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Axial and travel forces during friction stir welding of aluminum AA6063

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Abstract

A fixture too measure axial and travel forces during friction stir welding (FSW) was developed.FSW parameters viz. tool rotations, welding speed. pin diameter and shoulder diameter were systematically varied to understand their effect of process forces. These parameters were observed to significantly affect the forces generated during FSW. Axial force was primarily dependent on tool shoulder diameter whereas welding speed significantly affected travel force. Sufficient axial force was necessary to avoid defect formation during friction stir welding.

Introduction

Friction stir welding (FSW) is a novel joining process invented by The Welding Institute (TWI) UK. FSW of aluminum involves stirring of the abutted edges of the plates using high strength steel tool. The tool consists of thicker shaft which ends into a stepped thinner pin. The pin length is equivalent or slightly smaller than plate thickness and the shoulder sinks the top surface so that the pin just touches the backing plates [1,2]. Friction stir welding has also been carried out for steel and other non-ferrous alloys [3-5]. Measuring forces during FSW provides a useful insight into machine limitations and enhances tool optimization [6]. Soundararajan et al. gave a thermo-mechanical model for analysis of heat and forces during FSW of 6xxx series alloy [7]. Other studies have also tried to correlate force during welding with the defects formation [8]. Furthermore, force controlled friction stir welding has been reported to be better equipped for FSW as compared to position controlled systems [9]. Axial force has also been used as a process parameter for optimization of friction stir welding of 6xxx series alloy [10]. Therefore, in this study it was intended to make an appropriate device to measure and record forces during friction stir welding of 6063 alloy at different selected parameter varied according to L16 orthogonal array.

Experimental procedure

Friction Stir Welding of 5 mm thick AA6063 was carried out using a milling machine. A fixture was designed to measure both the axial and travel forces. Axial forces were measured suing two load cells placed below the upper and lower plates of the fixture. Travel force was measured using a S-shaped load cell mounted on a fixed plate and placed against the fixture . A PCL-818HG data acquisition card was used for analog to digital conversion of the force data recorded during welding. LabVIEW software was used for interfacing the data acquisition card with PC and store the data on the hard disk. AA6063 was selected as the material for the experiments. Nominal chemical composition and mechanical properties of this alloy are listed in Table 1. Weld joints were achieved by joining together two plates each measuring 150 mm x 75 mm. Initial weld trials were conducted to determine the applicable range of different parameters for the selected material and machine capabilities. Final levels of the parameters are listed in Table 2.

Table 1: Nominal Chemical composition and mechanical properties of AA6063

Mg	Fe	Si	Cr	Cu	Al	Tensile strength (MPa)	Yield Strength (MPa)	Elongation (%)
0.4±0.05	0.4±0.05	0.6±0.05	0.15±0.025	0.1±0.01	balance	220±10	180±10	12

Table 2: Process parameters and selected levels

Parameters	Level of Parameters			
	1	**2**	**3**	**4**
Welding speed (mm/min)	45	60	75	90
Tool rotations (rpm)	200	250	300	350
Shoulder diameter (mm)	10	12	14	16
Pin diameter (mm)	4	5	6	7

Results and discussion

Analysis of Variance (ANOVA) is conducted to determine the significant parameters that affect the desired response characteristics. Results of ANOVA analysis indicates that shoulder diameter is the most significant parameter that affects the axial force and its percent contribution is 51.9% (Table 3 and Fig. 1). The percent contributions of other parameters are welding speed (23.1%), tool rotations (17.3%) and pin diameter (5.7%). The axial force increased with increase in shoulder diameter as the contact area in the Z-direction (plunging) increases. Welding speed and tool rotation also affected axial force as both these parameters determine the amount of heat input per unit length (Fig. 2 and 3). Axial force was observed to reduce with increasing tool rpm as heat input per unit length increased and soften the material. Welding speed has a significant influence of the travel force as increasing welding speed material to be stirred also increases (Table 4). Also, pin diameter affects the travel force as the area of the material to be stirred increase with increasing pin diameter (Fig. 4) .

