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Efficiency Improvement of Friction Stir Welding Parameters on AZ91 Magnesium Alloy Joints

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Abstract: Friction Stir Welding (FSW) is a solid-state welding that permits an intensive formof 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 advancementof naval warships, cruise ships, littoral surface craft and merchant ships. FSW advancementhas 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 andbetter 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.

I. 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 wayconsolidating 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.

A. *Micro Structural Zones in FSW*

An FSW joint usually consists of four different regions. The different regions are (an) Unaffected base metal (b) Heat affected zone (HAZ) (c) Thermomechanically affected zone (TMAZ) and (d) stir (SZ) zone. The formation of above regions is affected by the material stream behaviour under the action of rotation non- consumable tool in any case; the material stream behaviour is predominantly influenced by the FSW tool profiles and FSW process parameters.

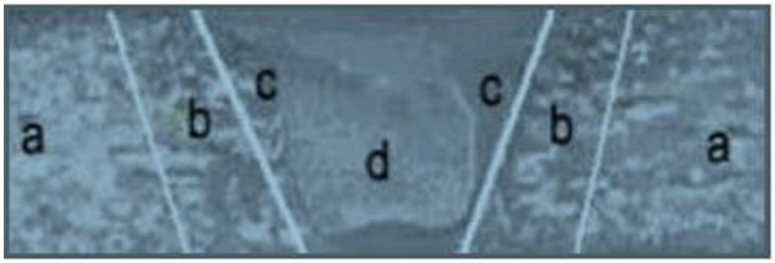

Fig 1.1 Different regions of FSW joint

1) Unaffected or parent material

This zone is remote from the weld zone, which isn't deformed, and which in spite of the fact that may have encountered a warm cycle because of the conductive dispersal of heat from the weld zone, isn't influenced by heat regarding microstructure or mechanical properties since the size of temperatures experienced are adequately lower.

2) Heat affected zone (HAZ)

This zone lies nearer to the weld center. Also, the material in this zone encounters a warm cycle than can alter the microstructure or mechanical properties. In any case, no plastic deformation happens here. Metallurgical changes in this zone are like those happening in the conventional fusion welding processes.

3) Thermo-mechanically affected zone (TMAZ)

It corresponds to a region where mechanical properties are changed by the friction heat and exceptional deformations caused by the rotational and translational movement of the tool. A particular limit regularly exists between the recrystallized (weld zone) and the deformed zones of TMAZ.

4) Weld nugget or stir zone (SZ)

The zone specifically underneath the tool shoulder and in the closet proximity to the friction stir welding tool is subjected to extensive plastic deformation and furthermore high peak temperature bringing about unique recrystallization. In this zone the first grain limits seem, by all accounts, to be supplanted with fine, equiaxed recrystallized grains.

B. Process variables of FSW

FSW involves complex material movement and plastic deformation. Tool geometry and weld parameters exert significant effect on the material flow pattern andtemperature distribution, thereby influencing the micro structural evolution of material.

II. LITERATURE SURVEY

A. Introduction

In this chapter, a brief overview on different optimizations and experimental investigation of Friction Stir Welding (FSW) regarding mechanical and metallurgical properties are carried out. Additionally the impact of different input parameters on selected responses namely rotational speed, traverse speed, axial force, tool pin diameter and tool tilt angle are also presented.

Ugender Singarapu, Kumar Adepu and Somi Reddy (2015)[d] were inspected the impact of tool material and rotational speed on mechanical properties of friction stir welded AZ31B magnesium alloy with 5mm thickness. In this investigation, the effect of friction stir welding (FSW) parameters such as tool material rotational speed, and welding speed on the mechanical properties of tensile strength, hardness and impact energy of magnesium alloy AZ31B was studied. The investigations were done according to Taguchi parametric design concepts and an L9 orthogonal array was utilized to examine the influence of various combinations of process parameters. Statistical optimization technique, ANOVA, was used to determine the optimum levels and to discover the significance of each process parameter.

N.D. Nam, M. Mathesh and M.Z. Bian (2016)[a] were clarified the role of friction stir welding and traveling speed in enhancing the corrosion resistance of 6061 magnesium alloy of 4 mm thickness.

The effect of traveling speed on the corrosion properties of 6061 magnesium alloy has been contemplated. The electrochemical tests indicate that an increase of traveling speed enhances the corrosion resistance due to increased film and charge transfer resistances. The corrosion resistance mechanism of FSW specimens can be related to the grain refinement and increase in homogeneity of microstructure which enhances the development of corrosion resistant film.

A. Yazdipour and A. Heidarzadeh (2016)[b] studied the effect of friction stir welding on microstructure and mechanical properties of dissimilar Al AZ91-H321 and316L stainless steel alloy of 5 mm thickness. The effect of tool traverse speed, offset and rotation direction during dissimilar butt friction stir welding was examined. The macrostructure and microstructure of the joints were examined using optical microscope and scanning electron microscope furnished with energy dispersive X-ray analysis. The tensile and hardness tests were directed to assess the mechanical properties of the joints.

A. Dorbane, B. Mansoor, G. Ayoub and A. Imad (2016)[c] were examined the mechanical, microstructural and fracture properties of dissimilar welds produced by friction stir welding of AZ31B and Al6061. Friction stir welding (FSW) has been usedfor joining AZ31B magnesium alloy and Al 6061-T6 magnesium alloy sheets of 3mm thickness. The mechanical and microstructural properties of dissimilar FSW welds were studied by evolving the tool rotation and translation speeds. Brittle fracture was observed on the specimens tested under tensile loading, with the fracture surface showing chevron pattern. The specimens have fractured along the welded joint with the fracture initiating in the IMCs between the Al and Mg.

Mohammad W. Dewan, Daniel J. Huggett and T. Warren (2016)[d] were done the prediction of tensile strength of friction stir weld joints of 2219-T87 magnesium alloy with 8.13 mm thickness. In the present examination three critical process parameters including spindle speed (N), plunge force (Fz), and welding speed are viewed as key factors in the assurance of ultimate tensile strength (UTS) of welded magnesium alloy joints. It is observed that all three process parameters have coordinate influence on UTS of the welded joints. Utilizing experimental data, an optimized adaptive neuro-fuzzy inference system (ANFIS) model has been developed to predict UTS of FSW joints.

A. Shojaei Zoeram, S.H. Mousavi and H.R. Jafarian (2017)[a] were played out the welding parameters investigation and microstructural evolution of dissimilar joints in Al/Bronze processed by friction stir welding and their effect on engineering tensile behaviour. The effect of welding parameters on the joint properties in dissimilar friction stir welding (FSW) between 5052 alloy and C22000 Bronze alloy of 2 mm thickness researched in this examination. The FSW process was carried out by considering the parameters such as rotational speed and welding speed. Results additionally demonstrated that the increase of rotational speed causes an increase in the fraction of intermetallic layer and the appearance of ring/layer pattern in nugget zone.

M.S.Srinivasa Rao, B. Ravi Kumar and M. Manzoor (2017)[b] were described experimental study on the effect of welding parameters and tool pin profileson the magnesium alloy of 5mm thickness FSW joints. In this investigation, anattempt has been made to understand the effect of rotational speed, welding speed and

tool pin profiles on the tensile strength and weld joint efficiencies were studied. Three different tool pin profiles have been used to fabricate the joints at three different rotational speeds and welding speeds. Tool pin profiles greatly influenced the tensile properties of joints. The tensile specimens are exhibited tunnel defect due to lower shoulder diameter because of that insufficient heat generation during welding processes.

Shuai Tan, Feiyan Zheng and Jingyu Han (2017)[c] studied the effects of process parameters on microstructure and mechanical properties of friction stir lap welded magnesium alloy to NZ30K magnesium alloy with 3 mm thickness. Various tool rotation and travel speeds were adopted to prepare the joints. Due to the effect of the tool rotation, the FSLW joints showed unsymmetric cross-section. And the micro hardness distribution indicated that the formation of intermetallic compounds may result in the higher hardness in the joints. By the analysis of the cross-section of the joints, the failure took place at the interface of the intermetallic layer between the Al and Mg alloy.

