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ARTIFICIAL NEURAL NETWORK MODELLING OF THE SURFACE ROUGHNESS OF FRICTION STIR WELDED AA7020-T6 ALUMINUM ALLOY

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ABSTRACT

In the present investigation, lap joints of the AA7020-T6 aluminum sheets were joined using friction stir welding (FSW). The AA7020-T6 sheets has 3 mm thickness. The FSW was carried out at three different tool rotational speeds of 1200 rpm, 1400 rpm and 1600 rpm; and three different welding speeds of 20 mm/min, 40 mm/min, and 60 mm/min. During FSW, the tool tilt angle and plunging depth were kept constant at 3º and 0.5 mm, respectively. The FSW was performed using a tool with a tapered pin profile and a flat shoulder. The surface quality of the FSW specimens was evaluated by the arithmetic average roughness value (Ra). The results revealed that increasing of the tool rotational speed and/or the welding speed increases the surface roughness of AA7020-T6 lap joints. The developed artificial neural network (ANN) model showed a good agreement between the predicted and experimental results. The ANN model exhibited mean relative error (MRE) of 3.8%.

KEYWORDS: Friction stir welding, Artificial neural network, Surface roughness, Design of Experiments.

1. INTRODUCTION

Friction stir welding (FSW) can be considered as the most significant development in welding of metallic materials in the past decades [1-3]. It is a green welding method due to its energy efficiency (low heat input), sustainable utilization of natural resources (less material waste, part count reduction, reduced material lead time, high weld quality and performance, longer life cycle), reduced environmental impact (no shielding gases required, part cleaning requirements reduced, no fumes/spattering/ozone produced, filler material addition not necessary) and process versatility (adaptable welding orientations and different thicknesses, microstructures, and compositions).

The influence of FSW process parameters on the characteristics of aluminum butt joints were extensively studied. However, the influence of the FSW process parameters on the characteristics for other joint configurations such as lap-joints, T-joints …etc. were rarely reported [4-6].

Artificial neural networks (ANNs) is one of the most important research areas in the field of science and engineering [7-10]. ANN is a complicated system composed of numerous nerve cells. It is also a new type of computer system which is based on the primary understanding of the organization, function structure, and mechanism of the human brain. With the aid of rapid progress in computers and material science, material design can now be performed based on the experience and knowledge of the fabricated materials. This method does not need any principles of physics. A knowledge base, an important part of an expert system, can be established quickly and easily with the aid of ANNs.

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 surface roughness 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 surface roughness of the lap-joints. Moreover, artificial neural network (ANN) models were developed to predict the surface roughness of the lap-joints.

2. EXPERIMENTAL PROCEDURES

The AA7020 wrought aluminum (Al) alloy was used in the present investigation. The chemical composition of the AA7020 Al alloy is shown in Table 1. The AA7020 Al alloy was recived in the form of large sheets and were cut to smallar sizes of 300 (length) × 100 (width) × 3 (thickness) mm. 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.

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.

The AA7020 Al alloy sheets were friction stir (FS) welded using lap configuration shown in Fig. 2. The FSW was carried out using a tool with a tapered pin profile and a flat shoulder with the dimensions shown in Fig. 3. The tool is made of K110 tool steel.

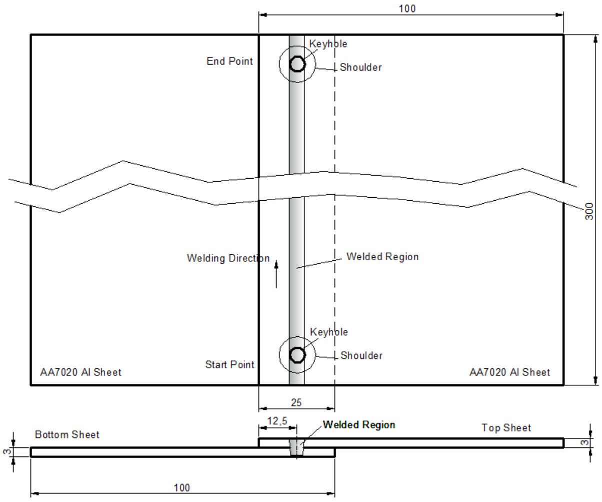

Figure 2. A schematic illustration of the AA7020-T6 joint.

