



Effect of Electrode Force on Mechanical Properties of Triple Joined Dissimilar Steel Sheets by Resistance Spot Welding

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Abstract

In this study, it was aimed to determine the effect of electrode force on tensile shear load, elongation, nugget diameter and indentation depth in triple welded FEP05 and FE 600 DP steel sheets by resistance spot welding (FEP05 sheet + FE 600 DP sheet + FEP05 sheet). When the electrode force were increased from 1.5 kN to 3.9 kN, the tensile shear load, elongation, and indentation depth values decreased while the nugget diameter increased up to 2.7 kN, then over 2.7 kN the nugget diameter decreased.

1 INTRODUCTION

Resistance spot welding (RSW) is a joining method that is widely used in industries such as automotive, truck trailer, railway, aircraft, and aviation [1][2]. In particular, in the automotive industry, RSW is a crucial welding method. RSW method is a melting welding method that combines the surfaces of the sheets without using any filler material with applying pressure and heat to the area to be joined. This method is ideal for welding of steels, aluminum alloys, and titanium alloys. RSW quality is influenced by various factors such as welding current, electrode pressing force applied to the sheets, thickness, the material of the sheet, welding time, and electrode diameter [3][4][5]. Good welding quality is important for the safety of the vehicle body and passenger. Therefore, efforts to improve the quality of welding are rapidly increasing [6][7].

In the automotive industry, advanced high strength steels (AHSSs) are generally used because of their high strength and good ductility properties. Especially, dual-phase (DP) steels are preferred because of their good formability, ductility, and high strength properties. Also, different type of steels is joined together in a car body to achieve the highest efficiency [8][9]. In the current study, the dual-phase FE 600 DP steel and galvanized low carbon FEP05 steel were joined as triple by RSW. The effect of electrode force on mechanical properties of welded joints was primarily investigated. Several studies have been done in the literature about the effects of electrode force on RSW. Yuan et al. [10] welded ultra-low carbon steel DC54D containing a ferritic phase with a thickness of 1.0 mm and galvanized DP600 exhibiting a ferrite–martensite DP with a thickness of 1.6 mm by RSW. They examined the effect of the electrode force on the mechanical properties and found that tensile–shear strength had a considerable increase and then a slight decrease with the increase of electrode force. Tutar et al. [11] have optimized the welding parameters using Taguchi method to combine TWIP steels by RSW. They determined that the effect rate of electrode force on mechanical properties was 8.63 %.

In this study, dissimilar steel sheets in different thicknesses were combined as triple by RSW to contribute to the triple welding process of the steel sheets in the automotive industry. Then, the effect of the electrode force on the tensile shear load, elongation, nugget diameter and indentation depth were investigated. Other all welding parameters were kept constant. Tensile shear tests were applied to determine the mechanical properties of the welded samples. Also, nugget diameter and indentation depth values were measured by using an ultrasonic method.

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2 MATERIAL AND METHOD

In this study, 0.7 mm thick FEP05 and 2.0 mm thick FE 600 DP commercial steel sheets were triple combined with RSW. Chemical compositions and mechanical properties of FEP05 and FE 600 DP steel sheets used in this study were given in Table I and Table II, respectively.

Table 1. Chemical compositions of FEP05 and FE 600 DP (wt.%)

Steel	C	Mn	P	S	Si	Al
FEP05	0.008	0.3	0.025	0.02	0.03	0.02
FE 600 DP	0.23	3.3	0.09	0.015	2.0	1

Table 2. Mechanical properties of FEP05 and FE 600 DP

Steel	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)
FEP05	140-180	270-330	36
FE 600 DP	340-400	590	20

In the RSW operations, welding current (8.5 kA) and welding time (27 cycle) were kept constant while electrode force increased from 1.5 to 3.9 kN with 0.4 kN intervals. The RSW parameters used in the study can be seen in Table 3.

Table 3. Welding parameters used in the study

Electrode Force (kN)	Welding Time (ms)	Welding Current (kA)
1.5	27	8.5
1.9	27	8.5
2.3	27	8.5
2.7	27	8.5
3.1	27	8.5
3.5	27	8.5
3.9	27	8.5

FEP05 and FE 600 DP sheets were triple welded with RSW. As shown in Figure 1, 2 mm thick FE 600 DP sheet was placed in the space of between two 0.7 mm thick FE P05 sheets. The tensile-shear tests of the welded samples were carried out in a computer-controlled UTEST-7014 universal tensile tester at a constant tensile speed of 10 mm/min at room temperature. A tensile shear test sample of the spot welds can be seen in Figure 2 [12].

