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STUDY OF TOOL PARAMETERS INFLUENCE ON PEAK TEMPERATURE DURING FRICTION STIR WELDING

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ABSTRACT

The influence of tool parameters on peak temperature during the friction stir welding process is discussed in this paper. The process parameters such as shoulder diameter, pin diameter and pin taper angle are considered for this analysis. Friction stir welding trails were conducted on 6 mm AA6061-T6 plates for different combination of process parameters using Taguchi orthogonal array. Thermocouples were inserted into the plates at different distances from weld center line and temperatures were measured during friction stir welding at regular intervals. Using the Taguchi method, Peak temperature has been calculated for untried combinations of process parameters. The peak temperature predicted by Taguchi method for various shoulder diameter, pin diameter and pin taper angle have been discussed.

Keywords: *Friction stir welding, Aluminium alloy, peak temperature, Taguchi method.*

1. Introduction

One of a solid state joining technique is friction stir welding (FSW) in which a specially designed non consumable rotating tool is used to weld plates together. The tool employed in FSW has larger diameter shoulder and a smaller diameter pin. FSW have significant advantage over fusion welding processes such as excellent mechanical properties, low distortion, no consumables, little porosity and environmentally friendly. It has potential for applications in many industries like aerospace, automotive and ship building [3,7]

The heat conducted into the plate during the FSW process determines the temperature of plate thereby influencing the material flow, defects, microstructure and mechanical properties in the weld zone. Therefore it is important to obtain information about temperature during FSW.

Since after the invention of FSW, it has been widely studied both experimentally and theoretically to better understand both the welding process and the welded materials. P. Ulysse [8] conducted experiments on friction stir welding up to a welding speed of 212.4 mm/min to determine the effect of welding speed and rotational speed on plate temperature and validated with the model. The effect of welding speed and rotational speed on peak temperature of friction stir welding up to a welding speed of 12 mm/min is demonstrated by Paul and Hugh[4]. The relationship between the welding speed (maximum of 350 mm/min) and peak temperature in the plate during FSW is developed by Tang et al[6]. The peak temperature of plate during FSW as a function of rotation speed is investigated up to a welding speed of 720 mm/min by Samir and Ali [5]. Hamilton et al[1] tabulated the peak temperature of the plate against the various welding speed (maximum of 480 mm/min) and rotational speed. Jacquin et al.[2] studied the extreme temperature in the weld as a function of welding speed (maximum of 400 mm/min) and rotational speed.

The literature survey indicates that most of the research works have been carried out to study the effect of one or two process parameter on peak temperature at welding speed up to 720 mm/min. Prediction of peak temperature using Taguchi method also not reported. Hence an attempt has been made to study the effect of tool parameters on peak temperature at welding speed up to 1800 mm/min using Taguchi method. The temperature during the FSW process has been measured up to the weld center line.

2. Experiment setup

The pictorial view of the FSW experimental setup which consists of tool, plates and temperature sensor is shown in Fig. 1. The material chosen for this study is aluminium alloy 6061-T6 due to its wide range of application such as building and construction, automotive and marine applications[3]. The rolled AA6061 aluminium alloy of 6 mm thick plate has been cut into required size of 150 x 75 x 6 mm. Specially made non-consumable tools made of M2 steel have been employed for this study. The differnt tool used in the study is shown in Fig.2. During the FSW process,

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temperatures at different locations were measured using four K-type thermocouples embedded in the advancing side located at a distance of 0 mm, 4 mm, 10 mm, 15 mm and 25 mm to the center line of the weld as shown in Fig. 3. The space between the thermocouples in the longitudinal and transverse direction is 10 mm and fixed at a depth of 0.5 mm. An agilent make data acquisition system is used to acquire data during the welding process at regular intervals.

Fig. 1 Experimental setup

Fig. 2 FSW tools

Fig. 3 Position of thermocouples

3. Taguchi Method

A large number of experiments are required to investigate the peak temperature as a function of five process parameters [shoulder diameter (D), pin diameter (d), pin taper angle (A), welding speed (V), rotational speed (N)]. In full factorial, 4^5 = 1024 experiments to be conducted for five factors with four levels. Taguchi method uses a specially designed orthogonal array to study the response with a small number of experiments. Hence Taguchi method is employed in this present analysis. As five factors and four levels are considered, L16 orthogonal array is selected as shown in Table1.

Table 1. L16 Orthogonal array with measured peak temperature

Experiments	D (mm)	d (mm)	Pin Taper Angle	Rotational Speed (rpm)	Welding Speed (mm/min)	Temperature (°c)
E1	15.40	5.5	5	300	300	362.583
E2	15.40	5.8	10	900	600	461.556
E3	15.40	6.1	15	1600	1200	503.784
E4	15.40	6.4	20	2400	1800	521.572
E5	16.24	5.5	10	1600	1800	491.658
E6	16.24	5.8	5	2400	1200	534.668
E7	16.24	6.1	20	300	600	361.854
E8	16.24	6.4	15	900	300	488.843
E9	17.10	5.5	15	2400	600	539.855
E10	17.10	5.8	20	1600	300	532.738
E11	17.10	6.1	5	900	1800	457.674
E12	17.10	6.4	10	300	1200	365.463
E13	18.00	5.5	20	900	1200	458.754
E14	18.00	5.8	15	300	1800	348.437
E15	18.00	6.1	10	2400	300	566.589
E16	18.00	6.4	5	1600	600	539.738

The degree of freedom for each factor is 3 (Number of levels - 1, ie. 4 - 1 = 3) and therefore Degree of freedom will be 5 x 3 = 15. Since degree of freedom of orthogonal array (16) is greater than degree of freedom of factor (15), the selected orthogonal array is suitable for study.