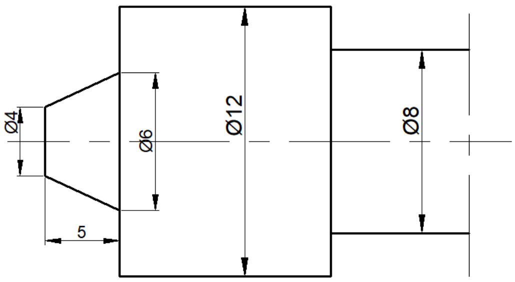

Figure 3. A schematic illustration of the tool (Dimensions in mm).

The FSW was carried out using a conventional semi-automatic milling machine using three different rotational speeds of 1200 rpm, 1400 rpm and 1600 rpm, and different traverse speeds of 20 mm/min, 40 mm/min and 60 mm/min. During FSW, the tool tilt angle and plunging depth were kept constant at 3^o and 0.5 mm, respectively.

The surface quality of the FSW specimen was evaluated by the arithmetic average roughness value (Ra) using Mitutoyo SURFTEST SJ-310 contact-stylus roughness tester. A typical roughness plot for FSW specimen welded is shown in Fig. 4. From each welded workpiece, three roughness measurements were performed at the begining, middle and end of the of the welded workpiece and the average value of R_a is calculated.

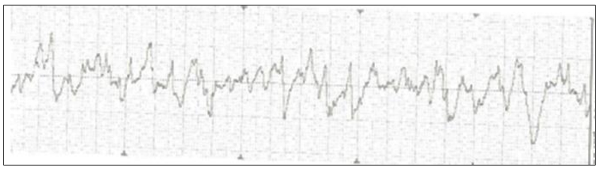

Figure 4. A typical roughness plot for FSW specimens.

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 surface roughness 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 smaller-the-better for surface roughness. The ANOVA calculations were performed using *Minitab* statistical commercial software.

An artificial neural network (ANN) model was developed to predict the influence of the tool rotational and welding speeds FSW parameters (independent variables) on the surface roughness. 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

Figures 5 typical surfaces of FS welded AA0750-T6 aluminum lap joints obtained at tool rotational and welding speeds. Several defects (flows) were observed on the surface of FS welded joints, typically, the macropores or cavities (see Figure 5b) and micropores (see Figure 5a and 5c). It is known that the better surface quality, the lower the machinability cost required to finish the surface of the upper plate of the weldments after FSW. The surfaces of the FS welded AA7020-T6 lap joints are identified by existence of semicircular streaks at the contact surface between the shoulder and the upper plates. It has been observed that the appearance of the streaks is determined by both the tool rotational and welding speeds. Table 2 lists the average surface roughness, Ra, of the upper plate surfaces of the FS welded samples. The minimum Ra (18 µm) was observed for surfaces developed using tool rotational and welding speeds of 1200 rpm and 20 mm/min, respectively. While the maximum Ra (42 µm) was observed for surfaces developed using tool rotational and welding speeds of 1600 rpm and 60 mm/min, respectively.

