



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 11, Issue 8, August 2022

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 8.118

 9940 572 462

 6381 907 438

 ijirset@gmail.com

 www.ijirset.com

Multiple Performance Characteristics Optimization of Friction Stir Welded Joint using Taguchi Coupled with GRA

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ABSTRACT: This study emphasizes the experimental study and improvement of crucial FSW process parameters for joints made of aluminium alloy 6061-T6 of 5 mm thick sheet employing H13 tool at a varied tool rotation speed, tool tilt angle & traverse speed to detect their distinct and combined effects on the tensile strength and percentage elongation of friction stir welded joints. This paper aims to find the operating conditions to achieve the maximum tensile and % elongation in the joint. Taguchi's design of experiments was used to minimize the number of trials. GRA is used for multi-response optimization, and ANOVA is done to find the contribution of individual factors using Minitab software. The tensile strength and % elongation of the joint is determined experimentally. The confirmation trials done using the optimized parameter's values shows the highest tensile strength and elongation at the tool rotation speed of 900rpm, tool tilt angle of 0° and welding speed of 200mm/min.

KEYWORDS: Gray relational analysis, Taguchi L9 OA, Multi-objective optimization, Friction stir welding.

I. INTRODUCTION

Friction stir welding (FSW) is a patented process designed and developed, especially for the joining of low melting point alloys at The Welding Institute by W. Thomas and E. Nicholas in the year 1991. [1], [2]. FSW has proven to be the state-of-the-art technology for the joining of various aluminium alloys to other low melting point alloys. This process does not require any consumable or shielding gas and the operating [3]. Heat is generated during the process due to friction between the rotating tool and the contact surfaces of the workpiece and plastic deformation of substrate materials. The rotating tool employed in the process moves in the direction of the abutting surfaces. The plastic deformation of the material and mechanical blending of the two pieces of the metal take place as the tool moves ahead. Lite pressure is applied on the joining plate surface by the tool surface. Intense intermixing of the material due to probe profile at higher temperature takes place in the FSW process and fine microstructure produces better mechanical properties [4]–[7]. FSW is superior to joining comparable and dissimilar alloys that are challenging to connect using the fusion welding technique due to its many benefits, including low stress, high strength, and non-pollution [8][9]. FSW technique has extensive applications such as in composite joining, trains, aerospace, the automobile, marine, etc. [10]–[12].

Similar and dissimilar Aluminium alloys, copper and its alloys, stainless steel, mild steel, and magnesium and its alloys are the most common metals welded using the FSW technique. AA6061 is a nonferrous alloy with a major percentage of aluminium. This is commonly accessible and applied for the manufacturing of the various frames & fittings of diverse engineering applications. Because of their outstanding strength, butt welded joints are used extensively in engineering, including in the automotive, offshore, bridge, and aviation industries.

Numerous authors have discussed their abundant research on solid state Friction welded joints of like and unlike materials. Mechanical properties and microstructure investigations of friction stir welded joints of AA6061 & AA5086 using different tool profiles reveals the better material flow, higher tensile strength, and higher hardness was obtained using threaded pin profile than straight cylindrical profile pin [13]. Various Microstructure formed using different joining parameters influences the weld quality and joint performance [14]. Research progress and issues like tool material and tool profile for joining of steel have been reviewed and summarized [15]. Maximum 75 % joint efficiency of friction stir welded joint of AA2219-T87 was reported by varying the process parameters [16]. Joint made using bolt head pin profile with traditional pin profile was investigated at various tool rotation speeds and welding speeds. Using straight hexagonal bolt heads (SHBH) improves material flow and uniformly distributes plastic deformation with fewer macroscopic flaws [17]. The tensile strength and joint