III. METHODOLOGY

A. Needs of DOE

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 inthe 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 trialdesigns 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.
Territories where DOE is utilized as a part of mechanical research, advancement and production:
1) Optimization of manufacturing processes
2) Optimization of analytical instruments
3) Screening and recognizable proof of important factors
4) Robustness testing of methods
5) Robustness testing of items
6) Formulation experiments

B. Taguchi Experimental Design

The Taguchi method includes lessening the variation in a process throughrobust 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,
1) An extensive number of experimental works must be done when the quantity ofprocess parameters increments. To tackle this issue, the Taguchi method utilizes orthogonal arrays to examine the whole parameter space with just few experiments.
2) 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 ofa given process.
3) 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.

a) 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:

- The number of factors and interactions of interest;
- The number of levels for the factors of interest;
- The desired experimental resolution or cost limitations;

The degrees of freedom for three parameters in each of three levels were calculated asfollows,
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

IV. EXPERIMENTAL WORK

A. *Material Selection*

The correct selection of the material is the most vital perspective to take into consideration in Friction Stir welding process. Since various materials have distinctiveworking parameters based of their properties. Magnesium Alloy (AZ91) material has been chosen for the application in ship building for construction of naval warships, cruise ships, littoral surface craft and merchant ships. The chemical composition (in weight percent) of AZ91 used in the present investigation is shown in Table 4.1. Table
Presents the mechanical properties of base materials

Table 4.1 Chemical composition of AZ91 (wt. %)

Name of the material : Magnesium Alloy (AZ91)									
Element	Si	Fe	Cu	Mn	Al	Cr	Zn	Ti	Mg
Percentage	0.12	0.29	0.014	0.65	4.55	0.088	0.006	0.031	Rem

Table 4.2 Mechanical properties of AZ91

S.no	Material : Magnesium Alloy (AZ91)	
1	ile Strengthin (Mpa)	317
2	ld Strengthin (Mpa)	228
3	Elongation in (%)	16
4	Modulus of Elasticity in (GPa)	70.3

B. *Experimental Method*

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 FSWmachine 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 themachine. 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.

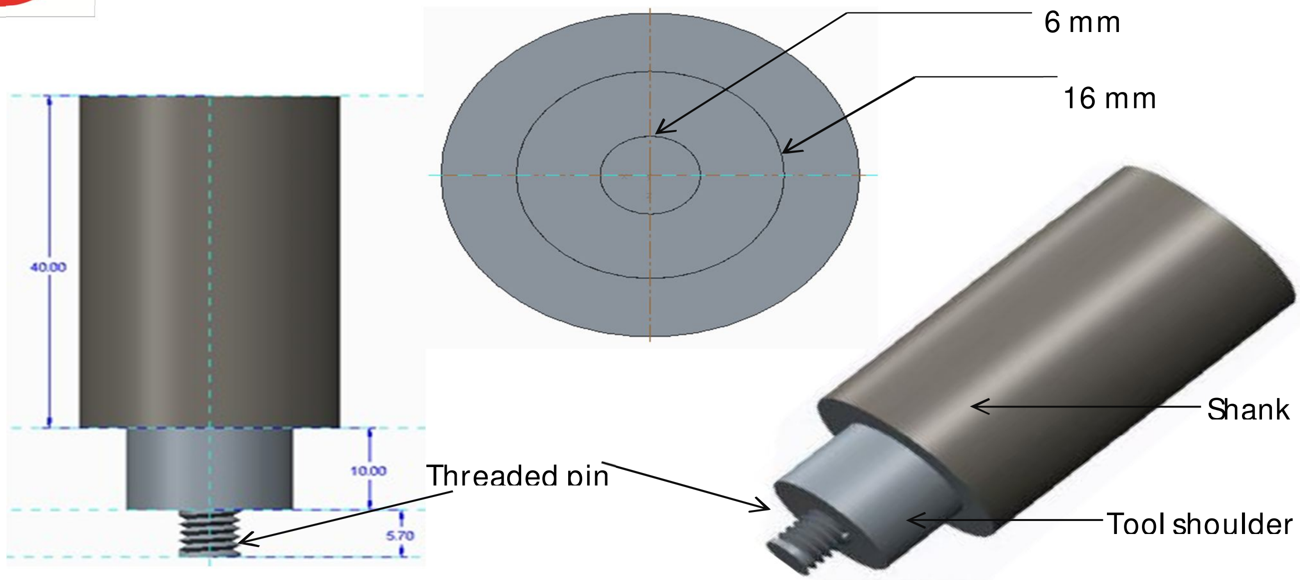

Fig 4.1 Geometry of the FSW tool

1) Taguchi Experimental Design And Analysis

Essentially, traditional experimental design procedures are too complicated andnot easy to use. A large number of experimental works have to be carried out whenthe number of process parameters increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. Taguchi methods have been widely utilized in engineering analysis and consist of a plan of experiments with the objective of acquiring data in a controlled way, in order to obtain information about the behaviour of a given process. The greatest advantage of this method is the saving of effort in conducting experiments; saving experimental time, reducing the cost, and discovering significant factors quickly.

2) Process parameters and their levels

Design of Experiments was done by Taguchi’s technique. For three parameters and three levels, L9 orthogonal array was selected. The independently controllable predominant process parameters that control aspect ratio were identified the range of parameters were decided based on the several experimental trails. Table 4.3 shows the Taguchi orthogonal array selector for the parameters and levels.

3) Selection of orthogonal array (OA)

The selection of which orthogonal array (OA) to use predominantly depends onthe following items, in order of priority:

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

As three levels and three factors are taken into consideration, L9 OA is used in thisinvestigation.

Table 4.3 Process parameters and design levels

S.no	Parameters	Levels		
		1	2	3
1.	Tool rotation speed (rpm)	560	730	900
2.	Welding Speed (mm/min)	60	80	100
3.	Tool tilt angle (degree)	0	1	2

Table 4.4 Layout of L9 Orthogonal Array

rialno.	Taguchi, Parameters = 3, Levels= 3		
	Rotational speed (rpm)	lding speed(mm/min)	l tilt angle(degree)
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

4) 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 testingmachine.

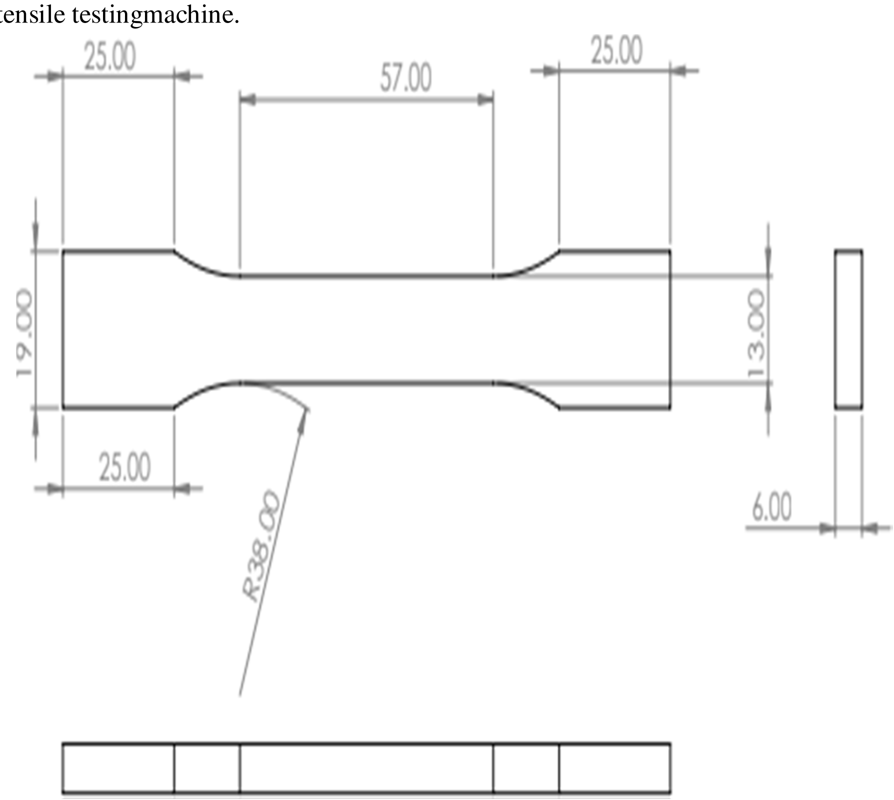

Fig 4.2 Dimensions of tensile specimen

Fig 4.3 Tensile test specimens taken out of the welded plates

The tensile strength of the friction stir welding joints was analyzed to study the effectsof the FSW process parameters. The prepared tensile specimens were subjected to tensile test and its ultimate tensile strength is evaluated. The following Table 4.5 gives the tensile test results for the experiment.

