ENGINEERING RESEARCH JOURNAL (ERJ)

Vol. 1, No. 45 July. 2020, pp. 1-6

Journal Homepage: http://erj.bu.edu.eg

# Optimization of Friction Stir Spot Welding Process Parameters on the Microstructure and Shear Load by Taguchi Method

**Basma.A.Salama[1],E. H. Mansour[2], A. M. Gaafer[2]**

[1]Teaching Assistant , Department of Manufacturing Engineering and Production Technology, Modern Academy for Engineering and Technology, Cairo Egypt.

[2]Mechanical Engineering Department ,Shoubra Faculty of Engineering,Benha University, Cairo, Egypt.

**Abstract.** : The aim of this study is to investigate the effect on shear load and microstructure of AA6061-O aluminum sheets joined using friction stir spot welding (FSSW) by different welding parameters and post-weld heat-treatments (PWHT) T4 and T6.Taguchi method was used as an experimental statistical model to determine the optimum FSSW parameters. Taguchi's L27 orthogonal array was used to arrange the experiments. Three tool rotational speeds of 1200, 1500 and 1800 rpm and three dwell times of 6, 8 and 10 sec were used to conduct the welding. After FSSW, the AA6061 joints were subjected to T4 and T6 heat treatments. The findings showed that the grain size of stir zone (SZ) increased by either increasing rotational speed or increasing dwell time. Shear load significantly increased as dwell time increased. Shear load for the welded joints after heat treatment (T4) are greater than(T6), both of them are greater than O-condition.

**Keywords**: Friction Spot Stir Welding (FSSW), Post Weld Heat-treatment (PWHT),AA6061 aluminum alloy ,Shear load, Taguchi method.

## 1. INTRODUCTION

Reducing weight without affecting the performance of safety is a major challenge in automotive manufacturing to enhance fuel economy, raising productivity, decrease emissions and save costs. Due to steel wide range of worthy properties, processing easily, recyclability and availability, it is popularly used in the automotive industry. Materials of lightweight such as aluminum, however, have apparent advantages more than steel with similar properties but the density is almost lowered three times, significant resistance of corrosion and high level of usage of 85-95%. Al alloys are promising applicants to replace equivalent steel assemblies and their use in automotive manufacturing has lately increased [1–3].

In order to replace steel with aluminum in the automotive structure, joining methods need to be explored that can be used efficiently with aluminum. For joining steels, resistance spot welding and self-piercing rivets are the current used panel welding methods, but these methods of welding haven't the ability to be applied on Al alloys due to its physical properties, especially oxide surface film. To join Al alloys, in 1991 TWI (Abington, UK) developed a new solid state joining method called FSSW. This newly method of joining is beneficial in the production of Al joints without porosity, contamination, cracks and holes [1].

FSSW is capable of welding similar materials overlapping joints and also welding dissimilar ones with decreasing in the consumption of energy 85% and capital costs 50% when compared with resistance spot welding. The process of FSSW comprises of three stages: plunge, stir and withdraw. Geometries of tool represented in the diameter and shape of shoulder and pin, and parameters of welding like depth of plunging, rotational speed of tool, dwell time and axial feed rate perform high influence on FSSW mechanical properties and microstructure. The formed bond around pin hole of FSSW is the same, thus the microstructures on the both sides of pin hole are symmetric, there is a region resulted with a specific width called bond width, where upper and lower sheets are bounded completely [4–10].

## 2. Experimental Procedure

FSSW of AA6061-O sheets with 2mm thickness as shown in Fig. 1, were joined as a lap joint by using CNC milling machine. Table 1presents the AA6061 alloy's chemical composition. A non-consumable tool with a 5° concave shoulder having12 mm diameter, and a tapered probe with 4 mm of smaller diameter with height 2.5 mm on chamfer value10° shown in Fig. 2, was used to weld the AA6061 Al sheets. Before welding, the sheets surface was cleaned with acetone. Tool rotation speed, dwell time, and heat-treatment are considered parameters for this process. Each parameter has three chosen levels, Table 2 presents the selected levels.