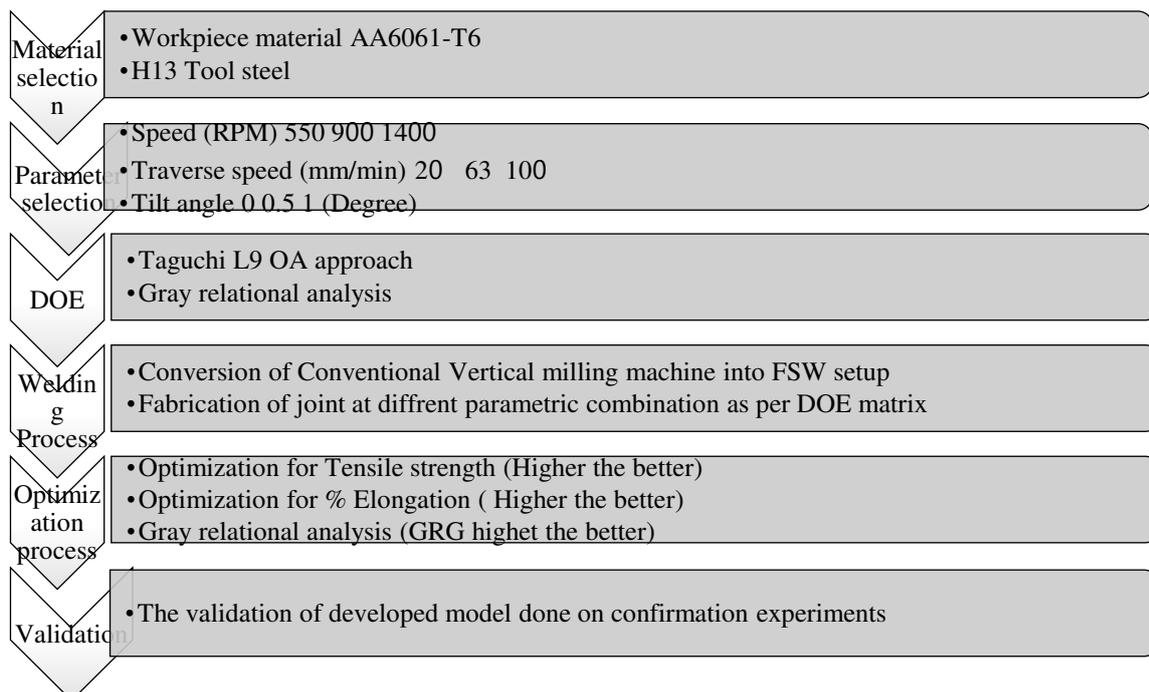


ductility and hardness values of friction stir welded joints of AA6061-T6 and AA8011 reveals maximum tensile strength 77MPa and 21.96 % elongation [4]. The lowest hardness was measured at the FSW junction of 6 mm thick metal sheets of AA6061-T651. The weld joint strength exhibits proportional relationship with welding speed irrespective of tool size and rotation speed [18]. The influence of tool rotation speed on mechanical properties and microstructure evolution of different regions of joints of AA2195-T8 were examined. Fine and equiaxed grains were seen in the pin-influenced zone in the joint made at a high rotation speed which was attributed to the re-precipitation at high rotation speed after dissolution [19]. Enhanced tensile strength and % elongation were obtained using the self-reacting tool in the joint made of 4 mm thick 6061-T6 AA at 600 rpm [20]. Response surface methodology (RSM) was used to analyze the influence of various process parameters and their levels on mechanical properties of the Friction stir welded joint made between AA2014 & AA6061 using a taper pin profile [21]. The impact of tool pin geometrical profile on FS welded joint of AA7075 and AA6061 was studied and examined. The joint was developed at 1100 rpm of spindle speed, 300 mm/min of traverse rate, and 30 tilt angles. According to the findings, flats on the pin's cone depart from the onion ring pattern and increase the welded joint's hardness and tensile strength [22]. The relationship was established between the tensile strength of friction stir welded joint of 5083-H321 and various pin profiles used in the joining process [23]. Dissimilar friction stir welding of 6061-T6 and 7075-T651 was conducted at various parameters, the results indicate higher tensile strength of joints formed at the higher feed rate, increasing rotating speed decreases the tensile strength on keeping constant feed. The highest wear resistance of joints occurred at 65 mm/min and 1850 rpm. Better intermixing of dissimilar materials was found at the tool rotation speed of 1250 rpm and of 110 mm/min traverse speed [24], [25]. The superplasticity of the AA7075-T651 alloy was examined in the research on the impact of the polygonal pin profile on friction stir processing. A non-uniform and uneven microstructure in the SZ caused the sticking of the workpiece material around the tool pin, as demonstrated by the polygonal pin profile. On the other hand, the sample made with the square pin tool shoulder produced a homogenous microstructure without cavitation [26]. A flaw less strong dissimilar weld joint of tensile strength around 45 MPa has attained optimal (tool rotation of speed 1600 rpm, traverse speed of 25mm/min, plunge depth of 0.2 mm and tool tilt angle 2°) processing parameters between the joint of AA5058 and PMMA [27].

It has been mentioned in the available literature [4][14], [20], [28][29] that FSW parameters pointedly affect the process and show noteworthy contribution in determining the quality of the joint fabricated.

In this paper, AA6061-T6 is joined by FSW to avoid the fusion welded defects. The design of the experiment was done following the Taguchi L9 Method. Gray relational and analysis used for multi-response optimization. ANOVA technique used to find the contribution of individual parameter using Minitab software. Statistical correlation is established between the selected set of variables and the measured tensile strength.

II. METHODOLOGY





III. EXPERIMENTAL DETAILS

3.1 Fabrication of Joint

The base material used in this work is 300mmx150mmx5mm thick Aluminium alloy. Single pass Butt joint was fabricated using a particularly designed hexagonal shape pin made of H13 tool steel. Tables 1 and 2 respectively list the chemical make-up and mechanical characteristics of the selected base material. Table 3 shows the chemical composition of tool material used.

Table 1 Chemical composition of AA6061

Material %	Mg	Si	Fe	Cr	Cu	Al
AA6061	0.92	0.6	0.33	0.18	0.25	97.72

Table 2. Mechanical properties of AA6061 material

Material	yield strength(MPa)	Ultimate tensile strength(MPa)	Hardness (HRA)
AA6061	0.92	0.6	0.33

Table 3. H13 tool material composition

AISI H13 tool steel	Cr	Mo	Si	V	C	Mn	Ni	Cu	P	S	Fe
Standard	4.75 - 5.50	1.1- 1.75	0.8- 1.5	0.8- 1.2	0.32- 0.45	0.2- 0.5	Max 0.3	Max 0.25	Max 0.030	Max 0.030	Ba 1
Tested	5.29	1.39	1.04	0.896	0.359	0.275	0.223	0.08	0.011	0.002	Ba 1

The vertical milling machine (make: HMT FM-2, 15 HP, 2500 r/min) employed in this research work, has a 40KN axial load capacity, and a 500 mm/min traverse speed. Three factors namely tool rotation speed, welding speed, and tilt angle were selected for joint fabrication. Factors and their levels were selected following the available literature and trial experiments. Hexagonal pin of 15 mm shoulder and 5 mm pin diameter of H13 tool steel were selected in this experimental work. The length of the pin is 4.5 mm. A rolled plate of 5mm thickness was cut into required shapes (300mmx150mm) using a power hacksaw, shaper, and milling machine. The specimen for testing were prepared following the ASTM E8 guidelines. The factors selected and their levels are given in Table 3.

