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Optimisation of Friction Stir Welding Parameters for AA 6061 and AA 7039 Aluminium Alloys by Response Surface Methodology (RSM)

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Abstract

Application of dissimilar aluminium alloys of 6xxx and 7xxx series has its significant application in automobile sector, defence, shipping industries etc. These alloys faces problems like hydrogen solubility, formation of aluminium oxides, solidification shrinkage etc when welded with fusion welding process. Friction stir welding is the process which is able to successfully weld these dissimilar alloys of aluminium. Process parameters like rotational speed, welding speed, tool design, vertical force plays important role in determining the joint properties. Rotational speed and welding speed has its major role in producing the necessary frictional heat to plasticise the material which on solidification produces the weld joint. The welds are taken on rotational speed of 800 rpm to 1000 rpm and welding speed for 30 mm/min to 50 mm/min. Response surface methodology is used to optimise the parameters and responses taken as mechanical properties like tensile strength, yield strength, impact strength, and hardness value.

Keywords:- Friction stir welding (FSW), response surface methodology (RSM), tensile strength, impact strength, yield strength, hardness value, rotational speed, welding speed and frictional heat.

Introduction

Friction stir welding (FSW) process was invented at The Welding Institute (TWI), UK in 1991. FSW is initially used to weld aluminium and its alloys because the defects like porosity, alloy segregation, hot cracking, hydrogen entrapment etc. are not encountered with this process those are mainly appeared in fusion welding processes [1]. Process uses a non consumable rotating tool which slides along with rotation on the faying surface of work-pieces to be weld. To obtain the desired strength, it is essential to have complete control over the relevant process parameters on which the quality of a weldment is based. The response surface methodology (RSM) is helpful in developing a suitable approximation for the true functional relationship between the independent variables and the response variables that may characterize the nature of the joints.

Dinaharan et.al [2] examined the welding of dissimilar materials and reported that better weld efficiency is obtained when material with high strength is placed on the retrieving side and with low properties on the advancing side. Elatharasan et.al [3] used RSM process to optimise the FSW parameters for dissimilar aluminium alloys for ultimate tensile strength. Sajid et.al [4] studied the effect of FSW parameters on mechanical properties and microstructure of 6061-T651. Chaitanya et.al [8] studied the effect of post weld het treatment on microstructure and mechanical properties of FSW joint of AA 7039

Table 1: Showing Chemical composition of AA 6061 T6 and AA 7039 T6

	Zn	Mg	Mn	Fe	Si	Cu	Al
AA6061	-	1.1	0.12	0.35	0.58	0.22	Bal.
AA7039	4.69	2.37	0.68	0.69	0.31	0.05	Bal.

Experimental details

The experiments were carried out on AA 6061 and AA 7039 aluminium alloys having 5mm thickness of each on a computer numerically controlled vertical machine. The chemical compositions of base material are shown in table 1. The plates were finished to a dimension of 100mm × 50mm ×5mm. A butt weld is been made by clamping the materials using fixtures by placing AA 7039 and AA 6061 on retrieving side and advancing side respectively by opting the parametric value as mentioned in central composite design matrix (As shown in table 2) using a HSS tool of shoulder dia. 16 mm and probe length 4.7 mm. The test specimens are prepared according to the ASTM standards.

Table 2: A central composite design matrix for response surface methodology using 2 factors at 2 levels.

Exp.no	Rotational speed	Welding speed	Tensile strength	Yield strength	Hardness value	Impact strength
1.	800	30	157	150	68.2	5.8
2.	1000	30	169	159	81.3	8.2
3.	800	50	150	143	63.6	5.2
4.	1000	50	159	151	71.6	7.9
5.	760	40	145	138	58.4	4.8
6.	1040	40	160	152	71.0	7.7
7.	900	26	175	163	79.5	7.9

8.	900	54	160	154	69.0	7.3
9.	900	40	166	157	76.1	7.5
10.	900	40	166	157	76.3	7.5
11.	900	40	165	157	76.1	7.4
12.	900	40	163	156	76.0	7.4
13.	900	40	166	157	76.3	7.5

Design of experiments

A central composite design is used for current response surface analysis for two numbers of factors at two levels each. The central composite design uses 4 factorial runs and 4 star runs taking α = 1.414. This design is made rotational about the value of α. The central runs taken in this experimentation are 5.

