Investigation of effects of process parameters on properties of friction stir welded joints

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Abstract: This work deals with application of friction stir welding (FSW) using application of Taguchi orthogonal array. FSW procedure is used for joining the aluminium alloy AA6063-T0 plates in butt configuration with orthogonal combination of factors and their levels. The combination of factors involving tool rotation speed, tool travel speed and tool pin profile are used in three levels. Grey relational analysis (GRA) has been applied to select optimum level of factors for optimising UTS, ductility and hardness of joint. Experiments have been conducted with two different tool materials (HSS and HCHCr steel) with various factors level combinations for joining AA6063-T0. On the basis of grey relational grades at different levels of factors and analysis of variance (ANOVA) ideal combination of factors are determined. The influence of tool material is also studied.

1. Introduction

Friction stir welding (FSW) was developed and patented at the welding institute (TWI), U.K. in 1991. FSW involves joining of parts placed on the backing plate and clamped using powerful fixture. A non consumable tool consists of typical pin geometry with cylindrical shoulder. When tool is plunged, rotated, and traversed along the joint line, material of work piece around the tool pin is frictionally heated, plasticised and extruded or forged. Then, the stirred material consolidates and cools down under hydrostatic pressure to form the joint [7]. Recent works in FSW like Chandrashekar et al [1] show that for various tools rotational speeds there is different optimum profile with respect to dependent parameters. Tensile strength varies significantly with tool profiles. According to Thube et al [2], tool pin design affects the heat input insignificantly. Same is true for tensile strength and power consumption. Irrespective of tool pin profile, there is an optimum combination of tool rotation rate and traverse speed which results in best tensile strength. The variation in joint characteristics with respect to input parameters is usual trend. Various optimization techniques had been utilized by the researchers, to select a window of operating parameters for a particular experiment to model FSW process parameters and their behaviour [1-6]. Grey relational based optimization has not been explored in detail in FSW literature [1-6]. This work is an attempt to study the effect of tool material along with testing the applicability of Taguchi based grey relational analysis to optimise the UTS, ductility and hardness of FSW joint with respect to tool rotation rate, tool traverse speed and pin geometry.

2. Experiment

The work piece material used for the experiment is a commercially available AA6063-T0. Here T0 indicates that no additional heat treatment has been given to work piece. Chemical analysis of work piece and tool material (HSS and HCHCR steel) has been summarised in table 1, table 2 and table 3 respectively. On the basis of trial experiments it had been found that 2000 RPM was threshold value and 2600 RPM was upper limit to rotation rate for making a sound joint when other two factors are held constant. Similarly the lower and upper bound for tool traverse speed had been selected. For considering the effect of pin geometry the simple geometry i.e. circular, square and triangular had been chosen for the sake of easy manufacturing of tools. Value of the process parameters have been shown in table 5. Combination of these factors has been decided on the basis of Taguchi L9 orthogonal array. Two sets of experiment with tool made of high speed steel (HSS) and high carbon high chromium (HCHCr) steel has been conducted with same set of process parameters.

Table 1: Percentage chemical composition of AA6063-T0

C	Cu	Mg	Fe	Zn	Ni	Mn	Cr	Ti	Sn	Pb	V	Al
0.424	0.0264	0.5042	0.5196	0.0608	0.0076	0.0491	0.0208	0.0149	<0.0010	0.0055	0.0078	98.34

Table 2: Percentage chemical composition of high speed steel (HSS)

C	Si	Mn	Cr	Ni	Mo	Cu	V	W	Co	S	P
1.04	0.441	0.40	4.14	0.133	4.54	0.144	1.75	5.67	0.845	0.0237	0.0284

Table 3: Percentage chemical composition of high carbon high chromium (HCHCr) steel

C	Si	Mn	Cr	Ni	Mo	Cu	V	W	S	P
2.25	0.337	0.588	11.89	0.0884	0.0044	0.0284	0.0353	<0.01	0.0226	0.0221

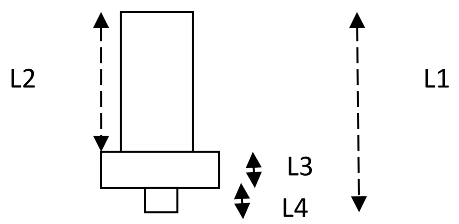

Figure 1: Front view of tool dimension with typical 2D geometry

Above figure 1 shows the front view of the tool dimension with different notations. Following table 4 summarises the geometrical details of tool dimensions with notations used in the experiment.