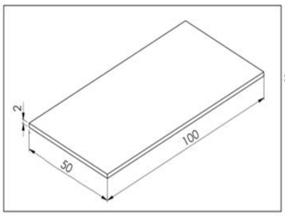


Fig 1 Specimen dimensions.

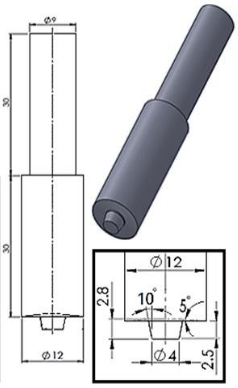


Fig 2 Dimensions of rotating tool.

Table 1AA6061 chemical composition.

| AA-6061 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Standard AA-6061 Composition | Element | Si | Mg | Ti | Fe | Cu | Cr | Zn | Mn | Al |
| | Min. | 0.4 | 0.8 | - | - | 0.15 | 0.04 | - | - | - |
| | Max. | 0.8 | 1.2 | 0.15 | 0.7 | 0.4 | 0.35 | 0.25 | 0.15 | Balance |
| Samples typical Composition | | 0.52 | 1 | 0.025 | 0.026 | 0.26 | 0.33 | 0.0059 | 0.0043 | 97.79 |

The number of experiments depends on the number of parameters and their levels. In this work, there are three parameters with three levels of each, therefore the number of experiments is $3^3$=27.Table 3 presents the experimental layout of L27 Taguchi orthogonal array of selected parameters which obtained from the MINITAB 17 software.

Table 2The parameters of welding and their levels

| Parameter | Level (1) | Level (2) | Level (3) |
|---|---|---|---|
| Heat Treatment | O | T6 | T4 |
| Dwell Time (sec) | 6 | 8 | 10 |
| Rotational Speed (rpm) | 1200 | 1500 | 1800 |

Table 3Taguchi L27 orthogonal array

| Run | Dwell time (sec) | Heat-treatment | Tool rotational speed (rpm) |
|---|---|---|---|
| 1 | 6 | O | 1200 |
| 2 | 6 | O | 1500 |
| 3 | 6 | O | 1800 |
| 4 | 6 | T6 | 1200 |
| 5 | 6 | T6 | 1500 |
| 6 | 6 | T6 | 1800 |
| 7 | 6 | T4 | 1200 |
| 8 | 6 | T4 | 1500 |
| 9 | 6 | T4 | 1800 |
| 10 | 8 | O | 1200 |
| 11 | 8 | O | 1500 |
| 12 | 8 | O | 1800 |
| 13 | 8 | T6 | 1200 |
| 14 | 8 | T6 | 1500 |

| | | | |
|---|---|---|---|
| 15 | 8 | T6 | 1800 |
| 16 | 8 | T4 | 1200 |
| 17 | 8 | T4 | 1500 |
| 18 | 8 | T4 | 1800 |
| 19 | 10 | O | 1200 |
| 20 | 10 | O | 1500 |
| 21 | 10 | O | 1800 |
| 22 | 10 | T6 | 1200 |
| 23 | 10 | T6 | 1500 |
| 24 | 10 | T6 | 1800 |
| 25 | 10 | T4 | 1200 |
| 26 | 10 | T4 | 1500 |
| 27 | 10 | T4 | 1800 |

Samples were divided into three groups, immediately after welding process PWHT. T4 treatment has been performed for the first group of samples where heated in furnace at 530°C for 1 hour, then quenched in water. Second group of samples was heat-treated at T6 where heated at 177°C for 8 hours then air cool. The third group remains at O-condition. Then some of samples from each group were cut to analyze their microstructure. Emery papers of increasing finesse up to 2000 grit were used to ground the metallographic samples then polished with 0.3 µm alumina suspension, followed by etching process using solution of 2.5 ml HNO3 + 1.5 ml HCl + 1 ml HF + 95 ml distilled water for 10-15 s at room temperature . Microstructural investigation was conducted using an optical microscope. JMicroVision v1.3.1 software is used for measuring the size of α-Algrains. Shear test done by using a computerized tensile testing machine with maximum load 200 kN and constant loading rate 5 mm/min at room temperature depict in Fig. 3, the shear load for each condition is measured by taking the average of shear loads of three specimens welded with the same welding parameters.