Table 4.5 Tensile test results obtained for various tensile specimens

rial no.	Rotational speed (rpm)	Welding speed (mm/min)	Tool tiltangle (degree)	Ultimatetensile strength (N/mm^2)
1	560	60	0	286.15
2	560	80	1	235.89
3	560	100	2	120.57
4	730	60	1	205.00
5	730	80	2	107.69
6	730	100	0	151.28
7	900	60	2	130.00
8	900	80	0	133.33
9	900	100	1	233.33

5) 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 (mm^2) are measured. The Vickers hardness number HV is obtained by dividing the size of the load F (kgf), applied bythe surface area A (mm), of the indentation. Thus the HV is given by

$$HV = \frac{F}{(d^2/\sin 68^\circ)} = F/(d^2/1.854) = 1.854F/d^2$$

Table 4.6 Hardness test results

Trial no.	Rotational speed(rpm)	Welding speed (mm/min)	Tool tilt angle (degree)	rdness(HV)
1	560	60	0	86
2	560	80	1	93
3	560	100	2	81
4	730	60	1	86
5	730	80	2	89
6	730	100	0	84
7	900	60	2	80
8	900	80	0	85
9	900	100	1	87

6) 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.

a) 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 shortchemical 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 kVand a current of around 4 nA, interfaced to an HKL channel EBSD system.

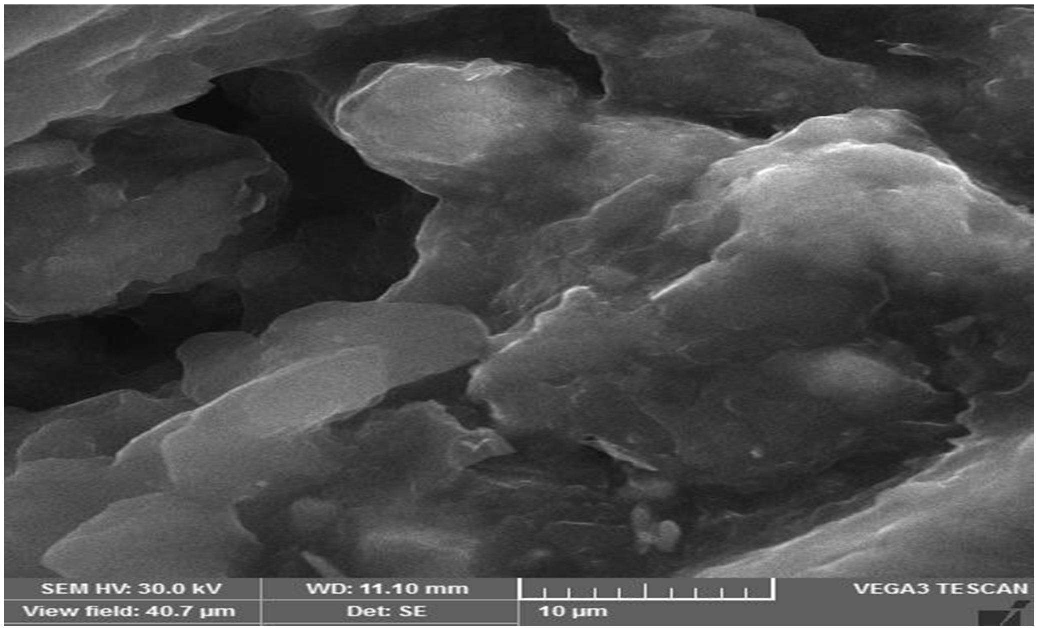

Fig 4.4 Microstructures of HAZ + TMAZ of FS welded joint

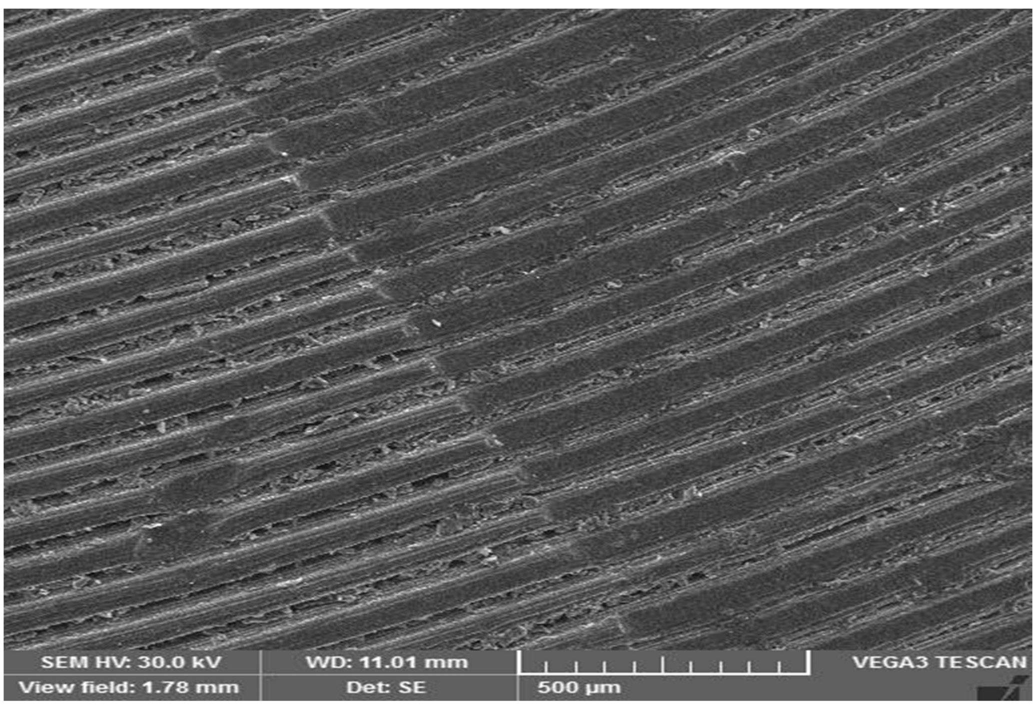

Fig 4.5 Microstructures of SZ of FS welded joint

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.

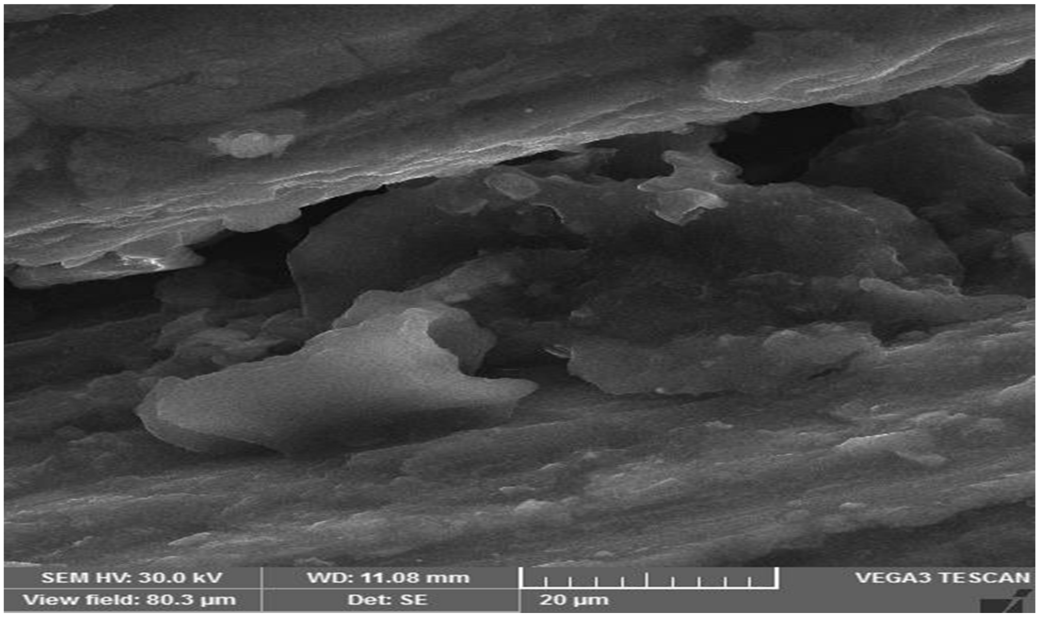

Fig 4.6 Microstructures of TMAZ + HAZ of FS welded joint

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.

