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Investigation on the effect of projection types on stud weld strength by taguchi method

Kabartı türlerinin saplama kaynak dayanımına etkisinin taguchi yöntemiyle incelenmesi

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Investigation on the Effect of Projection Types on Stud Weld Strength by Taguchi Method

Highlights

- *Optimization of Projection welding operation parameters*
- *The effect of different weld projection types on the mechanical properties of stud welds*
- *Analysis of welding operation parameters design with Taguchi L9 Method*
- *Rupture force analysis with ANOVA for different weld projection types of stud welding*

Graphical Abstract

In this study, different weld projection types (i.e. ring shaped and triple projection) were investigated using Taguchi experimental design for the optimization of the welding parameters. The test results were evaluated according to the ANOVA method for two different bolt types.

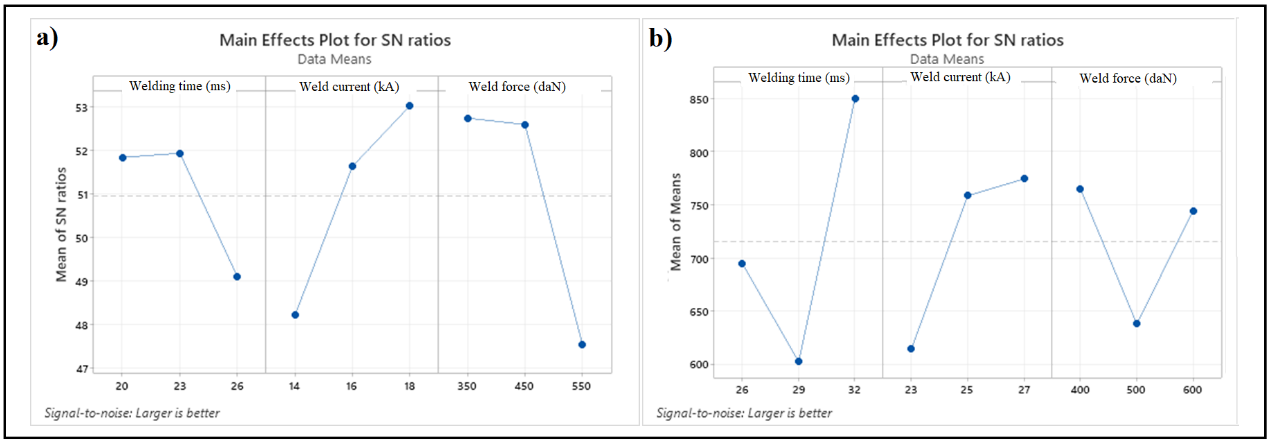

Figure.S/N plot of the effect of parameters on tensile rupture force for a triple projection stud weld bolt and a ring shaped projection stud weld bolt.

Aim

The aim of the study is to find out the optimum welding parameters by investigating the effects of different weld bolt types on the weld quality and feasibility of low weight stud weld bolts.

Design & Methodology

Triple projection and ring shaped projections were stud welded using different weld time, current and clamping force values designed by Taguchi methods. ANOVA method was used in the evaluation of the tensile test results.

Originality

In this study, three different welding parameters (welding time, welding current, clamping force) were studied for two different bolt head projection types that ring shaped welding bolt and triple projection type welding bolt.

Findings

The results of the study with the Taguchi experimental design were evaluated according to the rupture force test.

Conclusion

Ring shaped stud bolt strength values are generally higher than those of triple projection welding bolts.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Investigation on the Effect of Projection Types on Stud Weld Strength by Taguchi Method

Research Article

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ABSTRACT

In this study, the effect of different weld projections on the mechanical properties of stud welds was analyzed using the Taguchi experiment planning method, using a projection welding machine with a capacity of 100 kVA with MFDC transformer. The samples were subjected to the tensile rupture force test with a destructive test device. The aim of this study was to ensure product safety by capturing the spot-welding quality, which is determined by the specifications of the automotive main industry, using a bolt with a lower weight. In this study, 1.5 mm WSS-M1A365-A11 uncoated steel sheet and 8.8 quality M6x1.00x25 triple projection uncoated welding bolts and 8.8 quality M6x1.00x18.5 ring shaped weld bolts were used as stud welding bolts. Different welding times, different welding currents and different welding clamping forces were used on the WSS-M1A365-A11 steel sheet samples in the stud welding operation with bolts. Taguchi analysis showed that ring shaped stud weld bolts required welding parameters of 32 ms welding time, 27 kA welding current and 500 daN welding force, while triple projection stud welding was found to perform the best optimum weld with 23 ms welding time, 18 kA welding current and 350 daN force.

