cycle.

❖ A maximum micro hardness of around 350 HV is obtained in the Fused Zone (FZ) after welding with a current of 6.0 KA and 25 cycles. The high hardness value in this area is justified by the rapid solidification immediately after its fusion.

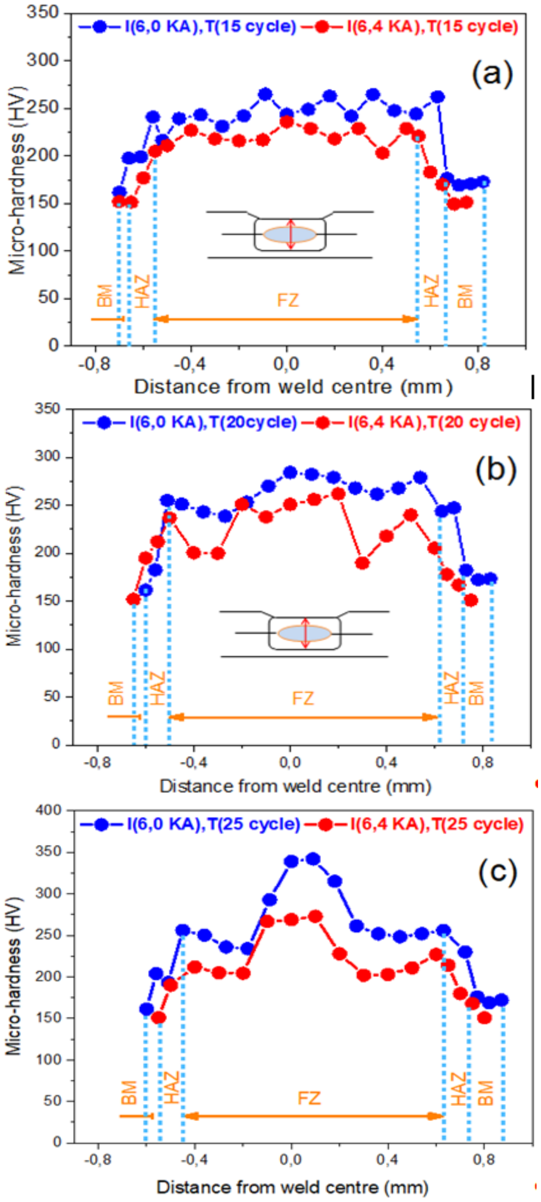

Fig 4. Micro hardness profiles of welded samples with welding current of 6.0 and 6.4 kA: (a) 15; (b) 20 and (c) 25 cycles

Traction Results

The tensile curves as a function of the welding current and the number of cycles are presented in Figure 5. According to this figure, the tensile strength increases with the welding current. This is justified by the increase in the diameters of the nuggets formed [11, 12] because of the greater heat in the welded areas. From the results, we can say that the effect of the number of cycles is more important than the effect of the welding current.

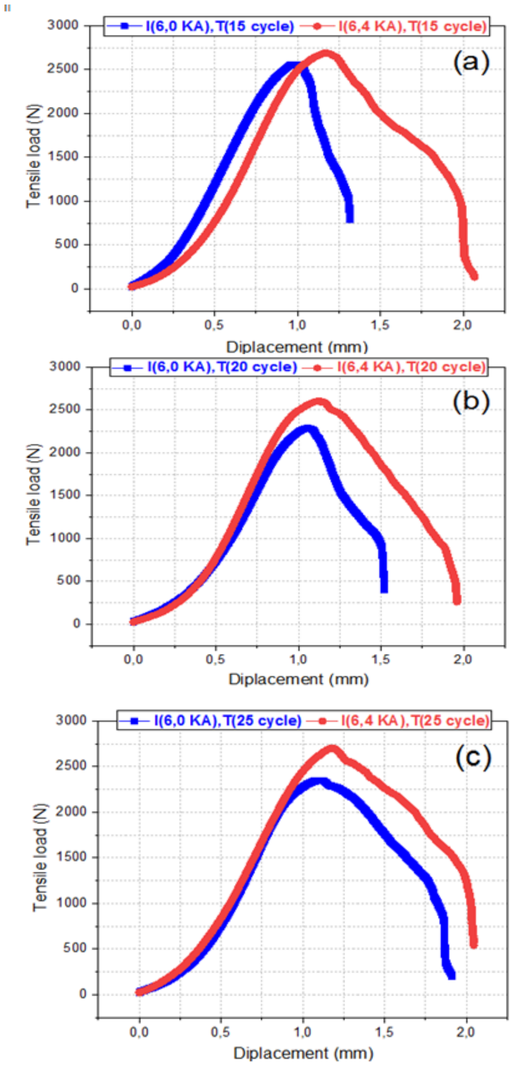

Fig 5. Tensile curves of under 6.0 and 6.4 KA welding currents, with: (a) 15; (b) 20; (c) 25 cycles.

Conclusion

After this work, we can advance the following conclusions:

❖ The Fused Zone (FZ) is constituted of two distinct regions in the weld nugget: an interior fusion zone with a fine dendritic morphology and an external zone with a coarse ferritic columnar structure.

❖ When the current increases the hardness decreases. On the other hand, when the number of cycles increases the hardness increases.

❖ The increase of the nuggets size during welding is accompanied by an increase in mechanical strength (a strong bond between the sheets).

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