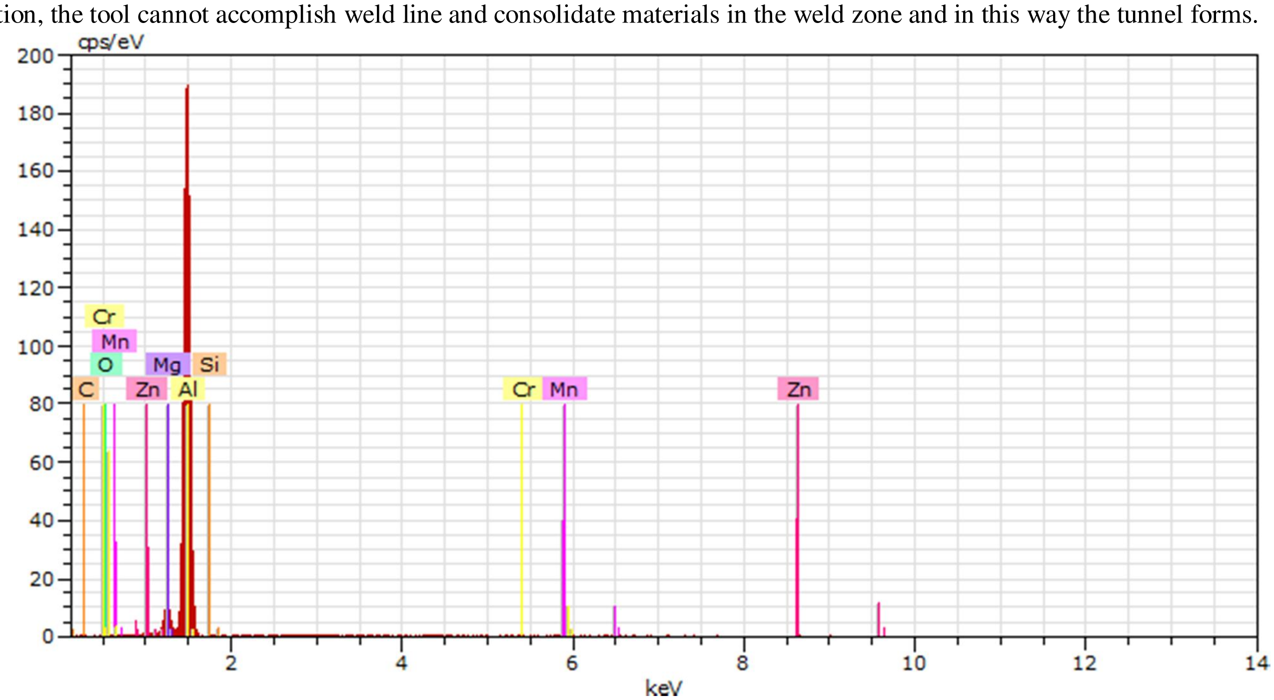

Fig 4.7 EDX mappings of the FS welded joint

Energy Dispersive X-Ray Analysis (EDXA) is an analytical technique used for the elemental analysis or chemical characterization of a sample. It relies on an interaction of some source of X-ray excitation and a sample. Its portrayal capabilities are expected in extensive part to the fundamental principle that each element has a unique atomic structure allowing a unique set of peaks on its electromagnetic emission spectrum. EDX analysis is useful in is helpful in recognizing materials and contaminants, and assessing their relative concentrations on the surface of the specimen.

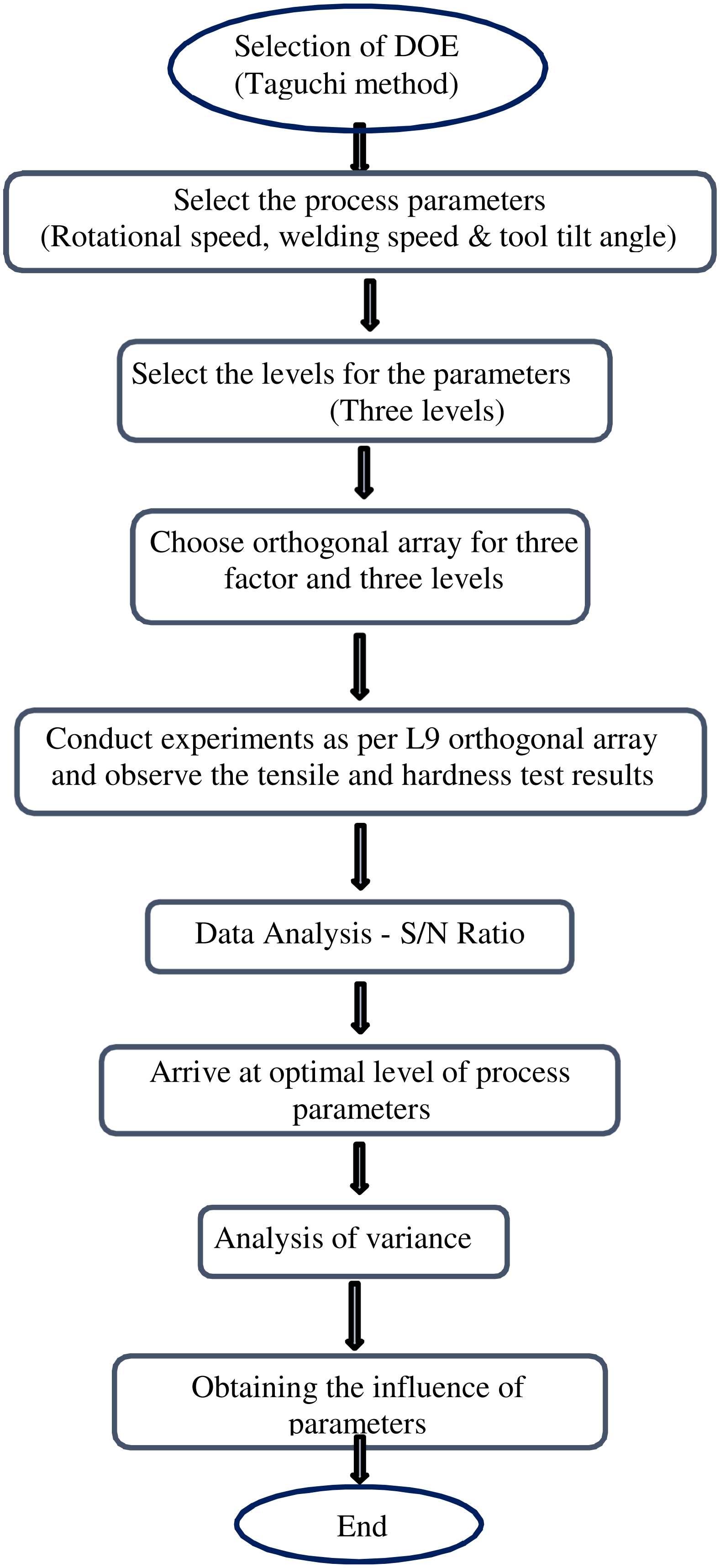

Fig 3.1 Procedure for experimental analysis

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b) 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.