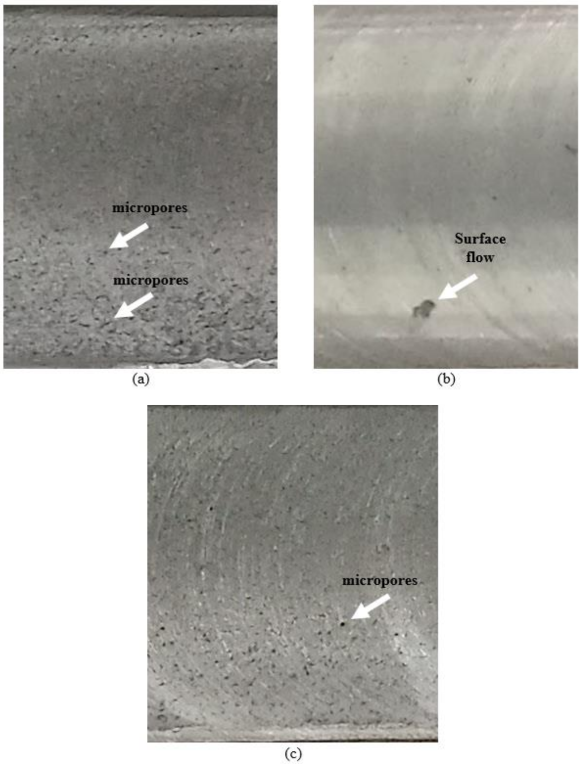

Figure 5. Photographs of typical surfaces of friction stir welded AA0750-T6 aluminum lap joints obtained at; (a) 1400 rpm and 60 mm/min; (b) 1200 rpm and 20 mm/min; and (c) 1600 rpm and 60 mm/min.

Table 2. The average Ra of the upper surfaces of FS welded lap joints.

Tool rotational Speed, ω (rpm)	Welding Speed, ν (mm/min)	Surface Roughness, Ra, (μm)
1200	20	18
	40	22
	60	26
1400	20	28
	40	33
	60	36
1600	20	33
	40	36
	60	42

Figure 6 shows the variation of the surface roughness, Ra, with the tool rotational speed at different welding speeds. The increase of the tool rotational speed and/or the welding speed increases the surface roughness (i.e. reduce the quality of the surfaces). For instance, at constant welding speed of 20 mm/min, increasing the tool rotational speed from 1200 rpm to 1600 rpm increased the Ra from 18 μm to 33 μm. Also, at constant tool rotational speed of 1600 mm/min, increasing the welding speed from 20 mm/min to 60 mm/min increased the Ra from 33 μm to 42 μm.

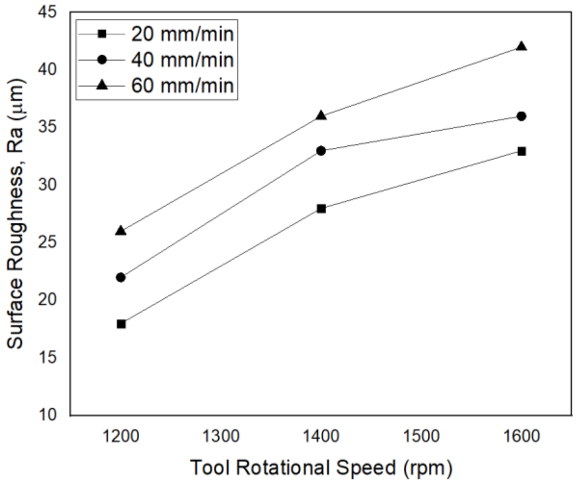

Figure 6. Variation of the surface roughness (Ra) with the tool rotational speed at different welding speeds.

The results revealed that the lowest rotational speed combined with slow welding speed developed low frictional heat, and therefore produced traces with lower depths. Too much heat and/or low cooling rate may affect negatively the quality of the surface

Table 3 shows the ANOVA results for the surface roughness, Ra. While, Table 4 shows the response signal to noise ratios (S/N) for the surface roughness. The results showed that the tool rotational speed (ranked #1 in Table 4) has higher significance influence on the surface roughness than the welding speed (ranked #2 in Table 4). This also approved using the P-value shown in Table 3. Since the P-values of the tool rotational and welding speed are 0.000 and 0.001, respectively.

Figure 7 shows the main effects plot for means of the surface roughness. Figure 8 shows the main effects plot for S/N ratios of the surface roughness. The results revealed that increasing the tool rotational speed and/or increasing the welding speed increase(s) the surface roughness of the FS welded joints. The minimum surface roughness value can be obtained when using tool rotational speed and welding speed of 1200 rpm and 20 mm/min (i.e. at levels W1V1), respectively.

