

Retraction

Retracted: Investigation on Tensile Behaviour of Different Weld Joints through Taguchi Approach

Advances in Materials Science and Engineering

Received 26 December 2023; Accepted 26 December 2023; Published 29 December 2023

Copyright © 2023 Advances in Materials Science and Engineering. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

This article has been retracted by Hindawi, as publisher, following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of systematic manipulation of the publication and peer-review process. We cannot, therefore, vouch for the reliability or integrity of this article.

Please note that this notice is intended solely to alert readers that the peer-review process of this article has been compromised.

Wiley and Hindawi regret that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

- [1] S. Kamal, V. Parthiban, G. Puthilibai et al., "Investigation on Tensile Behaviour of Different Weld Joints through Taguchi Approach," *Advances in Materials Science and Engineering*, vol. 2022, Article ID 5258014, 9 pages, 2022.

Research Article

Investigation on Tensile Behaviour of Different Weld Joints through Taguchi Approach

Shoab Kamal,¹ V. Parthiban,² G. Puthilibai,³ M. Thirumal Azhagan,⁴ Neel Kamal,⁵ T. S. Senthil,⁶ and Simon Yishak ⁷

¹Department of Electronics and Communication Engineering, MVJ College of Engineering, Bengaluru, Karnataka 560067, India

²Department of Mechanical Engineering, Agni College of Technology, Chennai, Tamil Nadu 600130, India

³Department of Chemistry, Sri Sairam Engineering College, Chennai, Tamil Nadu 600044, India

⁴Department of Production Technology, Madras Institute of Technology, Anna University, Chennai, Tamil Nadu 600044, India

⁵Department of Electrical and Electronics Engineering, Noida Institute of Engineering and Technology, Greater Noida, Uttar Pradesh 201306, India

⁶Department of Mechanical Engineering, Panimalar Engineering College, Chennai, Tamilnadu 600123, India

⁷College of Engineering and Argo-Industrial Technology, Sawla Campus, Arba Minch University, Arba Minch, Ethiopia

Correspondence should be addressed to Simon Yishak; simon.yishak@amu.edu.et

Received 13 March 2022; Revised 2 April 2022; Accepted 7 April 2022; Published 10 May 2022

Academic Editor: Palanivel Velmurugan

Copyright © 2022 Shoab Kamal et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Friction stir welding is a dependable method of joining metals and other materials. Relatively joint configuration-specific welding process parameters have not yet been tuned. This work is concerned with the Taguchi orthogonal arrays to perform an analysis of variance. In this study, FSW joint configurations of AA6262-T6 Al alloy, such as butt, lap, and T joints, were studied for optimization. An orthogonal array of welds was selected using the Taguchi method. After the welds were constructed, the ultimate tensile strength of each joint was examined for statistical optimization. The lack of parameter optimization studies for butt, lap, and T joints prompted this research to fill the void. As a result, each joint arrangement must be optimised for mechanical properties and a set of parameters must be developed.

1. Introduction

FSW has emerged as a potential replacement for traditional fusion welding techniques. Facing surfaces and the joining line, a spinning tool is introduced into the workpiece, generating a complicated stirring of the material in this solid-state joining procedure [1, 2]. New structural design concepts can be developed using FSW, a joining procedure with good reproducibility that has excellent promise in a variety of industries [3]. Welding aluminium, copper, and magnesium, as well as steel, titanium, and polymers, are important parts of this technology's exploration [4]. To mention a few, the high temperatures reached during the welding process result in FSW having no porous or fragmentation as well as low curvature and excellent mechanical qualities [5]. FSW does not require a shielding gas and it is

also environmentally friendly. It also prevents the flaws created during the metal's fusion and solidification processes. However, incorrectly calibrated process parameters can lead to product failure [6]. Failure to penetrate, fusion, cavities on the surface, and excessive flash and galling on the surface are some of the most prevalent faults related to FSW. To provide adequate process control for industrial use, it is still required to examine factor correlations and their impact on the combined structural rigidity [7, 8].