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

Where n is the number of measurements in a trial/row, in this case, n=1 and y_i is the measured value in a run/row.

c) 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 altogether influence the performance characteristic. In addition, the F-test was utilized to figure out which welding parameters significantly affect the responses. For the most part, the difference in the welding parameter significantly affects the performance characteristic when the F-value is extensive.

V. RESULTS AND ANALYSIS

A. Analysis of S/N Ratio

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,

$= -10\log_{10}[1/2 \times ((1/286.15^2) + (1/86^2))] = 41.32$ 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)	ool Tilt Angle (degree)	Tensile trength(MPa)	rdness(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
5	730	80	2	107.69	89	39.7372
6	730	100	0	151.28	84	40.3288
7	900	60	2	130.00	80	39.6774

8	900	80	0	133.33	85	40.1175
9	900	100	1	233.33	87	41.2353

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)	lding speed(mm/min)	l 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			

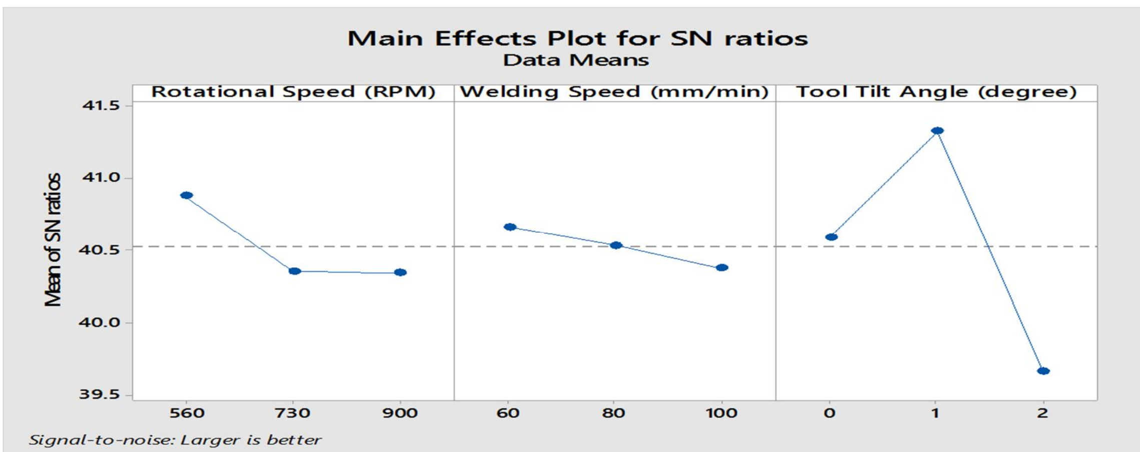


Fig 5.1 Main effects plot for SN ratios

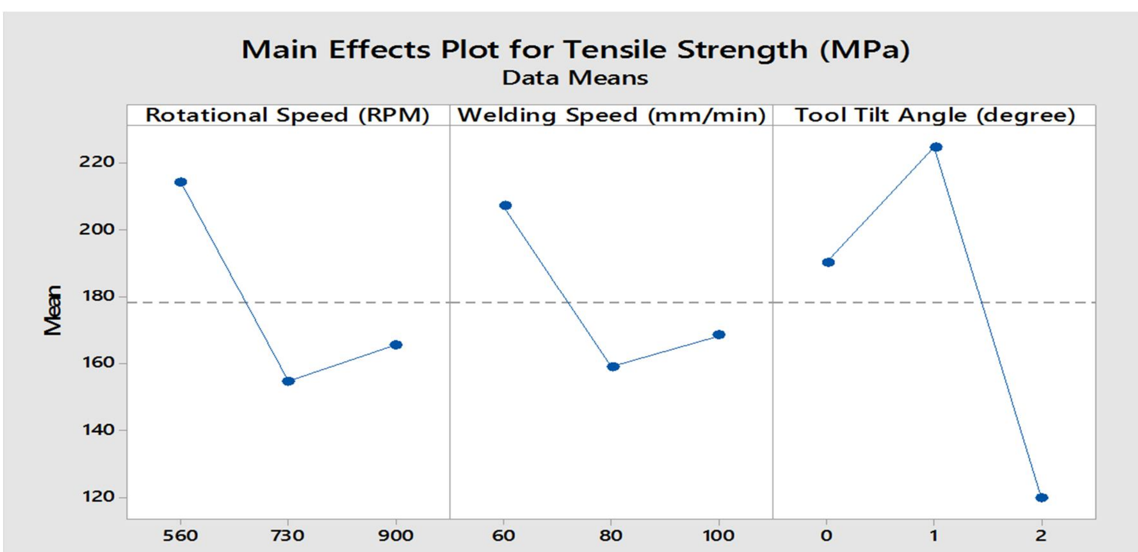


Fig 5.2 Main effects plot for Tensile strength (MPa)

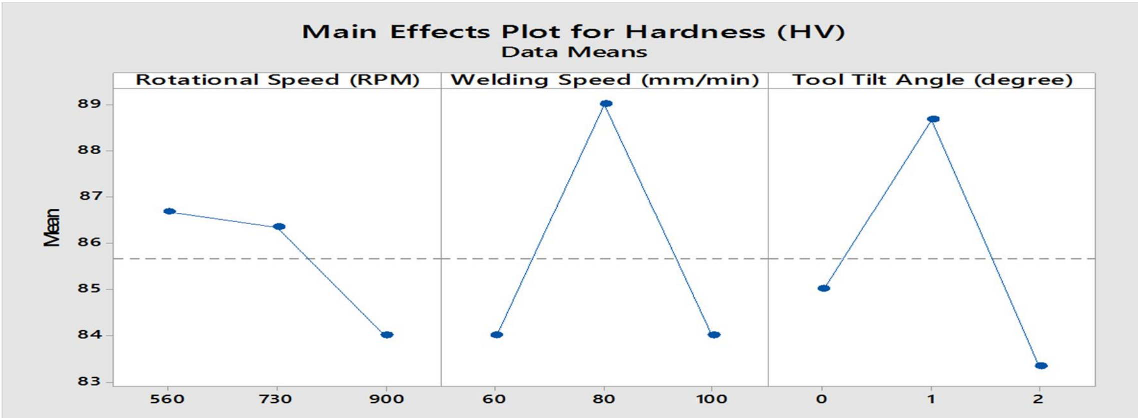


Fig 5.3 Main effects plot for Hardness (HV)

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 plots, 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 (C) = 1 degree).

B. Analysis of Variance (ANOVA)

ANOVA is a statistically based, objective decision-making tool for detecting any differences in the average performance of groups of items tested. ANOVA helpsin formally testing the significance of all main factors and their interactions by comparing the mean square against an estimate of the experimental errors at specific confidence levels. The use of ANOVA is to explore which welding parameters altogether influence the performance characteristic. Statistically, there is a tool called as F test, to see which design parameters have a significant effect on the quality characteristic. In the analysis, the F-ratio is traditionally used to determine the significance of a factor.

First, the total sum of squared deviations SS_T from the total mean S/N ratio η_m can be calculated as,

$$SS_T = \sum_{i=1}^{n}(\eta_i - \eta_m)^2$$

Where n is the number of experiments in the orthogonal array and η_i is the mean S/Nratio for the i^{th} experiment. The ANOVA results are illustrated in table 5.3.

Table 5.3 Analysis of Variance for S/N ratios

Source	DF	Adj SS	Adj MS	F	P
RotationalSpeed (RPM)	2	0.5634	0.28168	1.24	0.447
Welding Speed (mm/min)	2	0.1276	0.06378	0.28	0.781
Tool TiltAngle (degree)	2	4.1996	2.09980	9.22	0.098
Residual Error	2	0.4553	0.22765		
Total	8	5.3458			

In the ANOVA table (Table 5.3), the F value is used to test the significance ofa factor by comparing model variance with residual variance, which is calculated by dividing the model mean square by the residual mean square. If the variance values are near to each other, the ratio will be close to one and it is less likely that any of the factors have a significant effect on the response. A high F value for a parameter means that the effect of the parameter on the characteristics is large. The result in table 5.3 shows that the highest F value in the process was obtained for tool tilt angle equal to 9.22.