Table 4: Dimensions notations and values of tool

PARTICULARS	INDEX	VALUE
Total tool length	L1	56 mm
Head of tool	L2	30 mm
Shoulder length	L3	25 mm
Pin length	L4	1.3 mm
Diameter of shoulder	D	18 mm
Diameter of pin	d	6 mm
D/d ratio	D/d	3

Tool material: Tool 1: High speed steel (HSS) and Tool 2: High carbon High chromium (HCHCr) steel, Shoulder and pin hardness HV 700-760.

The diameter of the shoulder, diameter of pin and D/d ratio are the used on the basis of literature [7], Pin length has been selected based upon material thickness, other dimensions are based on welding set-up i.e. CNC machine setup which has been actually used in the experiment. The factors were selected on basis of literature review as shown in table 5. The factors levels are selected on the basis of trial runs on machine setup which had been used to make FSW joints.

Table 5: FSW process parameters (Factors and their Levels)

Symbol	FSW parameters (Factors)	Unit	Level 1	Level 2	Level 3
A	Tool rotation speed	RPM	2000	2300	2600
B	Tool traverse speed	mm/min	60	90	120
C	Tool pin profile	-	Circular (C)	Square (S)	Triangular (T)

Spectro analysis of work piece and tool material has been made at Narang Metallurgical and Spectro Services, New Delhi. Friction stir welding set up consist of SSMT-225S servo motor based CNC vertical milling machine tool in the CAM laboratory of mechanical engineering department of B.I.E.T. Jhansi. Tensile test has been conducted with UTM machine of 400 KN in the institute using ASTM E8 standard. Hardness data of welded joints has been recorded at Batra Metallurgical and Spectro Services, New Delhi. Figure 2 shows the experimental set up used for making FSW joint followed by the figure 3 showing the tools made from HSS and HCHCr steel used in the experiment.

Figure 2: Experimental set up used for making FSW joint [*CAM lab, MED, B.I.E.T. Jhansi*]

Figure 3: Tools made from HSS and HCHCr steel respectively

3. Results and Discussion

With help of subsequent tables formal outcome of experiment has been presented so as to access the applicability of Taguchi method, integrated with grey relational analysis. Highest grey relational grade represent the optimum level of factors which affects the responses considered in this experiment. Thus, it can be said that factor levels in experiment 4 using HSS tools and experiment 5 using HCHCr steel tool are best combinations which can give the optimum response values. ANOVA and grey relational grades at different levels provide the similar information for factor and their levels.

Table 6: Input values of process parameters in L9 orthogonal array

Exp. No.	**FRICTION STIR WELDING PROCESS PARAMETRS LEVEL**		
	A	B	C
1	2000	60	C
2	2000	90	S
3	2000	120	T
4	2300	60	S
5	2300	90	T
6	2300	120	C
7	2600	60	T
8	2600	90	C
9	2600	120	S

Table 7: Multi-response based grey relational grade

Experiment No.	**Values of reference sequence (Y)**						**Grey relational grade**	
	FSW joint with HSS tool			FSW joint with HCHCr tool			HSS	HCHCr
	UTS (Mpa)	Elongation (%)	Hardness (HV)	UTS (Mpa)	Elongation (%)	Hardness (HV)		
1	54.400	8.800	119	48.00	1.20	139	0.479551	0.429120
2	67.200	2.920	139	84.40	3.00	82	0.441807	0.581947
3	59.200	0.720	148	51.20	6.88	172	0.411955	0.672426
4	73.600	10.200	172	70.40	2.72	149	0.876542	0.543921
5	57.600	4.680	144	75.20	8.80	117	0.436646	0.708996
6	81.600	2.840	137	65.60	1.40	151	0.607542	0.513097
7	60.800	6.920	125	48.00	5.04	125	0.449039	0.456876
8	72.000	3.040	166	64.00	4.80	67	0.599970	0.429447
9	65.600	6.840	163	67.20	3.20	64	0.597041	0.412529

