Optimizing of Friction Stir Welded Dissimilar Joint of AZ91 Alloys by Controlling Mechanical Properties

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Abstract - **Friction Stir Welding (FSW) is a solid-state welding that permits an intensive form of parts and geometries to be welded with great nature of joints. The use of high-quality Magnesium alloys is extending in shipbuilding industry, particularly for the advancement of naval warships, cruise ships, littoral surface craft and merchant ships. FSW advancement has been seemed to have various focal points for the exploitation of Magnesium alloys structures, as it is a minimal effort welding process. The objective is to come across the optimum levels of the process parameters in which it yields maximum tensile strength and better hardness. A three-factor, three-level design is utilized for optimizing the FSW process parameters and a Taguchi L9 orthogonal array experimental set up is used to anticipate the responses. The system parameters considered are Rotational speed, Transverse speed and the Tool tilt angle. The Friction stir welding is processed for butt joining of Magnesium alloys (AZ91) plates with 6 mm thickness. Tensile testing is attempted on dog-bone kind test specimen for Magnesium alloys. Analysis of Variance (ANOVA) has been used to analyze the effect of different parameters regarding the responses. The microstructural attributes of the welded segments, including base metal, heat affected zone (HAZ), Thermo Mechanically Affected Zone (TMAZ) and Stir Zone (SZ) are examined through Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray (EDX) analysis carried out to quantify the chemical element allocation at the weld interface. The observed optimum condition for Magnesium alloys (AZ91) is 560 rpm, 60 mm/min and 1 degree.**

Index Terms - **Friction Stir Welding and Taguchi L9 concepts.**

1.INTRODUCTION

A technique of solid phase welding, which allows an extensive variety of parts and geometries to be welded are called Friction Stir Welding (FSW), was designed by W. Thomas and his associates at The Welding Institute (TWI), UK, in 1991. FSW is a genuinely late method that uses a non-consumable rotating welding tool to create frictional heat and plastic deformation at the welding area, in this way influencing the development of a joint while the material is in the solid state. The weld as a rule diminishes the parent metal by around 3-6 % of unique thickness. The rotating tool provides the stir action, plasticizing metal within a narrow zone while transporting metal from the leading face of the pin to the trailing edges. The work piece to be joined and the tool are moved with respect to each other to such an extent that the tool tracks along the weld interface. As the tool passes, the weld cools, in this way consolidating the two plates. Magnesium alloys have a few focal points, for example, low density, high strength, high formability, good corrosion resistance, and low weight. In spite of the fact that it has some appealing properties like great machinability and formability however welding of Magnesium alloys by conventional fusion welding procedures is very troublesome which deliver numerous deformities likes diminishing strength, porosity, hot cracking, brittle solidification and discontinuities. This procedure can locally wipes out the casting defects and refine microstructures; accordingly enhancing strength and malleability, increasing resistance to corrosion and fatigue, upgrading formability and enhancing different properties. The present work is aimed to optimize the process parameters such as rotational speed, traverse speed, and tool tilt angle for superior mechanical properties like Tensile strength and Hardness of the friction stir welded joint on Magnesium Alloy (AZ91). The experiments are devised by Taguchi Design concept. Three factor and three level design matrix is been developed by using MINITAB 17 software package.

2. METHODOLOGY

Design of experiments, DOE, is utilized as a part of numerous industrial sectors, for example, in the improvement and optimization of manufacturing processes. Run of the mill cases are the creation of wafers in the gadgets industry, the manufacturing of engines in the auto industry, and the amalgamation of compounds in the pharmaceutical industry. Another principle kind of DOE-application is the optimization of expository instruments. Numerous applications are found in the scientific literature depicting the optimization of spectrophotometers and chromatographic equipment. As a rule, be that as it may, an experimenter does not bounce straightforwardly into an optimization issue; rather introductory screening trial designs are utilized as a part of request to find the most productive piece of the trial area being referred to. Other principle kinds of use where DOE is valuable is robustness testing and blend design.

Taguchi experimental design

The Taguchi method includes lessening the variation in a process through robust design of experiments. The general goal of the method is to deliver brilliant product with ease to the producer. The Taguchi method was produced by Genichi Taguchi. Taguchi built up a method for designing experiments to research how different parameters influence the mean and variance of a process performance characteristic that characterizes how well the process is working. Reasons for selecting the Taguchi orthogonal array,

- An extensive number of experimental works must be done when the quantity of process parameters increments. To tackle this issue, the Taguchi method utilizes orthogonal arrays to examine the whole parameter space with just few experiments.
- Taguchi methods have been generally used in engineering analysis and comprise of a plan of experiments with the objective of acquiring data in a controlled way, keeping in mind the end goal to get data about the behaviour of a given process.
- The best favourable position of this method is the sparing of exertion in directing experiments; sparing experimental time, diminishing the cost, and finding significant factors rapidly.

