Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 11, Special Issue 8, 2023
DOI (Journal): 10.37591/JoPC

http://engineeringjournals.stmjournals.in/index.php/JoPC/index

Research JoPC

Process Parameter Optimization of Magnesium Alloy Material Welded by Friction Stir Welding Using UTM and Taghuchi Approach

Amit Hemkant Karwande[1,*], Srinivasa Rao Seeram[2]

Abstract

Welding is a fabrication process where materials are fused together which may similar or dissimilar according to requirement. Welding is a systematic approach where dissimilar and similar materials are welded with an application of heat. Friction stir welding (FSW) is a welding method where metals are converting to a molten phase and with a desirable application of pressure leads to metal joining. FSW is a metal joining process used in an industry in a various way of applications. In this paper different properties of alloy material (Alloy of magnesium i.e. AZ91 and A31) are obtained; these specimens are welded by using FSW method of solid joining along with the use of taper tool. Specimens with dimensions of 150 mm by 50 mm in length and width respectively and has a thickness of 5 mm; which welded and different mechanical properties are determined by using Universal Testing Machine (U.T.M.). Before, testing of weld specimen using UTM; welded parts are cut in the form of ASTM (American Society for Testing and Materials) for evacuation of different mechanical properties. L_9 *orthogonal array and Design of Experiment (DOE) is used as a tool in experimental work to have better results. Also, to correlate between different experimental data; Analysis of Variance (ANNOVA) is used as a statistical tool.*

Keywords: Analysis of Variance, Friction Stir Welding, Design of Experiment, Universal Testing Machine, Orthogonal Array

INTRODUCTION

Magnesium is an abundant metal on the planet, having numerous qualities such as little density, elevated strength and excellent machinability. Metals such as silicon, zinc, magnesium, aluminium, and copper in appropriate proportions are mixed with magnesium as the basis material to make magnesium alloy. Magnesium is the most often utilized metal for engineering applications because of machinability and availability [21]. Welding is a fabrication method in which materials are welded that may be similar or dissimilar as per different requirement. Friction stir welding (FSW) is a metal joining procedure that converts molten phase of metals with a desired application of pressure, resulting in metal joining. Because magnesium is machinable, it is used as a foundation metal for work pieces [23]. Welding is a fabrication method that is used to fuse materials together, most commonly metals or thermoplastics.

In his study, he investigates the ideal characteristics for materials like steel and Austenitic Stainless Steel. Friction stir welding method is utilized for welding proves with

***Author for Correspondence**
Amit Hemkant Karwande

[1]Research Scholar, Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation (Deemed to be University), Vijayawada, Andhra Pradesh, India
[2]Professor, Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation (Deemed to be University), Vijayawada, Andhra Pradesh, India

Received Date: November 27, 2023
Accepted Date: December 30, 2023
Published Date: January 01, 2024

Citation: Amit Hemkant Karwande, Srinivasa Rao Seeram. Process Parameter Optimization of Magnesium Alloy Material Welded by Friction Stir Welding Using UTM and Taghuchi Approach. Journal of Polymer & Composites. 2023; 11(Special Issue 8): S381–S392.

weldabilty of 5% SiC particulate aluminum matrix and different process parameters [1].

Aluminium matrix composites with the distribution of particles and particle size of the processed material by FSW are distributed. So, for an aluminium with consideration of reinforcing phase of particles as per different sizes of work piece [17]. Also, mechanical properties of weld are observed with experimental results [2]. The micro structural and mechanical features of 2060 Al-Cu-Li as a base material show huge pan-cake grain in the size of nuggets nugget and fine grains at welded region [3].

Researchers contributed to the application of FSW for pipe and pipe related applications; results were obtained for tool weld speeds of 775 rpm, 1000 rpm, 1300 rpm, and 1525 rpm [25]. This result is useful for selecting a dependent parameter such as the speed of rotation of tool as per specific range [4]. The geometry of the tool and pin profile are the major aspects for localizing heating action takes place near welded region [24]. So, it critical to lookout the type of material flow, which is heavily affects due to profile of pin, diameter of pin and process parameters [5]. Mechanical investigation of a friction stir weld; specifically, nugget's size of an aluminium alloy 2050, which changes as per variation in distance with respect to weld surface, plays a vital impact in the microstructure property [6]. Micro structural behaviour of dissimilar welds with the different process parameters are to determine the good conditions of weld. As per the findings of this study, placing aluminium weld side resulted in greater weld quality with tool advancement. The valuation of the hardness using the section joint results micro structural changes in gain size of a weld [7]. The key component in FSW weld tool; nevertheless, the tool degrades and changes shape during usage; nonetheless, only a very few experiments were carried out to understand the flow of materials and tool geometry and the confirmation of results using Computational Fluid Dynamics (CFD) [8].