1) Percentage contribution (P)

Percentage contribution can be used to evaluate the significance of change in the process parameters on the quality characteristics. The percentage contribution P can be calculated as

$$\text{Percentage contribution } (P) = \left(\frac{SS'A}{SST}\right) \times 100$$

Rotational speed (rpm) = 0.5634/5.3458 X 100 = 10.5% Welding Speed (mm/min) = 0.1276/5.3458 X 100 = 2.3%Tool Tilt Angle (degree) = 4.1996/5.3458 X 100 = 78.5%Error (E) = 0.4553/5.3458 X 100 = 8.5%

Table 5.4 Optimum condition and percentage contribution of parameters

S.no	Factors	Level description	Rank	Contribution (%)
1.	Rotational speed (rpm)	560	2	10.5%
2.	Welding Speed (mm/min)	60	3	2.3%
3.	Tool Tilt Angle (degree)	1	1	78.5%

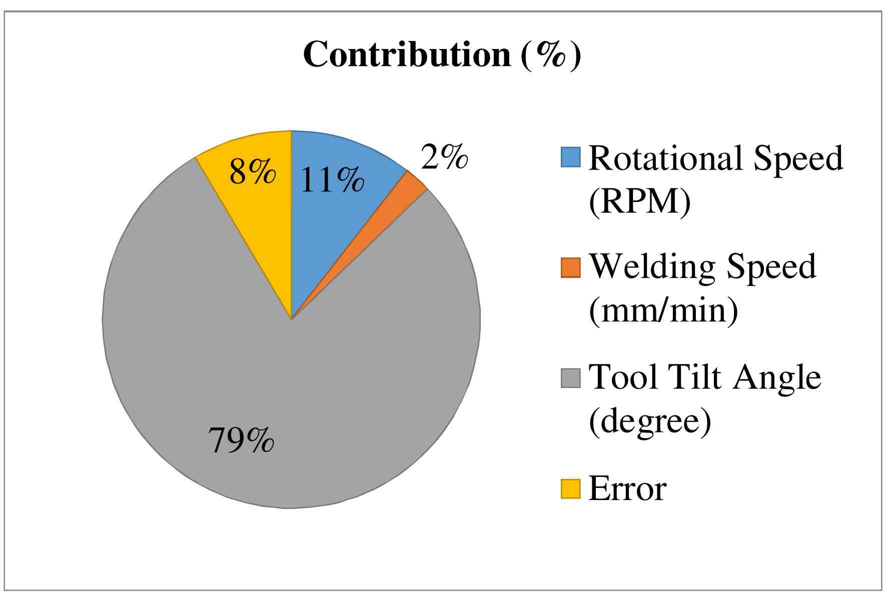


Fig 5.4 Contribution of process parameters

C. Regression Model Analysis

Regression analysis is one of the most important statistical tools widely usedfor analyzing multifactor data it provides simplest, conceptual method for investigating functional relationship among variables.

The multiple liner regression takes the following form.Y= a+b1x1+b2x2+b3x3+ +bkxk …… (2)

Where Y is response variable which is to be predicted X1, X2, X3 ………… XK are the k known variables on which the prediction is to be made and a, b1, b2, b3 is the coefficients, the value of which is determined by the method of least squares. Regression coefficients represent the mean change in the response variable for one unit of change in the predictor variable while holding other predictors in the model constant. Multiple regression analysis is used to determine the relationship between the dependent variable of weld strength with respect to welding parameters. A multiple linear regression analysis attempts to model the relationship between two or more predictor variables and a response variable by fitting a linear equation to the observed data. Based on the experimental results, a multiple linear regression model was developed using MINITAB 17.

Regression Equations for output response are respectively,

Tensile strength (MPa) = 395 - 0.143 Rotational Speed (RPM) -
0.97 Welding Speed (mm/min) – 35.4 Tool Tilt Angle (degree)

Hardness (HV) = 92.2 - 0.0078 Rotational Speed (RPM) + 0.0000 Welding Speed (mm/min) - 0.83 Tool Tilt Angle (degree)

Taking first trail,

Tensile strength (MPa) = 395-0.143(560)-0.97(60)-35.4(0)
= 256.75 Mpa

Hardness (HV) = 92.2 - 0.0078(560)+0.000(60)-0.83(0)
= 87.83 = 88 Hv

The predicted values of tensile strength and hardness were calculated using the aboveregression equations were listed in table 5.5 and 5.6.

Table 5.5 Actual values and predicted values of Tensile strength

Exp. No.	Tensile strength (MPa)	
	Actual value	Predicted value
1	286.15	256.72
2	235.89	201.92
3	120.57	147.12
4	205.00	197.01
5	107.69	142.21
6	151.28	193.61
7	130.00	137.30
8	133.33	188.70
9	233.33	133.90

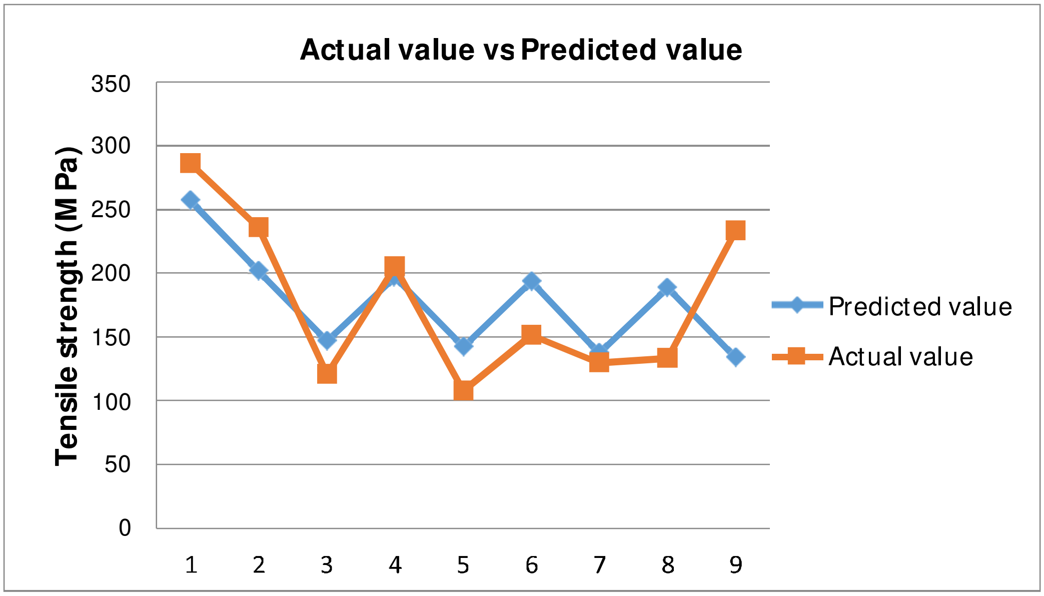


Fig 5.5 Comparison of Actual vs Predicted Tensile Strength (MPa)

Table 5.6 Actual values and predicted values of Hardness

Exp. No.	Hardness (HV)	
	Actual value	Predicted value
1	86	88
2	93	87
3	81	86
4	86	85
5	89	85
6	84	86
7	80	83
8	85	85
9	87	84

