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Mechanical Properties of Resistance Spot Welded Three-Sheet Stack Joints of Dissimilar Steels in Different Welding Time

Levent SELOVA[1], Hakan AYDIN[2], Oguz TUNCEL[*2], Oktay CAVUSOGLU[1,2]

[1]*TOFAŞ Türk Otomobil Fabrikası A.Ş.,16369,Osmangazi-Bursa, Turkey*
[2]*Bursa Uludag University, Mechanical Engineering Department, Engineering Faculty,16059, Görükle-Bursa, Turkey*

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Abstract

In this study, it was aimed to determine the effect of welding time on tensile shear load, elongation, nugget diameter and indentation depth of triple welded sheet joints by resistance spot welding (FEP05 sheet + FE 600 DP sheet + FEP05 sheet). The thicknesses of FE 600 DP and FEP05 steel sheets were 2 mm and 0.7 mm, respectively. In the welding processes, welding time was increased from 18 cycles to 36 cycles with three cycles increments and resistance spot welding operations were carried out successfully. When the welding time values were increased from 18 cycles to 36 cycles, tensile shear load slightly decreased. The indentation depth increased almost linearly. Also, with the increase of welding time up to 27 cycles, the nugget diameter increased and the elongation decreased, then over 27 cycles, the nugget diameter decreased and elongation value increased.

1 INTRODUCTION

It is known that the welding process is used as a common joining technique in the automotive industry for similar and dissimilar steel sheets. The most common welding method used in the joining of automobile body components is resistance spot welding (RSW). In today's conditions, a standard car body contains roughly 4.000-6000 spot welds. Table 1 shows the number of spot welds in cars of various brands. Approximately 85% of the welding work used for joining the car body is performed by RSW [1][2][3]. RSW process is an important joining technique for the automotive industry, and so many studies have been focused on this topic. Welding quality is crucial for car body resistance and safety of passengers in case of crash. Therefore, researchers have focused on RSW parameters that affect the quality of welding performance [4][5][6].

Table 1. Number of spot in cars of various brands[1]

Car Model	Number of Spot Welds
Model 1	3676
Model 2	3966
Model 3	3938
Model 4	4250
Model 5	4254
Model 6	4533
Model 7	5011
Model 8	5031
Model 9	5208
Model 10	5600
Model 11	5800

The RSW method is a melting weld method that combines the interface of the sheets without applying any filler material by applying pressure and heat to the area to be joined. This method is ideal for welding of steel and aluminum alloy sheets. The electrical resistance is influenced by various factors such as welding current, electrode force applied to the layers, sheet material, welding time and electrode diameter [7][8][9]. Several studies have been done in the literature on the effects of welding parameters on the weld mechanical properties. Wang et al. [10] combined 1 mm thick mild steel Q235 and stainless steel SUS304 with RSW in their study. Welding operations were conducted with and without 0.06 mm thick pure nickel interlayer. The welding time was applied

[*]otuncel@uludag.edu.tr

as 5, 10, 15 and 20 cycles and the effects of welding time on the nugget diameter and tensile shear strength were investigated. Both type of spot welds, the tensile shear strength and nugget diameter increased with welding time. Tuncel et al. [11] have examined the effect of welding current on mechanical properties of FEP05 and FE 600 DP steel sheet. In their study, tensile-shear strength increased with increasing welding current. Tutar et al. [12] have optimized the welding parameters by using the Taguchi method to combine TWIP steel sheets with RSW. They determined the welding time as an effective parameter with an effect rate of 8.9%.

Dual-phase (DP) steels are among the most preferred steel grades in the automotive industry due to its high strength and good elongation combination. To maximize efficiency in the automotive industry, it is also necessary to combine different types of steel sheets in the car body. In this study, FE 600 DP and galvanized FEP05 steel sheets were triple joined by RSW in different welding times. The effect of the welding time on the mechanical properties, the nugget diameter and indentation depth values of triple spot joints were investigated. In the experimental studies, tensile shear tests were applied to determine the mechanical properties of the welded samples. Also, nugget diameter and indentation depth were measured using an ultrasonic method.