Goals for improving experimental results to determine weld fatigue strength; different fatigue behaviour of weld is considered of aluminium materials [9]. Limitations of different type welding like fuse welding; different properties as corrosion resistance of base metal need to be improved [10]. One of the important variables affects friction stir weld quality is a weld tool. Tool profile is affected by the microstructure and pitting corrosion of different copper and aluminium alloy [11]. Mostly different manufacturing industries are using FSW for weld joints of copper and aluminium bars. SEM, EDS, and XRD examined micro structural behaviour. For additional experimental work, the surface temperature of weld specimen is measured using an infrared thermo graphic camera [11]. Three types of starting microstructures were linked by FSW with varying micro structure, angle boundries and densities for development in stir zone in FSW [12]. Weld samples consists of zenith strength for an aluminium alloy with a high Zn concentration rotating at 350 to 950 rpm and transverse tool speed of to 150 mm/min. It is discovered that as welding speed or tool rotation rate increased, the size of gain for the nugget zones reduced [13]. Different magnesium alloys used in this welding process are AZ91 and AZ31 with a different alloy material composition with tensile strength of 272 N/mm^2 for this experimental work [19]. The specimen size is taken as 150 mm by length, 30 mm by width and a thichness of 5 mm [14]. This experiment uses magnesium alloy materials such like AZ31 and AZ91. Both alloy's have a lower density than steel, it and less in weight. The materials used here are also strong, ductile, and corrosion resistant. For experimentation process parameter selected as a rotating seed, transverse speed, and materials are chosen [15].

METHODOLOGY

Methodology is an art of utilize different engineering principles and methods in systematic way to have a solution to problem statement. Selection of proper methodology is a important aspect of any research work; with regards to approach of Friction Stir Welding (FSW) different literature review studied to gather the useful information. Literature review approach is a monitoring tool by which we can evaluate and correlate our research work, methodology with other researcher's. In this research work, selection of material is important; a magnesium alloy material is preferred as a base material due to application, availability and several different mechanical advantages with other material [28]. While selecting the base material in FSW different properties like strength, water resistance, corrosion resistance and ozone resistance of metal is also considered. In this research work; base material is selected as magnesium alloy; selection of weld tool is also very important because in FSW welding tool is non consumable. Selection of tool is depends on nature of weld, material of tool and material to be selected for welding along with type of welding proffered by the user. Proper precautions and care should be taken while doing welding AZ31 and AZ91 base metal; as welding is dangerous process and safety considered as first priorities [27]. Proper guidelines should be follows prior to perform the welding operation like precautions to avoid fire, proper eye protection, ventilation near the weld area and clean area of weld [17]. In FSW, heat is generated rotating tool and base metal surface as shown in Figure 1, which is responsible to make softer surface; mostly near the tool region. Simultaneously advancing the tool transverse motion in a line and weld is propagated.

Figure 1. FSW process for butt welding [19].

After welding; testing of welded specimen in UTM is important parameter by which different mechanical properties are evaluated. Figure 2 represents the methodology adopted in this research work starting from literature review to results and conclusion.

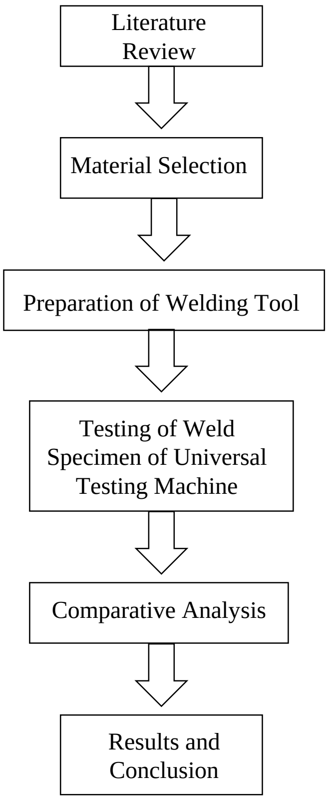

Figure 2. Flow process [14].

In FSW material selection procedure is indispensable part that is decided like for material of tool, speed of tool rotation, axial down force, speed of translation of tool and material types and various material combinations used [16]. AZ91 and AZ31 (Magnesium alloy materials) are selected because; these alloys have lesser dense nature than aluminum and steel. Figure 3 indicates the base material AZ1 and AZ91 used in welding process [27]. It is available in the round bars and sheets; as per material availability in the merchandise; this materials are selected the desired alloys of magnesium AZ31 and AZ91 of 5 mm thickness are selected in this work. Further the proper welding method knowledge is also essential with selection of different dependent parameter of weld prior to test weld specimen under U.T.M. [25]. After the following proper testing methodology different comparative analysis is conducted to comment on result. Table 1, indicates the different composition of base material used for welding.