Keywords: Projection welding, taguchi method, weld nozzle structure

Kabartı Türlerinin Saplama Kaynak Dayanımına Etkisinin Taguchi Yöntemiyle İncelenmesi

ÖZ

Bu çalışmada, MFDC trafolu 100 kVA kapasiteli projeksiyon kaynak makinası kullanılarak farklı kaynak kabartı yapılarının saplama kaynaklarının mekanik özelliklerine olan etkisi, Taguchi deney planlama yöntemi kullanılarak analiz edilmiştir. Numuneler tahribatlı test cihazı ile çekme koparılma kuvveti testine tabi tutulmuştur. Bu çalışmanın amacı, başta otomotiv ana sanayinin şartnamelerle belirlemiş olduğu punta kaynak kalitesini, ağırlığı daha düşük olan bir cıvata ile yakalayarak ürün güvenliğini sağlamaktır. Çalışmamızda 1,5 mm WSS-M1A365-A11 kaplamasız çelik sac ve saplama kaynak cıvatası olarak ise 8,8 kalite M6x1.00x25 üç kabartılı kaplamasız kaynak cıvatası ve 8.8 kalite M6x1,00x18,5 çember kabartılı kaynak cıvatası kullanılmıştır. WSS-M1A365-A11 çelik sac numuneleri üzerine, kaynak cıvataları ile nokta kaynak operasyonunda değişken olarak farklı kaynak süreleri, farklı kaynak akımları ve farklı kaynak baskı kuvvetleri kullanılmıştır. Taguchi analizleri göstermiştir ki, Ring kabartılı saplama kaynak parametreleri, 32 ms kaynak zamanı, 27 kA kaynak akımı ve 500 daN kaynak kuvveti gerektirirken, üç kabartılı saplama kaynak optimum kaynak civatası için 23 ms kaynak zamanı, 18 kA kaynak akımı ve 350 daN kuvveti olarak bulunmuştur.

Anahtar Kelimeler: Projeksiyon kaynak, Taguchi yöntemi, kaynak çentik yapısı.

1. INTRODUCTION

Energy saving is an important field of study in industries with mass production such as the automotive sector. With today's technology, materials used in the automotive industry are being developed and studies on production processes continue. In addition to the development of new production methods, it is aimed to increase efficiency by improving existing operations. For this reason, reducing energy and material losses in methods commonly used in industries is a priority issue.

One of the most common methods used in the automotive industry for assembling parts together is projection welding [1, 2, 3]. There are more than 350 projection welded joints in a vehicle body [4]. Projection welding is performed by the formation of a heat-affected zone (HAZ) on the material being welded by the force exerted by two copper electrodes [5]. This welding technique is a modification of the resistance welding method [2]. Welding current, welding time and electrode strength are important parameters for weld quality in projection welding as in spot welding [6]. Low current causes inadequate weld nugget, and high current causes burns on the weld surface [7]. The relief geometry of the part to be welded in projection welding also has an effect on the

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quality of the weld [8]. With the development of these operations, it is aimed to increase the efficiency of the process in different aspects by minimizing the waste. In order to improve the welding quality, studies are carried out on welding parameters. Since the welding operation is affected by many parameters, this process is a costly and labor-intensive process. Different optimization models are used for experimental design. One of these models is called Taguchi experimental design optimization method.