Table 4. friction stir welding input process parameters and their levels[30]

S. No	Parameter	Notation	Unit	Levels		
1	Tool rotation speed	N	rpm	560	900	1400
2	Tilt Angle	TA	Degree	0	0.5	1
3	WS or Feed (mm/min)	WS	mm/min	20	63	100

The Taguchi L9 Experimental technique was used to develop the welding coupons. The Vertical milling machine and hexagonal pin used in the research are shown in Fig.1.



Figure 2 FSW setup

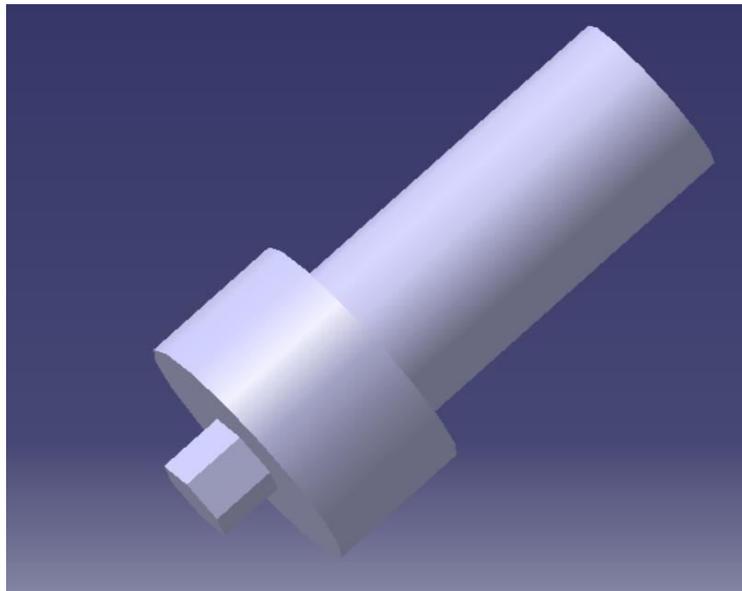


Figure 3 FSW tool

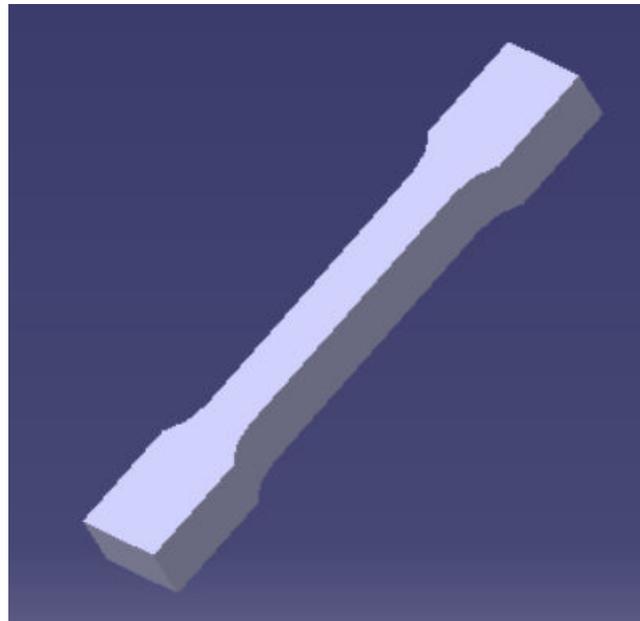


Figure 4. Tensile testing Sample Figure

Table 4. Taguchi DOE L9 and experimental values

Exp No.	Tool rotation speed (RPM)	Tilt angle (Degree)	Feed (mm/min)	Tensile strength (MPa)	Time is taken (min)	Elongation (%)
1	560	0	20	191	6.58	10.6
2	560	0.5	63	153	2.08	6.2
3	560	1	100	167	1.4	6
4	900	0	63	119	2.1	3
5	900	0.5	100	185	1.3	6.4
6	900	1	20	160	6.26	8
7	1400	0	100	191	1.2	10
8	1400	0.5	20	175	6.27	8
9	1400	1	63	155	1.2	4

A universal testing machine (UTM) was used to test the tensile test sample, which was prepared by the ASTM E8 standard. Table 4 lists the tensile strength and percent elongation findings that were attained. The specimen is shown in Fig. 4 both before and after testing.

The Taguchi philosophy is one of the quality improving technique developed by Dr. Genichi Taguchi in Japan in 1940[31]. To obtain the desired weld strength at a 95% confidence level, the process parameters are optimized using Taguchi optimization and ANOVA. The signal-to-noise (S/N) ratio response table is generated with the maximization of the larger the better and the value is arranged in table 5. Table 6 lists the mean value of the measured tensile strength. Table 7 tabulates the response table for the S/N ratio taking into account that the higher the better for percent elongation.

3.2 Processing factors affecting tensile property of material

The highest tensile strength of 191 MPa of the joint is observed in two cases. In the first when the Tool rotation speed is 560 rpm, tilt angle 0° and feed is 20 mm/min and in the second case tool rotation speed 1400 rpm tilt angle 0° and feed is 100 mm/min. but the time taken in both cases differs significantly. Therefore, less time-consuming condition i.e., rpm 1400, feed 100 mm/min seems to be more appropriate.



