ENGINEERING RESEARCH JOURNAL (ERJ)
Vol. 1, No. 46 October 2020, pp.6-10.
Journal Homepage: erj.bu.edu.eg

ARTIFICIAL NEURAL NETWORK MODELLING OF THE MECHANICAL CHARACTERISTICS OF FRICTION STIR WELDED AA7020-T6 ALUMINUM ALLOY

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ABSTRACT

In the current work, lap joints of the AA7020-T6 aluminum sheets of 3 mm thickness were welded using friction stir welding (FSW). Tensile-shear tests were conducted to evaluate the mechanical characteristics of the AA7020-T6 lap joints. A statistical analysis of variance (ANOVA) was performed to find which FSW process parameters (i.e. the tool rotational and welding speeds) are statistically significant. With the signal to noise (S/N) ratio and ANOVA analyses, the optimal levels of the FSW process parameters could be determined. Also, an artificial neural network (ANN) model was developed to predict the tensile-shear load of the AA7020-T6 Al alloy lap joints. It has been found that the reduction of the tool rotational speed and/or increasing the welding speeds increase(s) the tensile-shear load of the AA7020-T6 aluminum friction stir welded lap joints. The welding speed showed the highest statistical significance on the tensile-shear load of the AA7020-T6 aluminum lap friction stir (FS) welded joints when compared with the tool rotational speed. The developed ANN model showed a good agreement between the predicted and experimental results.

KEYWORDS: Friction stir welding, Artificial neural network, Tensile-shear load, Analysis of variance.

1. INTRODUCTION

Friction stir welding (FSW) is a relatively new solid-state joining process invented by "The Welding Institute" (TWI) in 1991. The FSW process combines frictional heating and plastic deformation to attain defects-free high-quality joints. The main advantage of the FSW is that the temperature during welding is lower than the melting temperature of the workpieces, accordingly the deformation (or residual stresses) is significantly lower than conventional arc welding technique. Nowadays FSW has become a practical welding technique for aluminum and other low/medium strength alloys such as magnesium and copper alloys [1-2]. However, the FSW is used for joining of high melting temperature materials such as titanium, nickel and steels [3]. FSW has several defects such as lower corrosion resistance, tunnel defects, cavities and voids, if the process parameters such as the rotational speed, welding speed, applied pressure, tilt angle …etc. are not chosen properly [4].

FSW is a very complex manufacturing process comprising several highly coupled physical phenomena. The complex geometry of some kinds of joints makes it difficult to develop an overall governing equations system for theoretical behavior analyze of the FS welded joints. Weld quality is predominantly affected by welding effective parameters, and the experiments are often time consuming and costly. On the other hand, employing artificial intelligence (AI) systems such as ANNs as an efficient approach to solve the engineering and science problems is considerable. Several investigations used the ANN approach in the field of FSW [5-7].

There are few investigations reported on the influence of the FSW process parameters on the mechanical characteristics for lap-joints configurations [8-10]. Accordingly, it is the aim of the present investigation to study the influence of the FSW process parameters, typically, the tool rotational and welding speeds on the tensile-shear load for AA7020-T6 aluminum lap-joints produced FSW. The analysis of variance (ANOVA) statistical approach was also used to find the significance of the FSW process parameters on the tensile-shear load of the lap-joints. Moreover, artificial neural network (ANN) models were developed to predict the tensile-shear load of the lap-joints.

2. EXPERIMENTAL PROCEDURES

In the present investigation, the AA7020 wrought aluminum (Al) alloy was used. The chemical composition of the AA7020 Al alloy is shown in Table 1. The AA7020 Al alloy sheets was heat treated to T6 condition before FSW. The heat treatment of AA7020 Al alloy was carried out at solutioninsing temperature of 540 ºC for 12 hours, followed by quenching in cold water and then subjected to ageing at 155 ºC for 6 hours. The AA7020 Al alloy sheets were FS welded at lap configuration shown schematically in Fig. 2. The FSW was carried out using a steel tool with a tapered pin profile and a flat shoulder shown schematically in Fig. 3.

Table 1. The chemical composition of AA7020 Al alloy (wt.-%).

Alloy	Elements (wt.-%)								
	Si	Fe	Zr	Mn	Mg	Zn	Cr	Ti	Al
AA7020	0.085	0.12	0.12	0.3	1.15	4.9	0.3	0.12	Bal.