The Taguchi method is used in the design and optimization of experiments carried out depending on the determined parameters [9]. While it gives efficient results for controllable factors, it creates an insensitive process in combinations of uncontrollable variables and noise factors [10]. While the Taguchi experimental design optimization method provides high quality process, performance and product development, it gives simple and successful results in solving the problem with a smaller number of experiments [11,12]. The competitive approach in the automotive sector aims to prevent the energy and raw material losses and to increase product quality. For this purpose, the Taguchi method is used in production methods where many variable parameters are studied such as in spot welding. The problem of expulsion of molten metal during stud welding process was minimized without compromising the mechanical behavior of the weld between projection and substrate. The projection dimensions and process parameters of the stud welding bolt were studied by the Taguchi method by which optimal results were obtained by determining the effective factors [13]. One of the experimental designs used is the classical DOE (Design of Experiments) experimental design method. Arc stud welding on galvanized and non-galvanized sheet metal was studied using the DOE experimental design method by Ramasamy et al. The aim of their work was to evaluate the robustness of the stud welding process under different parameters. The results were interpreted with statistical graphics. It has been concluded that large studs give the best performance on thick plates [14]. Resistance arc stud welding, one of the welding methods, is derived from resistance projection welding in relation to process requirements [15]. Arc stud welding is also dependent on the contact surface, as in the projection welding method. In this method, an increase in the cross-sectional area requires an increase in the required current [16]. Talaş et al. have joined steel studs on the plates produced with Fe+Al powder mixtures sintered in the microwave using the arc stud welding method. The aim of the study was to investigate the effect of welding current on the joint quality in sintered metallic parts. Results were obtained using X-Ray diffraction testing (XRD) and Scanning Electron Microscope (SEM). Weld depths were measured, and according to the results obtained, it was observed that the number of cracks increased with increasing discharge voltage [17]. Taguchi experimental design was also employed to determine the most important welding parameter affecting the welding performance from selected welding parameters during resistance spot welding of galvanized steels. Welding current and welding time were found to be the most effective welding parameters selected by L27 Orthogonal Taguchi approach. Repeated experimental results proved the accuracy of this method [18]. The L9 Taguchi orthogonal array in the process of joining TWIP steel sheets with electric resistance spot welding was also studied, and test results for TWIP sheets were evaluated according to the tensile damage rupture load. It was concluded that the welding current caused the highest effect from the welding parameters [19]. The experimental results were studied with the finite element method to determine the most suitable shape in the projection weld of the square nut. The Taguchi method optimized parameters to determine the optimum nut shape, which was concurred that the optimization process was highly reliable [20].

In this study, Taguchi experimental design method was established with different welding times, welding currents and weld clamping forces to study the effect of different stud projection types using WSS-M1A365-A11 steel.

2. EXPERIMENTAL DESIGN

In this study, screw head containing circular (ring) and screw head welding bolts containing 3 nozzles were welded to WSS-M1A365-A11 steel by projection welding method, respectively. Three different welding parameters; welding time, welding current and clamping force were studied for two different bolt head projection types. For the ring-shaped welding bolt (Experiment 1) and for the 3 projection (triple projection) type welding bolt (2. Experiment), 9 welding processes were performed, and they were repeated twice in both experiments in order to increase the measurement accuracy. In this study, a total of 36 welding processes were performed and the results were evaluated based on their fail/pass level. The L9 Taguchi method was used for the experimental design. ANOVA (analysis of variance) analysis was performed by evaluating the tensile rupture forces for optimum results of the welding parameters. In order to shorten the names of the samples in the Taguchi experimental design, the letter C was used for the 3-projection bolt and the letter R was used for the ring-shaped weld bolt. The signal to noise ratio (S/N) is defined as the performance assessment. The performance variability is minimized by finding the optimal test setting of the products based on the process parameters. The selection of parameters is aimed to maximize the S/N ratio as much as possible. Signal (S) represents the square of the mean value of the quality characteristic and noise is the measure of the variability of the characteristics of each parameter.

2.1. Steel and Bolts for the Welding Process

2.1.1. WSS-M1A365-A11 steel sheet and projection welding bolts

Uncoated commercial WSS-M1A365-A11 steel with a thickness of 1.5 mm was used in the experiments. The mechanical properties and the chemical properties of steel provided by the manufacturer are given in Table 1 and Table 2, respectively.

Table 1. Mechanical properties of WSS-M1A365-A11 steel sheet metal

	Yield Strength (Rp) N / mm2	**Tensile Strength (R) N / mm2**
WSS-M1A365-A11	140-280	270-410

Table 2. Chemical composition of WSS-M1A365-A11 (wt.%).