Table 5 S/N Ratio table
Larger is better

Level	TRS	TA	feed
1	44.59	44.25	44.85
2	43.65	44.63	43.00
3	44.76	44.11	45.14
Delta	1.12	0.52	2.14
Rank	2	3	1

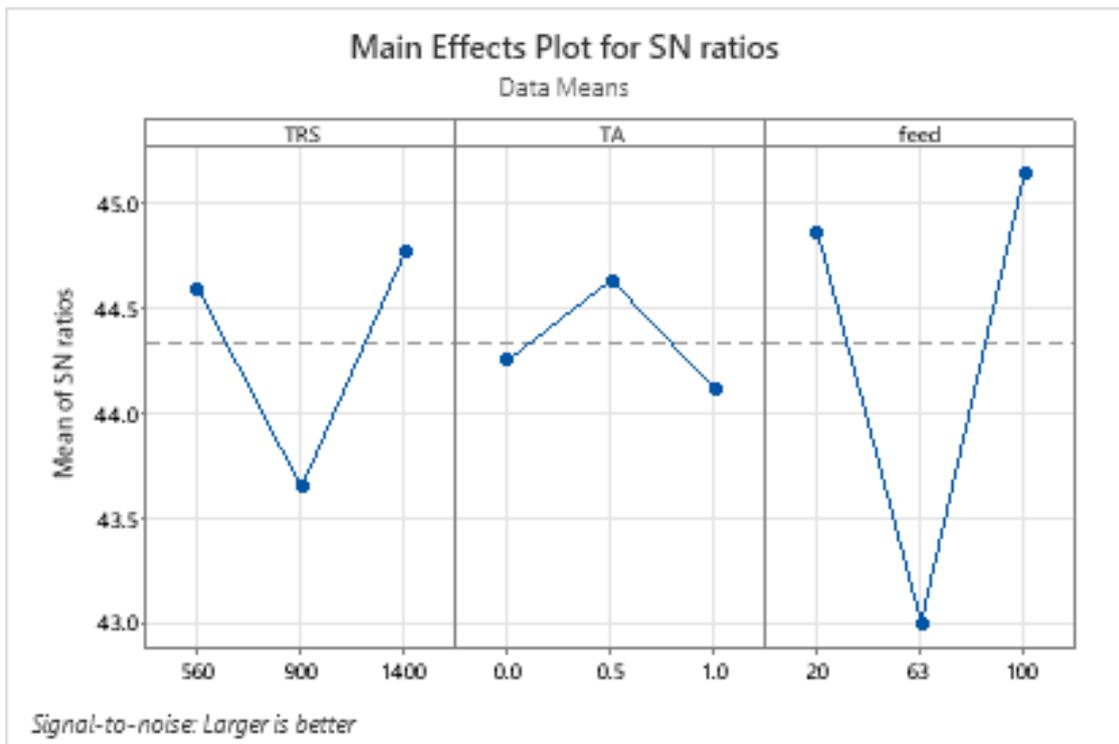


Figure 5 S/N ration for tensile strength

Table 6 Response Table for Meanof Tensile strength

Level	TRS	TA	Feed
1	170.3	167.0	175.3
2	154.7	171.0	142.3
3	173.7	160.7	181.0
Delta	19.0	10.3	38.7
Rank	2	3	1

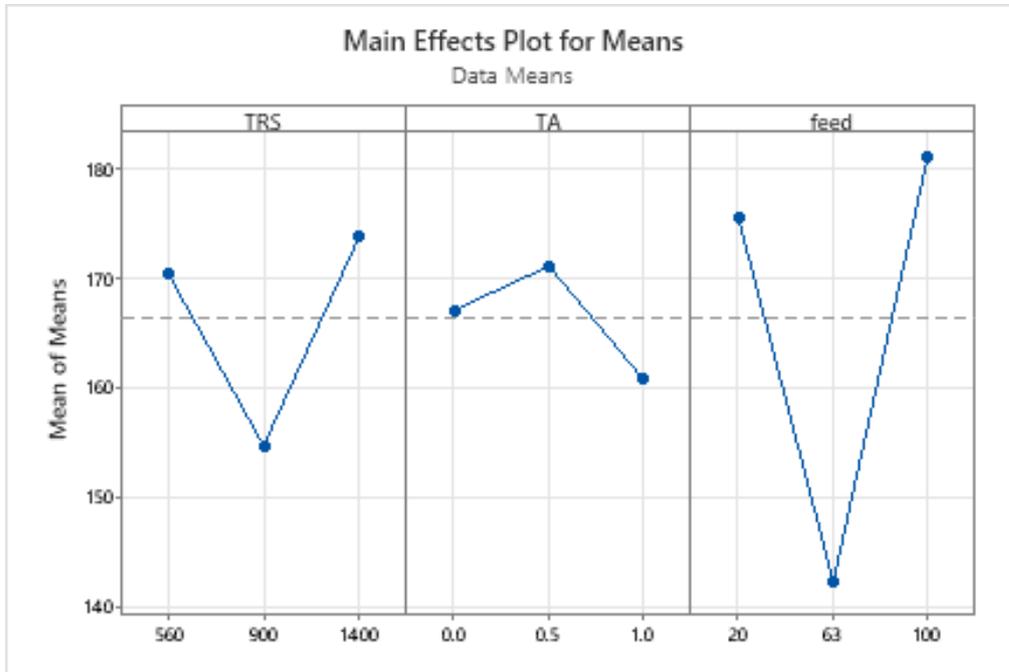


Figure 6 Main effect plot for means tensile strength

3.3 Effect of processing parameters on % Elongation

A higher % elongation of 10.6 and higher tensile strength is obtained at TRS 560 rpm, tilt angle 0° and feed 20mm/min but the time taken is higher due to low RPM condition. This can be the appropriate condition if time is not constrained.