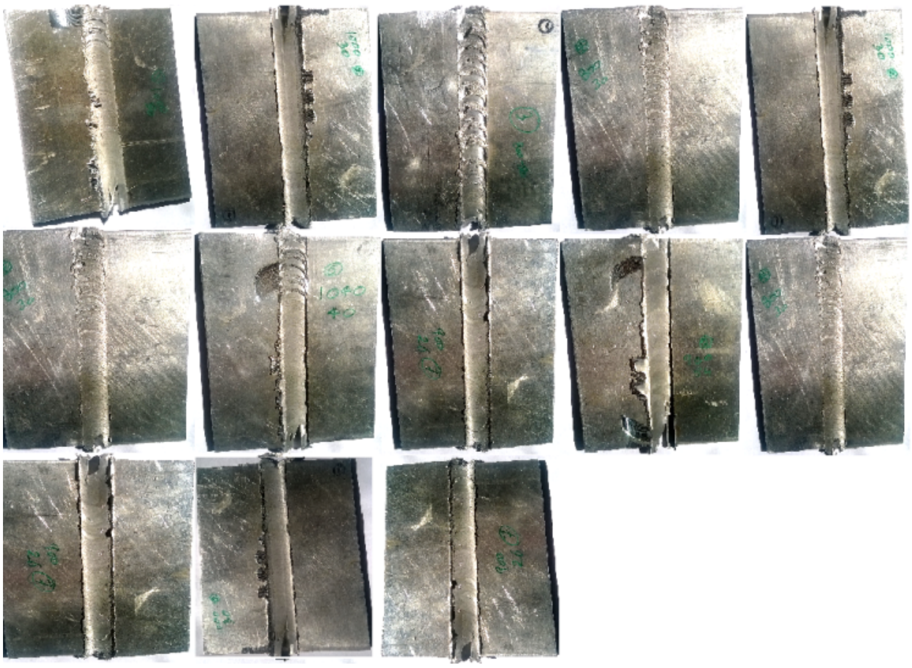

Fig. 1 material welded with friction stir welding

Results and Discussion

The quadratic model developed for the response variables tensile strength, yield strength, micro hardness and impact strength is tested by ANNOVA analysis (shown in table 3) on design expert software. The determination coefficient R-Squared indicates the goodness of fit which means there is less difference between the predicted and actual data. “Adeq Precision” measures the signal to noise ratio. A ratio greater than 4 is desirable. All the values above for Adeq precision are greater than 4 so these models can be used to navigate the design space.

Table 3: ANOVA table for response surface model

	Tensile strength	Yield strength	Micro hardness	Impact strength
R-squared	0.9842	0.9917	0.9843	0.9810
Adj R-squared	0.9730	0.9858	0.9731	0.9675
Pred R-Squared	0.9382	0.9535	0.8892	0.9087
Adeq precision	33.020	45.759	29.768	27.332

The mathematical expression for tensile strength, yield strength and micro hardness are as follows:-

Equation for tensile strength-

$$165.21 + 5.30 * A - 4.80 * B – 6.78 * A2 + 0.88 * B2 – 0.75 * A * B. \quad (1)$$

Equation for yield strength-

$$156.61 + 4.62 *A – 3.48 * B -6.15 * A2 + 0.74 * B2 – 0.25 * A * B. \quad (2)$$

Equation for micro hardness-

$$76.15 + 4.89 * A – 3.66 * B – 5.37 A2 – 0.50 * B2 – 1.27 * A * B. \quad (3)$$

Equation for impact strength-

$$7.32 + 1.16 * A – 0.22 * B – 0.58 * A2 + 0.11 * B2 + 0.075 * A * B. \quad (4)$$

Effect of rotational speed and welding speed on tensile properties, hardness value and impact strength

The experimental result shows that rotational speed and welding speed both have their significant effect on the mechanical properties of the weld joint. From which greater impact is been produced by the rotational speed. Rotational speed produces the frictional heat required to plasticise the material and also effect in proper mixing of the dissimilar alloys. The weld produces at low speed have good mechanical properties than the weld produces at higher speed. The mechanical properties increase with the rotational speed and welding speed but up to a certain level then they starts decreasing.