Table 3: ANOVA for mean effects of parameters on axial force

Source	DOF	Seq. SS	MS	F	%Contribution
Shoulder diameter (mm)	3	0.81	0.27	5.23	51.9
Welding speed (mm/min)	3	0.36	0.12	2.32	23.1
Tool rotations (rpm)	3	0.27	0.09	1.75	17.3
Pin diameter (mm)	3	0.09	0.03	0.58	5.7
Residual error	3	0.05			2
Total	15				100

Table 4: ANOVA for mean effects of parameters on travel force

Source	DOF	Seq. SS	MS	F	%Contribution
Welding speed (mm/min)	3	0.38	0.13	2.6	65.6
Pin diameter (mm)	3	0.08	0.03	0.58	14.6
Shoulder diameter (mm)	3	0.06	0.02	0.39	9.8
Tool rotations (rpm)	3	0.05	0.017	0.32	8.02
Residual error	3	0.06			1.98
Total	15				100

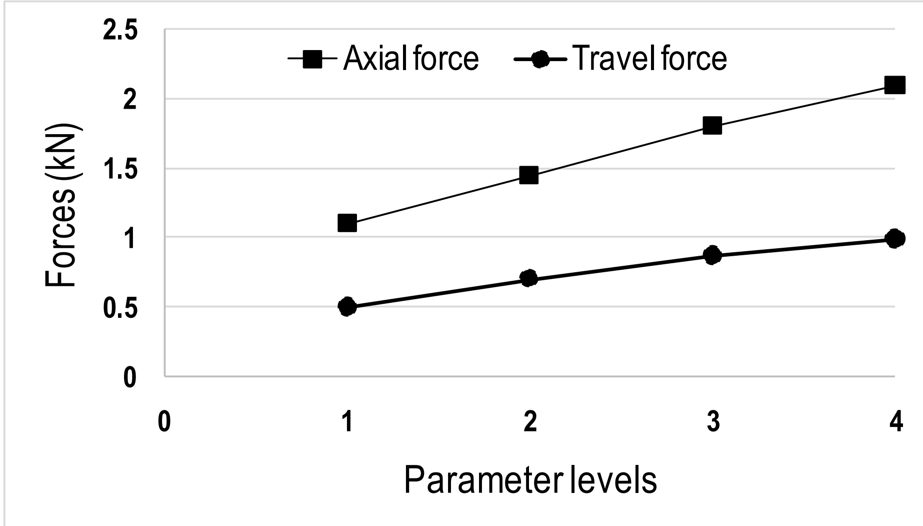

Fig. 1: Axial and travel forces as a function of tool shoulder diameter

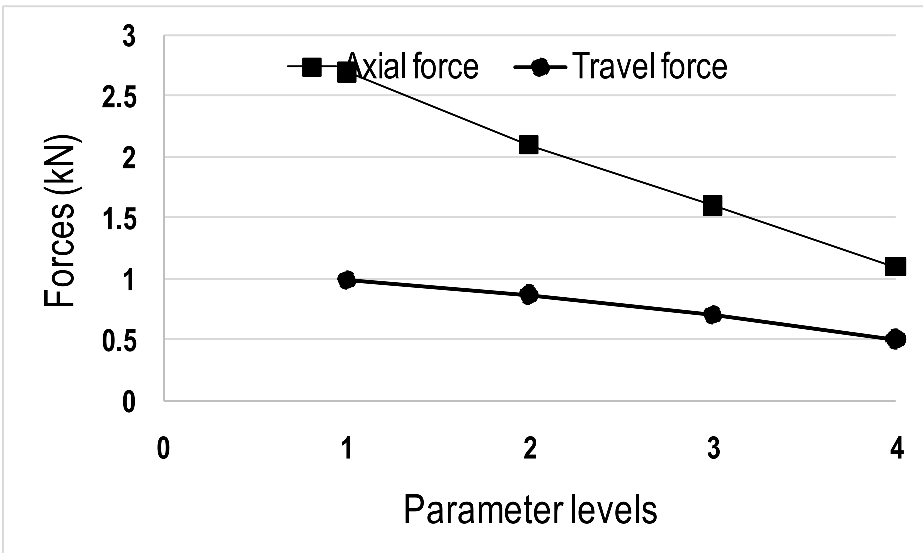

Fig. 2: Axial and travel forces as a function of tool rpm

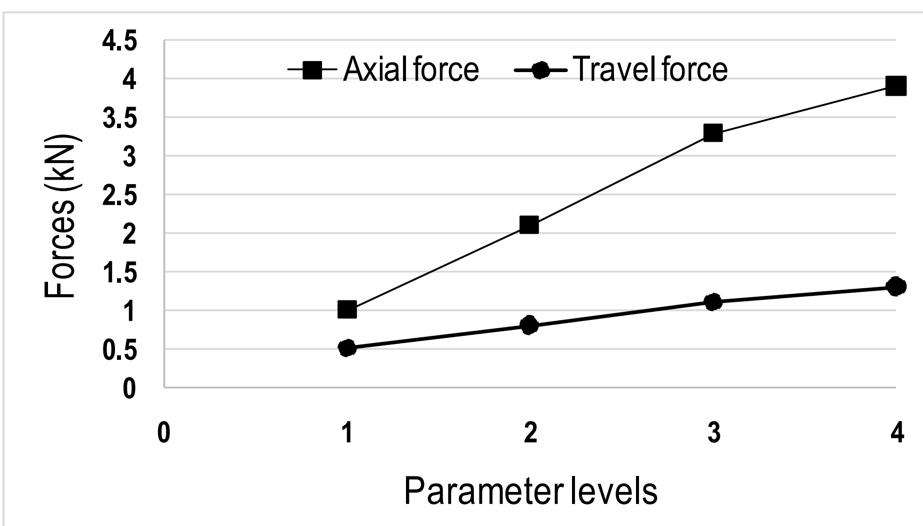

Fig. 3: Axial and travel forces as a function of welding speed

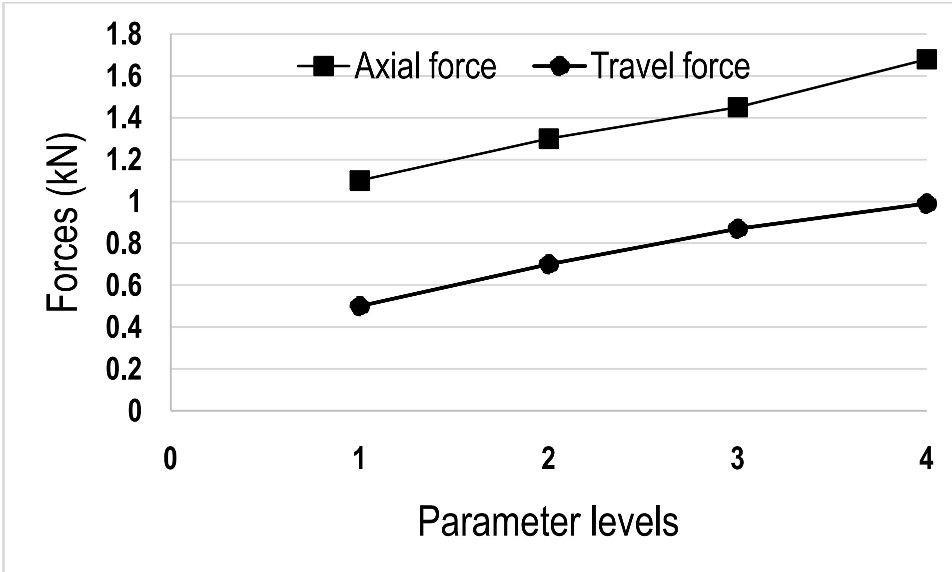

Fig. 4: Axial and travel forces as a function of tool pin diameter

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