Figure 1 reveals the schematic diagram of the FSW approach. FSW optimization is the subject of several research works in the literature, most of which concentrate primarily on the butts. For the FSW process, there is a dearth of research into the right identifying the most efficient criteria for a system [9]. The most frequent joint arrangement is the butt joint because it distributes load well and is

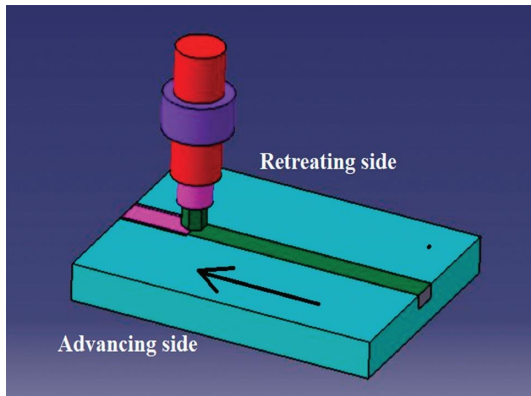


FIGURE 1: Schematic of FSW approach.

simple to set up. It is possible to find numerous examples of this joint arrangement being used in industry [10]. Resistance spot welding (RSW) has been replaced by other methods in the automobile sector. By avoiding the overlapping of two components, the weight of the joint is reduced. Many research works have been published as a result of the possible industrial use of FSW. Erbslöh et al. [11] explored the impact of welding conditions, whereas Acerra et al. [12] studied the mechanical and metallurgical qualities. Papadopoulos et al. [13] explored the production of faults on FSW butt joints of Al-Li alloy, while Zhang et al. [14] investigated the production of deviation occurs flaws. When the shape of the shoulder was analyzed, it was found that AA6262 FSW joints with scrolling or concave shoulders had better tensile properties than those with flat shoulders. A postweld heat treatment on AA6262 FSW joints improved the UTS and hardness, according to Yazdanian and Chen [15]. Using lower welding speeds also helped make this improvement more noticeable.

According to Dhas and Dhas [16], reveal an important geometry because they allow for improved thin skins' moment of inertia and toughness without adding a lot of bulk to the structure. Only a few research works have been done on FS welded T joints. Extruded AA6262-T6 aluminium alloy was tested for bending performance by Rajakumar and Balasubramanian [17]. The FS and MIG welded connections were evaluated. FSW-specific factors were also examined in the study. In cases where the radius of a fillet is to be circular, dissimilar joint studies were also conducted. Cui et al. [18] reported on an industrial case study of incompatible T-shaped pieces linked by FSW in the aerospace industry. The significance of shoulder configuration was also proven, as broader shoulders made it easier to weld accurately. Lap joints are extensively employed in mechanical structures, such as riveted connections or adhesive joints in aeronautical fuselages. The literature on FSW lap joint optimization is sparse. As Heidarzadeh et al. [19] have shown, FSW lap joints are an excellent alternative for riveted joints in primary aeronautical constructions due to their similar joint design. There are two crack-like unwelded areas at the overlap ends of lap joints. Hooking problem is the common name for this issue, which reduces the effective thickness of the sheet, with clear ramifications for the joint's

strength, as demonstrated by Lee et al. [20]. Probing length and welding speed were explored in [21] to see if they affected hooking phenomena. Longer probes did not result in stronger joints because of the amount of plastic agitated by a shorter probe length. Probe length and rotational speed were shown to be the two most important considerations.

Taguchi is the process optimization approach employed. The number of experiments can be reduced using design of experiment (DOE) procedures to save time and money. Taguchi is a frequently used DOE technique for optimizing the processing of materials. According to this method, complex systems can be easily analyzed and optimised using the orthogonal array (OA), fractional factorials that can be calculated via statistical analysis. Using ANOVA, The statistically significant correlation of the common UTS control factors was examined and verified the model's accuracy. The analysis of variance (ANOVA) approach is a standard technique used in association with the "Taguchi" process to validate the percentage contribution of each process parameter on the intended outputs. The use of Taguchi for the design of experiments to predict the mechanical properties of FSW has already been studied by several authors. On the other hand, this research focused primarily on improving the butt joint. In the investigations in references [22, 23], the welding and rotational speeds had a substantial impact on joint tensile strength. Taguchi can be utilized for this purpose. According to the study by Rajakumar and Balasubramanian [17], the Taguchi approach was used to optimise the FSW procedure for aluminium alloy joints. Welding parameters for AA6061 alloy were determined to be 1178 rpm, 115 mm/min, and 8.2 kN. The aim of this work is to make three possible joints of butt, lap, and T joint for AA6262-T6 that can be optimised for the tensile strength in the FSW process.

