EFFECT OF HEAT CONDUCTION ON MACHINE PARAMETERS OF FRICTION STIR WELDED ALUMINIUM ALLOYS

ABHISHESH MISHRA[1], RAJNISH SINGH[2], SAADAT ALI RIZVI[3]

Abstract. W.M. Thomas at The Welding Institute of UK in 1991 invented friction stir welding for the welding of aluminium alloys and as time progress use of light weight material and others which were difficult to weld by other conventional method increasing continuously in the field of aerospace, shipbuilding and marine, robotics and computers and other industries which motivated researchers for development and progress in friction stir welding. Friction stir welding method involve a non consumable tool with specially designed pin and shoulder is rotating and inserted into the faying surfaces and traverse along the line of joint, by this adiabatic shearing and mechanical mixing welded the material.

In friction stir welding material is heated at elevated temperature of the base material for which heat generation is an important factor. Less heat reduces the rheology and mixing of material whereas more heat reduces the strength of the welded material. This research is for obtain the suitable temperature for proper welding of material by friction stir welding.

The cylindrical tool shoulder and pin of diameter 17, 19 and 22 mm at tool rotation rate of 1,000, 1,500 and 2,000 rpm and tool traverse speed of 15, 20 and 25 mm/min is used to weld of 1,100 aluminium alloy. Experimental result implied that more heat is generated at higher tool rotation rate and tool shoulder diameter and less heat generate at high tool traverse speed. A3B1C1 is the optimum parameter. Tool shoulder diameter 22 mm, tool rotation rate 2,000 rpm and tool traverse speed 15 mm/min is the best parameter among all readings.

Key words: FSW, metal flow, rheology, process parameters, heat generation.

1. INTRODUCTION

Processing parameters of friction stir welding plays main role and many research are continuously occur to obtain best result for these parameters and is being developed to enhance the weld quality and process efficiency of welding joint. Friction stir welding (FSW) was invented by W.M. Thomas at The Welding Institute (TWI) of UK in 1991, is joined by a solid state technique in which a non

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[1] Department of Mechanical Engineering, IT SRMU Barabanki, U.P., India
[2] Department of Mechanical Engineering, KNIT Sultanpur, U.P., India
[3] University Polytechnic JMI, New Delhi, India, email: sarizvi1@jmi.ac.in, saritbhu@gmail.com

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consumable tool have a specific designed pin and shoulder is rotating state inserted into the faying surface of clamped sheets or plates to be welded and traversed along the line of joint. [1,6,7] The welding sheets or plates which are on the fixture base plate are clamped in a manner that prevents the faying surface from being forced apart on the welding application.

FSW as solid state joining technique, in it wear resistant rotating tool is inserted into the workpiece mating edge and traverse, thus generated frictional heat and plastic deformation which causes the material to stir and soften below melting point [2,4]. This softened material is transferred from tools leading edge to tools trailing edge and being forged by tool shoulder underneath and pin profile contact thus leaves a solid phase bonding between two workpieces [2]. Friction stir welding process is highly environment friendly and advantageous over conventional fusion welding process as exhibits low distortions and residual stresses, no arc flash, no fumes and spatters [3]. Development of tool is appreciably grown with this tool material have becoming better with properties and further improvement is needed as growing demand of high temperature melting point with high strength and hardened materials [2]. In friction stir welding heat affected zone is less thus reduces residual stresses, distortion of welded material and thermal cycle related microstructural changes [5].

For achieving desirable product quality by design, Taguchi suggests a three-stage process: system design, parameter design, and tolerance design. Parameter design which is used related to finding the appropriate design factor levels to make the system less sensitive to variations in uncontrollable noise factors, i.e., to make the system robust. Design of experiments (DOE) techniques, specifically Orthogonal Arrays (OAs), is employed in Taguchi's approach to systematically vary and test the different levels of each of the control factors. Commonly used OAs includes the L4, L9, L12, L18, and L27 in which L9 is used. The columns in the OA indicate the factor and its corresponding levels, and each row in the OA constitutes an experimental run which is performed at the given factor settings. The preferred parameter settings are then determined through analysis of the "signal-to-noise" (SN) ratio where factor levels that maximize the appropriate SN ratio are optimal [8,9,10].