Table 3. The ANOVA results for surface roughness, Ra.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
W	2	353.56	353.56	176.78	289.27	0.000
V	2	104.22	104.22	52.11	85.27	0.001
Error	4	2.44	2.44	0.61		
Total	8	460.22				

S = 0.781736 R-Sq = 99.47% R-Sq(adj) = 98.94%

Table 4. Response Table for S/N Ratios of surface roughness, Ra.

Level	W	V
1	-26.75	-28.14
2	-30.15	-29.45
3	-31.32	-30.63
Delta	4.57	2.49
Rank	1	2

Smaller is better

Figures 9 and 10 show the interaction plots for means and S/N rations of the surface roughness, Ra, respectively. The results showed that, within the investigated range of the FSW process parameters, a weak relationship between the tool rotational and welding speeds is found. A strong interaction occurs when the lines are more nonparallel.

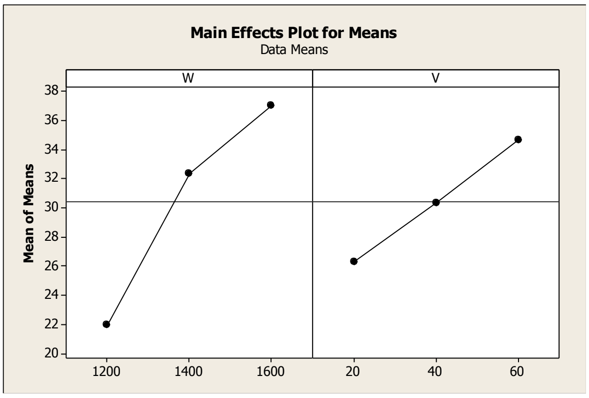

Figure 7. The main effects plot for means of the surface roughness, Ra.

The developed ANN model has a network layers structure of 2-5-1 with an actuating function of Tanh. The network exhibited a training performance of 0.998042. Figure 11 shows a 3D surface developed from the ANN model. The ANN model exhibited mean relative error (MRE) of 3.8%. Figure 12 shows a comparison between the experimental and predicted values of the surface roughness. The dashed line has an inclination angle of 45º and represents the perfect prediction of the data (i.e. the closer the points to this line, the better the prediction performance of the model). It is clear that the values of the surface roughness are close to each other.

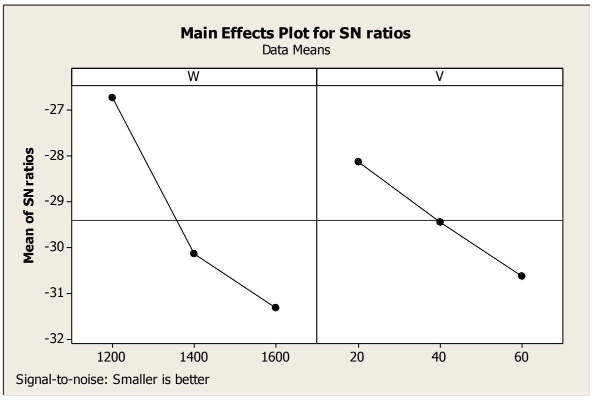

Figure 8. The main effects plot for S/N ratios of the surface roughness, Ra.

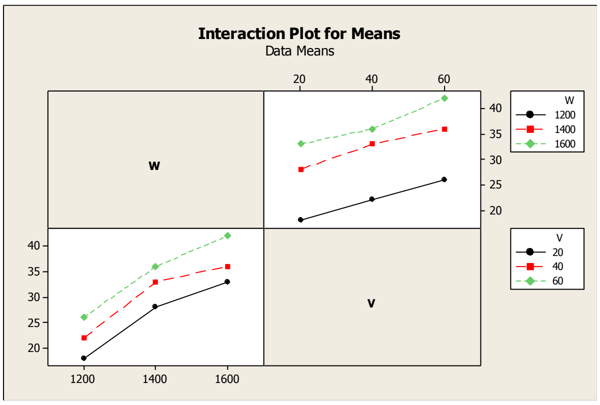

Figure 9. The interaction plot for means of the surface roughness, Ra.

