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Taguchi-based fuzzy logic approach to optimize friction stir welding of commercial Aluminium alloy Al6082 & Al6063 using multi-response performance index (MRPI)

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Abstract - Friction Stir Welding (FSW) is a state-of-the art welding technique in which a specially designed rotating tool consists of a shoulder and a pin that applies the frictional force. Friction causes to produce heat on the work piece to weld two work pieces clamped together on fixture. Current research articles covers the optimization of friction stir welding process parameters viz. tool pin profile, tool rotation and feed rate on the response parameter like tensile strength and hardness. Experimentation is carried out on the similar Aluminium alloy Al6082 and Al6063 which are commercial grades and widely used in different applications. Taguchi technique integrated with fuzzy logic is used to find the multi response parameter index (MRPI).

Keywords: FSW, Taguchi, Fuzzy logic, MRPI, Multiresponse, Welding.

Introduction

Welding is one of the most commonly used processes in the industry for joining of different materials. High quality joining of materials is need of time for industries and it is goal of many researchers to achieve it through different techniques. Welding of common materials used by small to large industries like aluminium, copper, nickel, titanium and its alloys still seem to be less efficient due to its high thermal conductivity and relatively low melting temperature. Friction stir welding (FSW) was invented by The Welding Institute (TWI) in 1991. FSW is a state-of-the art- technique in which a specially designed rotating tool consists of a shoulder and a pin which applies the downward force and friction produced causes to produce heat on the work piece to weld two work pieces clamped together on fixture and as illustrated in Figure 1. The friction causes the temperature of the work piece to increase to an extent where the material goes into plastic deformation phase but still not molten. After that, the rotation of the tool stirs the material and causes it to flow plastically; this is considered a deformation at a temperature under the melting temperature of the material causing various improvements in its properties and microstructure [9].

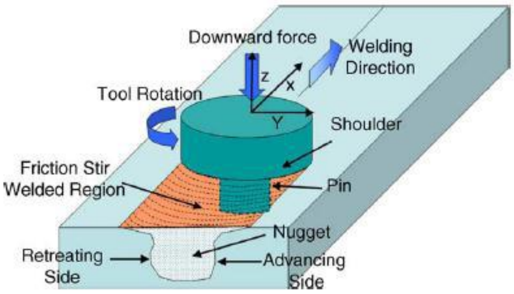

Fig. 1 FSW Process [9]

In present research work, multi-response performance index technique is used to investigate the effect of various welding conditions on the quality of the FSW joint of dissimilar commercial aluminium grades to find out the optimal input conditions for different responses.

LITERATURE REVIEW

Prakash kumar sahu et. al. carried out experimental study on FSW of Cu and Al joint with fuzzy assisted grey taguchi approach is used for optimization. By using fuzzy approach seven quality parameter is transformed into single quality parameter with L16 taguchi experimental array. With high level of welding speed and low levels of other parameters give optimum weld quality.[1]

An-Le Van et al investigated the effect of input parameters of friction stir welding like Speed, feed and depth of penetration and tool tilt angle on joining efficiency and specific welding energy. Taguchi technique is used to optimize the welding responses followed by the adaptive neuro-based-fuzzy inference system (ANFIS) model. In this article the JE by 2.3 % and MH by 6.4 % are improved at the optimal solution.[2]

Hedi Ahmadi et al performed an experimental study of friction stir welding to get the lap joint of polypropylene composite plates which has 20 wt% glass fiber. In this study, the effects of process parameters like rotational speed (tool), welding speed, tilt angle and tool pin geometry on tensile shear strength is investigated with the help of Taguchi technique. The results revealed that the tensile shear strength was enhanced when rotational speed, welding speed, tilt angle and tool pin geometry were 1000 rev/min, 20 mm/min and 1 degree respectively with threaded cylindrical-conical tool. [3]