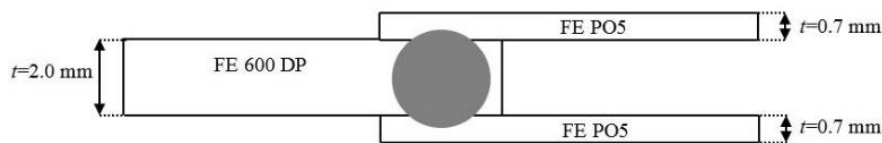


Figure 1. Schematic illustration of welded samples

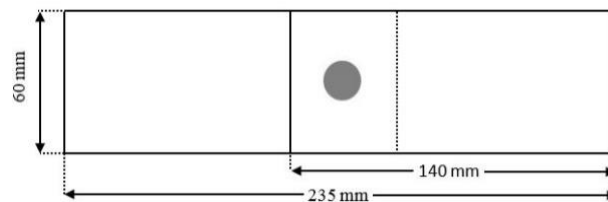


Figure 2. Tensile-shear test sample of the spot welds [12]

In the tensile shear tests, three replicates were applied for each different electrode force. In the experimental studies, it was determined that how the tensile shear load, elongation, nugget diameter and indentation depth changed with the electrode force. To determine the nugget diameter and indentation depth, TESSONICS RSWA ultrasonic spot welding control machine was used.

3 RESULTS

The effect of electrode force on tensile shear load (kN), elongation (mm), indentation depth (%) and nugget diameter (mm) was shown in Table 4.

Table 4. The effect of electrode force on elongation, tensile shear load, indentation depth and nugget diameter values

Electrode Force (kN)	Tensile Shear Load (kN)	Elongation (mm)	Indentation Depth (%)	Nugget Diameter (mm)
1.5	8.24	4.32	43.5	5.4
1.9	8.15	4.32	44.5	5.67
2.3	8.63	4.93	40	5.9
2.7	8.04	4.17	39.5	6.3
3.1	7.78	4.26	39.3	5.9
3.5	7.02	3.64	39	5.63
3.9	7.42	3.79	39	5.37

The change of the tensile shear load with the electrode force was shown in Figure 3. In general, the tensile shear load showed a decrease when the electrode force increased. The lowest tensile shear load value was measured as 7.02 kN for 3.5 kN electrode force. The tensile shear load reached maximum value as 8.63 kN for 2.3 kN electrode force. When the electrode force value increased from 2.3 kN to 3.5 kN, the tensile shear load decreased by 18.66%. Oiu et al. [13] were obtained similar results for the tensile shear load change with the electrode force. In their study higher electrode force suppressed the nugget growth so tensile shear load decreased.

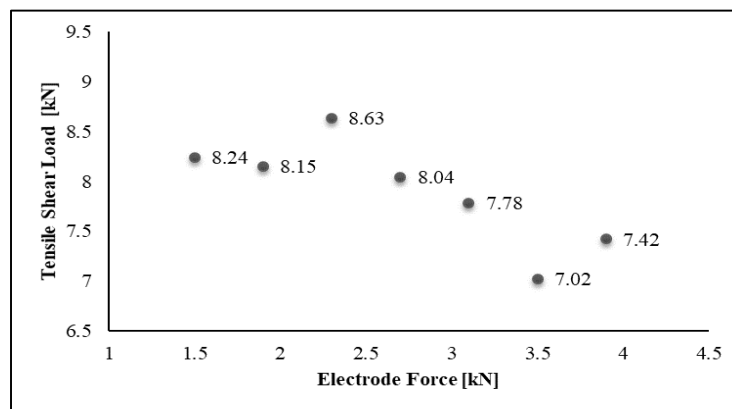


Figure 3. Tensile shear load of the spot welds versus electrode force

The effect of electrode force on elongation can be seen in Figure 4. When the electrode force increased, the elongation value slightly decreased. Similar to the tensile shear loads, the highest elongation value (4.93 mm) reached at electrode force of 2.3 kN, and the lowest elongation value of the sample welded at electrode force of 3.5 kN was 3.64 mm.