Fig 3 Computerized tensile testing machine.

## 3.Results and Discussion.

Macrostructure resulted three regions namely, Heat affected zone (HAZ), thermo mechanically affected zone (TMAZ) and stir zone (SZ), similar outcome has been noted by C. Sharma et al.[11], showed in Fig. 4,SZ microstructure consists of finer equiaxed grains with an average size of 10:19 µm, Fig. 5. It is observed that when increasing dwell time and/or increasing rotational speed, grain size of SZ increased due to raising in temperature and cooling slowly, this result agree well with F.F. Wang, et al.[12].

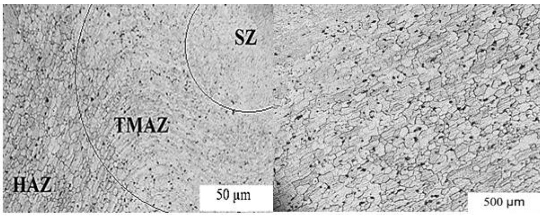


Fig 4 Macrostructure of HAZ, TMAZ and SZ at 1200 rpm and 6 sec.

Fig 5 Microstructure of SZ at 1500 rpm and 10 sec.

After shear test it is clear that the fracture occurred at the region of bond width as shown in Fig. 6, where increased with increasing dwell time, which causes increasing in shear load results, this result well agree with S. H. Lee, et al.[13], and Fujimoto, et al. [14]. Maximum shear load can be obtained at the lowest rotational speed, this shows the same tendency observed in a previous report by Arunabh [15].

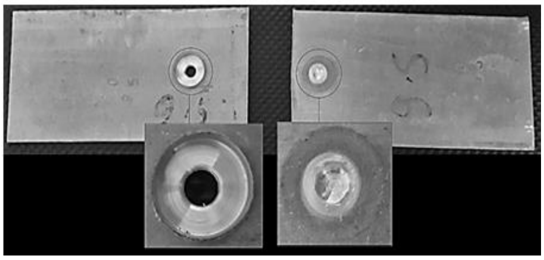

Fig 6 Joint after fracture

### 3.1- Taguchi optimization technique

For optimizing FSSW process parameters, the shear load and grain size were evaluated. For calculating the effect of factors on responses, the ratio of signal to noise (S/N) should by calculated first. The shear load was chosen as the larger-is-better criterion and grain size was chosen as the smaller-is-better to calculate the S/N ratios. Table 4 presented the results of experiments and the corresponding values of S/N ratios.

Table 4 Results of experiments and the calculated ratios of S/N.

| Run | Tensile fracture load (N) | S/N ratio | Average grain size (μm) | S/N ratio |
|---|---|---|---|---|
| 1 | 3065 | 69.73 | 12.86 | -22.19 |
| 2 | 2970 | 69.46 | 13.26 | -22.45 |
| 3 | 2633 | 68.41 | 14.37 | -23.15 |
| 4 | 3733 | 71.44 | 10.64 | -20.54 |
| 5 | 3073 | 69.75 | 11.62 | -21.30 |
| 6 | 3223 | 70.17 | 12.73 | -22.10 |
| 7 | 3968 | 71.97 | 10.36 | -20.31 |
| 8 | 4538 | 73.14 | 11.16 | -20.95 |
| 9 | 3968 | 71.97 | 12.58 | -21.99 |
| 10 | 3403 | 70.64 | 14.54 | -23.25 |
| 11 | 3725 | 71.42 | 15.63 | -23.88 |
| 12 | 3055 | 69.70 | 16.25 | -24.22 |
| 13 | 3883 | 71.78 | 12.91 | -22.22 |
| 14 | 4063 | 72.18 | 13.85 | -22.83 |
| 15 | 3345 | 70.49 | 14.66 | -23.32 |
| 16 | 4405 | 72.88 | 12.02 | -21.60 |
| 17 | 4608 | 73.27 | 13.04 | -22.30 |
| 18 | 4223 | 72.51 | 13.71 | -22.74 |
| 19 | 3940 | 71.91 | 17.36 | -24.79 |
| 20 | 3825 | 71.65 | 18.40 | -25.30 |
| 21 | 3358 | 70.52 | 19.25 | -25.69 |
| 22 | 3988 | 72.02 | 14.35 | -23.14 |
| 23 | 4130 | 72.32 | 14.81 | -23.41 |
| 24 | 3705 | 71.38 | 15.73 | -23.93 |
| 25 | 5148 | 74.23 | 13.25 | -22.45 |
| 26 | 4780 | 73.59 | 14.42 | -23.18 |
| 27 | 4243 | 72.55 | 15.02 | -23.53 |