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 sheets were given in Table 2 and Table 3, respectively.

Table 2. Chemical composition of FEP05 and FE 600 DP (wt.%)

Steel	C	Mn	P	S	Si	Al
FEP05	0.008	0.3	0.025	0.0.2	0.03	0.02
FE 600 DP	0.23	3.3	0.09	0.015	2.0	1

Table 3. 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 study, welding time (cycle) effect on the weld properties was analyzed. Welding current (8.5 kA) and electrode pressure force (2.7 kN) were kept constant while different welding times (18, 21, 24, 27, 30, 33, 36 cycles) were applied. The welding parameters used in the study were given in Table 4.

Table 4. The welding parameters used in the study

Welding Time (cycles)	Electrode Force (kN)	Welding Current (kA)
18	2.7	8.5
21	2.7	8.5
24	2.7	8.5
27	2.7	8.5
30	2.7	8.5
33	2.7	8.5
36	2.7	8.5

FEP05 and FE 600 DP sheets were combined with RSW in triple sheet joints. And, a schematic illustration of the weld configuration and tensile test sample was shown in Figure 1 and Figure 2.

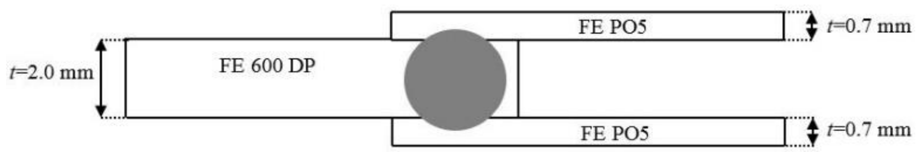


Figure 1. Schematic representation of triple welded samples

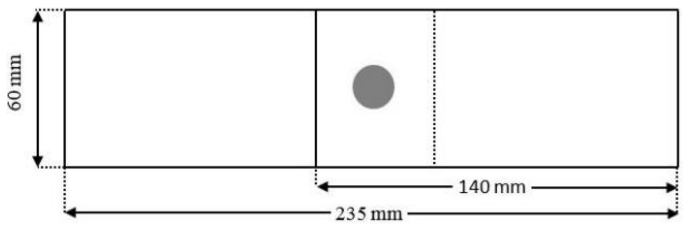


Figure 2. Schematic illustration of tensile shear test samples [13]

During the tensile shear tests, a 2 mm thick sheet was placed in the space between FEP05 sheets in the weld configuration to avoid the parasite of bending forces. The tensile-shear test of the welded samples was carried out in a computer-controlled UTEST-7014 universal tensile tester at a constant crosshead speed of 10 mm/min at the room temperature. In the tensile test, three replicates were applied for each welding time. Also, it was determined how the nugget diameter and indentation depth changed with the welding time by using an TESSONICS RSWA ultrasonic spot welding control machine.

3 RESULTS

Tensile shear load (kN), elongation (mm), indentation depth (%) and nugget diameter (mm) of the triple spot welds in different welding time can be seen in Table 5.

Table 5. Tensile shear load, elongation, indentation depth, and nugget diameter of the triple spot welds in different welding time

Welding Time (cycles)	Tensile Shear Load (kN)	Elongation (mm)	Indentation Depth (%)	Nugget Diameter (mm)
18	8.15	4.68	34.3	5.33
21	7.96	4.35	34.3	5.37
24	8.11	4.44	36	5.9
27	8.04	4.17	39.5	6.3
30	7.9	4.36	39	5.83
33	8.05	4.38	44.5	5.57
36	7.93	5.17	47	5.13

Figure 3 and Figure 4 show the variation of tensile shear load and elongation with the change of welding time, respectively. When the welding time increased, the tensile shear load showed a slight decrease. The lowest tensile shear load value was measured as ~7.9 kN at 30 and 36 cycles, and the highest tensile shear load value was measured as 8.15 kN at 18 cycles. When the welding time values were increased, the elongation decreased up to 27 cycles, and then the elongation increased. The lowest elongation value was measured as 4.17 mm at 27 cycles and the highest elongation value was measured as 5.17 mm at 36 cycles.