Taguchi orthogonal array

Orthogonal arrays are special standard experimental design that requires only a small number of experimental trials to find the main factors effects on output. The selection of which orthogonal array (OA) to use predominantly depends on the following items, in order of priority:

1. The number of factors and interactions of interest;
2. The number of levels for the factors of interest;
3. The desired experimental resolution or cost limitations;

The degrees of freedom for three parameters in each of three levels were calculated as follows, Degree of Freedom (DOF) = number of levels -1. For each factor, DOF equal to:

For (A); DOF = 3 – 1 = 2
For (B); DOF = 3 – 1 = 2
For (C); DOF = 3 – 1 = 2

Hence at least 9 experiments are to be conducted. Based on this orthogonal array (OA) is to be selected which has at least 9 rows i.e., 9 experimental runs. The 9-run array is more desirable (if cost and time permit) because for each level of any one parameter, all three levels of the other parameters are tested. Of course, either array here costs less to run than a full factorial analysis, since the number of required runs for a full factorial analysis is $N = L^P = 3^3 = 27$. Based on main factor, the variables are assigned at columns, as stipulated by orthogonal array.

Table 3.1 Taguchi L9 Orthogonal Array

Trial no.	Taguchi L9, Parameters = 3, Levels= 3		
	Rotational speed	Welding speed	Tool tilt angle
1	560	60	0
2	560	80	1
3	560	100	2
4	730	60	1
5	730	80	2
6	730	100	0
7	900	60	2
8	900	80	0
9	900	100	1

S/N RATIO

In Taguchi's design method the design parameters (factors that can be controlled by designers) and noise (factors that cannot be controlled by designers, such as environmental factors) are considered influential on the product quality. The Signal to Noise (S/N) ratio is used in this analysis which takes both the mean and the changeability of the experimental result into account. The S/N ratio depends on the quality characteristics of the product/process to be enhanced. Usually, there are three categories of the performance characteristics in the analysis of the S/N ratio; that is, the lower-the-better, the higher-the-better, and the nominal-the-better. The S/N ratio for every response is figured differently based on the classification of the performance characteristics and hence regardless of the class the bigger S/N ratio corresponds to a better performance characteristic. Where n is the number of measurements in a trial/row, in this case, n=1 and yi is the measured value in a run/row.

ANALYSIS OF VARIANCE (ANOVA)

ANOVA is a statistically based, target decision-making tool for recognizing any distinctions in the average performance of groups of items tested. It helps in formally testing the significance of every single principle factor and their interactions by looking at the mean square against an estimate of the experimental errors at particular certainty levels. The use of Analysis of Variance (ANOVA) is to explore which welding parameters.

HARDNESS TEST

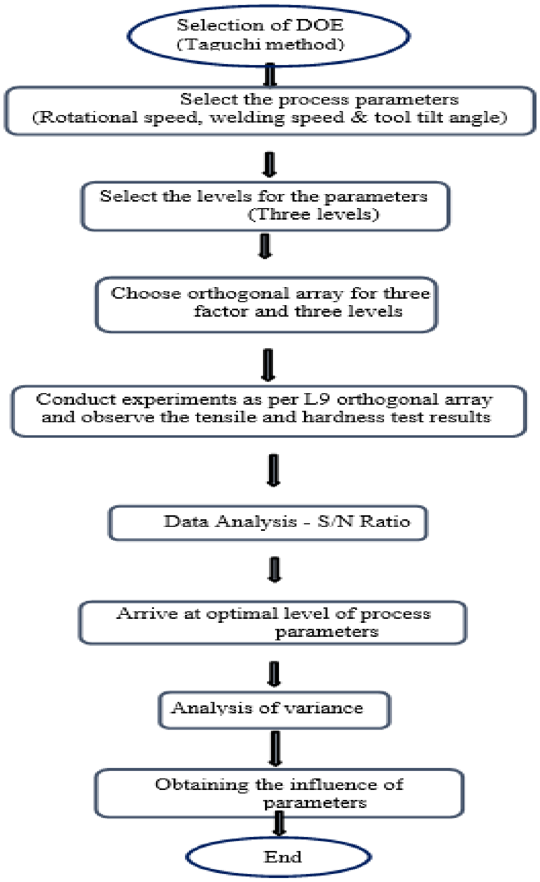
Micro hardness values along the welded zone of samples were measured by using Vickers micro hardness testing machine. Hardness measurements were taken at different points for an applied load 100gms using Vickers micro hardness testing method IS: 1501. In Vickers test, it involves a diamond indenter in the form of a square-based pyramid with an apex angle of 136°. The indenter is being pressed under load for 10 to 15 seconds into the surface of the specimen. After the load and indenter are removed the diagonals of the indentation d (mm2) are measured. The Vickers hardness number HV is obtained by dividing the size of the load F (kgf), applied by the surface area A (mm), of the indentation.