Tables5 and 6 present the response of S/N ratios, and Figs.7 and 8 show the main effect plot for S/N ratios for shear load and grain size respectively obtained from the MINITAB 17 software to identify the optimized process parameter set. Figures7 and 8 display the relationship between the mean ratios of S/N and welding parameters that were the tool's rotational speed, dwell time and heat-treatment. It is notice that the optimized levels of welding parameters to maximizing the shear load of the joint were heat-treatment of T4 (level 2), dwell time at 10 sec (level 3) and tool rotational speed at 1500 rpm (level 2). It is also observed that as the increase in dwell time the joint shear load is increased. PWHT increased the shear load where at T4 higher than T6. For minimizing grain size the optimized levels of welding parameters were dwell time at 6 sec (level 1), heat-treatment of T4 (level 2) and tool rotational speed at 1200 rpm (level 2)

Table 5 Response Table for S/N Ratios for shear load larger is better

| Level | Heat-treatment | Dwell time (s) | Tool rotational speed (rpm) |
|---|---|---|---|
| 1 | 71.28 | 70.67 | 71.84 |
| 2 | **72.9** | 71.65 | **71.86** |
| 3 | 70.38 | **72.24** | 70.86 |
| Delta | 2.52 | 1.57 | 1.01 |
| Rank | 1 | 2 | 3 |

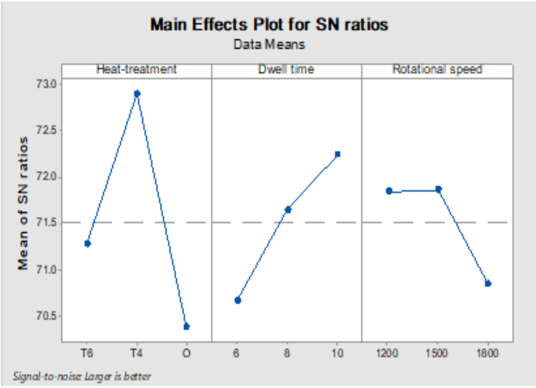


Fig 7 The main effect plot for S/N ratio for shear load.

Table 6Response Table for S/N Ratios for average grain size smaller is better

| Level | Heat-treatment | Dwell time | Tool rotational speed |
|---|---|---|---|
| 1 | -22.53 | **-21.67** | **-22.28** |
| 2 | **-22.12** | -22.93 | -22.84 |
| 3 | -23.88 | -23.93 | -23.41 |
| Delta | 1.76 | 2.27 | 1.13 |
| Rank | 2 | 1 | 3 |

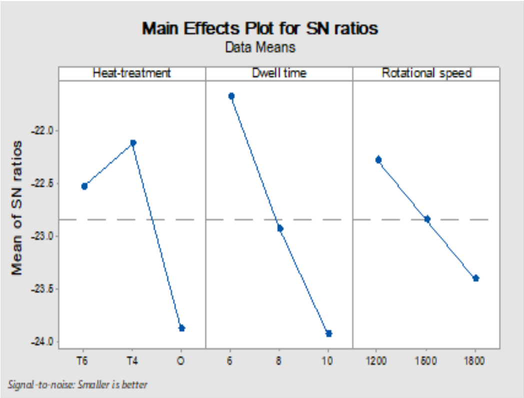


Fig 8 The main effect plot for S/N ratio for average grain size.

