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MECHANICAL BEHAVIOUR OF FRICTION STIR WELDED JOINT OF MEGNESIUM ALLOY (AZ31) BY TAGUCHI

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***Abstract-*An investigation has been carried out on the friction stir welding of magnesium alloy, AZ31 casting rolled samples have each been welded and their mechanical properties with H13tool steelvarying tool rotational rates and welding speeds were presented.Welding is a multi input-output process in which quality of welded joint depends upon a input parameter. Therefore optimization of input process parameter is required to achieve good quality of welding. There are so many methods of optimization in which Taguchi L_4 orthogonal array DOE method was selected for optimization of process.In this experiment the effect of process parameter on welded joint studied and optimizes the parameter by using Taguchi method and stated regression equation for tensile strength and calculated S/N ratios of each level of factors and studied the main effect plots and interactions plots by using ANNOVA. The study of friction stir welding of magnesium alloy sheets shows the improvement in welded joint quality by optimization of process parameter. The main process parameters which affect the strength of welded joint is tool rotational speed, welding speed.**

Keywords -Friction stir welding, tool rotation, Transverse speed, Taguchi DOE, L4 orthogonal array, Minitab software

1. INTRODUCTION

Magnesium is one of the most abundant elements in the earth's surface, with virtually inexhaustible supplies in the oceans. Over recent years the industrial output of magnesium alloys has been rising by almost 20% per annum, which is faster than that of any other metal. The increased use of magnesium alloys is of great interest to the automotive industry, with the goal of reducing the weight of road vehicles to make them more fuel-efficient or to increase the vehicle specification without adversely affecting its fuel efficiency. In recent years there has been a renewed interest in the use of magnesium parts for body components, many of which have made by pressure die casting [1,2,3]. These have limited ductility, contain gas occlusions, and are frequently difficult to weld satisfactorily by fusion welding techniques. With the major proportion of magnesium alloys being made by casting there has not previously been an extensive need for improved weldability to be developed. The solid state joining technique of friction stir welding (FSW) Fig.1, was patented in 1991, [4] and was initially used to extend the weldability of aluminiumalloys, some of which were difficult to join by fusion welding techniques because of cracking and porosity problems. The scope of this new welding process has since been extended to the welding of lead, zinc, copper, titanium and ferrous alloys, with some considerable success of particular interest to the joining of cast magnesium parts is the success of FSW cast. The cast material contained significant porosity, indicating trapped gases to be present, but whereas fusion welding methods would have encountered problems from their presence, FSW created a sound weld with no porosity in the weld bead or the immediate HAZ, [5, 6].

2. EXPERIMENTAL PROCEDURE

Friction Stir welding process accomplished by cylindrical tool with a pin on its end is plunged into a work piece moved along the joint to be welded. As the tool rotates generates frictional heat between the tool and the work piece. The softened material is transferred from leading edge to trailing edge of pin, where it consolidate to form a solid face bond along the joint as illustrated schematically in figure1.,

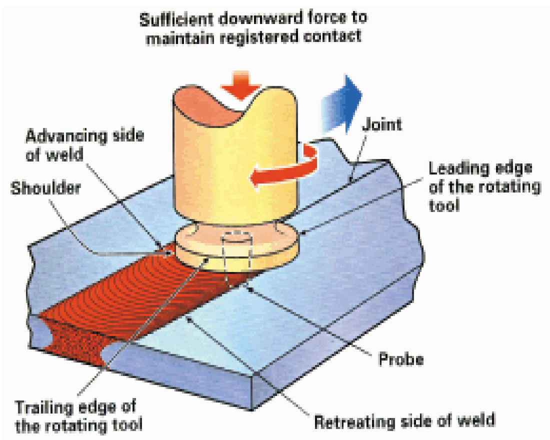

Fig. 1. Friction stir welding process

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Composition of work piece

Table 1: - Composition of rolled plate used in the weld trails.