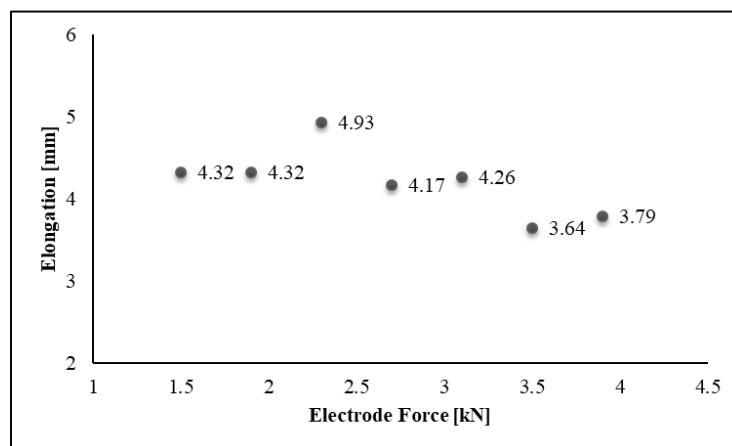


Figure 4. Elongation of the spot welds versus electrode force

An application example for the determination of nugget diameter and amount of indentation depth performed by the ultrasonic tester is shown in Figure 5. The change of indentation depth with the electrode force was shown in Figure 6. When the electrode force was increased, the indentation depth decreased parabolically. The coefficient of determination (R^2) for the parabolic correlation between the indentation depth and the electrode force was 0.81. The highest indentation depth value (44.5%) was observed for the electrode force of 1.9 kN and the lowest indentation depth value was measured as 39% for the electrode force of 3.9 kN. Yuan et al. [10] obtained similar results for indentation depth change with the electrode force. And, they observed that the large electrode force crushed the molten zone. According to the standards (in terms of appearance), the indentation depth value above 43% may be unacceptable for the automotive industry. So, the triple joints welded with 1.5 kN and 1.9 kN may be non-standard for the automotive industry.

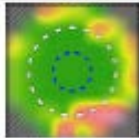
Weld	Decision		Diameter			Indentation			
C-Scan	Sfty	3T	Decision	Reason	Measured	Min.	Nom.	Measured	Required
	No	Yes	Pass		6.6	2.9	3.9	0.4	0.07...0.43

Figure 5. Example of ultrasonic nugget diameter and indentation depth for the electrode force of 2.7 kN

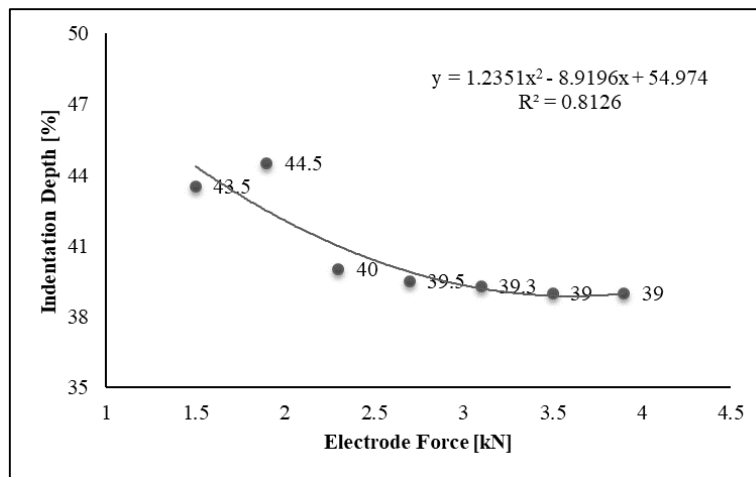


Figure 6. Indentation depth versus electrode force

The change of nugget diameter with electrode force was shown in Figure 7. When the electrode force values were increased, the nugget diameter values increased up to 2.7 kN, then the nugget diameter values decreased over 2.7 kN. The maximum nugget diameter value was measured as 6.3 mm for the electrode force of 2.7 kN and the lowest nugget diameter value was measured as ~ 5.4 mm at 1.5 kN and 3.9 kN.

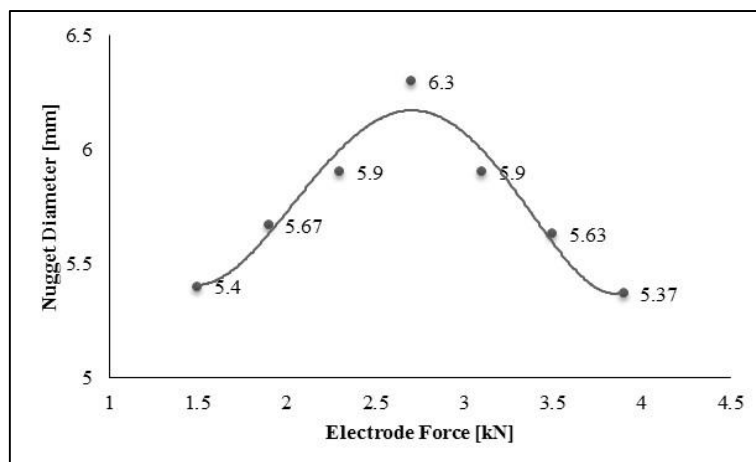


Figure 7. Nugget diameter versus electrode force

4 CONCLUSION

In this study, the effect of electrode force on the mechanical properties of triple RSWed FEP05 and FE 600 DP steel sheets were investigated. The results of the experimental studies can be summarized as follows:

- The tensile shear load tended to decrease with increase of electrode force.
- No significant correlation between the elongation and the electrode force could be detected and generally tends to decrease.
- The indentation depth decreased parabolically with the increase of electrode force. The triple joints welded at 1.5 kN and 1.9 kN may not meet the standard requirements of the automotive industry.
- A significant increase in the nugget diameter value was observed up to the electrode force of 2.7 kN. In contrast, a significant decrease was observed over the electrode force of 2.7 kN. The nugget diameter reached a maximum value at 2.7 kN.

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