This research shows the effect of friction stir welding process parameters (as tool shoulder diameter, tool rotation rate, tool traverse speed) on the heat generation for welding of material at the distance of $R + 5$ mm from outer edge, where R is the tool shoulder radius. Cylindrical pin type tool having shoulder diameter of 22, 19 and 17 mm, tool rotation speed of 2,000 rpm, 1,500 rpm and 1,000 rpm and tool traverse speed 15, 20 and 25 mm/min are selected for Taguchi optimization technique using Minitab 18 software. It has been found that the highest temperature is obtained at 22 mm tool shoulder diameter, 2000 rpm and tool traverse speed of 15 mm/min. Tool shoulder had a steep temperature gradient along the tool axis, and measured temperatures inside the tool were different from the surface temperatures by about 40ºC to 50ºC. It showed that the shoulder surface temperatures are higher than temperatures measured with thermocouples [15].

2. EXPERIMENTAL ANALYSIS

The experiment is designed with Minitab 18 software in which L9 Orthogonal arrays are employed. Based on L9 orthogonal array 9 experiments of friction stir welding on aluminium alloy 1100 material performed with tool shoulder diameter of 17, 19 and 22 mm, tool rotation rate of 1,000, 1,500 and 2,000 rpm and tool traverse speed of 15, 20 and 25 mm/min. The welded workpiece is shown in Fig. 1.

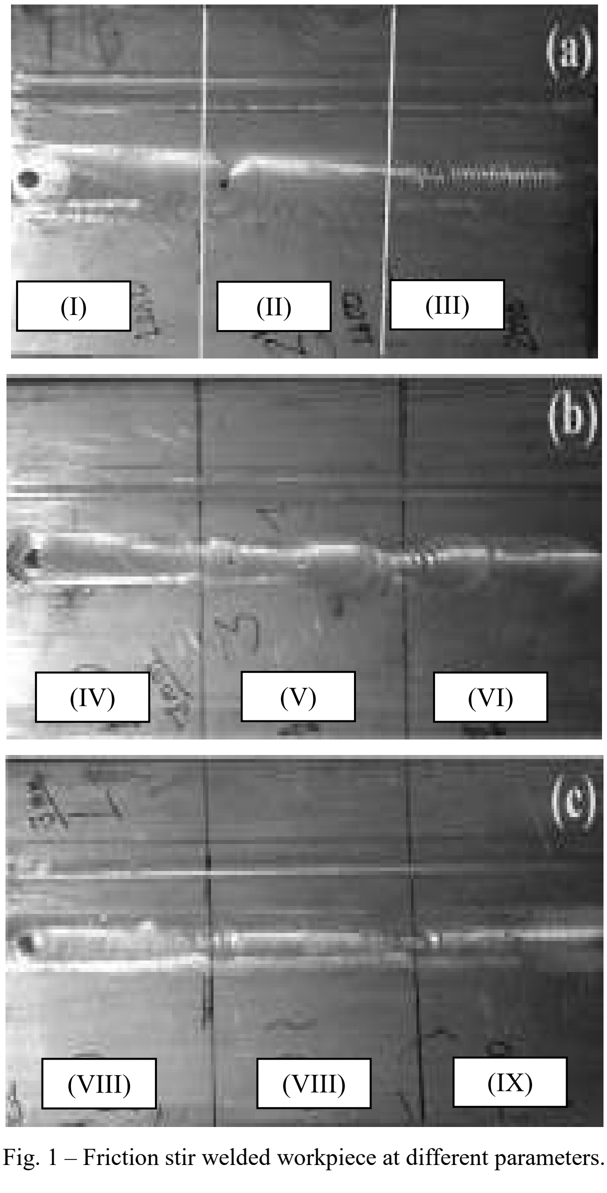

Fig. 1 – Friction stir welded workpiece at different parameters.

In this friction stir welding, temperature is measured at distance R + 9 mm from mating edge, by using alumel-chromel type thermocouple. Here R is the tool shoulder radius. The temperature obtained by this measurement with related parameters is shown in Table 1.