### 3.2- ANOVA ANALYSIS

ANOVA test was carried out to determine statistically significant welding parameters which affect shear load and average grain size. It provides a clear appearance as to how far the process parameter affects the response and the considered factor's level of significance.

The percentage of contribution of heat-treatment, dwell time and tool rotational speed were presented in Tables 9 and 10 for shear load and grain size respectively. The elevated value of contribution indicates that the factor is influence significantly in the response of the process. For shear load of the welds, heat-treatment is a highly influence factor. For average grain size, dwell time is the highest significant factor.

An ANOVA technique has evaluated the influenc e of individual process parameters on the shear load. Table 9presents the result of ANOVA with 91.59% confident level of calculated S/N ratio values for all the set of process parameters. It is presents that the most critical factor affecting the shear load is heat-treatment, which contributes 59.29% of the total variation. Followed by, dwell time and rotational speed contributing 20.72% and 11.58%, respectively.

An ANOVA technique has evaluated the influenc e of individual process parameters on the average grain size of the SZ. Table 10presents the result of ANOVA with 96.15% confident level of calculated S/N ratio values for all the set of process parameters. It is presents that the most critical factor affecting the average grain size is dwell time, which contributes 49.52% of the total variation. Followed by, heat-treatment and tool rotational speed contributing 34.95% and 3.85%, respectively.

Table 9 ANOVA table of shear load.

| Source | DF Degrees Freedom | SS Sum of Squares | MS Mean Square | F | P | PC Percent Contribution |
|---|---|---|---|---|---|---|
| Dwell time | 2 | 1987892 | 993946 | 24.65 | 0 | 20.7202513 |
| Heat-treatment | 2 | 5688587 | 2844294 | 70.53 | 0 | 59.29343857 |
| Rotational speed | 2 | 1110893 | 555447 | 13.77 | 0 | 11.57909088 |
| Error | 20 | 806585 | 40329 | | | 8.407219253 |
| Total | 26 | 9593957 | | | | 100 |

Table 10 ANOVA table of average grain size.

| Source | DF Degrees Freedom | SS Sum of Squares | MS Mean Square | F | P | PC Percent Contribution |
|---|---|---|---|---|---|---|
| Dwell time | 2 | 60.478 | 30.239 | 128.64 | 0 | 49.52828643 |
| Heat-treatment | 2 | 42.681 | 21.34 | 90.79 | 0 | 34.9534838 |
| Rotational speed | 2 | 14.249 | 7.124 | 30.31 | 0 | 11.6691781 |
| Error | 20 | 4.701 | 0.235 | | | 3.849870606 |
| Total | 26 | 122.108 | | | | 100 |

## 4.Conclusions

The effect of friction stir spot welding parameters and post weld heat-treatment on shear load and stir zone grain size was investigated with using Taguchi method.

The experimental and analytical findings achieved the following results:

1. The most influent parameter affect shear load is heat-treatment with percent contribution equal 59.293% followed by dwell time.
2. Maximum shear load can be obtained at the combination of parameters of 1500 rpm, 10 sec and T4 treatment.
3. Post weld heat-treatments and increasing of dwell time resulted higher shear load.
4. The most influent parameter affect average grain size is dwell time with percent contribution equal 49.52828643 %, followed by heat-treatment.
5. Smallest grain size of stir zone can be obtained at a combination parameters 1200 rpm, 6 sec and T4.
6. Increasing in dwell time and/or increasing in tool rotational speed causes grain growth

## References

[1] O. Dedeoğlu and H. Güler Özgül, “The Joint Properties of 5754 Aluminium Alloy by Friction Stir Spot Welding,” J. Manuf. Mater. Process., vol. 3, no. 1, p. 8, 2019.

