

RESISTANCE SPOT WELDING OF STEEL SHEET DP500 - INFLUENCE OF THE WELDING CURRENT ON THE MICROHARDNESS AND WELD NUGGET DIAMETER

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Abstract: Dual-Phase steel has been used in body-in-white in order to reduce the weight and enhance the safety of automobiles. One of the most used technology for joining steel in automotive industry is Resistance spot welding. This paper presents the analysis of the welding current influence on the microhardness and weld nugget diameter. It will be shown in the paper that the increased hardness of the fusion zones reduces the possibility of the necking in the base metal (i. e. Pull-out Fracture - PF mode), which is not considered as a favorable case. Specimens welded with current of 8 kA showed the best mechanical characteristics, the failure load was approximately 20000 N, the hardness of the fusion zone was approximately 350 HV and during the tensile-shear test they failed in PF mode.

1 INTRODUCTION

Advanced High-Strength Steels (AHSS) have been developed and commercialized over the past decade to help automotive companies meet lightweight construction requirements without compromising passenger safety requirements [1]. These categories of steel are expected to be predominantly used in automotive industry. These steels have an excellent combination of high strength and ductility, and are also very formable. AHSS steels require special consideration and research of their welding behavior for successful application in automotive construction. As one of the most common advanced high strength steels (AHSS), dual phase (DP) steel has the higher strength, lower yield rate, higher working hardening rate, higher strain energy absorbing and more excellent forming characteristics than the conventional high-strength low alloy steels with similar strength. DP steel has been used in body-in-white in order to reduce the weight and enhance the safety of automobiles [2]. DP steels are mainly composed of dispersed islands of martensite in a ferrite matrix. The ductility is controlled by the ferrite, while the strength is controlled by the martensite [3].

Resistance spot welding (RSW) is a predominant welding technique used for joining steels in automotive applications needs to be studied carefully in order to improve the mechanical properties of the spot welds [4]. Welding parameters have a great influence on the mechanical characteristics of the RSW joint of two DP steels [5]. One of the most important mechanical characteristics is microhardness, so this paper will present the analysis influence of the welding current on the microhardness and weld nugget diameter.

J.H. Ordoñez et al. [6] conclude in their research that heterogeneous behavior of the hardness in the RSW welded joints of DP 980 steel was observed, which was attributed to the peak temperatures reached during the welding process. The increase in hardness of the fusion zone (higher than 350 HV) was generated by the martensite formation during solidification. In contrast, the weld thermal cycles induced a soft zone formation (approximately 250 HV) in the heat affected zone.

The failure of resistance spot welds during the tensile-shear test can be described as a competition between the shear plastic deformation of the fusion zone (i.e. IF mode) and the necking in the base metal (i. e. PF mode) [7].

According to the industrial standards, the minimum size of the spot welds to guarantee the pull-out fracture follows the relation $D = K\sqrt{t}$, where D is the weld nugget diameter in mm, K is a process-dependent constant ranging from 3 to 6, and t is the minimum sheet thickness in mm [4]. Also, the strength and failure characteristics of resistance spot welds are functions of the nugget size (NS), the sheet thickness and the hardnesses of the weld [8]. It is expected that every RSW weld with larger nugget diameter will fail in PF mode, which is considered a more favorable case, so it is striving for that. Thus, the larger nugget diameter of the RSW joint reduces the possibility of failing in IF mode. Also, the higher ratio of $(H_{max})_{FZ}$ (maximum fusion zone hardness) and $(H_{min})_{BM}$ (minimum hardness of the base material) reduces the possibility of failing in IF mode, so the critical value of the RSW nugget diameter can be calculated by relation (1) developed by [9].

$$d_c = 0.53 \cdot t^{3.22} + 8.48 \left[\frac{(H_{max})_{FZ}}{(H_{min})_{BM}} \right]^{-1.24} \quad (1)$$

According to the microhardness profile, using the relation (1), in this the paper will be calculated the critical value of the nugget diameter of the RSW joint of DP500 steel.

2 EXPERIMENTAL SET UP

In this research, 1,5 thick sheet metals of DP500 steel were used as the parent metal to be lap welded. The chemical composition and basic mechanical characteristic of DP500 steel are shown in table 1. The experiment involved joining of two sheet metals using RSW machine manufactured by Kocevar & sinovi which is managed using the BOSH 6000 software. Welding was carried out using electrode type F1 (ϕ 7 mm) on specimens 30 \times 105 with overlap 35 mm what is according to standard ISO 14273:2016. Welding current I was selected for experimentation for three levels of factors. Other welding parameters such as electrode force ($F=3,68$ kN), weld time ($T=300$ ms), squeeze time ($SQZ=300$ ms), hold time ($HLD=300$ ms), pre-heating time (Pre-Weld=0 ms), Cool Time ($CT=0$ ms), Up Slope Time ($UST=0$ ms) and Down Slope Time ($DST=0$ ms) were constant during the experiment. Specimens with welding current 6 kA, 8 kA and 10 kA were marked as D1, D2, D3 respectively. Vickers micro-hardness tester Zwick/Roell ZHU 2.5 was used to measure the hardness variations cross the joint under the load of 5 N for 12 s. The tensile-shear tests were performed according to standard ISO 14273:2016 at a cross-head speed of 2 mm/min with a Beta 50-7 / 6 \times 14 testing machine. Nugget diameter was measurement cross the joint on a Keyence VX1000 microscope.