Alloy composition	Elemenst %							
	Al	Zn	Mn	Si	Fe	Cu	Ni	Mg
AZ31	28.7	0.72	0.30	0.08	0.005	0.05	0.005	remainder

Composition of tool

Table 2: - Composition of Tool

Material Composition	Elements %						
H13 tool steel	C	Mn	Cr	Mo	V	Si	Fe
	0.40	0.35	5.20	1.30	0.95	1.00	remainder

3. RESULTS AND DISCUSSIONS

L_4(2**2) Taguchi Design:-

The L_4 (2**2) Taguchi design which is considered For Analysis of friction stir welded joint is:
Taguchi Orthogonal Array Design

L_4 (2**2)
Factors: 2(Speed in R.P.M and Feed In mm/min)
Runs: 4
Levels: 2

The following are the 2 Levels which are considered in Taguchi design

- High 2
- Low 1

Table 3: L_4 (2**2) Taguchi Orthogonal Matrix

FACTORS / RUNS	C1	C2
1	**1**	**1**
2	**1**	**2**
3	**2**	**1**
4	**2**	**2**

Factors to be considered for Taguchi design of matrix

- Speed in R.P.M
- FEED IN MM/MIN

Response variables

- Tensile strength
- Hardnes

Friction STIR-welding factors used For 2 Levels

Table 4: Friction welding factors for 3 levels

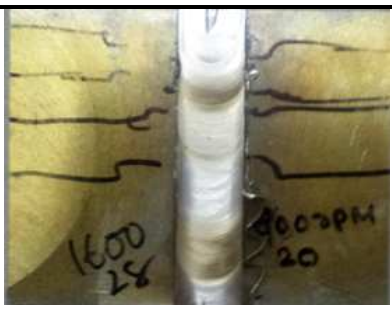
Factors \ Levels	High	Low
Speed (R.P.M)	1600	1200
FEED (MM/MIN)	28	24

INPUT Variables for 4Runs, 2Lvels and 2 Factors

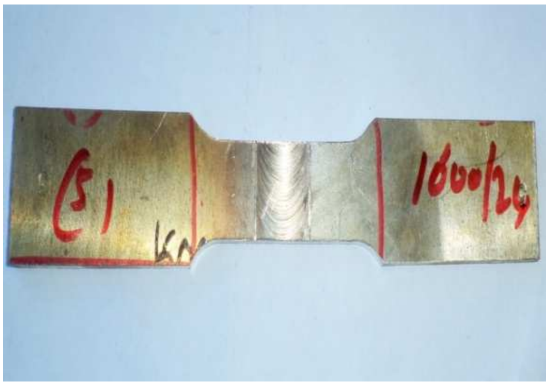
Table 5: Input variables for 4Runs, 2Lvels and 2 Factors

Runs	Speed(R.P.M)	FEED (MM/MIN)
1	1200	24
2	1200	28
3	1600	24
4	1600	28

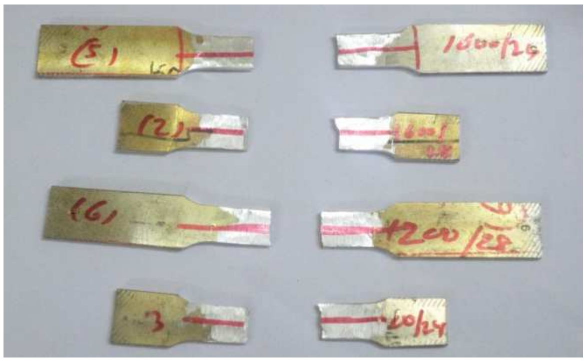
Specimens according to DOE



Specimens before tensile strength



Specimens after tensile strength



Ultimate Tensile Strength Test results:-

Table 6: Ultimate Tensile Strength Test results

RUNS	Speed(R.P.M)	FEED (MM/MIN)	Breaking or MAX. Load (KN)	Ultimate Tensile Strength (N/mm^2)
1	1200	24	8.80	120
2	1200	28	12.30	148
3	1600	24	11.90	148
4	1600	28	6.10	76

Taguchi Analysis: Tensile strength versus Speed, Feed

Larger is better

$$S/N= -10 \log [1/N \sum 1/y_i^2]$$

Table 7: Response Table for Signal to Noise Ratios

RUNS	Speed(R.P.M)	FEED (mm/min)	Ultimate Tensile Strength (N/mm^2)	S/N RATIO
1	1200	24	120	41.58
2	1200	28	148	43.40
3	1600	24	148	43.40
4	1600	28	76	37.61

Ratios

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Table 8: Signal to Noise Ratios for each level of factors

Factors \ Levels	1	2
Speed (R.P.M) **(A)**	42.49	40.50
FEED (MM/MIN) **(B)**	42.49	40.50

