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EXPERIMENTAL ANALYSIS OF FSW FOR DISSIMILAR ALUMINIUM ALLOYS AA6061 AND AA4043 USING CNC VMC

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Abstract:
Friction Stir Welding process (FSW) is a solid state welding process in which the relative motion between the tool and the work piece produces heat which makes the material of two edges being joined by plastic atomic diffusion. This method relies on the direct conversion of mechanical energy to thermal energy to form the weld without the application of heat from conventional sources. The rotational speed of the tools, the axial pressure, welding speed and the tool profile are the principal variables that need to be controlled in order to provide combined heat and pressure to form the weld. The scope of this investigation is to evaluate the effect of joining parameter on the mechanical properties of dissimilar aluminium alloys AA6061 and AA4043 joints produced by Friction Stir welding using CNC vertical machining centre. The Brinnel hardness and tensile strength of the joints are considered for the investigation. The results show that for optimal stir zone hardness, FSW parameter combination of 1200 rpm tool rotational speed, 10 mm/min welding speed and cylindrical tool profile should be used. For optimal joint tensile strength, the suitable parameters combination is 1200rpm, 20mm/min and taper thread tool profile. From the investigation, it is concluded that tool rotational speed is the major influencing factor for mechanical properties such as tensile strength and hardness.

Keywords: *Frictions stir welding, S/N ratio, Brinnel hardness testing, CNC vertical machining centre*

1.0 INTRODUCTION

Friction stir welding (FSW) is a solid-state joining process invented and patented by The Welding Institute, United Kingdom in 1991. In this process, a rotating non consumable cylindrical-shouldered tool with a profiled nib is transversely fed at a constant rate through the butted interface of the two clamped pieces of material [1]. The pin is slightly shorter than the weld depth required, with the tool shoulder riding atop the work surface. The frictional heat along with that generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without melting [2]. As the pin is moved forward, the plasticized material is moved from the front of the pin to the back of the pin where axial force exerted by the shoulder together with clamping force assists in a forged consolidation of the material. During the last stage of joining process, the tool compresses the plasticized material and allowing metallurgical bond to form between the two materials [3]. This method relies on the direct conversion of mechanical energy to thermal energy to form the weld without the application of heat from conventional sources. In this process, the material at the interface (stir zone) is subjected to severe solid state deformation involving dynamic recrystallisation of the base material [4].

2.0 EXPERIMENTAL PROCEDURE

The material used in this study is 6mm thick plate of AA6061 and AA4043 aluminium alloys. The plates were milled to achieve parallelism and flatness tolerances. The chemical compositions of the same are shown in table 01.

The rolled plates were cut into rectangular samples of 100x50mm and the welding was carried out using CNC vertical machining centre. The welding tool used in this study was High carbon-high chromium steel which has high resistance to thermal fatigue. The various pin profiles used in this work include cylindrical, cylindrical taper and taper threaded as shown in Fig 01-04.

The process parameters used in this work are given in table 02.

Table 02: Process parameters for FSW of AA6061 and AA4043Aluminium Alloys

S.NO	ROTATIONAL SPEED(RPM)	WELDING SPEED(mm/min)	TOOL
1	1000	10	C
2	1000	15	CT
3	1000	20	TT

4	1200	10	CT
5	1200	15	TT
6	1200	20	C
7	1400	10	TT
8	1400	15	CT
9	1400	20	C

In order to assess influence of factors, the standard tensile test specimens were prepared as per the dimensions given in Fig 05 by ASTM E8 standards

Table 04 Level and factors for Taguchi method

Parameters	Level		
	1	2	3
SPEED(rpm)-A	1000	1200	1400
FEED(mm/min)-B	10	15	20
Tool-C	C	Ct	Tt

The work pieces were mounted firmly on the machine table by using a fixture as shown in Fig 08 and checked for flatness.

The experimental process consists of nine experiments (L9) array by combining the parameters at three levels as in table 02.

Brinnel hardness tests were carried out at a load of 250kgf with indenter dia. 5mm ball and dwell time of 10 seconds.

3.0 RESULTS AND DISCUSSION

The response of S/N ratio and mean for hardness are given in table 5 and 6.