Raguraman et al investigated through experimental study. To get the optimum responses hybrid Taguchi-Grey relational analysis is used. For the experimentation two dissimilar metals AA6061 and AZ61 were selected to maximize the tensile strength and hardness. Optimum inputs rotational speed, axial load and transverse speed is obtained by applying the hybrid optimization technique. Analysis of Multi Response Performance Index (MRPI) hybrid with taguchi-anova technique revealed that that axial load is the dominant parameter which contributes by 75.67% towards MRPI, followed by transverse and rotational speed.[4]

Abbas K. Hussein et al perfomed optimization of friction stir welding of aluminum alloy (2024-T3) followed by taguchi based multi response optimization technique. In this study, various input parameters were considered like tool pin shoulder diameter, tilt angle, welding direction etc. author has compares single parameter and multi response optimization and found the optimum input parameter combination.[5]

Eyob Messele Sefenea et al performed experiment study and simulation analysis by keeping the temperature as targeted response parameter on AA 6061. Experimentation has done with taguchi and grey relation analysis. In the simulation part transient thermal analysis is carried out to know the optimum temperature.[6]

D.Vijayan et al have performed FSW experiments on AA2024 and AA6061 age hardenable aluminum alloys. Tensile strength (UTS) and tensile elongation (TE) were taken as target response parameters. A response surface method (RSM) based fuzzy grey relational approach is applied which indicate that RSM based fuzzy grey relational technique improved the tensile properties of FS welded AA2024 and AA6061 aluminum alloys than grey relational technique.[7]

B. Parida et al performed experimental study on FSW with a fuzzy assisted grey Taguchi method. The fuzzy inference system used to optimize multi response problem into single response problem followed by Taguchi technique. yield strength , ultimate tensile strength, weld bead thickness, % elongation, and hardness are taken as different multi response parameters.[8]

Methodology:

(a) Machine Selected: -

- Conventional Milling Machine. Vertical Stroke - 450mm
- Top speed- 1600 rpm Machine bed length-700mm Width- 250 mm
- Work piece dimension: 100 X 30 X 5 mm

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Fig.2 Conventional milling machine

(b) Material selection:

For the experimental study two dissimilar commercial aluminium grades are selected namely Al6063 and Al6082. Composition of these alloys are mentiond in table 1 & 2. For the experimentation nine workpieces of size 100x30x5mm are prepared.

Table 1 :Composition of (Al6063)

Grade	Al	Si	Iron	Copper	Mg	Cr	Zinc
Aluminium 6082	**0.95**	**0.7**	**0.5**	**0.1**	**0.6**	**0.25**	**0.2**

Table 2 : Composition of (Al6082)

Grade	Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
Aluminium 6063	98.2%	0.4%	0.35%	0.10%	0.10%	0.45%	0.10%	0.10%	0.10%

(a) (b) (c)

Fig.3(a) Cylidrical threaded, (b) Conical threaded, (c) Conical threaded with 2 face

c) FSW Tool:

It is to be considered as die and tool steel. D2 is a high carbon-high chromium air hardening tool steel, heat treatable to 60-62 Rc. D2 offers excellent wear and abrasion resistance so it is used to make stamping dies and forming dies also.

d) Process parameters & DOE:

Table 4.Process parameters

Parameters / Levels	1	2	3
Tool Pin profile	Cylidrical threaded	Conical threaded	Conical threaded 2 face
Tool Speed (RPM)	1000	1250	1600
Feed (mm / min)	10	16	25

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Experimental set up:
Al 6063(HE9) and 6082(HE30) plates were held together by bolts & table fixture shown in fig.4to absorb the shocks, vibrations, occuring while applying the axial load on plates.The tool being advance in vertically downward direction to plunged into the work peice. During the welding process the lubricant was not used. Different speed were maintained during the trials to facilitate the welding operation.