Table 1. The chemical composition and basic mechanical characteristic of DP500 steel

Chemical composition						
C	Si	Mn	P	S	Al	Nb+Ti
0.1%	0.5%	1%	0.025%	0.01%	0.015%	0.1%
Mechanical properties						
Yield strength $R_{p0.2}$ (Mpa)		Tensile strength R_m (Mpa)		Elongation A_{50} (min %)		Hardness (HV)
290-370		500-600		20		≈ 235

3 RESULTS AND DISCUSSIONS

Tensile-shear load-displacement curves of RSW joint for three specimens (D1, D2, D3) are shown on figure 1. Peak load for specimens welded with 6 kA, 8 kA and 10 kA is approximately 14000 kN, 19500 kN and 19000 kN respectively. This confirms previous research that increasing the welding current does not necessarily mean a higher load capacity of the weld.

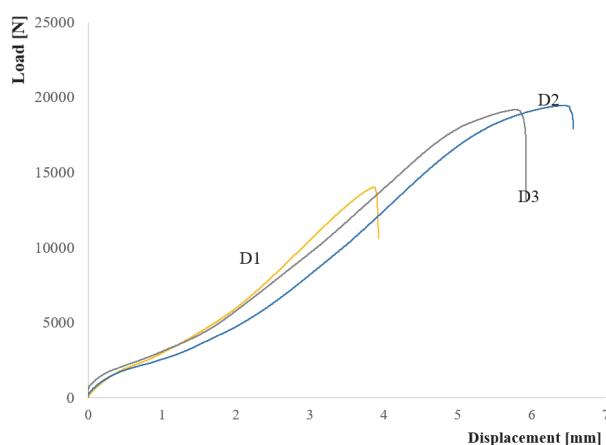


Figure 1. Tensile-shear load-displacement curves of DP500 steel RSW joint

Typical pull-out fracture (PF mode) is shown by specimens welded with 8 kA and 10 kA, while specimen welded with 6 kA shows a typical interfacial fracture (IF mode), what is shown on figure 2.

Microhardness profile for all three specimens are shown on figure 3. The hardness of the basic material obtained from these three samples ranged from 233 to 236 HV. Also, in all three samples it is noticed that the highest hardness is at the transition between the heat affected zone and the fusion zone. A sample marked as D1 has a higher hardness in the fusion zone (approximately 385 HV) compared to samples marked as D2 and D3 (approximately 355 HV), leading to the conclusion that the RSW joint of a DP steel which having a high fusion zone hardness will fail in IF mode. As previously emphasized, the diameter of the weld nugget has a great influence on the failure mode. Based on relation (1), it is possible to determine the critical diameter value based on the hardness of the fusion zone and the base material, which will not lead to fail in IF mode. In order to prove the possibility of applying the relation to RSW joints of two DP steels, a comparison of the weld nugget diameter obtained experimentally and by calculation based on relations (1) was made, the results are given in Tables 2.