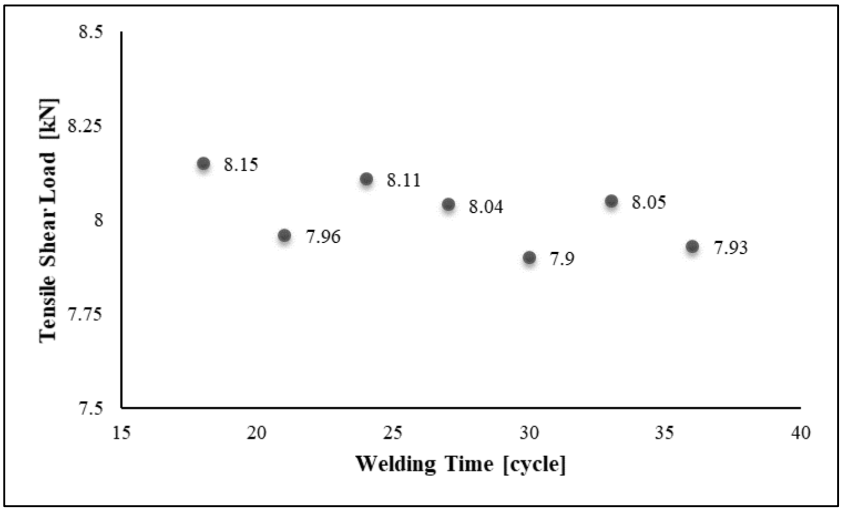


Figure 3. The effect of welding time on tensile shear load

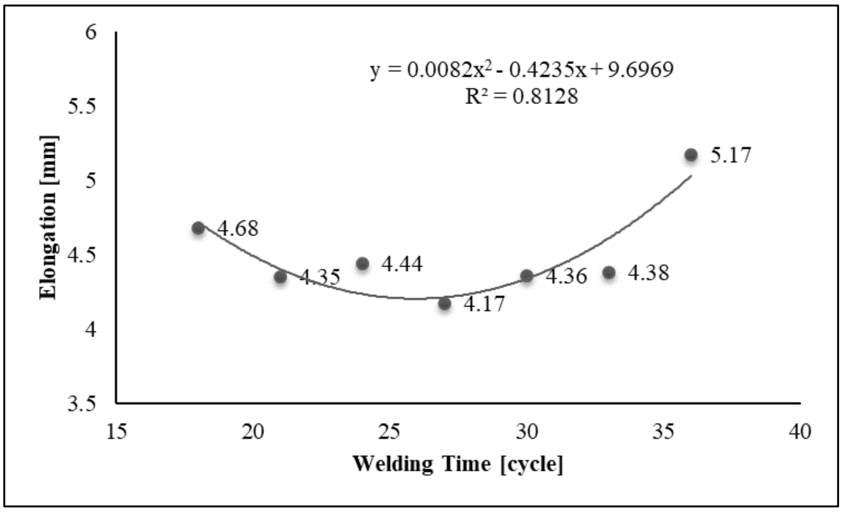


Figure 4. The effect of welding time on elongation

An example of the determination of nugget diameter and percentage of indentation depth with ultrasonic tester can be seen in Figure 5. The effect of welding time on the indentation depth and nugget diameter can be seen in Figure 6 and Figure 7. A good correlation between welding time and indentation depth was observed: Indentation depth increased almost linearly with increasing welding time (R^2=0.9163) (Figure 6). The highest indentation depth value was measured as 47% at 36 cycles and the lowest indentation depth value was measured as 34.3% at 18 cycles. According to the standards (in terms of appearance), the indentation depth value above 43% is unacceptable for the automotive industry. So, the triple joints welded at 33 and 36 cycles are non-standard for the automotive industry. When the welding time increased from 18 cycles to 36 cycles, the percent of indentation depth value increased by 37.03%. When the welding time values were increased up to 27 cycles, and then above 27 cycles the nugget diameter decreased. The nugget diameter reached the maximum value at 27 cycles.