2. Experimental Works

Joints such butt, T, and double-pass overlap were employed for the welds, as depicted in Figure 2. For the welds on the butt and T joints, 3 mm thick aluminium alloy plates were employed; in contrast, 2 mm thick plates to create the lap joints were employed. The mechanical properties of the alloy utilized in this application are mentioned here. Probe penetration control was used to ensure that the welds were made in the correct rolling direction. Table 1 displays the factors used in the creation of each joint, along with a comparison of their values. Aspect and dimension (probe/shoulder ratio), determined by shoulder diameter fluctuation) were kept constant. Unlike butt joints, where a wide nugget (bigger joint surface) is the primary goal, lap joints are focused on minimizing or eliminating the hook defect, which has a significant impact on joint strength. The joint fillets and tunnel faults and bond defects must be avoided in T joints. There was no study conducted on the effect of the shoulder diameter on lap joints, thus it was kept at 15 millimetres. The distance between the two weld runs (weld beads) was evaluated as a parameter for this joint arrangement. An OA determining the optimal set of

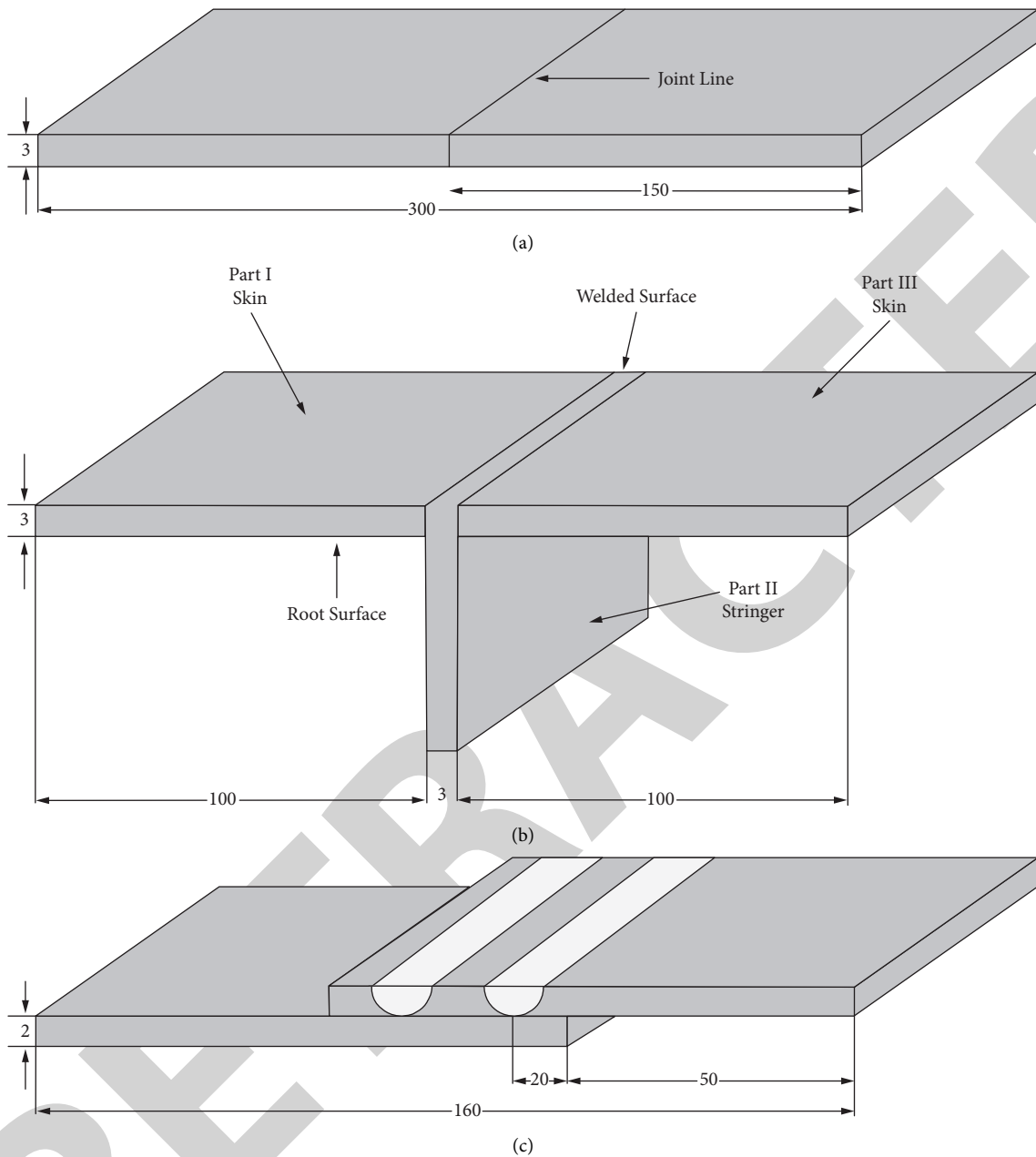


FIGURE 2: Joint configurations of (a) butt joint, (b) T joints, and (c) lap joints are employed.

variables was selected for each joint arrangement. Welded together were 27 butt and T joints and eight lap joints. After the welding process was completed, we performed tensile testing. Samples were machined transverse to the weld line in accordance with ASTM E8-M. Butt and T joints were constructed with a 60 and 12.5 mm-wide section length, respectively, to save space. Skins were loaded perpendicular to the stiffener in T joints with a 10 mm-high stiffener. The tensile specimens for lap joints have a diameter of 20 mm. Tensile testing was carried out at a cross-head speed of one millimeter per minute. For the purpose of performing an ANOVA with a 95% confidence interval, the UTS is used as the response data. As a result of a statistical study known as ANOVA, the impact of each parameter on the UTS was

quantified and the statistically significant difference and insignificance of several variables were determined.