Table 7 Response Table for Signal to Noise Ratios
Larger is better

Level	TRS	TA	feed
1	17.31	16.68	18.88
2	14.58	16.68	12.48
3	16.70	15.22	17.23
Delta	2.73	1.46	6.40
Rank	2	3	1

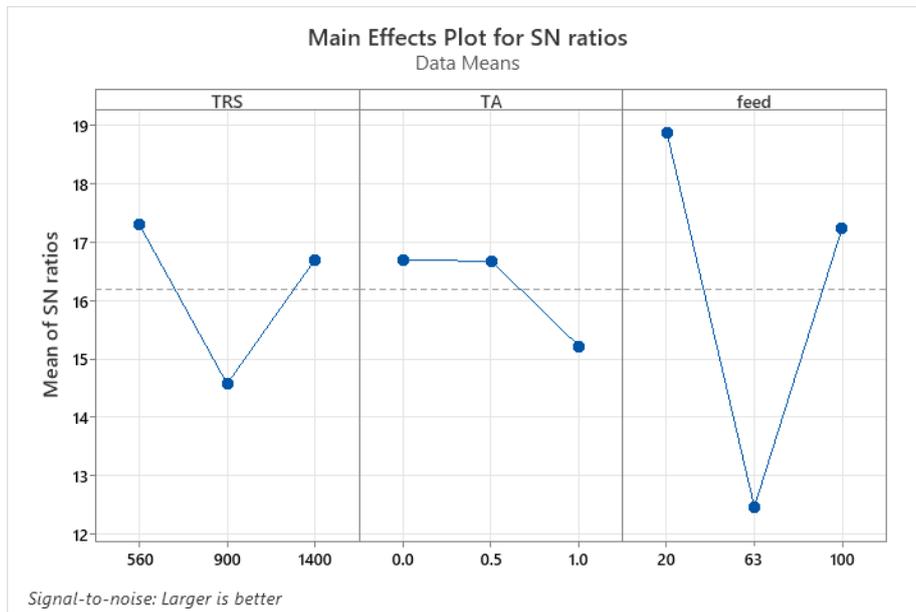


Figure 7 S/N ratio for % elongation

Table 8 Response Table for Means of % Elongation

Level	TRS	TA	feed
1	7.600	7.867	8.867
2	5.800	6.867	4.400
3	7.333	6.000	7.467
Delta	1.800	1.867	4.467
Rank	3	2	1

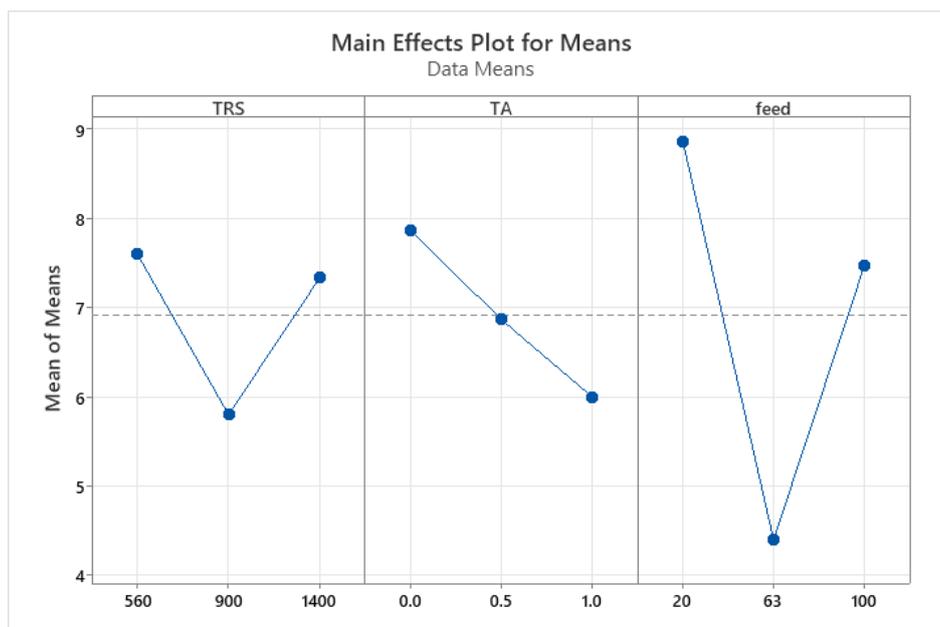


Figure 8 main effect plot for % elongation

3.4 Gray Relational Analysis:

A powerful method for multi-response optimization, Gray relational analysis is utilized to resolve the complex interrelationship among the multiple responses[32]. Normalization of the experimental value of responses in the range 0



to 1 is the first step in GRA then calculating gray relational coefficient (GRC) from the normalized data in the second step to represent the correlation between desired and actual experimental data. Averaging the coefficients to get a gray relational grade (GRG) corresponding to each performance characteristic

Table 9. Normalize value, Gray Relational Coefficient (GRC) & GRG of the response data