TENSILE TEST

Tensile test specimens from each welded plate were prepared as per the ASTM E8M-04 standards. The dimension of the tensile testing specimen is shown in Fig. 4.2. The tensile test specimens as shown in Fig. 4.3 were prepared with the help of a wire cut EDM. Transverse tensile specimens with a gage length of 57 mm and a width of 13 mm (overall length: 136 mm) were prepared from the weld samples. Room-temperature tensile tests were conducted on nine samples on a universal tensile testing machine.

METALLOGRAPHIC OBSERVATIONS

Metallographic examination of the transverse cross sections was carried out to study the microstructures of different zones of the welded samples. The different microstructural zones such as Stir Zone (SZ), Heat-Affected Zone (HAZ) and Thermo Mechanically Affected Zone (TMAZ) of similar FS welded joint have been identified due to difference in grain size and their orientation using Scanning Electron Microscopy (SEM). A clear interface between the HAZ, TMAZ and SZ region of the FSW joint can be observed.



3. EXPERIMENTAL WORK

The materials used in this study are 6 mm thick plates of Magnesium alloy Z91. The rolled plates were cut and machined into required shapes of 120 mm long and 100 mm wide for friction stir welding. Welding was carried out in a FSW machine where a tool is mounted with a suitable collate. The vertical tool head can be moved along the vertical guide way (Z axis), the horizontal bed can be moved along X and Y axis. The mechanical clamps are used to clamp the plate in the work table of the machine. The butt joints were fabricated normal to the rolling direction. The process parameters are tool rotational speed, tool transverse speed and tool tilt angle. Cylindrical tool of High Speed Steel (HSS) with threaded pin having 16 mm shoulder diameter, 5.7 mm pin length and 6 mm pin diameter was used for FSW. The pin was positioned at the center of the joint line.

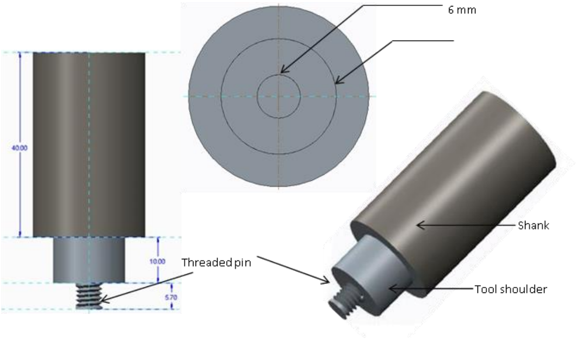


Fig 4.1 Geometry of the FSW tool

RESULTS AND ANALYSIS

Taguchi method focuses on the significance of studying the response variation using the signal-to-noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. The tensile strength and hardness were considered as the quality characteristic with the concept of "the larger-the-better". The S/N ratio used for this type response is given by;

$$S/N = -10 \log_{10} \left(\frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2} \right)$$

Where n is the number of responses in a trial/row, in this case, n=2 and y is the measured value tensile strength and hardness in a run/row.

Taking first trial,

$= -10 \log10 [1/2 \times ((1/286.15^2) + (1/86^2))] = 41.32$ dB

The response values and their corresponding S/N ratios are listed in table 5.1.

Table 5.1 Response values and S/N ratio values for experiments

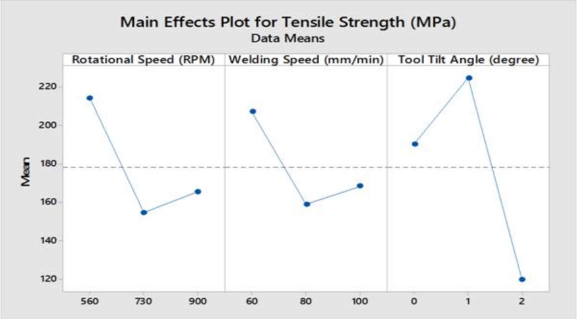
Exp. no	Rotational Speed (RPM)	Welding Speed (mm/min)	Tool Tilt Angle (degree)	Tensile Strength (MPa)	Hardness (HV)	S/N Ratio
1	560	60	0	286.15	86	41.3247
2	560	80	1	235.89	93	41.7525
3	560	100	2	120.51	81	39.5610
4	730	60	1	205.00	86	40.9962

Regardless of the category of the performance characteristics, a greater S/N value corresponds to a better performance. The response table for the rotational speed; welding speed and tool tilt angle was created in the integrated manner and the results are given in table 5.2.