Interpretation: -from theabove signal to noise ratios of each level of factor it is concluded that the best setting of factor level to achieve maximum tensile strength is A_1 and B_1 which are having maximum s/n ratios i.e speed is 1200 R.P.M and FEED is 24 mm/min

Regression Analysis: Tensile Strength versus speed, feed

The regression equation is

Tensile strength = 343 - 0.055 speed - 5.5 feed

Predictor	Coef	SE Coef	T	P
Constant	343.0	370.0	0.93	0.524
SPEED	-0.0550	0.1250	-0.44	0.736
FEED	-5.50	12.50	-0.44	0.736

S = 50 R-Sq = 27.9% R-Sq(adj) = 0.0%

Interpretation: -The R^2 value implies that 27.9% of variation in tensile strength with changes in speed and feed can be explained by the equation Tensile strength = 343 - 0.055 Speed - 5.5 Feed. In the output above, if the speed variable increases by 1 unit and the other variables stay the same, Tensile strength decreases by about 0.05 units on average.If the Feed variable increases by 1 unit and the other variables stay the same, Tensile strength decreases by about5.5 units, on average.

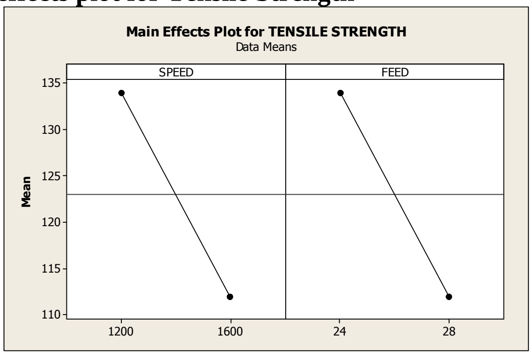
Taguchi Analysis by Minitab software for Means of Tensile strength

Table 9:Response Table for Meansof Tensile strength

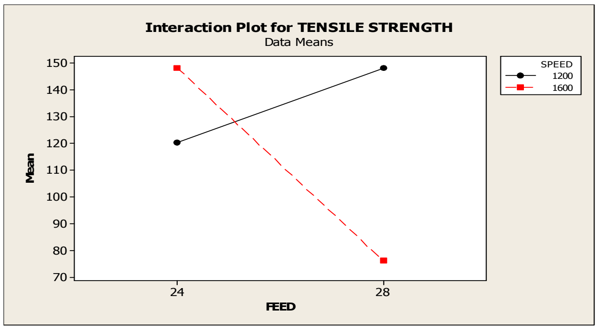
Level	Speed	FEED
1	134.0	134.0
2	112.0	112.0
Delta	22.0	22.0
Rank	1	1

Interpretation: - From the delta values it assigns the rank to each factor which are having more influence on the mean of tensile strength, but in this for both factors rank was same so it concluded that both factors are having same influence on the mean of tensile strength

Main effects plot for Tensile Strength



Interpretation: The main effects plot shows that, with the speed 1200 R.P.M and Feed 24 mm/min the tensile strength is maximized



Interaction plot for Tensile strength:-

Interpretation: The above plot indicates an interaction between the all levels of all factors which are considered, for high tensile strength.

Hardness:-

Table 4: Hardness Test results

Runs	Speed(r.p.m)	Feed (mm/min)	Breaking or max Load (kn)	Hardness
1	1200	24	8.80	56.3
2	1200	28	12.30	62.4
3	1600	24	11.90	95
4	1600	28	6.10	56.3

Taguchi Analysis: Hardness versus SPEED, FEED

Larger is better

$$S/N= -10 \log [1/N \sum 1/y_i^2]$$

Table 5: Response Table for Signal to Noise Ratios

RUNS	Speed (R.P.M)	FEED (MM/MIN)	HARDNESS	S/N RATIO
1	1200	24	120	35.01
2	1200	28	148	35.90
3	1600	24	148	39.55
4	1600	28	76	35.01

Table 6: Signal to Noise Ratios for each level of factors

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Levels / Factors		1	2
Speed (A)	(R.P.M)	35.45	37.28
FEED (B)	(MM/MIN)	37.28	35.45