Desirability approach

Desirability method for solving multiple response problems is opted due to its simplicity, flexibility and ease of availability in software. This method converts the multiple response values into a dimensionless measures of performance called the overall desirability function whose range are between 0 to 1. The predicted optimal results from the above technique are ultimate tensile strength 163.86 Mpa, Yield strength 155.62 Mpa, Hardness value of 74.3 and impact strength of 7.8 joules. The optimisation part in design expert software gives the combined desirability value of 0.741.

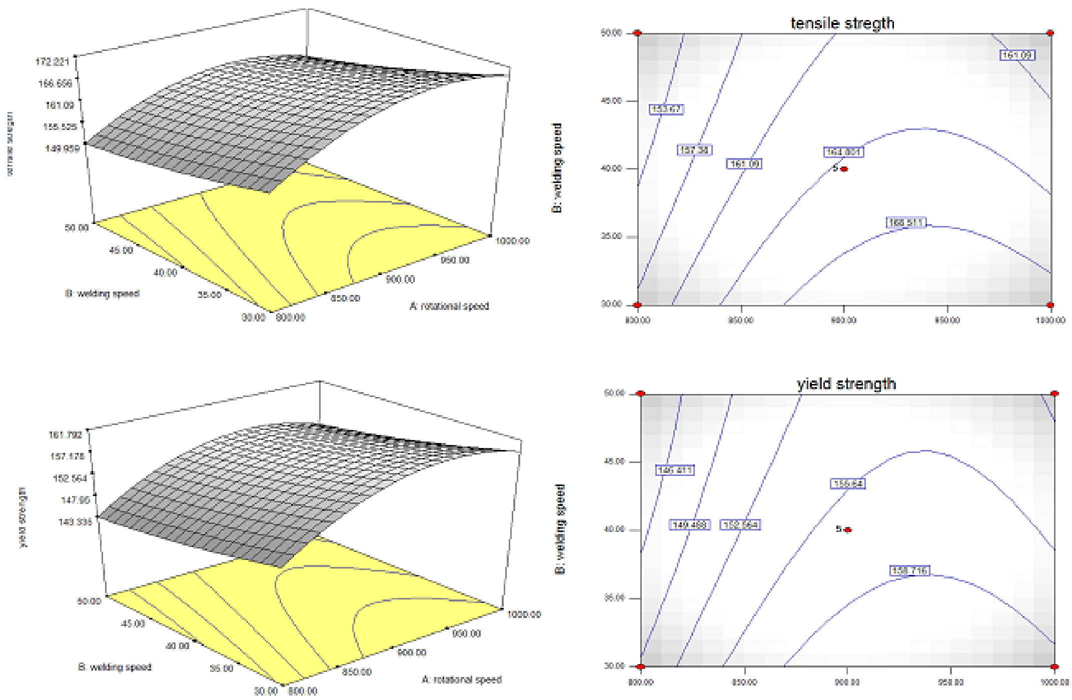

Fig. 2 showing 3D contours for tensile and yield strength

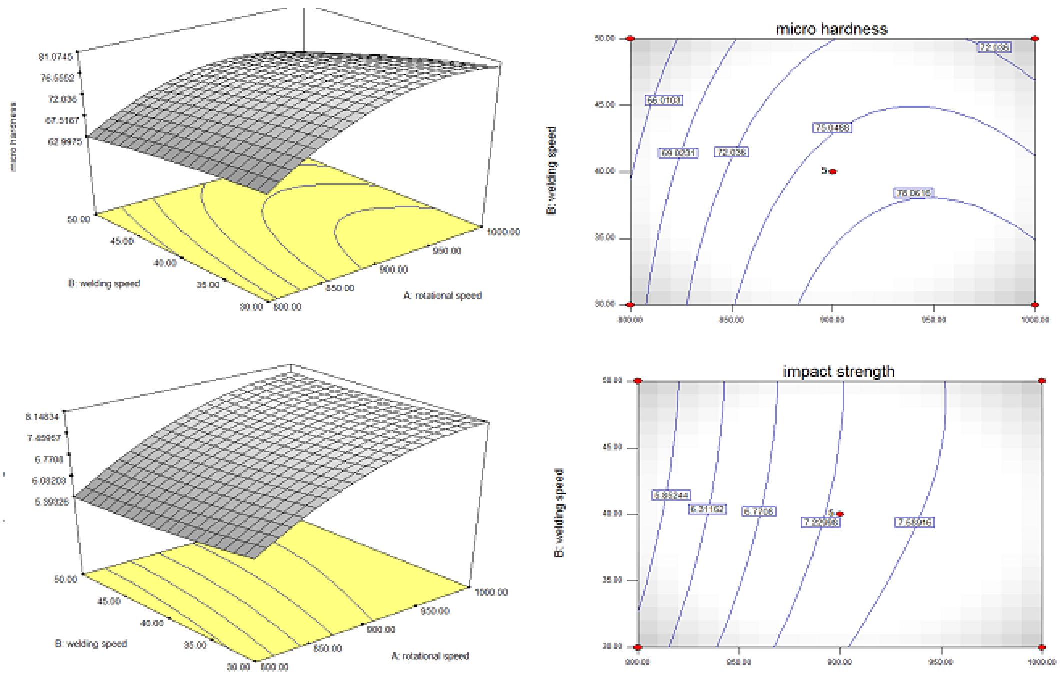

Fig. 3 showing 3D contours for hardness value and impact strength

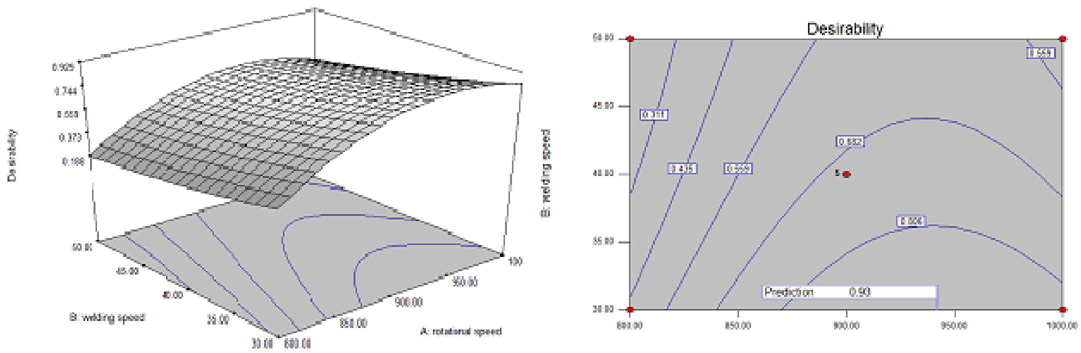

Fig. 4 showing 3D contours for desirability

Conclusion

The optimum range of process parameters for quality of friction stir welding joint of dissimilar AA 6061 and AA 7075 have been achieved. Multi objective optimization using RSM is a useful technique to optimize the friction stir welding parameters to obtain the optimum ultimate tensile strength, yield strength, hardness value and impact strength of dissimilar friction stir welded joint at 95% confidence level. Following conclusion has been concluded from the current investigation work:-

- Aluminium alloys of grade AA 6061 and AA 7039 can be successfully welded by the friction stir welding process.
- Rotational speed and welding speed contributes much in producing the necessary frictional heat and has significant impact on the mechanical properties.
- The mechanical properties increases as the parameters change their levels from low to high but up to a certain limit then they start decreasing.
- The results obtained from design expert software were found to be optimal and satisfies the optimum response value.

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