Table 5.2 Response Table for Signal to Noise Ratios

Level	Rotational speed (rpm)	Welding speed (mm/min)	Tool tilt angle (degree)
1	40.88	40.67	40.59
2	40.35	40.54	41.33
3	40.34	40.38	39.66
Delta	0.54	0.29	1.67
Rank	2	3	1
Larger is better			

Fig 5.2 Main effects plot for Tensile strength (MPa)



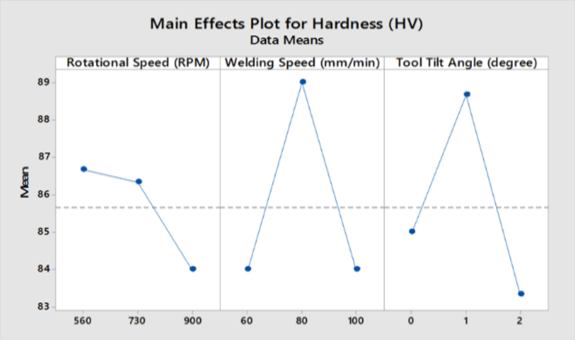


Fig 5.3 Main effects plot for Hardness (HV)

On examination of the Delta values from table 5.2, tool tilt angle is found to be most significant factor, next is rotational speed and followed by welding speed. By using the response values and S/N ratio values given in Table 5.1, the main effect plots have been made using MINITAB 17 software as shown in Figure 5.1, 5.2 & 5.3. While calculating S/N ratios values, larger-the-better criteria have been applied. In a main effect plot, if inclination of the line is more, then the corresponding parameters is more significant parameter and inclination is less, then the effects of the corresponding factor is less. Optimum parametric setting can be found from the main effect plots at highest S/N ratio values of response variables corresponding to each factor. From Figure 5.1, it is observed that the optimum condition is A1 B1 C2 (i.e. Rotational speed (A) = 560 RPM, Welding speed (B) = 60 mm/min and Tool tilt angle

4.METALLOGRAPHIC PROCEDURE

The microstructural work was performed on the transverse (YZ) plane according to ASTM E-2142. The material was segmented in the appropriate direction, mounted and cleaned to expel any residual damage from the cutting process. For optical microscopy, it was sufficient to finish the polishing process with a short chemical polish in OPS solution before etching in a solution of 4 ml HF, 4 ml H_2SO_4, 2 g CrO_3 in 90 ml water. The more demanding requirements of scanning electron microscopy (SEM) required electro polishing of the sample in 30% nitric acid/methanol for around 20–30 s. SEM images and electron backscatter diffraction (EBSD) patterns were produced using a Philips XL30 FEGSEM operated at 15–30 kV and a current of around 4 nA, interfaced to an HKL channel EBSD system.