Table 1. Material composition of AZ91 and AZ91 [15].

S.N.	Material Composition of AZ91	Material Composition of AZ31
1	a. Aluminium percentage- 8.67 b. Iron percentage- 0.002 c. Zinc percentage- 0.85 d. Magnesium percentage- 0.03 e. Tensile strength- 240 N/mm^2	a. Aluminium Percentage- 2.75 %, b. Iron percentage- 0.001 c. Zinc percentage-0.91 d. Magnesium percentage- 0.01 e. Tensile strength- 272 N/mm^2

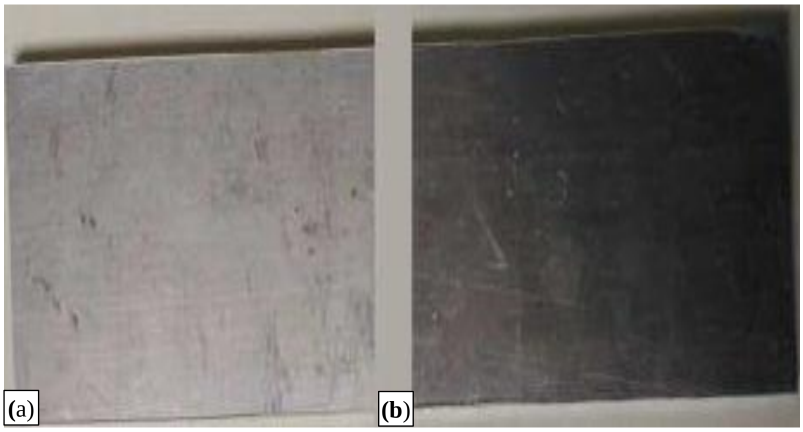

Figure 3. (a) Base material AZ31 and (b) AZ91 [15].

H13 steel is used as a weld tool as sown in Figure 4; which is a High Speed Steel generally proffered in welding. Due to maximum toughness and most stability in nature it is generally used in heat treatment applications.

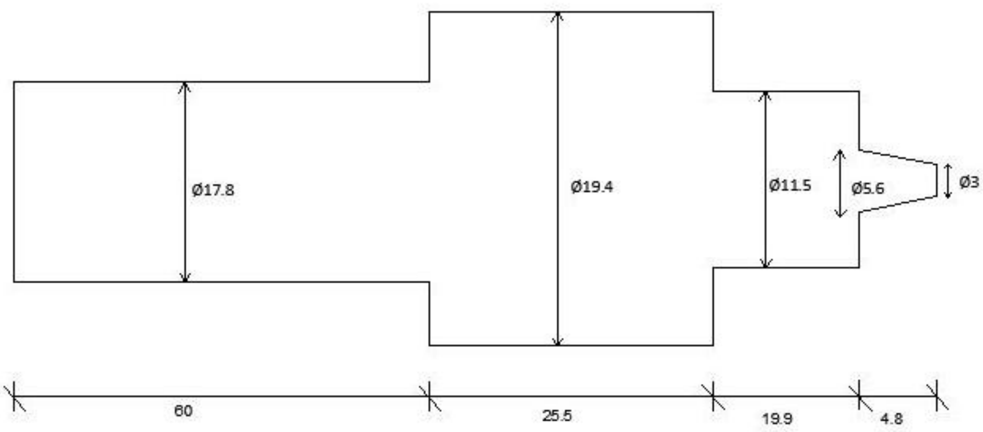

Figure 4. Geometry of tool (All dimensions are in mm) [15].

As per FSW; quality of welding material is concern huge impact by the geometry and quality of weld tool. Also, the weld tool tip plays an vital impact as per quality of weld is concern. Overall length of tool is taken as 110 mm with a design tolerance of 5 mm as per design consideration. It generally, consists of three basic geometries; pin, shoulder and body part which are are 4.8 mm, 19.9 mm and 85.5 mm in length respectively. Basic component of weld is shown in figure 5. Appropriate tool tilt angle also useful for determination of microstructure and different relevant weld parameters [22]. While selecting proper weld tool different parameter of tool along its effect on weld is also considered. Because; the different parameter has its own specific effect on tool and on to the weld quality. Table 2 revealed different effect of weld on weld parameter.

Table 2. Control parameter and their effects [4]

S.N.	Control Parameter	Effects on welding
1	Speed of Rotation	Heating at welding point, stirring, oxides of weld
3	Speed of Welding	Control in weld heat, Weld appearance

FSW weld not only depends on tool geometry but also on different control parameters. Control parameter and its effects on welding is represented in Table 2. Tool geometry is also depends on the required application of weld. Figure 5, actual tool used in welding process [26].

Figure 5. Actual tool for welding [15].