Table 1

FSW temperature generation result

Experiment no.	Tool Shoulder Diameter [mm]	Rotation [rpm]	Traverse [mm/min]	Heat Input [ºC]
1	22	1,000	25	135
2	22	1,500	20	145
3	22	2,000	15	175
4	19	1,000	20	115
5	19	1,500	15	140
6	19	2,000	25	95
7	17	1,000	15	155
8	17	1,500	25	99
9	17	2,000	20	128

3. RESULTS AND DISCUSSIONS

After friction stir welding result obtained for heat generation is analysed by Taguchi robust design method to obtain the temperature changes and their effect at different parameters. The results obtain by ANOVA (analysis of variance) and DOE (design of experiment) by Minitab 18 software is shown in Table 2 by SNRA, MEAN column and graph. The controlling factors are tool shoulder diameter [mm], TRR [rpm] and TTS [mm/min] and response is heat generation or temperature obtained.

Table 2

SN ratio and mean result for heat generation of FSW experiments

Run	Tool [mm]	Rotation [rpm]	Traverse [mm/min]	Heat Input [ºC]	SNRA	MEAN
1	22	1,000	25	135	42.9844	132.556
2	22	1,500	20	145	43.4637	145.222
3	22	2,000	15	175	45.1536	177.222
4	19	1,000	20	115	41.5836	117.222
5	19	1,500	15	140	42.6067	137.556
6	19	2,000	25	95	40.4238	95.222
7	17	1,000	15	155	44.0824	155.222
8	17	1,500	25	99	40.6685	101.222
9	17	2,000	20	128	42.4115	125.556

Results obtained in Fig. 2 at different tool shoulder diameter (TSD), TRR and TTS for SN ratio and mean are clearly showing that as Tool shoulder diameter changes its SN ratio and mean for heat conducted first decreases then increases from tool shoulder diameter 17 mm to 22 mm and maximum for tool diameter 22 mm, though slope from tool diameter 17 mm to 19 mm is less than from 20 mm to 22 mm. This was due to variation of surface area for frictional heat. From Fig. 2 tool having 17 mm shoulder diameter less heat conducted as compare to others tool. But at some instant it was also found to be conducted heat was maximum at 22 mm shoulder diameter at very slow feed rate.

In Fig. 2 as the tool rotational speed at higher magnitude found maximum heat conducted and minimum heat conducted at intermediate rotational speed. This can also be surmised that heat generation not only dependent on the amount of surface area but also movement of tool also. In this difference in vertical force is also affected a lot. In Fig. 2 as TTS increases from 15 to 25 mm/min heat generation decreases continuously. This occurs due to the fact that at high TTS less friction and less time generates less heat.

By comparing Figs. 1, 2 and 3, the following result is obtained: TSD 22 mm, TRR 2,000 rpm and TTS 15 mm/min is the best choice for welding to generate more heat. Temperature generation is a function of tool rotational speed and temperature rises when the rotational speed increases. The temperature profile changes with respect to welding time [15].