On application of ANOVA at 95 % confidence interval, it is observed that tool rotational rate, tool traverse speed and tool pin profile have 33.36 %, 10.36 %, and 37.57 % contribution respectively for joint with HSS and 43.68 %, 14.94 %, and 39.29 % contribution respectively for joint with HCHCr steel.

Table 8: Grey Relational Grades (GRG) at different levels

Factor	Tool rotational speed	Tool traverse speed	Tool pin profile
Level 1	0.444438	0.601711*	0.562354
Level 2	0.640243*	0.492801	0.638463*
Level 3	0.548683	0.538846	0.432547
Max - Min	0.195805	0.108910	0.205916
Rank	2	3	1

Table 9: Grey Relational Grades (GRG) at different levels

Factor	Tool rotational speed	Tool traverse speed	Tool pin profile
Level 1	0.561164	0.476639	0.457221
Level 2	0.588671*	0.573463*	0.512799
Level 3	0.432951	0.532684	0.612766*
Max - Min	0.155720	0.096824	0.155545
Rank	1	3	2

4. Conclusions:

The results show that optimal combination of process parameters for the high speed steel (HSS) tool is the second level of tool rotational speed of 2300 RPM, first level of tool traverse speed of 60 mm/min and second level of tool pin profile of Square pin. The optimal combination of process parameters for the high carbon high chromium (HCHCr) steel tool are the second level of tool rotational speed of 2300 RPM, second level of tool traverse speed of 90 mm/min and third level of tool pin profile i.e. Triangular pin. It can be observed that Taguchi method may be integrated with grey relational based optimization for selecting the operating parameters and their optimum levels. Experiments show that tool material does contribute significantly to joint characteristics. The percentage contribution of tool rotation rate and tool pin geometry changes insignificantly when tool materials are changed for making FSW joint with same set of independent factors at same levels.

References:

[1] Chandrashekar A, Reddappa H N, Ajaykumar B S 2016 Influence of tool profile on mechanical properties of friction stir welded aluminium alloy 5083, I*nternational Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering*, **10** 1 8-14.

[2] Thube R.S, Pal S K 2014 Influnces of tool pin profile and welding parameters on friction stir weld formation and joint efficiency of AA5083 joints produced by friction stir welding, *International Journal of Innovative Research in Advanced Engineering* **1** 4 1-8.

[3] Reddy B, Surpraja Reddy B, Ram Gopal 2015 Effect of tool geometry and process parameters on mechanical properties and micro-structure of various dissimilar aluminium alloys welded by friction stir welding-Review, *International Journal of Engineering Technology, management and Applied Sciences* **3** 4 316-328.

[4] Padmanaban R, Balusamy V, Nouranga K.N, 2015 Effect of process parameters on the tensile strength of friction stir welded dissimilar aluminium joints, *Journal of Engineering Science and Technology* **10** 60 790-801.

[5] Balasubramanium S, Ganpaty S 2011 Grey Relational Analysis to determine optimum process parameter for wire electro discharge machining (WEDM), *Int J Eng Sci Tech* **3** 1 95-101.
[6] Gokuul V, Ragvendran M, Naresh R, Senthilkumar V S 2014 Effects of tool rotational speed on friction stir welding of AA6061 and AA7075, *International Journal of Chem Tech Research* **6** 3 1753-1756.
[7] Mishra R S, Ma Z Y 2005 Friction stir welding & processing, *Material science & Engineering* **50** 1 1-78.