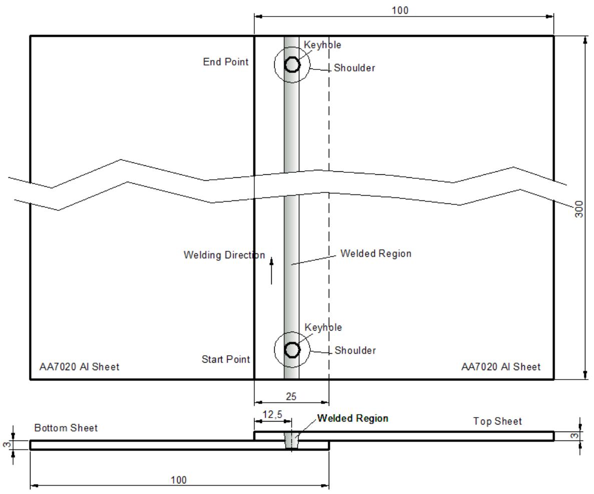

Figure 2. A schematic illustration of the AA7020-T6 joint.

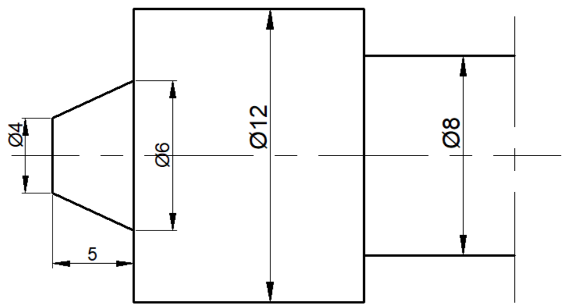

Figure 3. A schematic illustration of the tool (Dimensions in mm).

The FSW was carried out using a conventional milling machine using the parameters listed in Table 2. During FSW, the tool tilt angle and plunging depth were kept constant at 3° and 0.5 mm, respectively. Tensile-shear tests were carried out using the specimens with the dimensions shown in Fig. 4. Lap-shear specimens were machined from the FSWed sheets with the FSW was located at its center. The tensile-shear tests were performed using *Shimadzu* universal testing machine at constant cross head of 1 mm/min. A minimum of three tests, from each FSSW condition, were carried out and the tensile-shear load was determined.

Table 2. The FSW parameters and their levels.

FSW Parameter	Level		
	Level 1 (min.)	Level 2 (avg.)	Level 3 (max.)
Rotational speed (rpm), W	1200	1400	1600
Welding Speed (mm/min), V	20	40	60

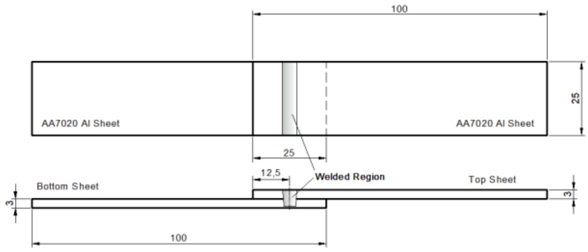

Figure 4. Tensile-shear testing specimen configuration (Dimensions in mm).

The analysis of experimental results was performed using the analysis of variance (ANOVA) statistical technique. From ANOVA results, the most and lowest significant FSW parameters influencing the tensile-shear strength of the joints were determined. Moreover, the S/N (signal-to-noise) ratio was calculated using the average values by considering the quality characteristics the larger-the-better for tensile-shear strength. The ANOVA calculations were performed using Minitab V16 statistical commercial software.

The welding quality data was collected from the present experimental investigation was used to develop an artificial neural network (ANN) model to predict the influence of the tool rotational and welding speeds FSW parameters (independent variables) on the tensile-shear load. The developed ANN model is based on feedforward neural networks, typically, Multi-Layer Perceptron (MLP). The ANN calculations were carried out using *Statistica* commercial software

3. RESULTS AND DISCUSSION

3.1. Tensile-Shear Tests Results

The variation of the tensile-shear load (TSL) of the AA7020-T6 Al FS welded lap joints with the tool rotational speed at different welding speeds is illustrated in Figure 5. The maximum TSL of 12.5 kN was observed for joints FS welded using tool rotational and welding speeds of 1200 rpm and 60 mm/min, respectively. While, the minimum TSL of 6.7 kN was observed for joints FS welded using tool rotational and welding speeds of 1600 rpm and 20 mm/min, respectively. Increasing the tool rotational speed reduces the TSL. For example, at constant welding speed of 40 mm/min, increasing the tool rotational speed from 1200 rpm to 1400 rpm reduces the TSL from 10.6 kN to 9.4 kN. Further increase in the tool rotational speed to 1600 rpm reduced the TSL to 8.9 kN. In contrast, increasing the welding speeds increases the TSL at constant tool rotational speed. For example, at constant tool rotational speed of 1400 rpm, increases the welding speed from 20 mm/min to 40 mm/min increases the TSL from 8.2 kN to 9.4 kN. Further increase in the welding speed to 60 mm/min increased the TSL to 11.9 kN.