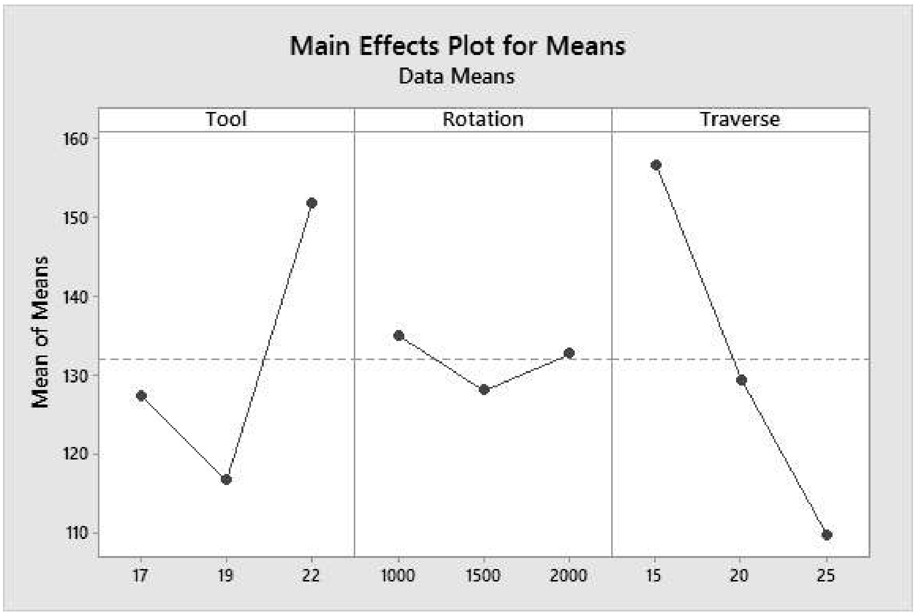

Fig. 2 – SN_H *versus* Tool no, TRR and TTS graph for temperature generation.

3.1. Interaction plot for heat generation

Interaction plot is generated by Minitab software though ANOVA analysis the effect of heat conducted though welded plate as the friction stir welding proceeds. The conducted heat was plotted as shown in Fig. 3. It clearly mentions the effect of process parameters.

Interaction plot between TSD, TRR and TTS

- Responses: Temperature generation at $R + 5$ mm (ºC),
- Factors: Tool Shoulder Diameter (mm), Tool Rotation Rate TRR (rpm) and Tool Traverse Speed TTS (mm/min).

Figure 3 reveals that the factors TSD, TRR and TTS interference played very important role in the vicinity of heat conducted through plate. It was indicated that at minimum traverse speed of 15 mm/min at very high rotational speed of 2,200 rpm maximum heat was conducted through aluminum.

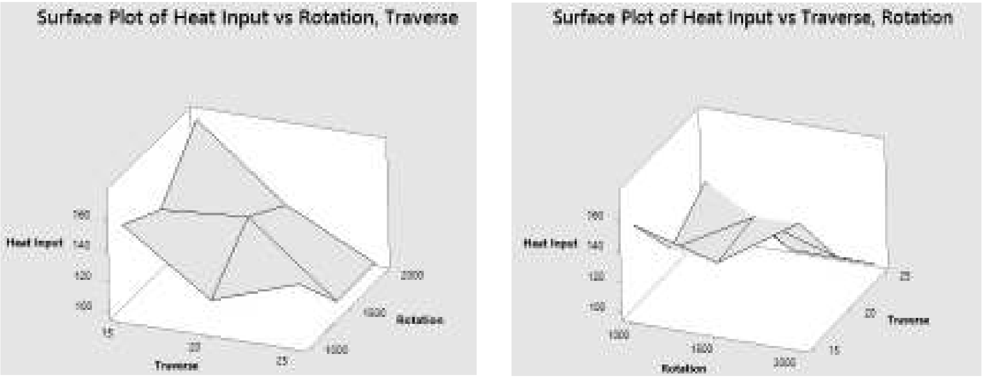

Fig. 3 – Interaction plot between TSD, TRR and TTS for temperature generation.

Above output for the best result of heat generation shows that as friction and rheology increases heat generation increases. In this research within given parameters, tool shoulder diameter 22 mm, tool rotation rate 2,000 rpm and tool traverse speed 15 mm/min is the best choice of these parameters.

4. CONCLUSION

Friction stir welding results and its analysis concluded that FSW leads to significant microstructural refinement and homogenization. Increasing in traverse speed reduces the heat generation, stirring time, and area of stir zone with its grain size, rheology (deformation & flow of matter) of the plastic material but tool rotation rate and tool shoulder diameter affect inversely. At higher tool rotation rate and tool shoulder diameter heat generation increases which enhances better particle distribution with this grain size, stir zone area also increases.

From experimental result it is cleared that more heat is generated at higher tool rotation rate and tool shoulder diameter and less heat generate at high tool traverse speed. A3B1C1 is the optimum parameter. Tool shoulder diameter 22 mm, tool rotation rate 2,000 rpm and tool traverse speed 15 mm/min is the best parameter among all readings.

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