The experiments were conducted and temperatures were measured for 16 different combinations of parameters as per the taguchi's L16 orthogonal arrays. The effect of parameters at deferent levels was calculated using SN ratio expression.

The SN ratio $= -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right]$

Where n = number of experiments, y_i = observed temperature value. Then the mean effect of parameters at each level was obtained. Finally, temperature for the all possible combination of parameters was calculated.

4. Results and discussion

4.1 Effect of shoulder diameter on Peak temperature

This part presents the contribution and effect of process parameters such as shoulder diameter, pin mean diameter and pin taper angle peak temperature during FSW. The peak temperature predicted by Taguchi method for FSW process as a function of shoulder diameters corresponds to pin diameter of 6.1 mm, pin taper angle of 10 degrees and rotational speed of 900 rpm is shown in Fig.4. It shows that the peak temperature is directly proportional to shoulder diameter and inversely proportional to the welding speed. When shoulder diameter increases, shear area under the shoulder increases and heat generated by the shoulder increases. As, a result, total heat generation increases and hence peak temperature increases.

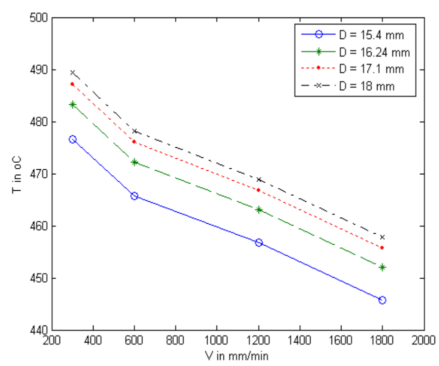

Fig.4 Peak temperature as a function of welding speed for various shoulder diameters

4.2 Effect of pin diameter on Peak temperature

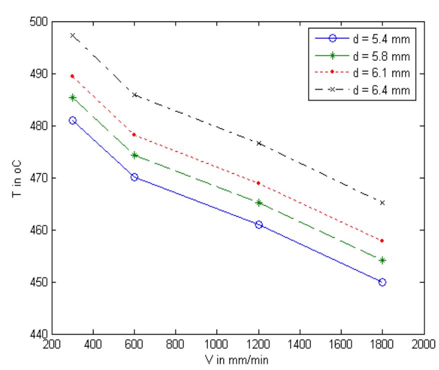

Fig.5 Peak temperature as a function of welding speed for various pin mean diameters

The relation between the peak temperature and different welding speed for various pin mean diameters corresponds to shoulder diameter of 18 mm, pin diameter of 10 degree and rotational speed of 900 rpm is shown in Fig.5. It shows that peak temperature is directly proportional to pin mean diameter. As pin mean diameter increases, shear area around the pin increases, as a result, heat generation increases and hence Peak temperature is increased.

4.3 Effect of pin taper angle on Peak temperature

The Fig. 6 indicates the peak temperature as a function of welding speed for various pin taper angles corresponds to shoulder diameter of 18 mm, pin diameter of 6.1 mm, rotational speed of 900 rpm.

When pin taper angle increases, shear area around the spin increases whereas shear area under the shoulder decreases. So heat generated by the pin increases and heat generated by shoulder decreases. The increase in heat generation at the pin is less than decreases in heat generation under the shoulder. Hence total heat generation decreases. As a result the pin taper angle is inversely proportional to peak temperature. However the variation of peak temperature against pin taper angle is not significant.

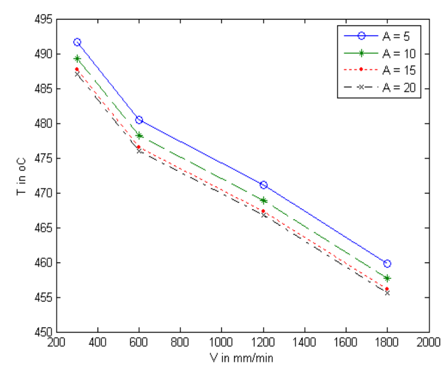

Fig.6 Peak temperature as a function of welding speed for various pin taper angles

5. Conclusions

Friction stir welding of 6061-T6 aluminium alloy has been carried out under various tool and welding parameters based on Taguchi's orthogonal array. The temperatures during the process were measured experimentally. The peak temperature of friction stir welding due to tool parameters are studied. The results shows that the peak temperature is directly proportional to shoulder diameter and pin mean diameter whereas peak temperature is indirectly proportional to pin taper angle and welding speed. However the variation of peak temperature against pin taper angle is not significant.

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