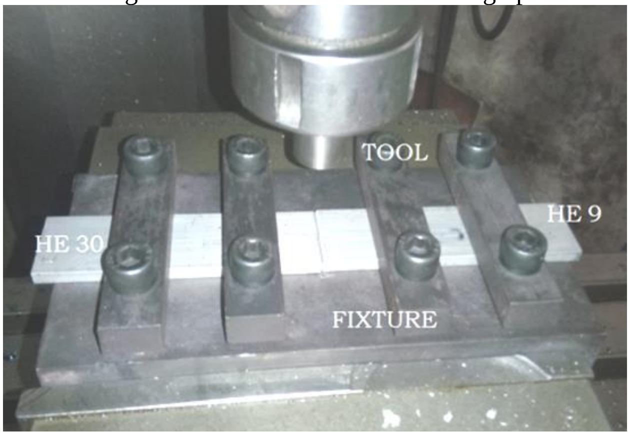

Fig.4 Expermiental Set Up

Table 3.L9 orthogonal array (DOE)

Sr. No.	Input Process parameters			Output parameters		S/N values	
	TOOL PIN PROFILE	RPM	FEED mm/min	UTS N/mm2	Hardness in HV	S/N - (UTS)	S/N- (Hv)
1	CYLIDRICAL THREADED	1000	10	99.87	51	40.0	34.2
2	CONICAL THREADED	1000	16	54.57	53	34.7	34.5
3	CONICAL THREADED 2	1000	25	123.23	50	41.8	34.0
4	CONICAL THREADED	1250	10	105.42	53	40.5	34.5
5	CONICAL THREADED 2	1250	16	105.34	54	40.5	34.6
6	CYLINDRICAL THREADED	1250	25	103.30	46	40.3	33.3
7	CONICAL THREADED 2	1600	10	87.70	46	38.9	33.3
8	CYLIDRICAL THREADED	1600	16	96.02	49	39.6	33.8
9	CONICAL THREADED	1600	25	112.99	52	41.1	34.3

The fuzzy logic:
The fuzzy model consists of a fuzzifier, an inference engine, the membership functions, the fuzzy rules, and defuzzifier In the study, the fuzzifier uses membership functions to fuzzify the normalized values of the S/N ratios, and the inference system completes a fuzzy based on fuzzy rules to create the fuzzy index. The fuzzy rules are generated from the group IF&THEN rules of the parameter inputs. Inferring rules, fuzzifying input data, and defuzzification are the three phases that make up the fuzzy logic approach. Making a critical value out of a language variable is called fuzzification.

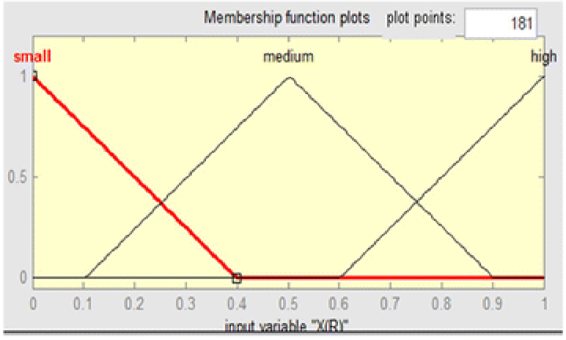

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Fig.5 Membership function for Input S/N ratios (Matlab)