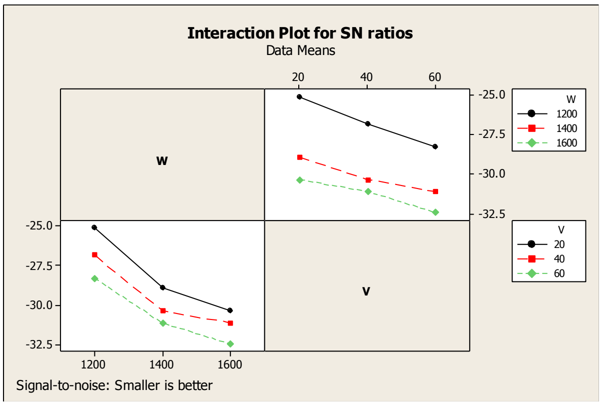

Figure 10. The interaction plot for S/N ratios of the surface roughness, Ra.

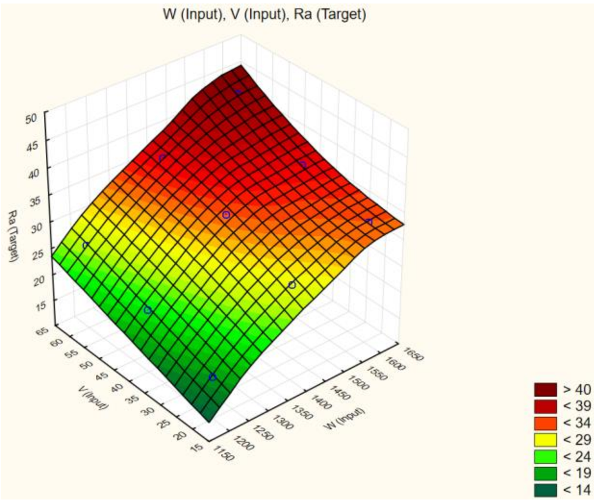

Figure 11. 3D surface plot showing the variation of the surface roughness, Ra, with the tool rotational and welding speeds.

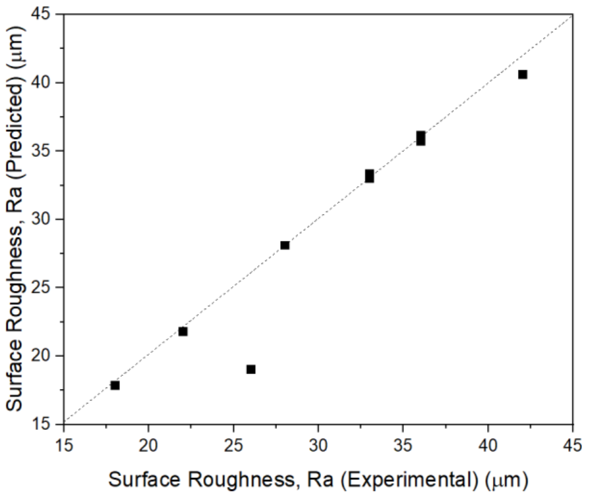

Figure 12. A comparison between the experimental and predicted
values of the surface roughness, Ra.

4. CONCLUSIONS

The surfaces of the FS welded AA7020-T6 lap joints are identified by existence of semi-circular streaks at the contact surface between the shoulder and the upper plates. Increasing of the tool rotational speed and/or the welding speed increases the surface roughness of AA7020-T6 lap joints. The minimum surface roughness value can be obtained when using tool rotational speed and welding speed of 1200 rpm and 20 mm/min. The ANN model exhibited mean relative error of 3.8%.

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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.