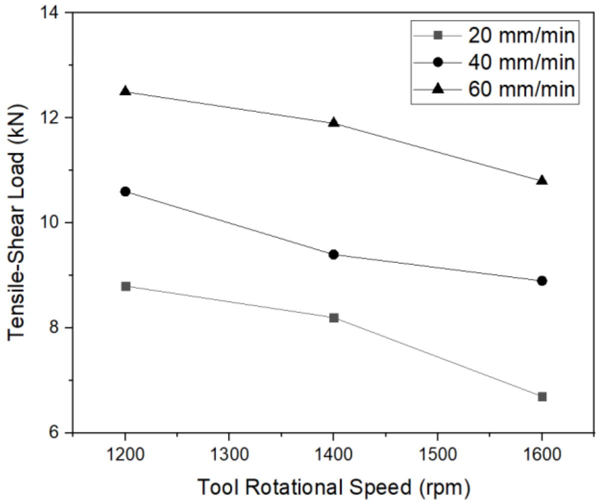

Figure 5. Variation of the tensile-shear load of the AA7020-T6 Al FS welded lap joints with the tool rotational speed at different welding speeds.

3.2. The ANOVA Results for the tensile-shear load of the Lap Joints

Table 3 lists the ANOVA results for the TSL of AA7020-T6 aluminum FS welded lap joints. The ANOVA table shows the percentage contribution of the tool rotational and welding speed FSW process parameters. Table 4 shows the response table for S/N ratios for the TSL of AA7020-T6 aluminum FS welded lap joints with the larger is better condition. It is clear that the welding speed has higher statistical and physical significance on the TSL of the AA7020-T6 aluminum lap FS welded joints when compared with the tool rotational speed. As shown in Table 3, the tool rotational and welding speed exhibited P-Values of 0.003 and 0.000, respectively. In Table 4 the welding speed is ranked #1, while the tool rotational speed is ranked #2.

Table 3. The ANOVA for the TSL of AA7020-T6 Al FS welded lap joints.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
W	2	5.0689	5.0689	2.5344	35.64	0.003
V	2	22.1089	22.1089	11.0544	155.45	0.000
Error	4	0.2844	0.2844	0.0711		
Total	8	27.4622				

S = 0.266667 R-Sq = 98.96% R-Sq(adj) = 97.93%

Table 4. The response table for S/N ratios for the TSL of AA7020-T6 Al FS welded lap joints.

Level	W	V
1	20.44	17.90
2	19.75	19.65
3	18.73	21.37
Delta	1.72	3.48
Rank	2	1

Larger is better

Figures 6 and 7 show the main effects plots for means and S/N ratios for the TSL of AA7020-T6 alloy FS welded lap joints, respectively. Figure 6 shows that increasing the tool rotational speed reduces the TSL of the AA7020-T6 FS welded lap joints. However, increasing the welding speed increases the TSL of the AA7020-T6 FS welded lap joints. Based on the analysis of the S/N ratios shown in Table 3.15 and Figure 7, the optimum parameters were obtained at tool rotational speed of 1200 rpm and at welding speed of 60 mm/min. Therefore, the optimum level of FSW process parameters to obtain the maximum TSL of AA7020-T6 Al FS welded lap-joints is W1 and V3; which corresponds to tool rotational speed of 1200 rpm and welding speed of 60 mm/min. The interaction plots for means and S/N ratios between the tool rotational and welding speeds are illustrated in Figures 3.8 and 9. It can be seen that the lines are nearly parallel each other, which indicates that there are some interactions between tool rotational and welding speeds.

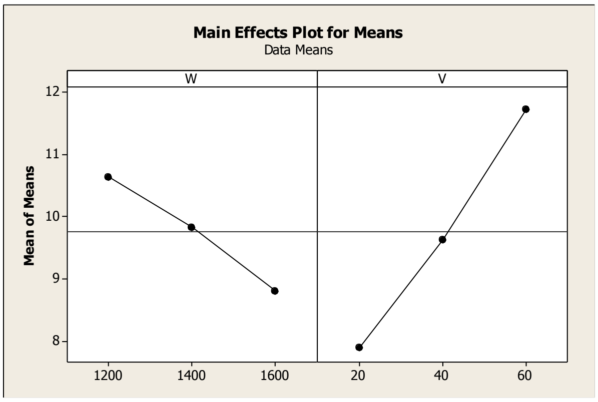

Figure 6. Main effects plot for means of the TSL of AA7020-T6 FS welded lap joints.