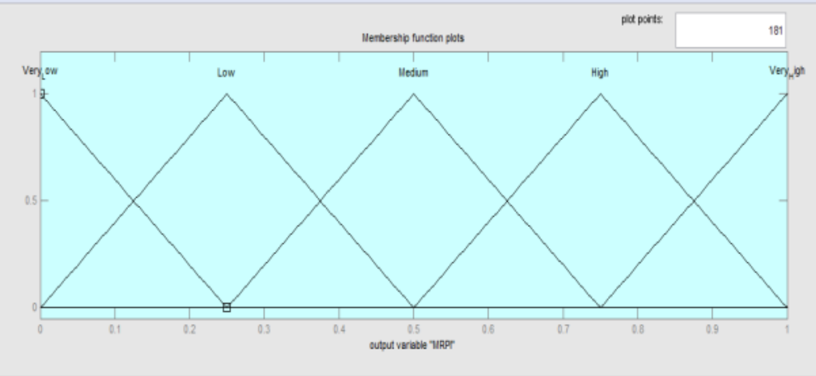
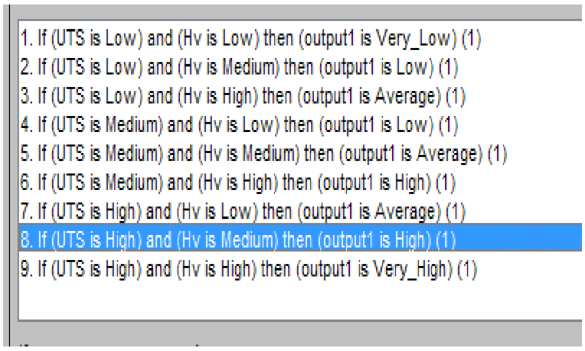


Fig.6 Membership function of the MRPI (Matlab)

Membership rules



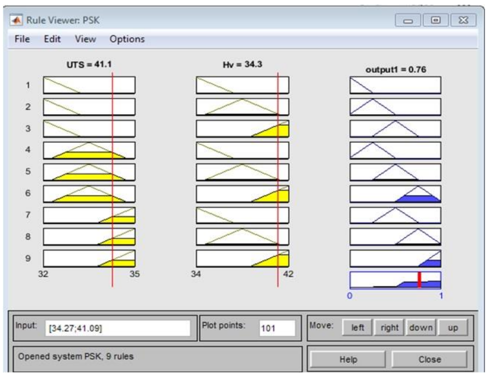


Fig.7 Membership rules (matlab) Fig.8 Rule viewer (Matlab)

Result & Discussion:

MRPI (Multi Response Parameter Index)

Table 4.MRPI values

Expt. No.	S/N (UTS)	S/N (Hv)	MRPI
1	40.0	34.2	0.647
2	34.7	34.5	0.431
3	41.8	34.0	0.755
4	40.5	34.5	0.717
5	40.5	34.6	0.755
6	40.3	33.3	0.653
7	38.9	33.3	0.512
8	39.6	33.8	0.589
9	41.1	34.3	0.76

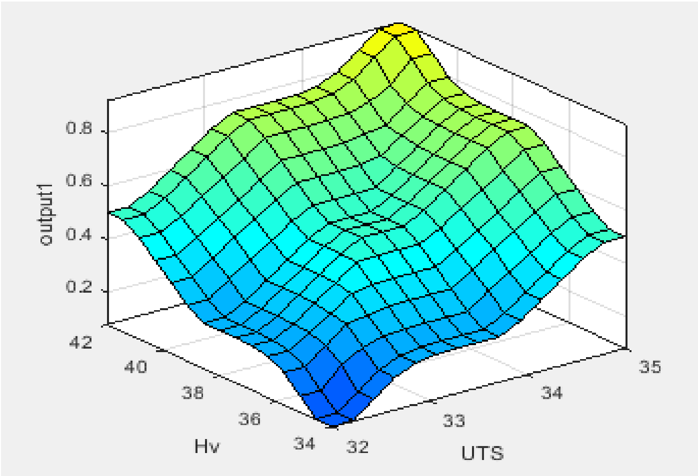


Fig.9 Effect of fuzzy output on Hardness and Tensile strength (Matlab)

Conclusion

- The higher value of MRPI means comparability sequence has a stronger correlation to the reference sequence.
- The optimal setting of the FSW process parameters is found to correspond to experimental no. 9 i.e. 1. Tool rotation:1600 rpm, 2. Feed : 25 mm/min , 3. Tool Pin profile: Conical threaded

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