Normalize value		Deviation sequence		GRC		GRG	Rank
Tensile strength (MPa)	% Elongation	Tensile strength (MPa)	% Elongation	Tensile strength	% Elongation		
1.00	1.00	0.00	0.00	0.33	1.00	0.67	1
0.47	0.42	0.53	0.58	0.51	0.46	0.49	6
0.67	0.39	0.33	0.61	0.43	0.45	0.44	7
0.00	0.00	1.00	1.00	1.00	0.33	0.67	1
0.92	0.45	0.08	0.55	0.35	0.48	0.41	9
0.57	0.66	0.43	0.34	0.47	0.59	0.53	4
1.00	0.92	0.00	0.08	0.33	0.86	0.60	3
0.78	0.66	0.22	0.34	0.39	0.59	0.49	5
0.50	0.13	0.50	0.87	0.50	0.37	0.43	8

Numerous performance factors are evaluated altogether based on the predicted grey relationship grade. As a result, optimizing the complex numerous performance criteria is replaced by optimizing a single grey relational grade. The ideal level is represented by the parameters that correspond to the highest grade. To identify the important parameters, more ANOVA is run. ANOVA and grey relational analysis are used to determine which set of process parameters will work best together.

3.5 Optimum Levels of the Factors

The better-quality qualities are implied by a higher Gray relational grade. Table 10 includes the optimal levels of the components as well as the average Gray relationship grade. The Gray relational grade indicates that TRS2TA1F1 is the optimal level of performance attributes. Confirmation experiments validate the obtained optimum parameters.

Table 10. The average GRG at each level

Level	TRS	TA	feed
1	0.5320	0.6439*	0.5633*
2	0.5371*	0.4651	0.5294
3	0.5079	0.4679	0.4843
Delta	0.0292	0.1788	0.0790
Rank	3	1	2

- Indicates the optimal level of factors
- Average GRG is 0.5257

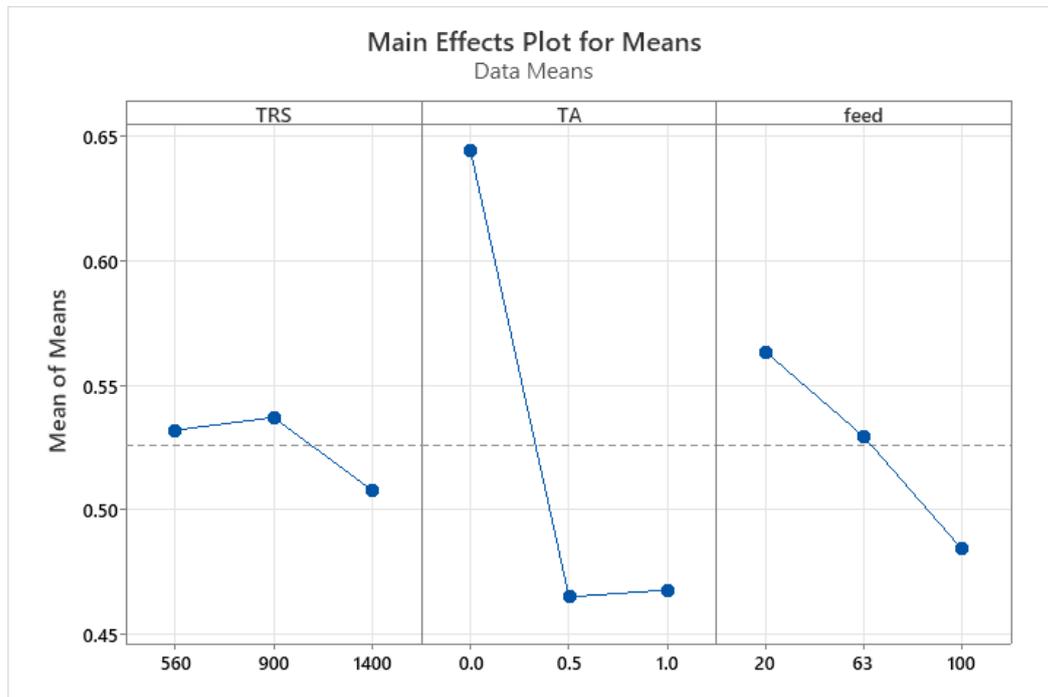


Figure 9 Main effect plot for means of GRG

3.6 ANOVA:

ANOVA is used to identify statistically significant components. It gives a clear picture of the extent to which the process parameters affect the response and the relative importance of the component taken into account. Table 11 calculates and displays the GRG's ANOVA.

Table 11. Analysis of Variance for means

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
TRS	2	0.001459	1.92%	0.001459	0.000729	0.70	0.588
TA	2	0.062963	82.93%	0.062963	0.031481	30.24	0.032
feed	2	0.009417	12.40%	0.009417	0.004708	4.52	0.181
Error	2	0.002082	2.74%	0.002082	0.001041		
Total	8	0.075921	100.00%				

The F test indicates the significance of the parameters. A higher value indicates highly significant factors affecting response. In this paper, the tilt angle is a highly significant factor that strongly affects the tensile strength of the material.