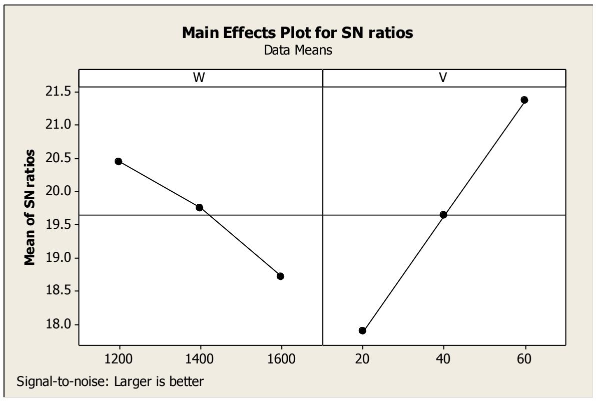

Figure 7. Main effects plot for S/N ratios of the TSL of AA7020-T6 FS welded lap joints.

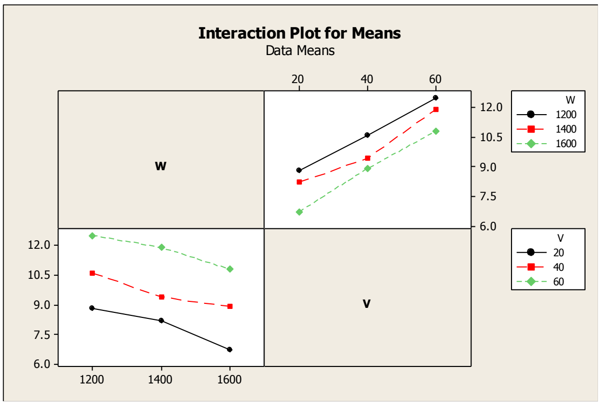

Figure 8. Interaction plot for means of the TSL of AA7020-T6 FS welded lap joints.

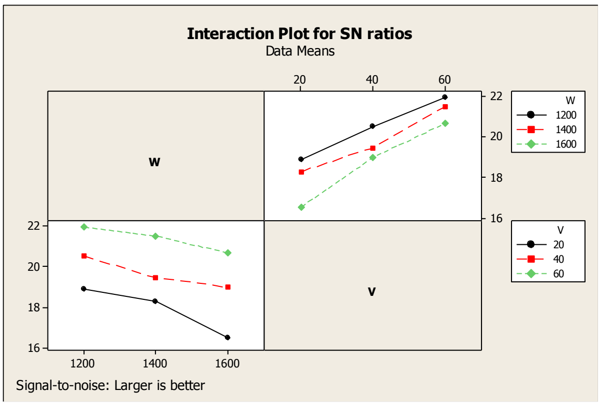

Figure 9. Interaction plot for means of the TSL of AA7020-T6 FS welded lap joints.

3.3. The ANN Modelling Results for the Tensile-Shear Load of the AA7020-T6 Welded Lap joints

The developed ANN model has a structure of 2-7-1 with an exponential activation function. The model exhibited a training performance of 0.981189. Figure 10 shows 3D surface plots for the variation of the TSL with the tool rotational and welding speeds resulted from the ANN model. Figure 10 shows a comparison between the experimental and predicted values of the TSL of AA7020-T6 FS welded lap joints. The results of the TSL ANN model presented in Figure 10 clearly indicate that the developed ANN model has a good accuracy. The mean relative error (MRE) of the developed ANN model for the TSL of the AA7020-T6 lap joints was about 3.42%.

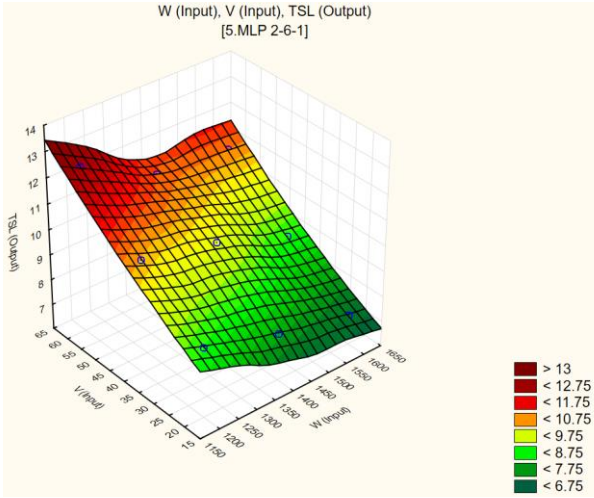

Figure 3.1. 3D surface plot showing the variation of the TSL of AA7020-T6 FS welded lap joints with the tool rotational and welding speeds.