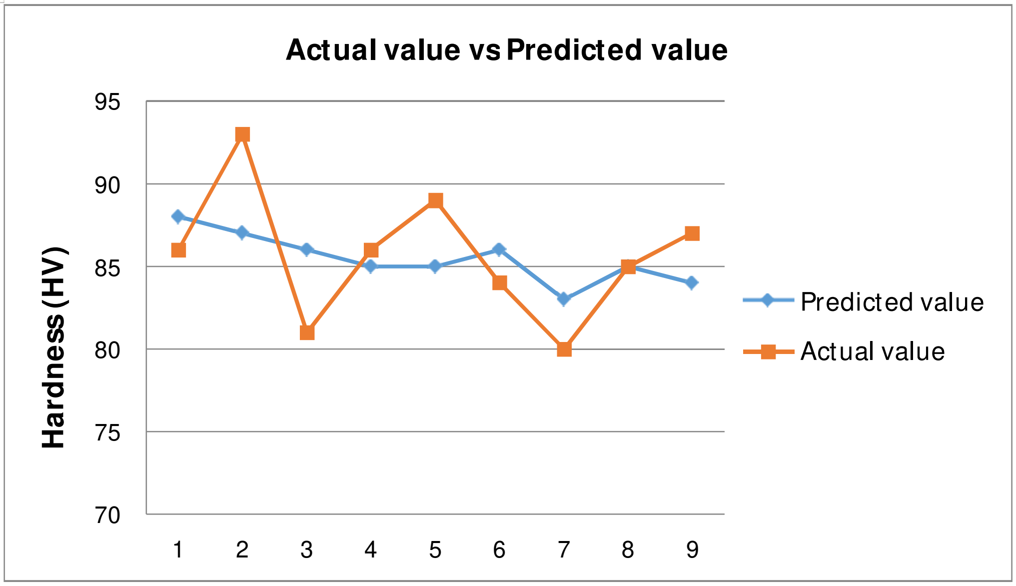


Fig 5.6 Comparison of Actual vs Predicted Hardness (HV)

The graph plot displays ordered pairs of X and Y variables in a coordinate plane. It gives a good visual picture of the relationship between the two variables, and aids the interpretation of the regression model. The experimental values and thepredicted values of weld strength and hardness obtained from the regression models are plotted and are almost closer in Fig.5.5 & 5.6 which clearly indicates a good fit of the developed regression models.

D. Interaction Effects of Process Variables

From the final mathematical models, it is noted the process variables have many interaction effects on the tensile strength and hardness, but only a few select andimportant interaction effects are presented in graphical form for analysis.

Fig 5.7 Interaction effects of rotational speed & welding speed on Tensile strength

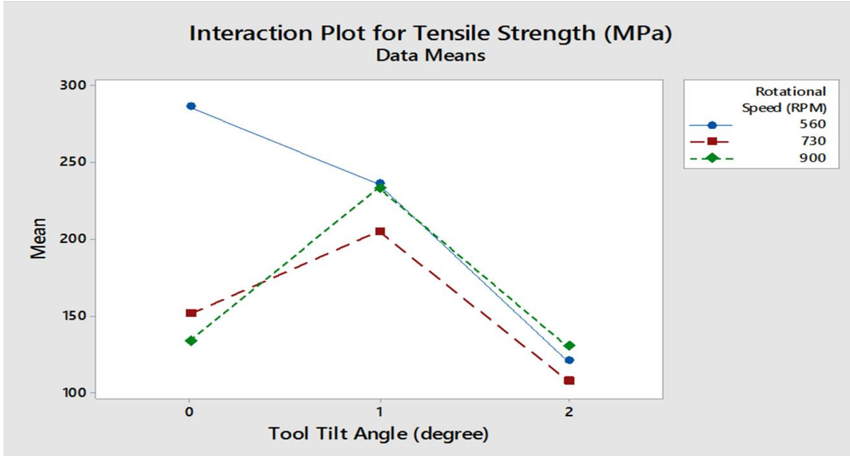


Fig 5.8 Interaction effects of rotational speed & tool tilt angle on Tensile strength

Interaction effects of the selected process variables on tensile strength are shown in Fig. 5.7 and 5.8. The effect of rotational speed and welding speed on Tensile strength is lower. Whereas effect of rotational speed and tool tilt angle on Tensile strength is higher.

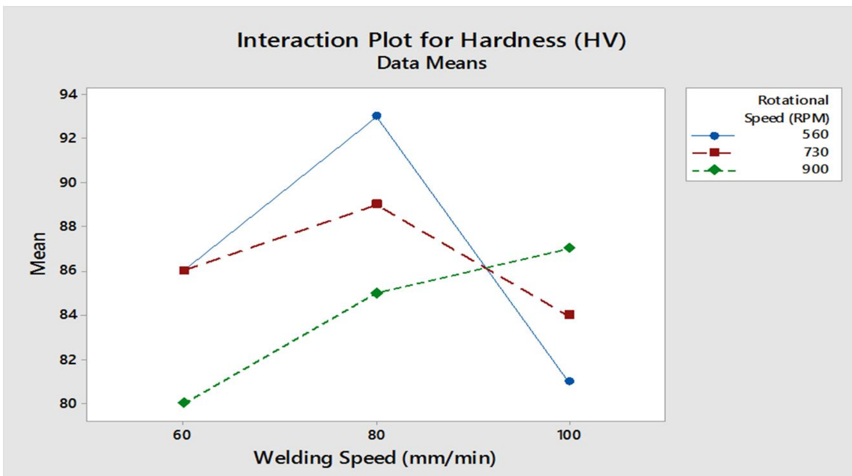


Fig 5.9 Interaction effects of rotational speed & welding speed on hardness

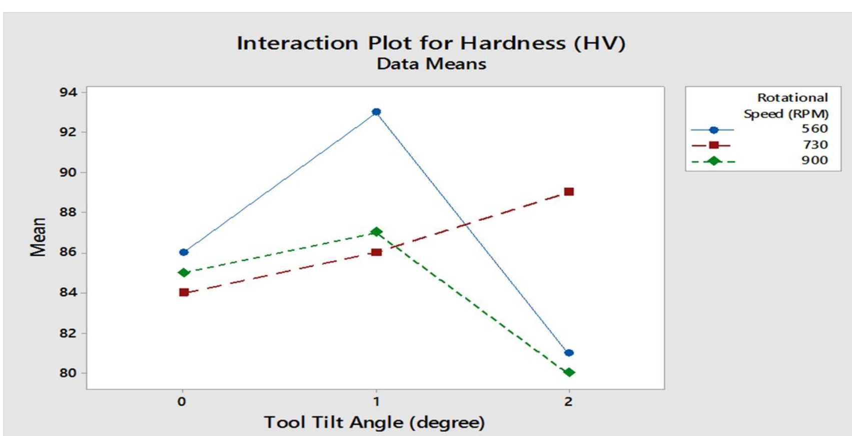


Fig 5.10 Interaction effects of rotational speed & tool tilt angle on hardness

From the fig. 5.9 and 5.10, the impact concerning rotational speed and welding speed over hardness is lower. Whereas effect regarding rotational speed and tool tilt angle over hardness is higher.