Three parameters were also examined in relation to each other, as well. In all joint designs, we evaluated the impact of tool rotational speed on weld speed. For butt and T joints, there were two additional interactions that were influenced by tool rotating speed (D/d) and welding speed (S/d). Tool rotational speed and welding speed were taken into account while calculating lap joint penetration for lap joints. These analyses allowed us to identify the most important parameters and their interactions on the UTS, which was a significant accomplishment. Mean main effects and inter-parameter plots were used to determine the trend of each parameter's influence on the other parameters.

TABLE 1: Experimental design for each joint arrangement is planned out.

Orthogonal arrays Taguchi Levels	Butt joint L27 (3^{13})			T joint L27 (3^{13})			Lap joints L8 (2^7)	
	1	2	3	1	2	3	1	2
(A) Rotational speed (rpm)	725	1100	1600	520	1100	1600	830	1600
(B) Welding speed (mm/min)	206	300	380	79	220	400	82	310
(C) Tilt angle ($^{\circ}$)	1	2	3	—	—	—	—	—
(D) Probe penetration (mm)	1.95	3.75	3.95	4.0	4.0	4.2	2.8	3.5
(E) Shoulder/probe ratio (D/d)	3.4	3.8	4.4	3.4	3.7	4.6	—	—
(F) Weld run distance (mm)							21	22

3. Results

3.1. Tensile Test Results. According to the OA that was chosen, the tensile outcomes are displayed in Table 2. In the test results, maximum weld joint efficiency was found to be 78% for butt welding, 60% for T joints, and 39% for lap joints.

3.2. ANOVA Analysis. Using a degree of confidence of 90%, ANOVA was conducted to examine the impact of each parameter/user-to-user communication. Analyses of important parameters (90 percent confidence level) yielded these percentages. As far as butt joints are concerned, the shoulder-to-probe diameter ratio appears to be the most important measure. There is a higher percentage contribution ($A * E$, $B * E$) for these interactions (A , E) in relation to the shoulder/probe diameter ratio; hence, the choice of welding or rotating speed depends on this ratio. The UTS was shown to be influenced primarily by the rotational speed of T joints. As a result, it has a higher percentage of influence on the shoulder/probe diameter ratio, indicating that the two are strongly linked. The welding and rotational rates have a significant impact on the UTS in lap joints, and it is shown in Figure 3.