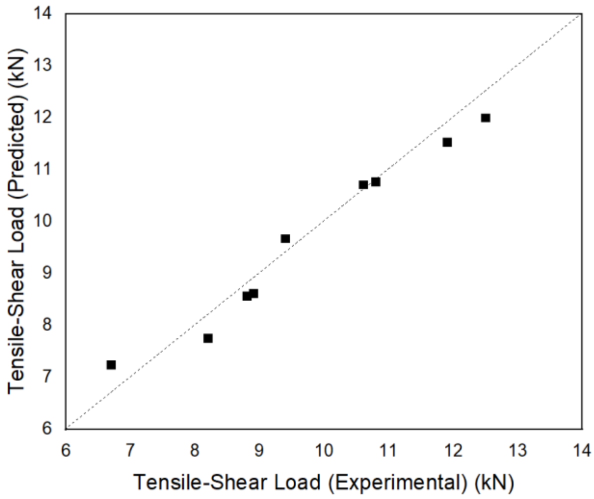

Figure 3.2. A comparison between the experimental and predicted values
of the microhardness at the center of SZ of AA7020-T6 welded regions.

4. CONCLUSIONS

The conclusions of significance are drawn as follows: -

1. Reducing the tool rotational speed and/or increasing the welding speeds increase(s) the tensile-shear load of the AA7020-T6 aluminum friction stir welded lap joints.
2. The optimum levels of FSW process parameters to obtain the maximum tensile load of AA7020-T6 Al FS welded lap-joints corresponds to tool rotational speed of 1200 rpm and welding speed of 60 mm/min.
3. The mean relative error of the developed ANN model for the tensile-shear load of the AA7020-T6 lap joints was about 3.42%.

REFERENCES

[1] Yoo, J. T., Yoon, J. H., Min, K. J., and Lee, H. S., "Effect of Friction Stir Welding Process Parameters on Mechanical Properties and

Macrostructure of Al-Li alloy", 2nd International Materials, Industrial, and Manufacturing Engineering Conference, MIMEC2015, Procedia Manufacturing, 2, 2015, pp. 325 – 330.

[2] Zhang, F., Su, X., Chen, Z., Nie, Z., "Effect of welding parameters on microstructure and mechanical properties of friction stir welded joints of a super high strength Al–Zn–Mg–Cu aluminum alloy", Materials & Design, 67, 2015, pp:483-491.

[3] Watanabe, T., Takayama, H., &Yanagisawa, A., "Joining of aluminium alloy to steel by friction stir welding", Journal of Materials Processing Technology, 178, 2006, pp. 342–349.

[4] Shirazi, H., Kheirandish, S., Safarkhanian, M. A., "Effect of process parameters on the macrostructure and defect formation in friction stir lap welding of AA5456 aluminum alloy", Measurement, 76, 2015, pp: 62–69.

[5] Vahid Moosabeiki Dehabadi, Saeede Ghorbanpour, Ghasem Azimi, "Application of artificial neural network to predict Vickers microhardness of AA6061 friction stir welded sheets", J. Cent. South Univ., 23, 2016, pp. 2146-2155.

[6] Ghetiya N. D., Patel K. M., "Prediction of tensile strength in friction stir welded aluminium alloy using artificial neural network", Procedia Technology, 14, 2014, pp. 274−281.

[7] Kudzanayi Chiteka, "Artificial Neural Networks in Tensile Strength and Input Parameter Prediction in Friction Stir Welding", Int. J. Mech. Eng. & Rob. Res., 3(1), 2014, pp. 145-150.

[8] Chen ZW, Yazdanian S., "Friction Stir Lap Welding: material flow, joint structure and strength", Journal of Achievements in Materials and Manufacturing Engineering, 55, 2012, pp. 629-637.

[9] Yazdanian S, Chen ZW, Littlefair G., "Effects of friction stir lap welding parameters on weld features on advancing side and fracture strength of AA6060-T5 welds", Journal of Materials Science, 47(3), 2012, pp. 1251-1261.

[10] Salari E, Jahazi M, Khodabandeh A, Ghasemi-Nanesa H., "Influence of tool geometry and rotational speed on mechanical properties and defect formation in friction stir lap welded 5456 aluminum alloy sheets", Materials & Design, 58, 2014, pp. 381-389.