RESULT AND DISCUSSION

In this research paper; different experimental run performed as per factorial design and carried analytical work. When a number of experiments are more; process parameter is also increases. In experimental set up different post welding is narrated to get different conclusive output. Experimental work with comparative analysis will provides an idea about the different statistical tools and methods which imparts in this research work.

Experimental Set Up

Here, FSW welding process tool requires the cylindrical shoulder with a profiled probe with a pin. AZ91 and AZ31 are joining together similarly or dissimilarly using FSW process; proper fixture is also important to perform welding operation properly [27]. Backing plate which is a part used to provide support to work piece along with anvil is used in this work. Tools rotation speed selected with given experimental revolution per minute (RPM) data along with translation velocity along weld line so as to perform welding operation properly. For simplicity in experimentation DOE (Design of Experiments) used in this work [28]. Different regression techniques like factorial design which mostly preferred in engineering research work is apply for this experimental data [18]. Regression technique is one of the statistical method; where linear relationship between the process parameter are established or within multiple variables used in experimentation. Also, using regression technique, different variable results are modeled by using linear prediction function which will provide linear model. Linear regression technique mostly gives joint probability between different variable under consideration. This technique uses experimental data in a controlled manner as per experimental run values. Table 3 indicates different levels and working parameters; this work also narrates the number of experiments by full factorial design and carried analytical work which depends on the ANOVA.

Table 3. Working parameters with levels [14].

S.N.	Experimental Level	Speed of Tool Rotation (rpm)	Speed of Tool Transverse (mm/min.)
1	1400	80	AZ91 & AZ31
2	1200	75	AZ91
3	1000	60	AZ31

Table 4. Parameter response with L_9 orthogonal Array [15].

S.N.	P1	P2	P3	R1	R2	R3
1	P11	P21	P31	R11	R21	R31
2	P11	P22	P32	R12	R22	R32
3	P11	P23	P33	R13	R23	R33
4	P12	P21	P32	R14	R24	R34
5	P12	P22	P33	R15	R25	R35
6	P12	P23	P31	R16	R26	R36
7	P13	P21	P33	R17	R27	R37
8	P13	P22	P31	R18	R28	R38
9	P13	P23	P32	R19	R29	R39

Figure 6. Centering the tool on the work piece joining line [15].

Table 4 shows the response parameter in the form of orthogonal array. Main objective here to utilise different optimization techniques to obtained the set the influential variables so that the effects with unrestricted variables are minimized. In this investigation, the outcome as control parameters such as rotating speed, speed of tool transverse and axial load on alloy AZ91 and AZ31 is to be studied [29]. Here, P is Parameter and R is Response. FSW performed with more care along with many procedures and precautions too. Micro structural or mechanical properties are depends on process parameter to avoid any damage of equipment too. Experimentation work conducted as per L_9 orthogonal array and Taghuchi approach. ANOVA which is statistical optimization technique, that not only optimum levels but to find the significance of each process parameter. Here vertical milling machine is used for perform welding process which has travel capacity as 1600 mm for x axis, 800 mm for y axis and 750 mm for z axis. Also, running speed limit is 30 to 7500 revolutions per minute and load application up to 1800 kg. A fixture is needed to design as per work piece dimensions and specification of milling machine.

Comparative Analysis

Figure 6 and 7 are represents tool centering in FSW and actual weld plate after welding process respectively. Taguchi technique which is an optimization tool used in this research work for intensify quality of product and process parameters [20].

Figure 7. Plate after weld [15].

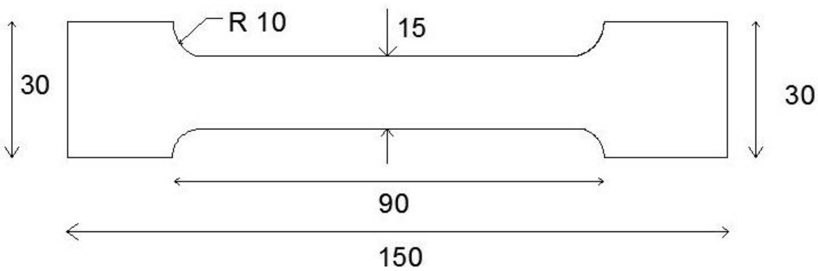

Figure 8. Weld specimen dimensions as per ASTM Standard (All dimensions are in mm) [14].

Figure 9. Specimen cut in I section as per standard [14].

As per the guidelines of ASTM weld specimen are prepared and tested in UTM machine to calculate different mechanical properties. For testing in weld specimen; cross sectional area is 5 mm × 15 mm = 75 mm^2 and Gauge length = 90 mm are taken in consideration. Figure 8 shows the ASTM standards for welded specimen. While; Figure 9 represent the I-section of welded specimen.