% Element	**C**	**Si**	**Mn**	**P**	**S**	**Al**	**Ti**	**Cu**
WSS-M1A365-A11	Max. 0,12	Max. 0,5	Max. 0,6	Max. 0,055	Max. 0,035	Min. 0,010	Max. 0,30	Max. 0,30

M6 holes for stud welding were drilled on the samples made of WSS-M1A365-A11 steel sheet material, and holes were drilled on the steel sheet by giving a tolerance of a tenth of a gap. The 3 projection bolts used in the experiments were 8.8 quality M6x1.00x25 and weigh 7.04 gr, (Figure 1), and the welded test specimens made of sheet material are given in Figure 2.

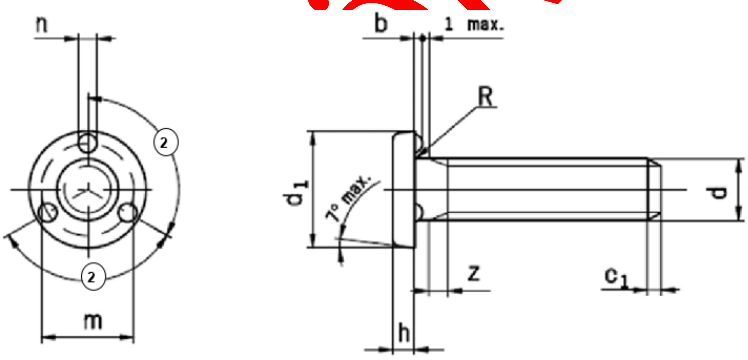

Figure 1. Triple projection weld stub/bolt

Figure 2. Test specimens made of WSS-M1A365-A11 steel with triple projection bolts welded for the study

The welding parameters (Table 3) for bolt studs with 3 projections was set to 20, 23 and 26 ms. The welding current was applied as 14, 16 and 18 kA and the welding clamping force (i.e., upsetting or weld force) values were 350, 450 and 550 daN. The welding parameters for bolt studs with ring projection was set to 26, 29 and 32 ms. The welding current was applied as 23, 25 and 27 kA and the welding clamping force values were 400, 500 and 600 daN.

Table 3. Welding parameters and specimens codes

Specimens	**Weld duration (ms)**	**Weld current (kA)**	**Weld clamping force (daN)**
C1	20	14	350
C2	20	16	450
C3	20	18	550
C4	23	14	450
C5	23	16	550
C6	23	18	350
C7	26	14	550
C8	26	16	350
C9	26	18	450
R1	26	23	400
R2	26	25	500
R3	26	27	600
R4	29	23	500
R5	29	25	600
R6	29	27	400
R7	32	23	600
R8	32	25	400
R9	32	27	500

The ring projection type stud welding bolt used in the second part of the experiments is of 8.8 quality and has the dimensions of M6x1.00x18.5 and a weight of 5.06 gr. The technical drawing of the ring projection type stud welding bolt is given in Figure 3 and test specimens welded by projection welding are given in Figure 4.

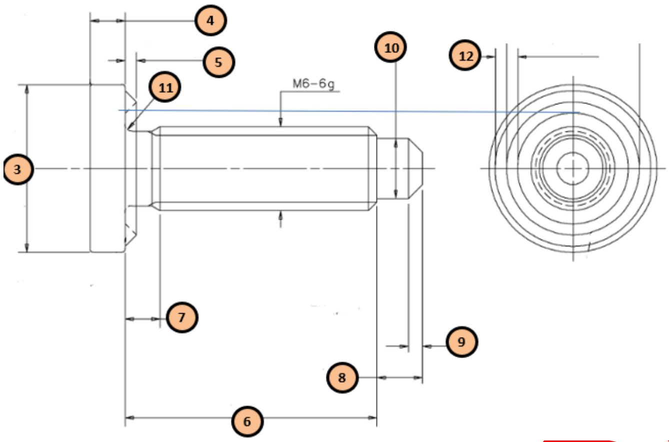

Figure 3. Ring shaped stud welding bolt schematic

Figure 4. WSS-M1A365-A11 steel with ring shaped projection bolts welded for the study

2.2. Welding operation with projection welding

The bolt centering process is shown in Figure 5. Welding process parameters and levels are given in Table 4 and Table 5 for the L9 experimental design proposed by Taguchi method of welding parameters in bolt stud welding process in projection welding. Table 4 shows the values of triple projection weld bolts and Table 5 shows the values of the ring-shaped weld bolt.