IV. RESULT AND DISCUSSION

4.1 Predicted optimized conditions:

Based on the experiments the optimum setting of levels is TRS₂TA₁F₁. The predicted grey relational is evaluated as

$$GRG (\text{Predicted}) = TRS_2 + TA_1 + F_1 - 2T$$

$$= 0.5371 + 0.6439 + 0.5633 - 2 * 0.5257 = \mathbf{0.6929}$$

4.2 multi-objective optimization of FSW Process

Table 12 Experimental results for the optimized parameter

Exp. No	TRS(RPM)	TA	Feed	Tensile strength	% Elongation
1	900	0	20	190	6.9

4.3 Confirmation Run

The validation test was conducted with the best parameter settings. The rotational speed, tilt angle, and feed were set at 900 rpm, 0 degrees, and 20mm/min respectively. The Tensile strength of 190 MPa and 6.9% elongation were obtained in the confirmation test as tabulated in Table 12.

V. CONCLUSION

This work is the experimental investigation of friction stir welded joint of AA6061-T6 by altering parameters, tool tilt angle, tool rotation speed and feed rate produced. The Taguchi experimental design on AA6061-T6 were conducted successfully. The process parameters were optimized first by using ANOVA to evaluate the influence on Tensile strength and % elongation. Furthermore, the multiobjective optimization using GRA is done to identify the optimum levels of parameters. Tool rotation speed 900 rpm, Tilt angle 0° and feed 20mm/min are the optimized parameters obtained. Tilt angle is found to be the most influencing parameter.

REFERENCES

- [1] W. M. Thomas, K. I. Johnson, and C. S. Wiesner, "Friction stir welding-recent developments in tool and process technologies," *Adv. Eng. Mater.*, vol. 5, no. 7, pp. 485–490, 2003, DOI: 10.1002/adem.200300355.
- [2] W. M. W. Thomas, E. D. Nicholas, J. C. Needham, M. G. Murch, P. Temple-Smith, and C. J. Dawes, "Friction stir welding process developments and variant techniques," *Google patents*, pp. 1–21, 1991, [Online]. Available: <http://www.google.com/patents/US5460317%5Cn>
- [3] M. Mijajlovic and D. Milicic, "Analytical Model for Estimating the Amount of Heat Generated During Friction Stir Welding: Application on Plates Made of Aluminium Alloy 2024 T351," *Weld. Process.*, 2012, DOI: 10.5772/53563.
- [4] N. Khanna, P. Sharma, M. Bharati, and V. J. Badheka, "Friction stir welding of dissimilar aluminium alloys AA 6061-T6 and AA 8011-h14: a novel study," *J. Brazilian Soc. Mech. Sci. Eng.*, vol. 42, no. 1, 2020, DOI: 10.1007/s40430-019-2090-3.
- [5] J. H. Ouyang and R. Kovacevic, "Material Flow and Microstructure in the Friction Stir Butt Welds of the Same and Dissimilar Aluminum Alloys."
- [6] S. Verma and J. P. Misra, "A Critical Review of Friction Stir Welding Process," no. January 2015, pp. 249–266, 2015, DOI: 10.2507/dream.scibook.2015.22.
- [7] M. Song and R. Kovacevic, "Numerical and experimental study of the heat transfer process in friction stir welding," *Proc. Inst. Mech. Eng. Part B J. Eng. Manuf.*, vol. 217, no. 1, pp. 73–85, 2003, DOI: 10.1243/095440503762502297.
- [8] S. D. Ji, Q. Y. Shi, L. G. Zhang, A. L. Zou, S. S. Gao, and L. V. Zan, "Numerical simulation of the material flow behavior of friction stir welding influenced by rotational tool geometry," *Comput. Mater. Sci.*, vol. 63, pp. 218–226, Oct. 2012, DOI: 10.1016/J.COMMATSCI.2012.06.001.
- [9] R. Padmanaban, V. Ratna Kishore, and V. Balusamy, "Numerical simulation of temperature distribution and material flow during friction stir welding of dissimilar aluminum alloys," *Procedia Eng.*, vol. 97, pp. 854–863, 2014, DOI: 10.1016/j.proeng.2014.12.360.
- [10] M. Cabibbo, A. Forcellese, E. Santecchia, C. Paoletti, S. Spigarelli, and M. Simoncini, "New approaches to friction stir welding of aluminum light-alloys," *Metals (Basel)*, vol. 10, no. 2, 2020, DOI: 10.3390/met10020233.
- [11] K. M. Venkatesh, M. Arivarsu, M. Manikandan, and N. Arivazhagan, "Review on friction stir welding of steels," *Mater. Today Proc.*, vol. 5, no. 5, pp. 13227–13235, 2018, DOI: 10.1016/j.matpr.2018.02.313.
- [12] V. K. Parikh, A. D. Badgujar, and N. D. Ghetiya, "Joining of metal matrix composites using friction stir welding: a review," *Mater. Manuf. Process.*, vol. 34, no. 2, pp. 123–146, 2019, DOI: 10.1080/10426914.2018.1532094.
- [13] M. Ilangovan, S. Rajendra Boopathy, and V. Balasubramanian, "Effect of tool pin profile on microstructure and