[2] H. Güler, “The Mechanical Behavior of Friction-Stir Spot Welded Aluminum Alloys,” Jom, vol. 66, no. 10, pp. 2156–2160, 2014.

[3] H. Güler, R. Ertan, and R. Özcan, “Characteristics of 30MnB5 boron steel at elevated temperatures,” Mater. Sci. Eng. A, vol. 578, pp. 417–421, 2013.

[4] M. N. Hamzah, “Effect of Pin Shape and Rotational Speed on the Mechanical Behaviour and Microstructures of Friction Stir Spot Welding of AA6061 Aluminum Alloy,” vol. 20, no. 1, pp. 129–139, 2017.

[5] K. Sillapasa, S. Surapunt, Y. Miyashita, Y. Mutoh, and N. Seo, “Tensile and fatigue behavior of SZ, HAZ and BM in friction stir welded joint of rolled 6N01 aluminum alloy plate,” Int. J. Fatigue, vol. 63, pp. 162–170, 2014.

[6] S. Legutko, “Ratnesh Kumar Somnath Chattopadhyaya Sergej Hloch Grzegorz Krolczyk Wear characteristics and defects analysis of friction stir welded joint of aluminium alloy 6061-t6 Charakterystyka zużycia i analiza uszkodzeń złącza ze stopu aluminium 6061-T6 zgrzewaneg,” vol. 18, no. 1, pp. 128–135, 2016.

[7] A. C. B. Smith, J. F. Hinrichs, and P. C. Ruehl, “Friction Stir and Friction Stir Spot Welding - Lean , Mean and Green,” Detroit Am. Weld. Soc. Sheet Met. Conf., pp. 1–8, 2004.

[8] J. Q. Su, T. W. Nelson, R. Mishra, and M. Mahoney, “Microstructural investigation of friction stir welded 7050-T651 aluminium,” Acta Mater., vol. 51, no. 3, pp. 713–729, 2003.

[9] T. U. Seidel and A. P. Reynolds, “Visualization of the material flow in AA2195 friction-stir welds using a marker insert technique,” Metall. Mater. Trans. A Phys. Metall. Mater. Sci., vol. 32, no. 11, pp. 2879–2884, 2001.

[10] Y. Li, E. A. Trillo, and L. E. Murr, “Friction-stir welding of aluminum alloy 2024 to silver,” J. Mater. Sci. Lett., vol. 19, no. 12, pp. 1047–1051, 2000.

[11] C. Sharma, D. K. Dwivedi, and P. Kumar, “Effect of post weld heat treatments on microstructure and mechanical properties of friction stir welded joints of Al-Zn-Mg alloy AA7039,” Mater. Des., vol. 43, pp. 134–143, 2013.

[12] F. F. Wang, W. Y. Li, J. Shen, S. Y. Hu, and J. F. dos Santos, “Effect of tool rotational speed on the microstructure and mechanical properties of bobbin tool friction stir welding of Al-Li alloy,” Mater. Des., vol. 86, pp. 933–940, 2015.

[13] S. H. Lee, D. M. Lee, and K. S. Lee, “Process optimisation and microstructural evolution of friction stir spot-welded Al6061 joints,” Mater. Sci. Technol. (United Kingdom), vol. 33, no. 6, pp. 719–730, 2017.

[14] P. Taylor, M. Fujimoto, D. Watanabe, N. Abe, S. S. Yutaka, and H. Kokawa, “Effects of process time and thread on tensile shear strength of Al alloy lap joint produced by friction stir spot welding,” vol. 6, pp. 37–4, November 2014.

[15] Arunabh,"Friction Stir Welding Of Aluminium Alloys:Mechanical Properties And Metallurgical Observations Dissertation Ii", Submitted In Partial Fulfilment Of The Requirement For Award Of The Degree Of Master Of Technology In Mechanical Engineering, Mani T. 2017.

.