Table 4. Triple projection Welding Bolt welding process parameters and levels

Symbol	Parameters	Level 1	Level 2	Level 3
A	Weld duration (ms)	20	23	26
B	Weld current (kA)	14	16	18
C	Weld clamping force (daN)	350	450	550

Table 5. Ring shaped Welding Bolt welding process parameters and levels

Symbol	Parameters	Level 1	Level 2	Level 3
A	Weld duration (ms)	26	29	32
B	Weld current (kA)	23	25	27
C	Weld clamping force (daN)	400	500	600

2.3. Tensile Rupture Test

Tensile rupture test of welded specimens was carried out with destructive rupture load test. The tensile rupture force test process is shown in Figure 5. The test device has a measuring capacity of 20 kN and shows the thrust force at the moment of rupture when applying pressure to the sample.

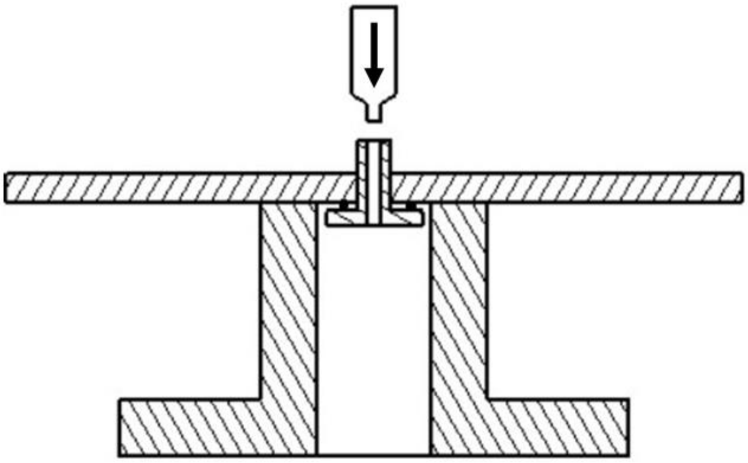

Figure 5. Testing procedure for destructive tensile rupture test.

3. RESULTS AND DISCUSSION

In projection welding, the current is concentrated at the points where the embossed surfaces of the parts to be joined come into contact. Projection welding occurs as a result of the force and current applied to these surfaces [20]. Projection welding is used for joining fasteners such as nuts and bolts to sheet metal due to its automation, reliability and low cost. [20-21]. If the welding projection is not formed in the welding bolt or if the 3 projections on the bolt head are not at equal height, the desired tensile rupture failure load value is not achieved since the welding current will not be distributed evenly and will prevent all the projections from melting at the same time. Hence, the weld clamping force is one of the prime factors for the best performance of the welds with weld current to achieve a strong joint of bolts onto the substrate. Other factors which are kept constant during the operations such as weld current, type and number of projections and weld time are also equally important, however, are not user dependent and can be set prior to the stud welding operation [22].

Welding clamping forces were selected as 350, 450 and 550 daN for triple projection stud welding bolt and 400, 500 and 600 daN for ring shaped stud welding bolt and stud welded 200x20x1.5 mm WSS-M1A365-A11 steel plates were prepared from each welding. After the stud centering, the results of the tensile rupture forces were compared as a result of the full destructive test. Images of the fully destructive specimen test are shown in Figure 6 and Figure 7 for the triple projection stud weld bolt and the ring-shaped stud weld bolt, respectively. The values of the tensile rupture force obtained as a result of these tests are given in Table 6 and Table 7 in the same order in Taguchi L9 matrix layout.