Table 05: Response of S/N ratio for Hardness

Table 06: Response of S/N ratio for Tensile strength

Level	Rotational Speed(rpm)	Welding speed(mm/min)	Tool
1	41.30	39.30	40.39
2	40.41	38.28	40.01
3	37.95	40.08	39.26

Level	Speed	Welding Speed	Tool
1	41.57	41.66	44.14
2	42.03	40.45	43.60
3	41.13	42.63	41.99

In order to assess influence of factors on response, means and signal-to-noise ratios(S/N) for each control factor is calculated. Signals are indicators of effect on average responses and measures of deviations from experiment output. In this study, S/N ratio was chosen according to criterion larger- the- better, in order to maximize the response in Taguchi method, S/N ratio is used to determine deviation of quality characteristics from desired value

η_j= -10 log (1/n $\sum 1/y_{ijk}^2$])

Where n is number of tests and Yijk is experimental value of ith quality characteristic in jth experiment at kth test. In percent study, TS and hardness data were analyzed to determine the effect of FSW process parameters. Thus friction stir welding process has been successfully carried out on dissimilar aluminium alloys AA6061 and AA4043.The weldability and mechanical properties of these aluminium alloys were examined. ANOVA has been performed to identify statically significant process parameters, which affects tensile strength and hardness of FSW joints. Results of ANOVA give suitable parameters for best tensile strength and hardness. The weldability and mechanical properties of these dissimilar alloys are examined. The best parameters for the speed, welding speed and tool profile are chosen among 3 levels. It is found out using Taguchi method. For the best hardness nature of the welded area, the suitable parameters are 1200rpm speed, 10mm/min welding speed and cylindrical tool profile. The percentage contribution of speed is 34.51%, welding speed is 15.69 %, and tool is 15.77 % for the hardness property using ANOVA. For the best tensile nature of the welded area, the suitable parameters are 1200rpm speed, 20mm/min welding speed and taper thread tool profile. The percentage contribution of speed is 52.01%, welding speed is 3.30 %, and tool is 24.4% for the tensile property using ANOVA.

4.0 OPTIMIZATION OF FSW PARAMETERS

In this process three parameters are considered for optimization, the parameters are given optimum values for which desired output variables will be high. In this method two outputs are considered namely Tensile Strength and hardness. The observed values for nine experiments are shown in Table 09. The process parameters considered for Taguchi method involves control factors, noise factors and output variables as given in table 04.

Table 09 Observed value for FSW process

SI.No	Rotational Speed(rpm)	Welding speed(mm/min)	Tool	Tensile strength Mpa	Hardness BHN
1	1000	10	C	124.7	101.9
2	1000	15	CT	130.3	96.9
3	1000	20	TT	136.6	104
4	1200	10	C	196.8	121
5	1200	15	CT	142.8	83
6	1200	20	TT	202.5	114.7
7	1400	10	C	111.2	88.3
8	1400	15	CT	144.3	94
9	1400	20	TT	127.7	84.9

4.1 OPTIMIZATION BASED ON HARDNESS

The hardness is optimized by finding the S/N ratio and Means for the values and evaluating as per procedure to find the best. The mean for all the nine experiments were found using the Minitab 17 software (fig 11 & 12).

Table 11 Hardness value at three levels

LEVEL	FACTOR			TOTAL	X_1^2	X_2^2	X_3^2
	X_1	X_2	X_3				
1	104.9	98.9	107	310.80	11004.01	9781.21	11449
2	121	83	114.7	318.70	14641	6889	13156.09
3	87.3	95	83.9	266.40	7621.29	9025	7039.21
TOTAL	313.20	276.90	305.60	895.90			

From the table 08 & 09, it is observed that best parameters for hardness are 1200 rpm, 10mm/min welding speed and cylindrical tool. From the ANOVAs table 8 & 9, it is concluded that the percentage contribution of speed is more with 36.51.

4.2 OPTIMIZATION BASED ON TENSILE STRENGTH

The tensile strength is optimized by finding the S/N ratio and Means for the values and evaluating as per procedure to find the best.

Table 12 Tensile strength values at three levels

Level	Factors			Total	X_1^2	X_2^2	X_3^2
	X_1	X_2	X_3				
1	125.7	140.3	137.6	403.60	15800.09	19684.09	18933.76
2	196.8	142.8	202.5	542.10	38730.24	20391.84	41006.25
3	101.2	164.3	125.7	391.20	10241.44	26994.49	15800.49
Total	423.7	447.4	465.8	1336.9			

The mean for all the nine experiments were found using the Minitab 17 software(fig 13 &14).Table 11 & 12 it is observed that best parameters for tensile strength are 1200 rpm, 20mm/min and cylindrical tool. From the ANOVAs table 13 it is observed that the percentage contribution of speed is more with 52.01.

CONCLUSION

Thus, friction stir welding process has been successfully carried out on dissimilar aluminium alloys of AA6061 and AA4043. From the experiments carried out, it is concluded that speed is the major factor influencing the mechanical properties such as tensile strength and hardness. The best parameters are obtained by this experimental study. FSW process data base may be developed in future for wide variety of metals and alloys for optimum process parameters for efficient weld.

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