3.3. Parameter Effect on Butt Joints. According to Figure 4, each parameter and its interactions are plotted in relation to UTS response for different joints. Rotor motion of 1100 rpm was discovered to improve the UTS of butt joints by analyzing the mean plot data. There is a considerable rise in UTS as the rotating speed increases from 735 to 1100 rpm. To get the finest joint mechanical qualities, we welded at a lower speed (206 mm/min). After studying welding speeds and rotational speeds, it was revealed that 1100 rpm with 300 mm/min led to an increase in UTS.

The best depth of probe penetration was found to be 3.75 mm (level 2). This can lead to considerable root deformation, or it can cause tool damage if a probe is too close to its rear plate, causing plastic deformation. Root defects might result from incomplete probe penetration. Because of the friction between the shoulder and the workpiece surface, a larger contact area is necessary to generate more heat in FSW. The usage of a bigger diameter ($D/d=3$) was also found to significantly decrease the UTS. However, as compared to the 15 mm diameter, the 12 mm diameter shoulder ($D/d=3.4$) has no significant impact on the UTS.

TABLE 2: The UTS of a material with different joints.

Trial run number	Ultimate tensile strength (MPa)		
	Butt	T	Lap
1	215	127	98
2	237	146	83
3	234	135	127
4	210	37	126
5	194	148	115
6	217	104	112
7	152	27	102
8	205	113	114
9	211	124	
10	241	162	
11	210	169	
12	238	109	
13	248	135	
14	208	131	
15	249	139	
16	147	131	
17	248	172	
18	251	141	
19	244	162	
20	235	110	
21	197	137	
22	191	141	
23	234	143	
24	174	163	
25	219	150	
26	221	149	
27	231	109	

There were noticeable improvements in joints when 1100 rpm and a 12-millimetre shoulder were combined. Larger shoulder sizes result in reduced UTS only when combined with faster welding speeds, as the two variables interact significantly. Shoulder diameter of 12 mm or 15 mm and probe penetration of 3.75 mm (90 percent plate thickness) should be used in butt welds to achieve high UTS.

3.4. T Joint Impact on Various Parameters. Each parameter and its interactions are plotted in Figure 4. Improved UTS was found to be most beneficial for T joints when rotated at 1100 revolutions per minute (rpm). The optimum joint mechanical qualities were found to be achieved by welding at a low speed. Although similar results were reported for the butt joint analysis, this is not entirely unexpected. It was found that while welding at 1100 rpm or even 1600 rpm, the