Where, A-Speed of tool rotation (rpm), B-Transverse speed (mm/min), C- Work piece material,1-AZ31 Mg Alloy, 2-AZ91 Mg Alloy, 3- AZ91 and AZ31 Mg Alloy, UTS-ultimate Tensile Strength, YS-Yield Strength and %ELO- percentage Elongation. Table 5 given the different result as per Taghuchi method. The experiments conducted as per Taguchi approach along with the L_9 orthogonal array to find impact of various combinations of process parameters [20]. The ANOVA results are the initial step in analyzing factors that affect a given data set. After test, NNOVA comes into play to find information about different parameters relationship with respect to dependant and independent variables [30]. F ratio analysis allows the multiple parameters analysis for checking different sample variability. ANOVA is rapid method of analysis for variances present in the fisher test (F test); which give advantages like statistical significance in analysis. As per practical implementation it is valid for all sample sizes. Analysis is conducted with the significance of 5%, i.e. the level of confidence 95%

Table 5. Results as per taguchi method [15].

S.N.	A	B	C	UTS	YS	% ELO
1	1000	60	1	204.3	178.2	11.2
2	1000	70	2	192.7	172.6	4.1
3	1000	80	3	180.3	169.7	6.3
4	1200	60	2	196.5	174.7	4.3
5	1200	70	3	188.6	162.5	6.7
6	1200	80	1	211.4	182.6	12.9
7	1400	60	3	191.2	167.1	7.1
8	1400	70	1	218.1	186.2	13.3
9	1400	80	2	198.6	175.5	5.1

Table 6. Ultimate Tensile Stress results by ANOVA [15]

S.N.	Source	DF	Seq SS	Adj MS	F	P
1	A	2	159.4	79.72	54.85	0.018
2	B	2	15.61	7.8	5.37	0.157
3	C	2	923.9	461.9	317.8	0.003
4	Error	2	2.91	1.91	-	-
5	*Total*	8	-	-	-	-

Table 7. Yield stress results by ANOVA [15].

S.N.	Source	DF	Seq SS	Adj MS	F	P
1	A	2	16.71	8.35	0.48	0.676
2	B	2	11.64	5.82	0.33	0.749
3	C	2	379.2	189.6	10.89	0.084
4	Error	2	34.83	17.41	-	-
5	*Total*	8	442.4	-	-	-

Table 8. Percentage elongation by ANOVA [15].

S.N.o	Source	DF	Seq SS	Adj MS	F	P
1	A	2	2.562	1.281	11.19	0.082
2	B	2	0.576	0.288	2.51	0.285
3	C	2	101.6	50.78	443.2	0.002
4	Error	2	0.229	0.114	-	-
5	*Total*	8	104.9	-	-	-

Where, percentage contribution for Source A, B and C are 14.58%, 1.52% and 83.9% respectively. Also, R-Sq=93.32%, R-Sq (adj) =73.28%. Tables 6 and 7 indicates that ANOVA valus for for ultimate tensile stress and yield stress. Table 8 also indicates that ANOVA result for percentage elongation. From the Table 6, 7 and 8; which indicates that the parameter speed is very crucial parameter affecting tensile test followed by weld speed (rotation speed of tool) and material. F value is found to be larger for speed. From ANOVA analysis the value of P is less than 0.712 for all parametric sources. Therefore it is clear that weld speed and material have the influence on the tensile test.

Where, percentage contribution for Source A, B and C are 8.76 %, 5.63 % and 85.61 %

respectively R-Sq = 92.13% R-Sq (adj) = 68.51%

For Tensile Stress regression equation is

$$UTS = 194 + 0.0255\ A - 0.028\ B - 12.3\ C \quad (1)$$

For Yield stress regression equation is

$$YS = 173 + 0.00692\ A + 0.130\ B - 7.95\ C \quad (2)$$

For percentage elongation regression equation is

$$\%\ ELO = 7.8 + 0.00325\ A + 0.028\ B - 2.88\ C \quad (3)$$

Here R_2 is defined as coefficient of determination i.e. ratio of explained variation with respect to total variation. Also, when R_2 is towards unity which gives good model results; for above experimental work R_2 calculated 0.99 and which is acceptable. Similarly, 0.9226 and 0.9315 are the values obtained for samples S_1 and S_2 respectively.

Table 9 addresses about regression equation result; which represented good explanation about independent factors and response. Also, Figure 10, 11 and 12 indicates results in terms of graphs for ultimate tensile stress, yield stress and percentage elongation respectively with respect to experiment run. Also; Figure 13 represents that the contribution of different parameters like U.T.S., Y.S. and Percentage Elongation with respect to different experimental runs.