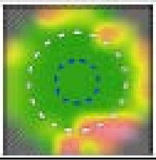
Weld	Decision				Diameter			Indentation	
C-Scan	Sfty	3T	Decision	Reason	Measured	Min.	Nom.	Measured	Required
	No	Yes	Pass		6,6	2,9	3,9	0,4	0,07…0,43

Figure 5. Example of ultrasonic nugget diameter and indentation depth for 27 cycles

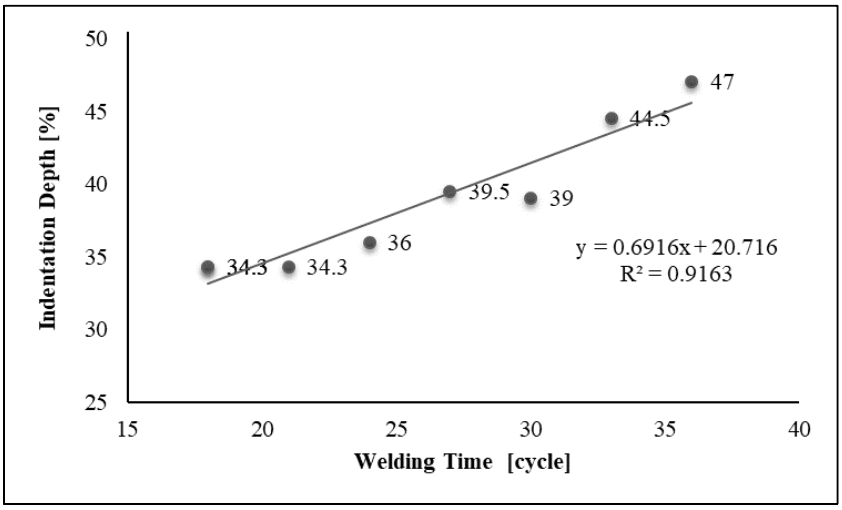


Figure 6. The effect of welding time on indentation depth

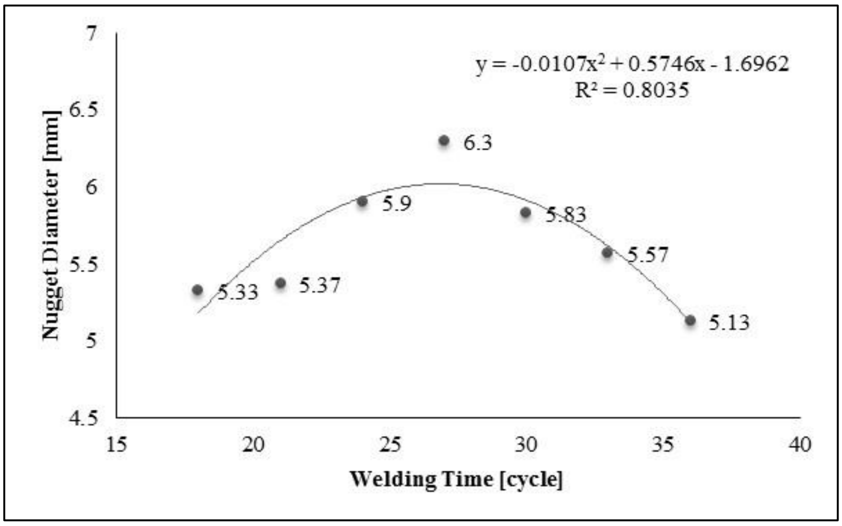


Figure 7. The effect of welding time on nugget diameter

4 CONCLUSION

In this study, the effect of welding time on the mechanical properties of triple RSWed FEP05 and FE600 DP steel sheets were investigated. The outputs of the experimental studies can be summarized as follows:

- The welding time was not significantly affected the tensile shear load and a negligible decrease was observed with the increase of welding time.
- A decreased tendency was observed in the amount of elongation up to 27 cycles. Above 27 cycles, a significant increase in the elongation was detected.
- Nugget diameter increased up to 27 cycles, and then nugget diameter decreased above 27 cycles. The nugget diameter value reached maximum value at 27 cycles.
- Indentation depth value increased almost linearly with increasing welding time. the triple joints welded at above 33 cycles does not meet the requirements of the automotive industry.

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