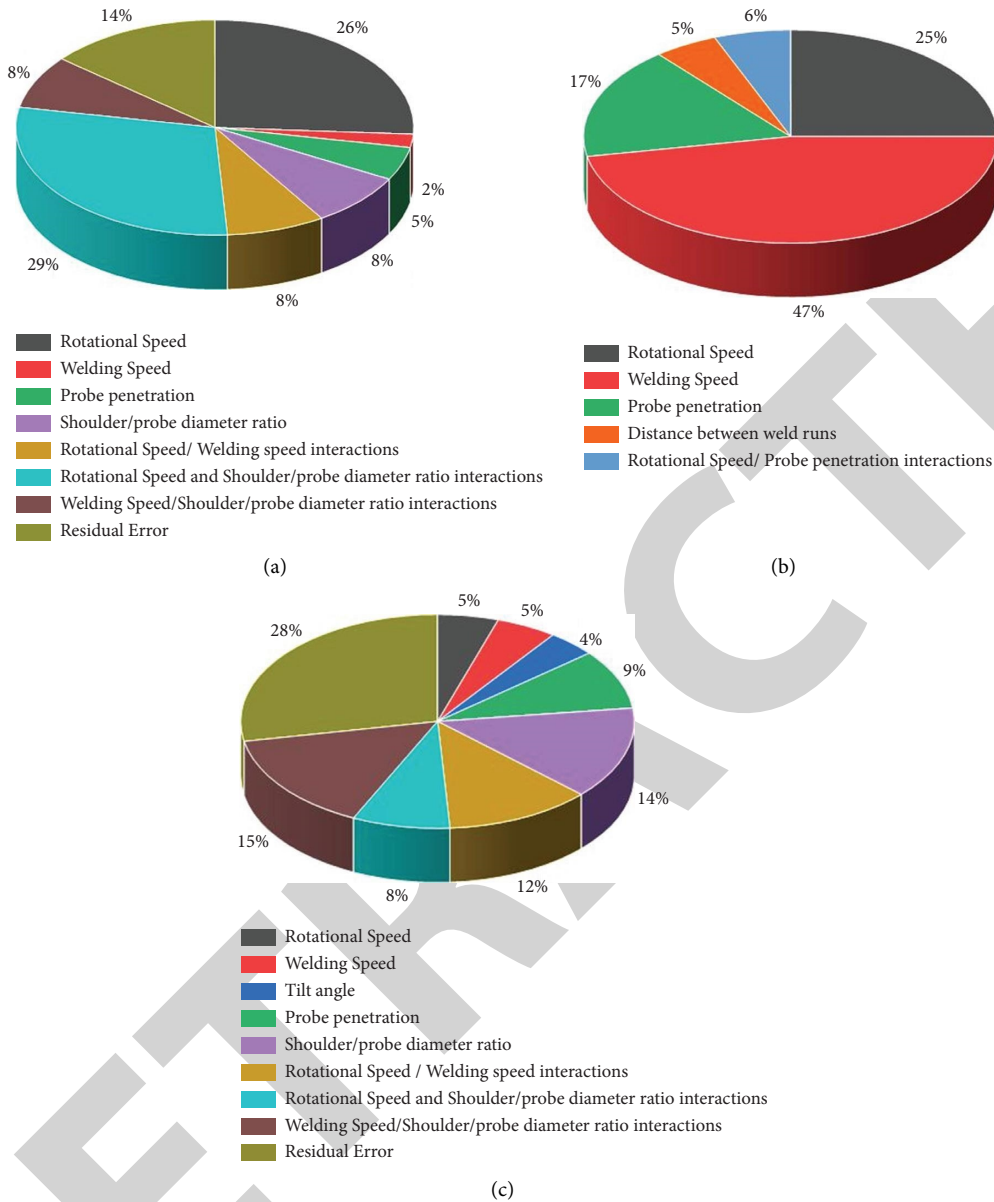


FIGURE 3: Percentage of the contribution of the significant parameters determined from ANOVA analysis for each joint configuration. (a) Butt joint. (b) T joint. (c) Lap joint.

UTS is not significantly affected by welding speed. The increased speed of welding has a clear negative effect on the process when the rotating speed is kept low.

With the average effect of the separate parameters, as well as the interactions between them, it is safe to say that using 1100 or 1600 rpm to weld T joints produces good UTS regardless of the speed used. The corners of T joints must be filled, and hence, the deformation in this place is helpful. Thus, a deeper probe penetration could result in better joints. In the mean plot, you can see this pattern. When comparing shoulder/probe diameter ratios (D/d), the average main effect analysis found that the 15 mm shoulder diameter ($D/d = 3.4$) can produce sound joints, just like butt joints. Smaller shoulder diameters ($D/d = 3.4$) and larger diameters ($D/d = 4.6$) have different compared to the intermediate diameter (15 mm; $D/d = 3.7$) in the T joint arrangement.

It was shown that only when smaller shoulders were used did the speed/shoulder/probe ratio combination have a significant impact on the UTS. Using modest welding speeds in this scenario ensures that the material is heated and mixed thoroughly, resulting in a better joint UTS. Low-diameter shoulders necessitate a high rotational speed, much like when utilizing larger shoulders. Speeds of 79 mm/min, 1100 rpm, 15 mm shoulder diameter ($D/d = 3.7$), and 4 mm probe penetration yield the best UTS in T joint welds (as a percentage of the plate thickness, it is around 130 percent).