Interpretation: -from the above signal to noise ratios of each level of factor it is concluded that the best setting of factor level to achieve maximum hardness is A_2 and B_1 which are having maximum s/n ratios i.e. speed is 1600 R.P.M and FEED is 24 mm/min

Regression Analysis: HARDNESS versus SPEED, FEED

The regression equation is
Hardness = 116 + 0.0407 Speed - 4.08 Feed

Predictor	Coef	SE Coef	T	P
Constant	116	165.7	0.70	0.610
SPEED	0.0407	0.05600	0.73	0.600
FEED	- 4.08	5.600	- 0.73	0.600

S = 22.4 R-Sq = 51.4% R-Sq(adj) = 0.0%

Interpretation: - The R^2 value implies that 51.4% of variation in hardness with changes in speed and feed can be explained by the equation.HARDNESS = 116 + 0.0407 SPEED - 4.08 FEED In the output above, if the speed variable increases by 1 unit and the other variables stay the same, Tensile strength increases by about 0.0407 units on average. If the Feed variable increases by 1 unit and the other variables stay the same, hardness decreases by about4.08 units, on average.

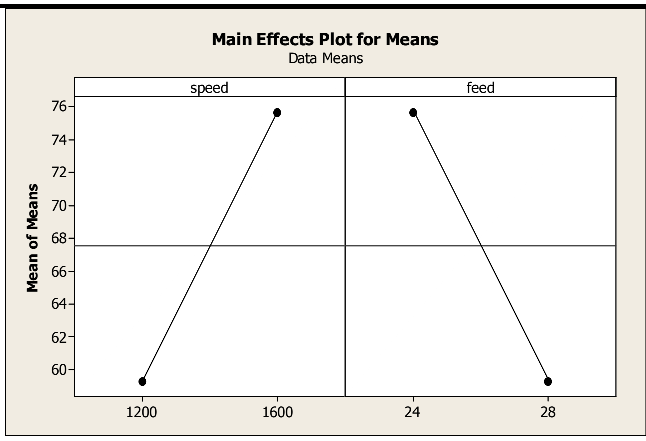
Taguchi Analysis by Minitab software for Means of Hardness:-

Table 7:Response Table for Meansof Hardness

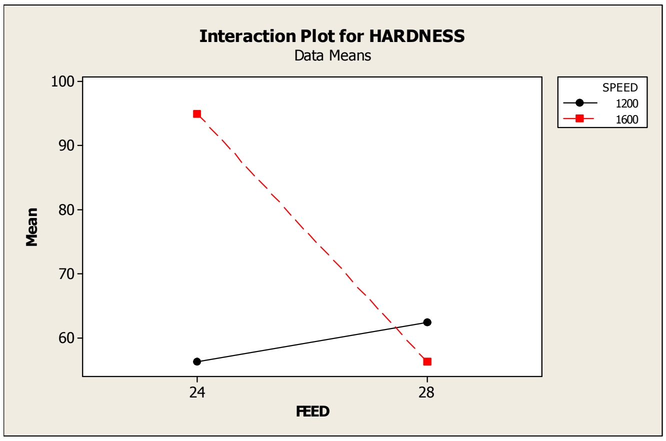
Level	Speed	FEED
1	59.35	75.65
2	75.65	59.35
Delta	16.30	16.30
Rank	1.5	1.5

Interpretation: - From the delta values it assigns the rank to each factor which are having more influence on the mean of hardness, but in this for both factors rank was same so it concluded that both factors are having same influence on the mean of hardness.

Main effects plot for hardness:-



Interpretation: -The main effects plot shows that, with the speed 1600 R.P.M and Feed 24 mm/min the hardness is maximized **Interaction plot for hardness:-**



Interpretation: -The above plot indicates an interaction between the all levels of all factors which are considered, for high hardness. From the above graph concluded that both factors are dependent on each other, and not independent.

4. CONCLUSION

A study of friction stir welding for magnesium alloys has been conducted, in which alloys have been welded to themselves and to each other. It has been possible to develop procedures giving sound welds for all combinations, and initial indications are that mechanical properties will meet expectations.

1) Observed that the both factors are having same influence on the mean of tensile strength.
2) Observed that the 1200 r.p.m and 24 mm/ min feed were best to maximize the tensile strength.
3) Observed that the both factors are having same influence on the mean of hardness.
4) Observed that the 1600 r.p.m and 24 mm/ min feed were best to maximize the hardness.

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