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Optimization of electrical parameters in Resistance Spot Welding of dissimilar joints of micro-alloyed steels TRIP sheets

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Abstract

The Resistance Spot Welding (RSW) process in dissimilar joints of micro-alloyed steels TRIP (Transformation Induced Plasticity) sheets was herein optimizing. The welding electrical parameters (time and current intensity) had an important effect in the final Shear Tensile Resistance of these kind of joints. Taguchi Design of Experiments was employed in order to optimize the process by the signal-to-noise ratio. Furthermore ANOVA analysis determined the relevance of each parameter in the final mechanical resistance of the welds. The optimum welding conditions were established inside the lobe curve that maximize the response of the experiment.

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Keywords: Resistance Spot Welding, TRIP, DOE, Taguchi, ANOVA.

1. Introduction

Resistance Spot Welding (RSW) is widely used in industry to joint metal sheets because it is an inexpensive and fast process for large batches of this kind of parts. Furthermore, the equipment that is usually applied is not very complex and suitable for incorporating in a robot [1]. Advanced High Strength Steels (AHSS) such us Transformation

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Induced Plasticity (TRIP) steel are adequate for car bodies since its great strength permits a good combination of light weight and strengthen, that is, safety and energy efficiency of welded structures in automotive industry. Moreover, other metals with lower strength are required in order to manufacture stamped parts to be incorporated to those structures. Consequently, dissimilar RSW of both steels appears in many car body joints [2]. A lot of tests have been widely used in order to characterize Resistance Spot Welds according to some welding or joint behavior parameters such us welding current, the microstructure involved in the heat affected zone (HAZ), micro-hardness and tensile and shear strength [3]. Particularly, shear tension test is widely used in automotive industry due to this test not only permits determining the resistance of welds but also identifying the grade of integrity of the joints.

The strength of the joints will be given by welding parameters. The higher the current intensity is, the larger amount of fused material, so a higher size of nuggets are consequently obtained. The size of the nugget is directly related to its mechanical strength of this, but if welding current exceeds a critical value the nugget does not increase more but an expulsion of liquid metal out of the joint takes place; that is, some fused metal is expelled from the nugget zone. Particularly, homogeneous welds of δ-TRIP steel reveals that the retained austenite in the metal improves the ductility of the welded joints by reducing the difference of microhardness between the welded and the base material zones [4]. Furthermore, some authors concluded that the transition between the different failure modes that may affect this kind of joints, pull out and interfacial fracture, and it depends strongly on the welding electrical parameters [5]. Radakovic et al. [5] inquired into the relationship between the kind of failure and the sheet thickness and nugget diameter. Both parameters reached a critical value from which the pull out-failure mechanism appeared. Conversely, lower values of those parameters implied an Interfacial fracture mode. Welds that present the first failure mechanism presented higher strength that the second one and could reach a strength greater than 90 % of the predicted value if interfacial fracture mechanism that would take place; that is, for the same diameter if pull out happened, the load-carrying capacity of the joint was much larger if interfacial mechanism did not appear. These facts implies that the variables values involved in welding process must be selected according to the before indicated, that is, the range must be from the minimum value that leads to a pull-out-failure mechanism to a maximum defined by the onset of metal expulsion. Nevertheless, the onset of this phenomenon can be considered an indicator of a good executed process [6]. Dissimilar joints of AHSS and High Formability Steels (HFS) have the same failure mechanism than homogenous welds but in the particular case that pull-out-fracture occurs, this always happens in the HFS due to its lower strength. Previous papers collected the microhardness (mHV) distributions in dissimilar joints Duplex Phase 600 steel-low carbon DC-05steel, DP600-DC05, and the welded zone presented a value above 80% respect to the corresponding to the AHSS steel, higher than the microhardness of DC05 steel. Thus, as expected, during shear tensile test, plastic deformation and necking appeared in the heat affected zone (HAZ) of the high formability sheet and finally the fracture occurred here [7].

The optimization of the welding process is other important aim of this work; in order to do it Taguchi´s approach for Design of Experiments (DOE) is employed. This method allows identifying the most relevant variables of the process and its optimization. This method considers that not all the variables have the same influence in the process and uses the signal-to-noise ratio, S/N, to identify this [8]. In Taguchi method, S/N ratio represents the quality characteristic of the ith measurement in an experiment; that is, it reveals the relationship between the desirable value (signal) and the undesirable value (noise). Eq. 1 establishes how to work out S/N value for an experiment of n trials for the ith measurement whose response is Y_i.

$$(S/N) = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Y_i^2}\right) \quad (1)$$

Thus, DOE is widely used for optimizing multivariable processes [8-10] and some authors state that this method is more effective than other methods as fractional factorial design [11]. Shafee et al. [10] demonstrated that S/N ratio allowed evaluating welding parameters for optimizing the shear tension strength of low carbon steel similar joints. They stated that this method was more effective than fractional factorial design.

The aim of this paper is to contribute to the optimization of the electric parameters of dissimilar RSW joints made with advanced high strength steels (AHSS) and high formability steels that are widely used in the automotive industry. Firstly, the suitable ranges for the parameters herein studied were determined, particularly for welding time and current. After that, a Taguchi´s DOE was carried out in order to optimize the response of the welds in Shear Tensile