3.5. *The Impact of Parameters on the Lap Joints.* The UTS response for lap joints is shown in Figure 5 in average main effect plots and their correlations. Using high rotating rates

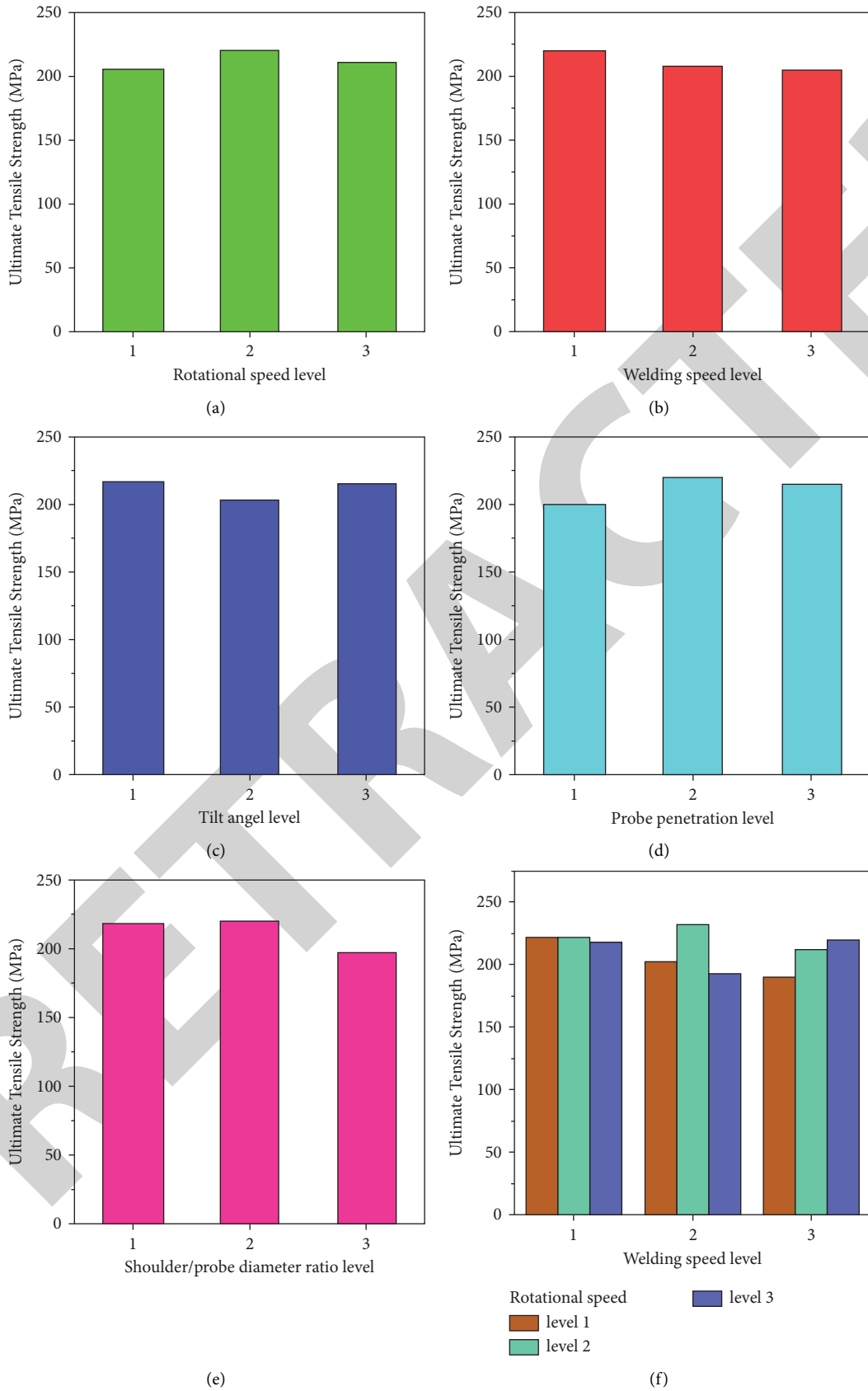


FIGURE 4: Continued.