Table 9. Results obtained from regression equation [14]

S.N.	A	B	C	UTS	YS	Percentage Elongation
1	1000	60	1	205.52	179.77	10.9
2	1000	70	2	192.94	173.12	4.3
3	1000	80	3	180.36	166.47	6.9
4	1200	60	2	198.32	173.204	4.2
5	1200	70	3	185.74	166.554	6.5
6	1200	80	1	210.06	183.754	11.06
7	1400	60	3	191.12	166.638	7.3
8	1400	70	1	215.44	183.838	12.3
9	1400	80	2	202.86	177.188	5.8

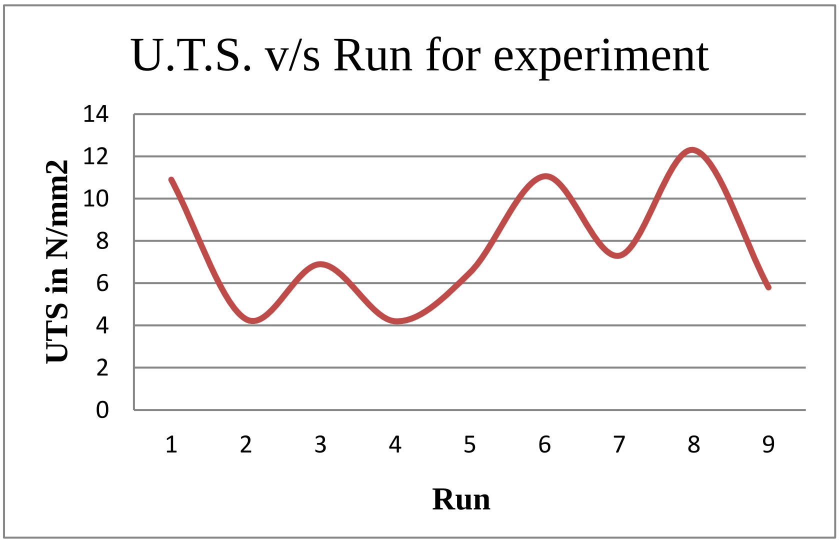

Figure 10. U.T.S. vs. run for experiment [14].

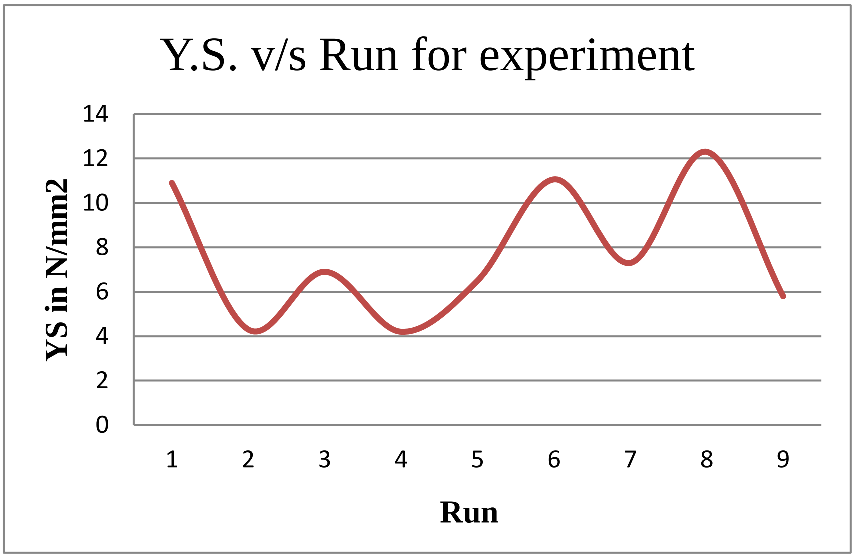

Figure 11. Y.S. vs. RUN for experiment [14].

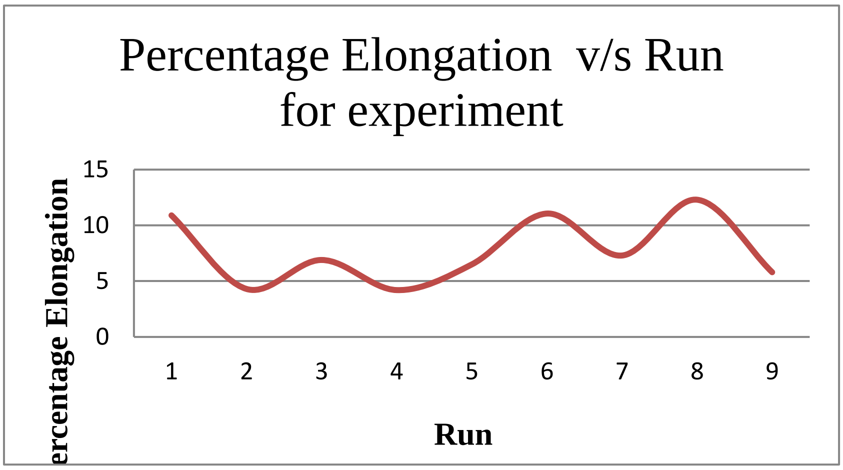

Figure 12. Percentage elongation vs. run for experiment [14].