VI. CONCLUSION

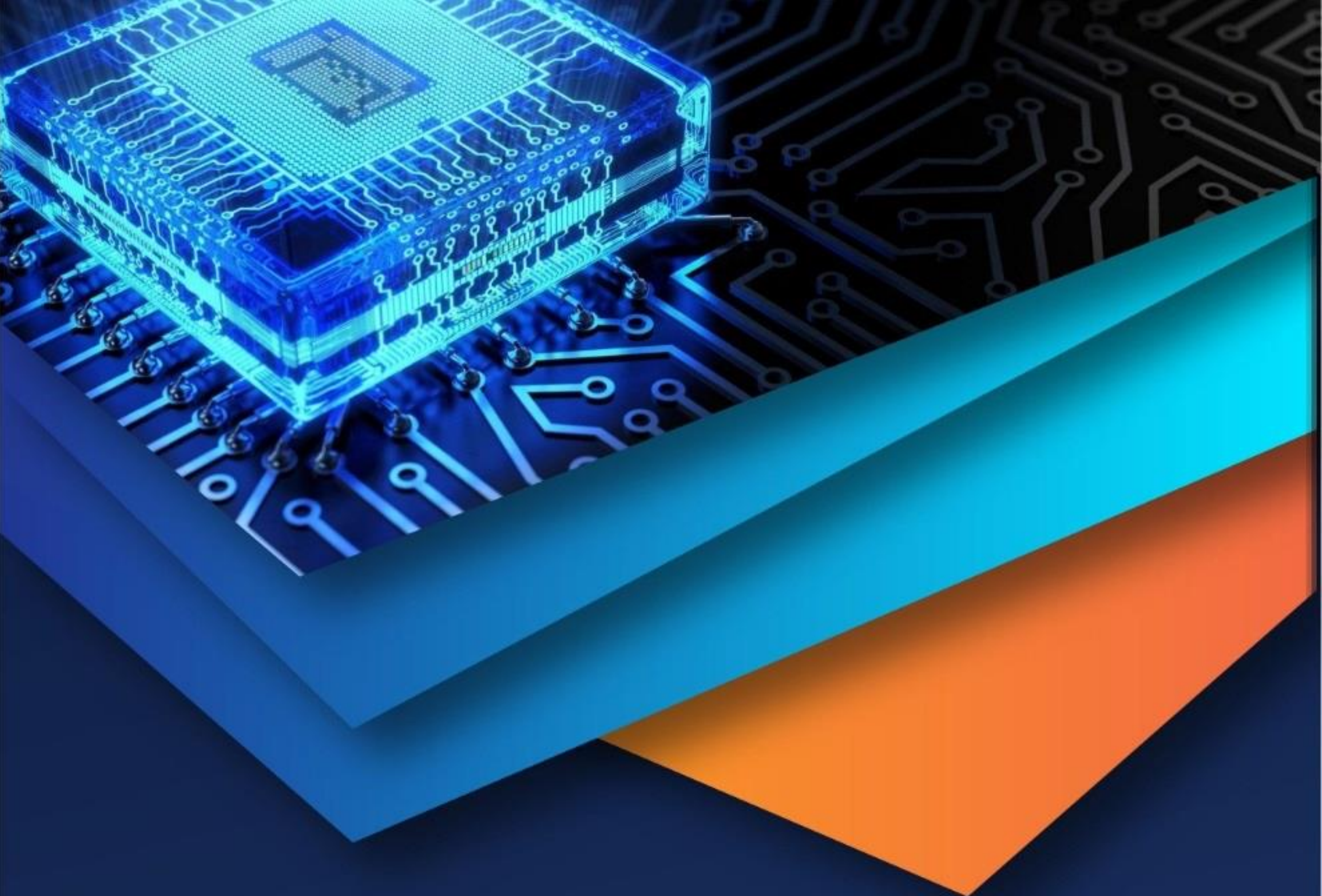
A broad experimental investigation is carried to analyze the effect of important process parameters of FSW with experimental analysis and results. The Taguchi L9 orthogonal designed experiments have been proposed as a way of studying the FSW parameters for Magnesium Alloy (AZ91) welded joint. Main effects 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.

REFERENCES

[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', Materialsand 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.
[9] Watanabe T, Takayama H, Yanagisawa A (2006), 'Joining of aluminum alloy to steel by friction stir welding', Journal of Materials Processing Technology; 178:342-9.
[10] Abdollah-Zadeh A, Saeid T, Sazgari B (2008), 'Microstructural and mechanical properties of friction stir welded magnesium/copper lap joints', Journal of Alloy Compounds; 460:535–8.
[11] Esmaeili A, Zareie Rajani HR, Sharbati M, Givi MKB, Shamanian M (2011), 'The role of rotation speed on intermetallic compounds formation and mechanical behaviour of friction stir welded brass/magnesium 1050 couple', intermetallics; 19: 1711–9.
[12] Fujii H, Cui L, Tsuji N, Maeda M, Nakata K, Nogi K (2006), 'Friction stir welding of carbon steels', Materials Science and Engineering, 429: 50−57.
[13] Hirata T, Oguri T, Hagino H, Tanaka T, Chung SW, Takigawa Y (2007), 'Influence of friction stir welding parameters on grain size and formability in AZ91 aluminum alloy', Materials Science and Engineering; 456:344-9
[14] Geiger M, Micari F, Merklein M, Fratini L, Contorno D, Giera A (2008), 'Friction stir knead welding of steel magnesium butt joints', International Journal of Machine Tools & Manufacture; 48:515-21.
[15] Nalbant M, Gökkaya H, Sur G (2007), 'Application of Taguchi method in the Optimization of cutting parameters for surface roughness in turning', Materials and Design; 28:1379–85.
[16] Tanaka T, Morishige T, Tomotake Hirata T (2009), 'Comprehensive analysis of joint strength for dissimilar friction stir welds of mild steel to magnesium alloys', Scripta Materialia; 61:756-9.
[17] Shojaeefard MH, Akbari M, Tahani M, Farhani F (2013), 'Sensitivity analysis of the artificial neural network outputs in friction stir lap joining of magnesium to brass', Advanced Material Science Eng; 2013:7.
[18] Seighalani KR, Givi MKB, Nasiri AM, Bahemmat P (2010), 'Investigation on the effects of the tool material, geometry and tilt angle on friction stir welding of pure titanium', Journal of Materials Processing Technology; 19:955-62.
[19] Ouyang J, Yarrapareddy E, Kovacevic R (2006), 'Microstructural evolution in the friction stir welded 6061 magnesium alloy to copper', Journal of Material Processing Technology; 172:110–22.
[20] Tang W, Guo X, McClure JC, Murr LE, Nunes A (1998), 'Heat input and temperature distribution in friction stir welding', Journal of Materials Processing Technology 7:163-9.
[21] J.M.T. Holt, Technical Ed, in: C.Y. Ho (1996), 'Structural Alloys Handbook', 1996 Edition, CINDAS/Purdue University, West Lafayette.
[22] A.P. Zhilyaev, G.V. Nurislamova, B.K. Kim, M.D. Baro, J.A. Szpunar, T. Langdon (2003), 'Acta Materials', 51; 753.
[23] M. Shamanian, M. Mohammadnezhad, J. Szpunar (2014), Journal of Alloy Compounds 615; 651.
[24] S.Z. Han, M. Goto, C. Lim, S.H. Kim, S. Kim (2009), Journal of Alloy Compounds. 483; 159.
[25] E.D. Nicholas (1998), 'Developments in the friction stir welding of metals, in: IC -6: 6th International Conference on Magnesium Alloys', Toyohashi, Japan.'
[26] Gurmeet Singh, Kulwant Singh, Jagtar Singh (2011), 'Effect of process parameter on microstructure and mech. Properties in FSW of Al- Alloys', Transactions pf Indian Institute of Metals. 64:1.
[27] Gurel Cam, Celcuk Mistikoglu (2014), 'Recent developments in FSW of Al- Alloys. Journal of Material Eng. and process', 23: 1-2.
[28] H. K Mohanty, M.M. Mahapatra, P. Kumar, P. Biswas, N.R. Mandal (2012), 'Modeling the effect of tool shoulder and probe profile geometries on friction stirred magnesium welds using RSM', Journal of Marine Science 11: 493-503.

[29] Chakradhar D, Venu Gopal A (2011), 'Multi-objective optimization of electrochemical machining of EN31 steels by grey relational analysis', International Journal of Modeling and Optimization, 1(2), 113-117.
[30] Yahya Bozkurt (2012), 'The optimization of Friction stir welding process parameters to achieve maximum tensile strength in polyethylene sheet', Materials & Design 35: 440-445.
[31] M. Koilraj, V. Sundareswaran, S. Vijayan, S.R Koteswara Rao (2012), 'Friction stir welding of dissimilar Magnesium alloys 2219 to AZ91 optimization of process parameters using Taguchi technique', Materials & Designs 42: 1-7.
[32] R. Nandan, T. DebRoy, H.K.D.H. Bhadeshia (2008), 'Recent advances in friction-stir welding – Process, weldments structure and properties', Progress in materials science, 53:9-10, 20.
[33] Sefika Kasman (2013), 'Multi-response optimization using Taguchi-based grey relational analysis: case study of dissimilar friction stir butt welding of 6082 - 5754', International Journal of Advanced Manufacturing Technology, 68:1-2.



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