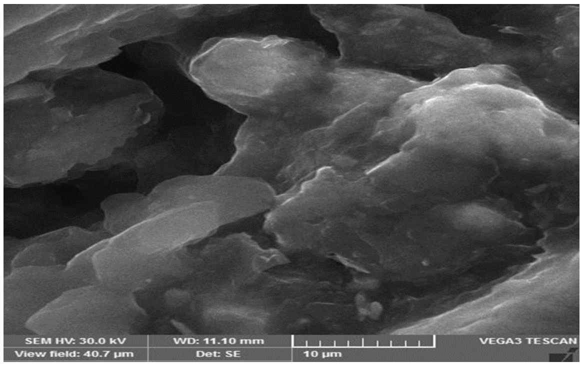


Fig 4.4 Microstructures of HAZ + TMAZ of FS welded joint

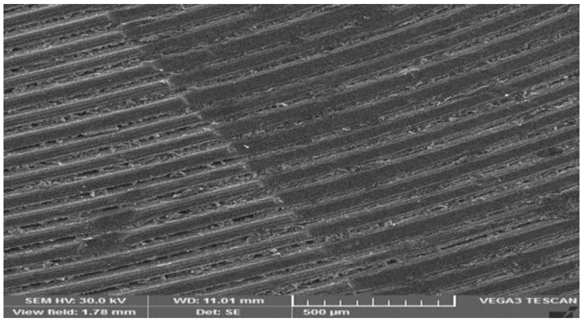


Fig 4.5 Microstructures of SZ of FS welded joint

The FSW process is a solid-state process, therefore the solidification micro- structure is absent in the welded metal and the presence of brittle inter dendritic and eutectic phases is avoided. So the large grains in the base metal were dynamically recrystallized in the stirred zone which can be attributed to the higher plastic deformations and high temperatures. Fig. 4.6 shows that the grains at Stir region exhibits fine, equiaxed grains as compare to other region which shows elevated mechanical strength and ductility. TMAZ experiences both temperature and deformation during FSW process. Recrystallization did not occur in this zone due to insufficient heating, although it underwent plastic deformation to some extent. The HAZ is unaffected by any mechanical effects and plastic deformation in the HAZ is absent.

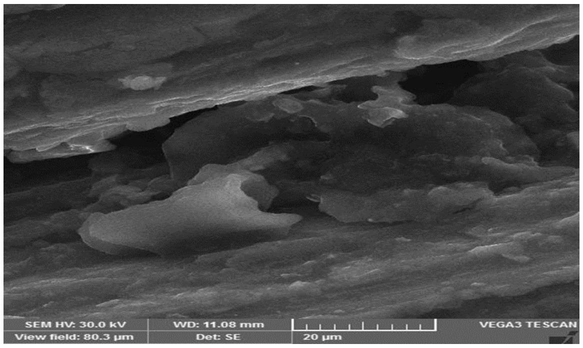


Fig 4.6 Microstructures of TMAZ + HAZ of FS welded joint

At higher welding speed the quantity of tunnels and pores increases and defects move upright into magnesium weld nugget. Because the tool has shorter time to plasticize and move the materials around the pin; and as the maximum temperature of weld decreases, the flow stress of materials increases and causes inadequate plastic deformation of material at welding area. Under such a condition, the tool cannot accomplish weld line and consolidate materials in the weld zone and in this way the tunnel forms.

5.CONCLUSION

A broad experimental investigation is carried to analyze the effect of important process parameters of FSW with experimental analysis and results. The Taguchi L9 orthogonal designed experiments have been proposed as a way of studying the FSW parameters for Magnesium Alloy (AZ91) welded joint. Main effects plots and ANOVA table revel that tool tilt angle and rotational speed are the factors which has considerable influence on tensile strength and hardness. While welding speed has lesser influence. The process parameters were optimized with respect to maximum tensile strength and hardness of the welded joint and the optimum levels of tool rotational speed, welding speed and tool tilt angle are 560 rpm, 60 mm/min and 1 degree respectively. Also the prediction made by Regression Analysis is in great concurrence with comparison results.

REFERENCE

[1] Mishra RS, Ma ZY (2005), 'Friction stir welding and processing', Material Science Eng: R: Rep; 50:1–78.

[2] Behnagh RA, Besharati Givi MK, Akbari M (2011), 'Mechanical properties, corrosion resistance, and microstructural changes during friction stir processing of AZ91 magnesium rolled plates', Material Manufacturing Process; 27:636–40.

[3] Shojaeefard MH, Behnagh RA, Akbari M, Givi MKB, Farhani F (2013), 'Modelling and Pareto optimization of mechanical properties of friction stir welded 7075/ AZ91 butt joints using neural network and particle swarm algorithm', Materials and Design; 44:190–8.

[4] Lee WB, Yeon YM, Jung SB (2003), 'The improvement of mechanical properties of friction-stir-welded A356 Al alloy', Mater Science Engineering; A355:154.

[5] Cao X, Jahazi M (2009), 'Effect of welding speed on the quality of friction stir welded butt joints of a magnesium alloy', Materials and Design; 30: 2033.

[6] Uzun C, Dalle Donne C, Argagnotto A, Ghidini T, Gambaro C (2005), 'Friction stir welding of dissimilar Al 6013-T4 To X5CrNi18-10 stainless steel', Materials and Design; 26:41-6.

[7] Elrefaey A, Gouda M, Takahashi M, Ikeuchi K (2005), 'Characterization of aluminum/steel lap joint by friction stir welding', Journal of Materials Engineering and Performance; 14:10-7.

[8] Kimapong K, Watanabe T (2005), 'Effect of welding process parameters on mechanical properties of FSW lap joint between aluminum alloy and steel', Materials Transactions; 46:2211–7.