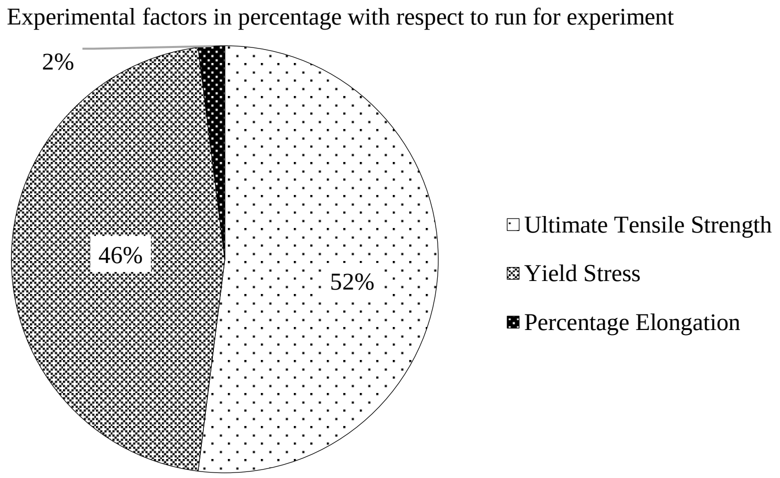

Figure 13. Percentage of different measuring factors vs. Run for experiment [15].

CONCLUSION

The suggested Taghuchi approach with ANOVA results gives new insights for study relation between weld specimen and weld parameter. Also, regression equation found for permissible range of errors (+/- 5% to 10%) when compared with experimental values. The welding of alloy of magnesium material shows good material properties of its weld specimen under observed using UTM. A mechanical property like strength is observed in weld for 1400 rpm with the transverse speed of 70 mm/min of process parameter for AZ31 alloy. Similarly different mechanical properties like ultimate tensile strength, yield strength and percentage of elongation are observed in similar plates of AZ31 alloy material with its maximum values. Minimum value of tensile strength, yield strength and percentage of elongation are observed in joint of AZ31 and AZ91 i.e.in unlike plates. ANOVA results shows that material and strength are the most influencing parameter amongst the remaining control parameters.

Acknowledgments

I am glad to express my kind appreciation to my supervisor, Dr. Srinivasa Rao Seeram, for his valuable guidance and support throughout this research project. His expertise and knowledge in technical filed giving me proper direction to accelerate my research work. I am also grateful to the Head of the Department of Mechanical Engineering, Dr. T. Vijaya Kumar, for his support and for providing a conducive research environment.

REFERENCES

1. Devanathana C. & Suresh Babub A. (2014). Friction Stir Welding of Metal Matrix Composite using Coated tool, 3rd International Conference on Materials Processing and Characterisation, 6, 1470–1475.
2. Kurtyka P., Sulima I., Wojcicka A., Ryłko N. & Pietras A. (2012). The influence of friction stir welding process on structure and mechanical properties of the AlSiCu/SiC composites. Journal of Achievements in Materials and Manufacturing Engineering, 55(2), 339–344.
3. Caia B., Zheng Z., He D., Li S. & Li. H. (2015). Friction Stir Weld of 2060 Al-Cu-Li Alloy: Microstructure and Mechanical Properties. Journal of Alloys and Compounds, 649, 19–27.
4. Hasein A., Akber A. & Khleif A. (2022). Mechanical Properties Evaluation in Friction Stir Welding of Different Pipes. Journal of Nature, Science & Technology, 2, 1–4.
5. Dawood I., Mohammed K., Rehmat A. & Uday M. (2015). Effect of small tool pin profiles on microstructures and mechanical properties of 6061 aluminum alloy by friction stir welding. Transactions of Nonferrous Metals Society of China, 25(9), 2856–2865.
6. Dhondt M., Aubert I., Saintier N. & Olive J. (2015). Mechanical behavior of periodical microstructure induced by friction stir welding on Al–Cu–Li 2050 alloy. Materials Science & Engineering A, 644, 69–75.
7. Dorbane A., Mansoor B., Ayoub G., Shunmugasamy V. & Imad A. (2015). Mechanical microstructural and fracture properties of dissimilar welds produced by friction stir welding of AZ31B and Al6061. Materials Science and Engineering: A, 651, 720–733.
8. Hasan A., Bennett C. & Shipway P. (2015). A numerical comparison of the flow behaviour in Friction Stir Welding (FSW) using unworn and worn tool geometries. Materials & Design, 87, 1037–1046.
9. Infante V., Braga D., Duarte F., Moreira P, Freitas M. & Castro P. (2015). Study of the fatigue behaviour of dissimilar aluminium joints produced by friction stir welding. International Journal of Fatigue, 82(2), 310–316.
10. Rao V., Reddy G. & Rao K. (2015). Microstructure and pitting corrosion resistance of AA2219 AleCu alloy friction stir welds e Effect of tool profile. Defence Technology, 11, 123-131.
11. Wei Y., Li J., Xiong J. & Zhang F. (2016). Investigation of interdiffusion and intermetallic compounds in Al–Cu joint produced by continuous drive friction welding. Engineering Science and Technology, an International Journal, 19, 90–95.
12. Yoon S., Ueji R. & Fujii H. (2015). Effect of initial microstructure on Ti–6Al–4V joint by friction stir welding. Materials and Design, 88, 1269–1276.
13. Zhang F., Su X., Chen Z. & Nie Z. (2014). Effect of welding parameters on microstructure and