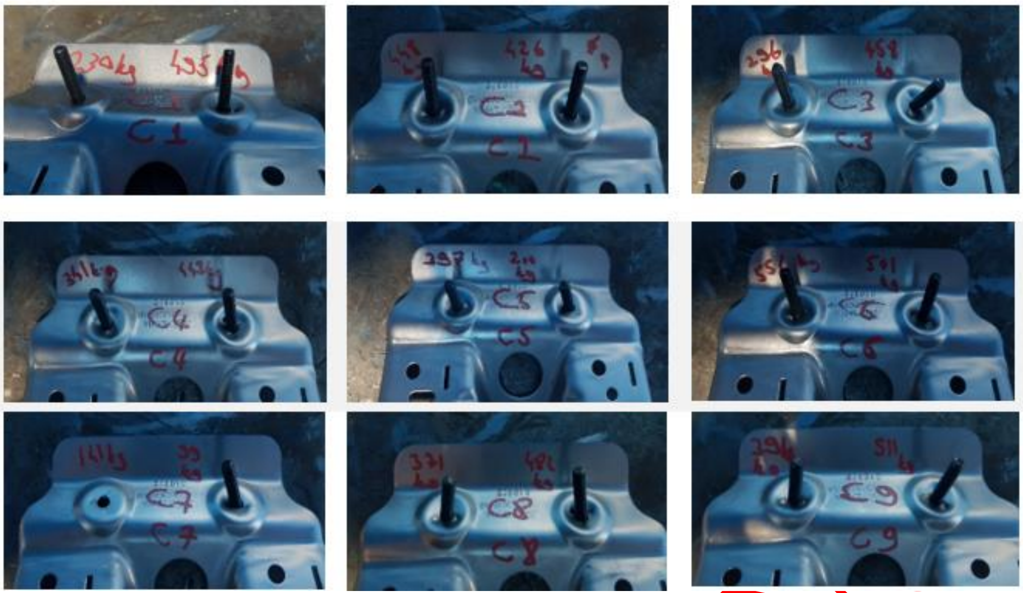

Figure 6. Images of triple projection stud bolt tensile rupture test pieces. Please note that C7 weld has failed during the test (Codes are given on the images).

Figure 7. Images of ring-shaped weld bolt tensile rupture test pieces.

Table 6. Triple projection stud bolt L9 Taguchi test matrix and tensile rupture test results

Specimen	Weld Duration (ms)	Weld Current (kA)	Weld clamping force (daN)	Rupture Force (daN) (Avr.)
C1	20	14	350	410.93
C2	20	16	450	437.27
C3	20	18	550	394.40
C4	23	14	450	398.63
C5	23	16	550	331.00
C6	23	18	350	528.83
C7	26	14	550	123.67
C8	26	16	350	433.72
C9	26	18	450	460.06

Table 7. Ring shaped stud bolt L9 Taguchi test matrix and rupture test results

Specimen	Weld Duration (ms)	Weld Current (kA)	Weld clamping force (daN)	Rupture Force (daN) (Avr.)
R1	26	23	400	673.37
R2	26	25	500	761.93
R3	26	27	600	714.66
R4	29	23	500	365.5
R5	29	25	600	755.94
R6	29	27	400	812.82
R7	32	23	600	878.88
R8	32	25	400	839.61
R9	32	27	500	881.80

The tensile rupture force values are given in Table 7 which showed that some non-regular results obtained as a result of the destructive tensile rupture inspection test of the stud welded bolts. This is believed to be usual variability of the ambient conditions of the welding machine during the experiments; however, there is no coating on the surface of sheet metal which is provided in ungreased condition which is the case for all specimens. The data obtained as a result of the study were evaluated with the S/N ratio, which is the signal/noise ratio, taking into account the tensile rupture force values. In the analysis of the data, the highest tensile rupture force expresses the best parameter values, so the "the larger is better" method was preferred. In Figure 8, the effect of the parameters on the tensile rupture force for the triple projection and the ring shaped projection stud weld bolt is given by the S/N response graph.