- tensile properties of friction stir welded dissimilar AA 6061–AA 5086 aluminium alloy joints,” *Def. Technol.*, vol. 11, no. 2, pp. 174–184, 2015, DOI: 10.1016/j.dt.2015.01.004.
- [14] A. Heidarzadeh *et al.*, *Friction stir welding/processing of metals and alloys: A comprehensive review on microstructural evolution*. Elsevier Ltd, 2020. DOI: 10.1016/j.pmatsci.2020.100752.
- [15] D. G. Mohan and C. Wu, “A Review on Friction Stir Welding of Steels,” *Chinese J. Mech. Eng.*, vol. 34, no. 1, 2021, DOI: 10.1186/s10033-021-00655-3.
- [16] K. S. Arora, S. Pandey, and M. Schaper, “Effect of process parameters on friction stir welding of aluminum alloy 2219-T87,” no. October, 2010, DOI: 10.1007/s00170-010-2560-3.
- [17] J. C. Verduzco Juárez, G. M. Dominguez Almaraz, R. García Hernández, and J. J. Villalón López, “Effect of Modified Pin Profile and Process Parameters on the Friction Stir Welding of Aluminum Alloy 6061-T6,” *Adv. Mater. Sci. Eng.*, vol. 2016, 2016, doi: 10.1155/2016/4567940.
- [18] F. C. Liu, Y. Hovanski, M. P. Miles, C. D. Sorensen, and T. W. Nelson, “A review of friction stir welding of steels: Tool, material flow, microstructure, and properties,” *J. Mater. Sci. Technol.*, vol. 34, no. 1, pp. 39–57, 2018, DOI: 10.1016/j.jmst.2017.10.024.
- [19] P. Chen *et al.*, “Effect of rotation speed on microstructure evolution and mechanical properties of nugget zone in 2195-T8 Al-Li alloy friction stir welding joints,” *Mater. Charact.*, vol. 176, no. March, p. 111079, 2021, DOI: 10.1016/j.matchar.2021.111079.
- [20] H. J. Liu, J. C. Hou, and H. Guo, “Material and Design Effect of welding speed on microstructure and mechanical properties of self-reacting friction stir welded 6061-T6 aluminum alloy,” *J. Mater.*, vol. 50, pp. 872–878, 2013, DOI: 10.1016/j.matdes.2013.03.105.
- [21] P. Hema, K. Sai, and K. Ravindranath, “ScienceDirect Prediction of Effect of Process Parameters on Friction Stir Welded Joints of dissimilar Aluminium Alloy AA2014 & AA6061 Using Taper Pin Profile,” *Mater. Today Proc.*, vol. 4, no. 2, pp. 2174–2183, 2017, DOI: 10.1016/j.matpr.2017.02.064.
- [22] M. M. Hasan, M. Ishak, and M. R. M. Rejab, “Effect of pin tool design on the material flow of dissimilar AA7075-AA6061 friction stir welds,” in *IOP Conference Series: Materials Science and Engineering*, Nov. 2017, vol. 257, no. 1. doi: 10.1088/1757-899X/257/1/012022.
- [23] P. Cavaliere, “Friction stir welding of Al alloys: Analysis of processing parameters affecting mechanical behavior,” *Procedia CIRP*, vol. 11, pp. 139–144, 2013, DOI: 10.1016/j.procir.2013.07.039.
- [24] B. R. Gopal, “Effect of pin tool design on the material flow of dissimilar AA7075-AA6061 friction stir welds Effect of pin tool design on the material flow of dissimilar AA7075-AA6061 friction stir welds,” 2017, DOI: 10.1088/1757-899X/257/1/012022.
- [25] O. P. Abolusoro and E. T. Akinlabi, “Effects of processing parameters on mechanical, material flow and wear behaviour of friction stir welded 6101-T6 and 7075-T651 aluminium alloys,” *Manuf. Rev.*, vol. 7, no. 1, 2020, DOI: 10.1051/mfreview/2019026.
- [26] G. K. Padhy, C. S. Wu, and S. Gao, “Friction stir based welding and processing technologies - processes, parameters, microstructures, and applications: A review,” *J. Mater. Sci. Technol.*, vol. 34, no. 1, pp. 1–38, 2018, DOI: 10.1016/j.jmst.2017.11.029.
- [27] H. A. Derazkola, R. Kashiry Fard, and F. Khodabakhshi, “Effects of processing parameters on the characteristics of dissimilar friction-stir-welded joints between AA5058 aluminum alloy and PMMA polymer,” *Weld. World*, vol. 62, no. 1, pp. 117–130, 2018, DOI: 10.1007/s40194-017-0517-y.
- [28] X. He, F. Gu, and A. Ball, “Progress in Materials Science A review of numerical analysis of friction stir welding,” *Prog. Mater. Sci.*, vol. 65, pp. 1–66, 2014, doi: 10.1016/j.pmatsci.2014.03.003.
- [29] G. Çam and S. Mistikoglu, “Recent developments in friction stir welding of al-Alloys,” *J. Mater. Eng. Perform.*, vol. 23, no. 6, pp. 1936–1953, 2014, DOI: 10.1007/s11665-014-0968-x.
- [30] D. Maneiah, D. Mishra, K. P. Rao, and K. B. Raju, “Process parameters optimization of friction stir welding for optimum tensile strength in Al 6061-T6 alloy butt welded joints,” *Mater. Today Proc.*, vol. 27, no. XXXX, pp. 904–908, 2020, DOI: 10.1016/j.matpr.2020.01.215.
- [31] A. Dar, “AN APPLICATION OF TAGUCHI L9 METHOD IN BLACK SCHOLES MODEL FOR EUROPEAN CALL,” no. March 2018.
- [32] P. Taylor, S. Vijayan, R. Raju, and S. R. K. Rao, “Materials and Manufacturing Processes Multiobjective Optimization of Friction Stir Welding Process Parameters on Aluminum Alloy AA 5083 Using Taguchi-Based Grey Relation Analysis Multiobjective Optimization of Friction Stir Welding Process Parameters on A,” no. November 2012, pp. 37–41, DOI: 10.1080/10426910903536782.



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