mechanical properties of friction stir welded joints of a super high strength Al-Zn-Mg-Cu aluminum alloy. Materials & Design, 67, 483–491.
14. Karwande A. & Rao S. (2018). Welding parameter optimization of alloy material by friction stir welding using Taguchi approach and design of experiments. AIP Conference Proceeding, 1952, 1–5.
15. Karwande A. & Rao S. (2019). An experimental analysis and welding parameter optimization in friction stir welding for aluminum and magnesium alloy materials. International Journal of Mechanical and Production Engineering Research and Development 9(3), 729–736.
16. He X., Gu F. & Ball A. (2014). A review of numerical analysis of friction stir welding. Progress in Materials Science, 65, 1–66.
17. Jedrasiak P. & Shercliff H. (2018). Small strain finite element modelling of friction stir spot welding of Al and Mg alloys. Journal of Materials Processing Technology, 263, 207–222.
18. Olubunmia B., Karmakar B., Aderemi O., Uduak A., Auta M. & H. Gopinath. (2020). Parametric optimization by Taguchi L9 approach towards biodiesel production from restaurant waste oil using Fe-supported anthill catalyst. *Journal* of Environmental Chemical Engineering, 8(5), 104288.
19. Sunil B., Reddy P., Mounika A., Sree, P. Pinneswari P., Ambica I., Babu A. & Amarnadh P. (2015). Joining of AZ31 and AZ91 Mg alloys by friction stir welding. Journal of Magnesium and Alloys, 3(4), 330–334.
20. Ghani J., Choudhury I. & Hassan H. (2004). Application of Taguchi method in the optimization of end milling parameters. Journals of Materials Processing Technology, 145, 84–92.
21. Radj B. & Senthivelan T. (2018). Analysis of mechanical properties on friction stir welded magnesium alloy by applying Taguchi Grey based approach. Materials Today Proceeding, 5, 8025-8032.
22. Raj A., Kumar J., Rego A. & Rout I. (2021). Optimization of friction stir welding parameters during joining of AA3103 and AA7075 aluminium alloys using Taguchi method. Materials Today Proceeding, 46(17), 7733–7739.
23. Kang H. & Ahn J. (2021). Model Setting and Interpretation of Results in Research Using Structural Equation Modeling: A Checklist with Guiding Questions for Reporting. Asian Nursing Research, 15(3), 157–162.
24. Sarolkar A. & Kolhe K. (2017). Effect of process parameters on weld bead geometry and micro-hardness of welding AA 6082 using GTAW process. Journal of Emerging Technologies and Innovative Research, 4(10), 200–207.
25. Shukla S. & Sahu V. (2015). Weld Quality Prediction of Mild Steel Pipe Joint during Shielded Metal Arc Welding through ANN. International Journal of Engineering Research & Technology, 3(20), 1–4.
26. Shimpi R., Kumar C. & Katarane R. (2020). Friction Stir Welding Processing, Materials and its Applications. IOP Science Publishing, 810, 1–13.
27. El-Sayeda M., Shash A., Abd-Raboub M. & El-Sherbiny M. (2021). Welding and processing of metallic materials by using friction stir technique: A review. Journal of Advanced Joining Processes, 3, 10059.
28. Richmirea S., Hall K. & Haghshenas M. (2018). Design of experiment study on hardness variations in friction stir welding of AM60 Mg alloy. Journal of Magnesium Alloys, 6(3), 215–228.
29. Singh K., Singh G. & Singh H. (2018). Review on friction stir welding of magnesium alloys. Journal of Magnesium Alloys, 6(4), 399–416.
30. Ahmadkhaniha D., Sohi M., Zarei-Hanzaki A., Bayazid S. & M. Saba. (2015). Taguchi optimization of process parameters in friction stir processing of pure Mg. Journal of Magnesium Alloys, 3, 168–172.