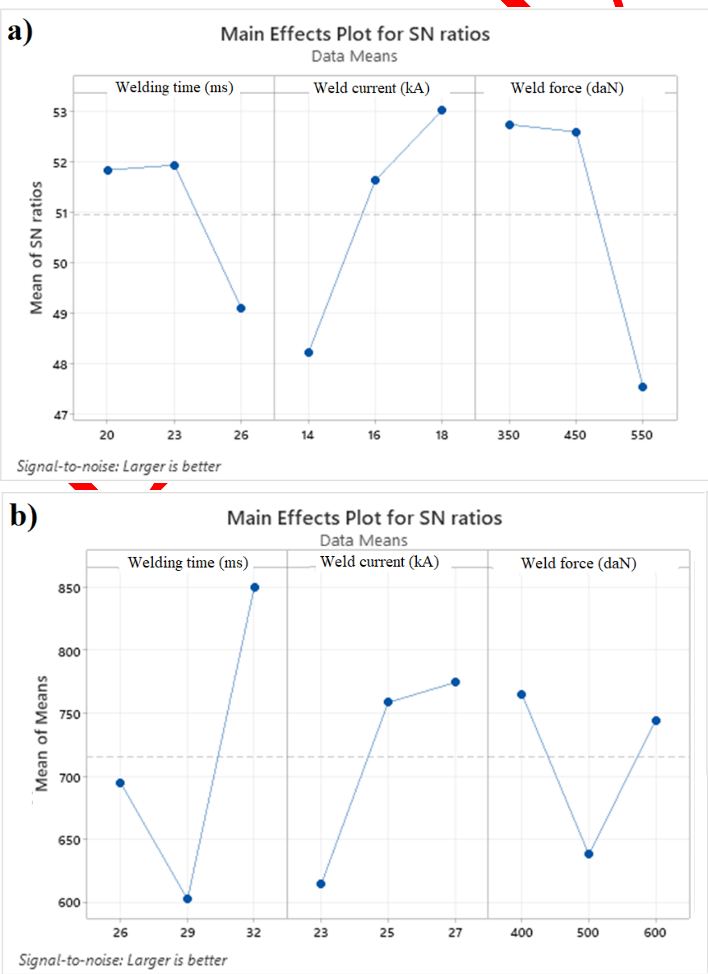

Figure 8. S/N plot of the effect of parameters on tensile rupture force for a triple projection weld bolt.

According to graphs given in Table 6 and Figure 8a, it can be concluded that the optimum welding parameters for the triple projection welding bolts are 23 ms weld time as the second level parameter, 18 kA weld current as the third level parameter and 350 daN weld clamping force as the first level parameter for the optimum welding. However, the variation in tensile rupture results are systematically decreasing with increasing amount of weld time with respect to weld clamping forces in triple projection stud weld bolts. Figure 8b and Table 7 show that the optimum welding parameter values of the ring-shaped stud welding bolt are 32 ms as the 3rd value for the welding time, 27 kA as the 3rd value for the welding current, and 500 daN as the 2nd value for the welding clamping force. It is reasonable to suggest for both triple projection and ring-shaped stud weld bolts that as the welding force is increased, the molten volume or weld volume of the projection weld tend to increase and hence, as given Table 6 in this study, the weld rupture tests result in higher values with respect to 550 and 600 daN weld clamping forces [23, 24]. The clamping force variation is similar to the weld time in both projection types but the lowest clamping force is also very efficient with the highest weld current, which would be reasonable to claim that high clamping force is the reason for high shear forces occurring during the clamping of projections, which would plastically deform and hence decrease the contact resistance by increasing contact surface area, i.e. density of current per area. However, the lower weld clamping force would allow the small deformation but limit the surface contact area which would give out higher weld temperature and melting efficiency [25, 26, 27].

Signal to Noise ratios are given in Table 8 and 9. The most suitable experimental parameters obtained in this study were not restudied for verification purposes. This is because the optimum experimental parameters were studied within the Taguchi experimental design. The triple projection stud welding bolt S/N ratio gives the highest tensile rupture load at 2-3-1 parameter levels, while the ring shaped stud welding bolt gives the highest tensile rupture load at 3-3-1 parameter level.

Table 8. Triple projection weld bolt S/N response rates

Level	Weld Duration (ms)	Weld Current (kA)	Weld clamping force (daN)	Heat Input
	51,84	48,21	52,74	54.9
2	51,94	51,64	52,60	**<u>59.08</u>**
3	49,10	53,03	47,54	57.16
Delta	2,84	4,82	5,21	
Rank	3	2	1	

Table 9. Ring shaped weld bolt S/N response rates

Level	Weld Duration (ms)	Weld Current (kA)	Weld clamping force (daN)	Heat Input
1	56,82	55,03	57,62	67.8
2	54,93	57,57	55,35	69.7
3	58,59	57,74	57,37	**<u>75.9</u>**
Delta	3,66	2,71	2,27	
Rank	1	2	3	