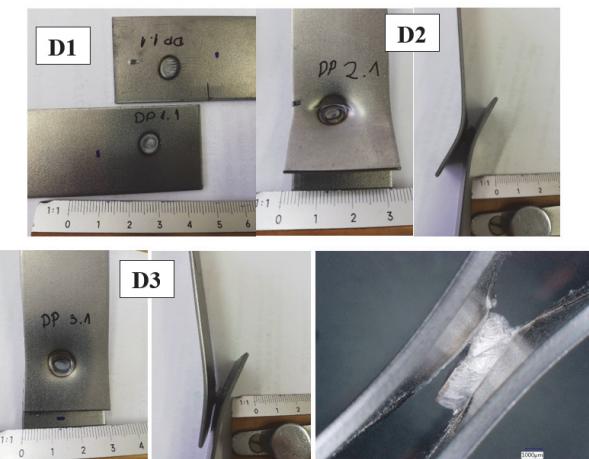


Figure 2. Typical fracture mechanism of DP500 steel RSW joint

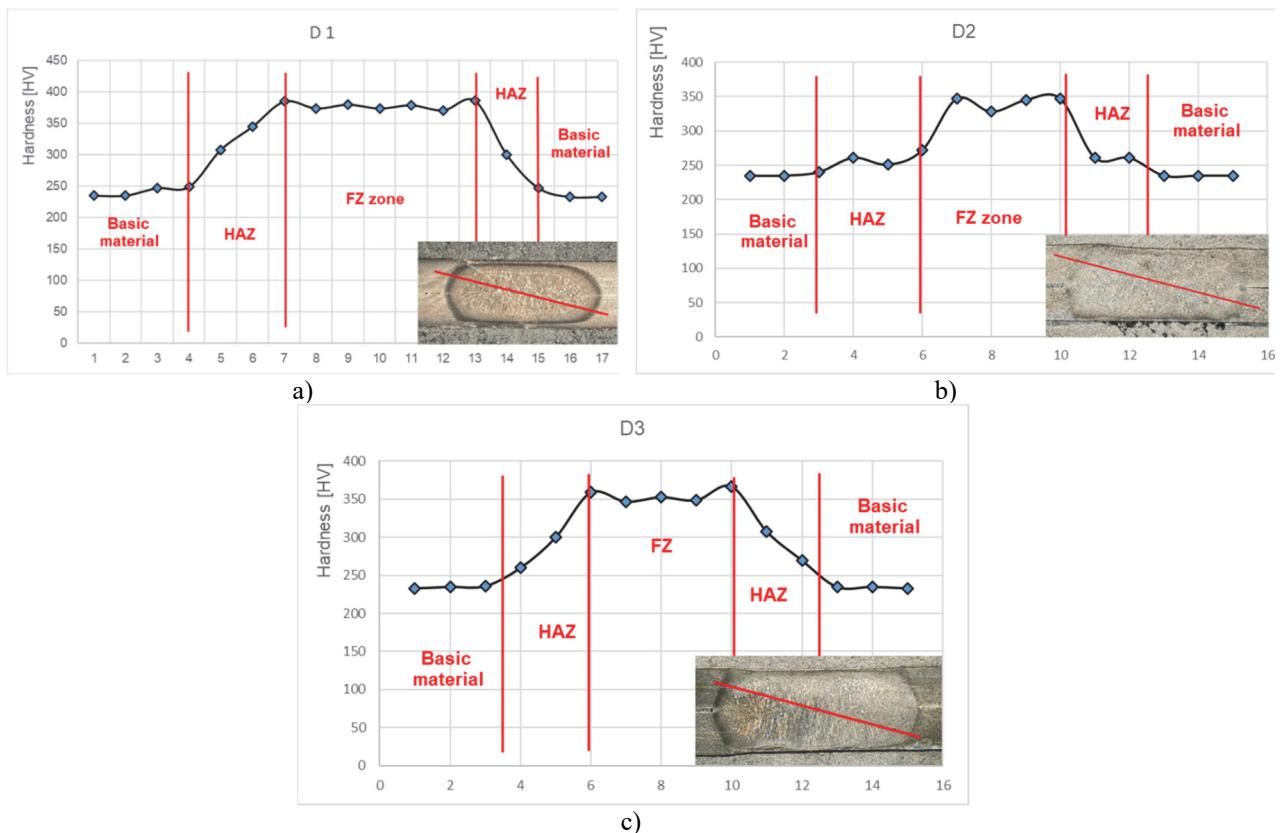


Figure 3. Microhardness profile of DP500 steel RAW joint: a) specimen D1; b) specimen D2; c) specimen D3

Table 2. Comparison of the weld nugget diameter obtained experimentally and by calculation based on relations (1)

Mark	Minimum value of basic material hardness (HV)	Maximum value of fusion zone hardness (HV)	Calculated critical value of weld nugget diameter according to relation (1)	Experimental value of weld nugget diameter
D1	233	386	6.49	6.23
D2	233	348	7.11	7.17
D3	233	369	6.75	6.77

Based on the data shown in Table 2, it can be concluded that relation 1 can be used to determine the critical value of the weld nugget diameter RSW joint of two DP500 steels. By sample D1, the calculated critical value of the weld nugget diameter is larger than the experimentally determined value, which leads to the conclusion that the sample will fail in the IF mode, which was confirmed by experimental testing. The same can be concluded for samples marked as D2 and D3, only that the failure mode is PF.

Finally, according to the relation 1 and hardness testing can be concluded that the RSW joint of two 1,5 thick DP500 steel will fail in PF mode if the hardness of fusion zone is smaller than 355 HV and weld nugget diamtere is haiher then 7 mm.

4 CONCLUSION

This paper presents investigations of the influence of hardness on the RSW joint failure mode. Experimental research first established that the welding current has a great influence on both the hardness of the joint and the static load capacity, but also was confirmed the previous research that increasing the current does not mean necessarily improve the mechanical properties of the joint. During the tensile-shear test, the samples welded with a welding current of 6 kA had the lowest static load capacity and weld nugget diameter, but the highest hardness of the fusion zone, which caused a that it fail in the interface module. The samples welded with a welding current of 8 kA showed the best mechanical characteristics, the failure load was approximately 20000 N, the hardness of the fusion zone was approximately 350 HV and during the tensile-shear test they faile in PF mode. Also, at the end of this paper, it was concluded by the method of generalization that thethe RSW joint of two 1,5 thick DP500 steel will fail in PF mode if the hardness of fusion zone is smaller than 355 HV and weld nugget diamtere is haiher then 7 mm. Future research will be focused on the analysis of the behavior of given joints under fatigue loading.

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