Welding parameters affect the experimental design at different rates. This effect ratio is expressed by the ANOVA method. The most effective parameter in projection welding of WSS-M1A365-A11 steel sheet material with triple projection stud welding bolts was found to be the weld clamping force with 52.82 %; ANOVA test results are given in Table 10. According to the ANOVA analysis, an error rate of 2.06% was determined in the experimental analysis of the triple projection stud weld bolt, and this value is within the acceptable range for industrial applications. For the ring-shaped welding bolt, the most effective welding parameter was found to be welding time (ms) with a rate of 40.26 %. ANOVA analysis values of the ring-shaped stud weld bolts are given in Table 11. The error values were found to be high for ring shaped stud bolts group. However, when the optimum welding parameters are considered, it was equal to the value giving the highest tensile rupture force. It is expected that factors such as increasing the number of experiments and improving the environmental conditions in which the experiment is carried out would reduce the test error values.

Table 10. Triple projection stud weld bolt ANOVA test results

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Weld Duration (ms)	2	9021	8,43%	9021	4511	4,08	0,19674
Weld Current (kA)	2	39276	36,69%	39276	19638	17,78	0,05326
Weld clamping force (daN)	2	56540	52,82%	56540	28270	25,59	0,03761
Error	2	2210	2,06%	2210	1105		
Total	8	107047	100,00%				

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
33,2382	97,94%	91,74%	44743,5	58,20%	*	92,65

Table 11. Ring shaped stud weld bolt ANOVA test results

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Weld duration (ms)	2	94375	40,26%	94375	47188	1,44	0,410
Weld Current (kA)	2	46635	19,90%	46635	23317	0,71	0,584
Weld clamping force (daN)	2	27941	11,92%	27941	13970	0,43	0,701
Error	2	65451	27,92%	65451	32725		
Total	8	234401	100,00%				

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
180,902	72,08%	0,00%	1325381	0,00%	*	123,15

4. CONCLUSIONS

In this study, stud bolts with triple and ring-shaped projections have been welded to WSS-M1A365-A11 steel sheet material in order to study the effects of weld time, clamping force and weld current on the tensile rupture strength of stud welds using Taguchi optimization method. L9 orthogonal index Taguchi method was used for the experimental study. The data were interpreted according to the ANOVA analysis values. The following findings have been obtained from this study:

1. Ring shaped stud welding optimum parameters based on the average breaking force values obtained by the tensile tests are as follows: welding time 32 ms, welding current 27 kA and weld clamping force of 500 daN. The optimum welding parameters for the triple projection stud welding bolts are 23 ms welding time, 18 kA welding current and 350 daN weld clamping force.

2. Ring shaped bolt strength values are generally higher than those of triple projection welding bolts. Triple projection stud weld bolts yield maximum 528.83 daN tensile rupture force at optimum current and welding time values, while ring shaped bolts gives 881.8 daN rupture force at optimum current and welding time values due possibly to the fact that ring shaped projections has continuous weld bead compared to three point joint in triple projection studs.

3. Experimental design and analysis were carried out with the Taguchi method and the results were evaluated with the S/N ratio and ANOVA analysis, and it was concluded that experimental studies could be performed with the least possible material consumption using determined optimum parameters.

4. High clamping forces is most likely to introduce plastically deformed high-surface-to-contact area where density of electric current is low whereas high current low clamping force combination is likely to produce higher current density and therefore higher heat input per unit area which would result in better and optimized weld strength performance.

5. The clamping force variation is similar to the weld time in both projection types, but the lowest clamping force is very also efficient with the highest weld current.

6. This study contributes to literature with respect to stud welding bolts of ring-shaped projection and the optimum parameters where the joint produces very high rupture force compared to well investigated stud welds of triple projection stud bolts.

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DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Hilal KIR: Contributed to the development of the conceptual processes of the study, data collection, data analysis and interpretation, drafting the article, and the realization of the welding processes.

Mustafa YAZAR: Contributed to the development of the conceptual processes of the study, data collection, data analysis and interpretation, drafting the article, and the realization of the welding processes.

Şükrü TALAŞ: Contributed to the conceptual process determination; contribute to the literature study and discussion of the article and the final approval of article.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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