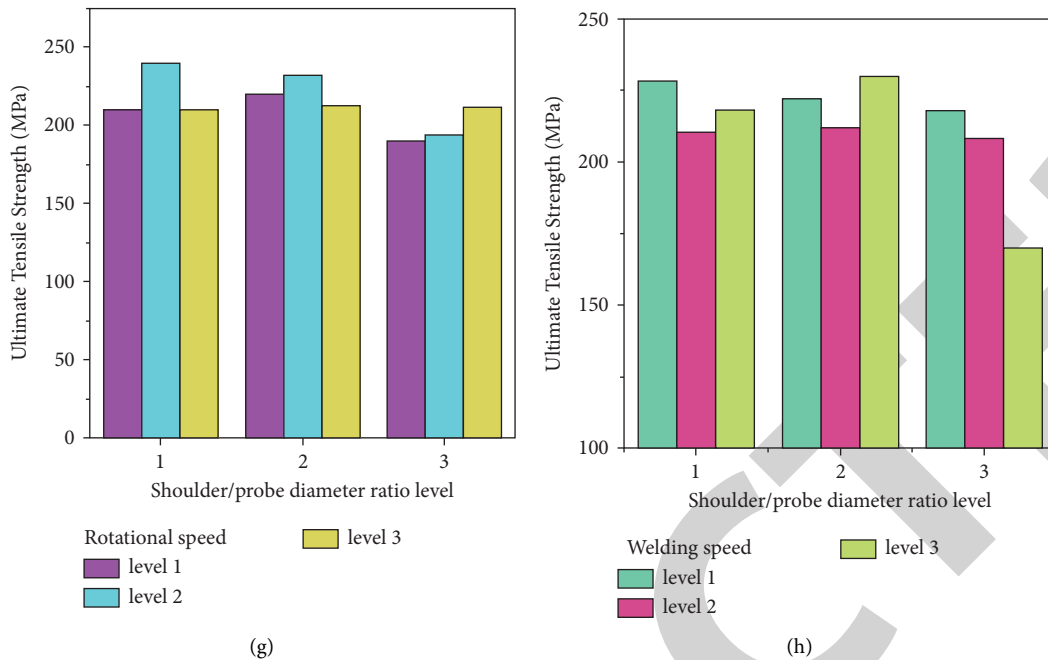


FIGURE 4: Ultimate tensile strength of different weld speeds and diameter ratios.

for lap joints has been proven to yield the greatest results (1600 rpm). Instead of the butt and T joints, welding speeds were found to be on the opposite end of the spectrum. Lap joints can be improved by using high welding speeds. Using the same welding speeds, the best characteristics were generated. It was only in lap joints that double weld runs were applied because of their tendency to form a hooking flaw on the retreating side. The lower UTS was seen when the distance between passes increased.

Neither of the characteristics had a significant impact on each other. Only the estimation of the interplay between rotational speed and probe penetration is of interest here. Only when a high penetration is used can the rotating speed have a major impact, requiring a high rotational speed. High probe penetration depths necessitate faster rotational speeds to agitate huge amounts of material. UTS can be increased by employing 1600 rpm, 3.5 mm probe penetration at 310 mm/min, according to this study (50 percent of plate thickness). In our experiments, we observed that the welding and rotational speeds had little effect each other. These settings were discovered to be the right quality: 1600 rpm and 310 mm/min.

4. Discussion

At weld, the shoulder's contact with the metal plate produces a lot of heat. The right combination of spinning and soldering rates is crucial in order to minimize heat input. Due to the greater friction surface, a big shoulder generates more heat. The time allotted for heating the material is determined by the welding speed. The use of high welding speeds may result in poor joint efficiency. It is also important to note that the rotating speed is directly linked to heat generation through friction; increasing the speed results in more

friction, which results in more heat being generated. Slower rotational rates might result in turbulence in the material flow, whereas higher speeds can cause higher temperatures. In both cases, joint mechanical characteristics may be compromised.

It is one of the most essential factors in determining the amount of heat that can be generated. There is a reason why the butt and T joint configurations have differing effects on the shoulder diameter. A diameter of 15 mm was found to be ideal for both types of joints. As for T joints, smaller diameters should be avoided, whereas larger dimensions should be prevented in butt joints. As opposed to T joints, which require the heat of three pieces, butt joints only need two. Consequently, in T joints, tiny shoulder diameters do not produce enough heat and are thus undesirable. In order to meet the joint fillets, forging activity is required; it takes more heat input to make FSW T joints. Large shoulder diameters are therefore advised.

Depending on the type of joint, heat and flux stirring needs can vary widely. The material must flow upwards in T and lap joints, while flux is required only in butt joints. It is dependent on the thermal conductivity and volume of heated material on how much heat is required for each joint design. The heating requirements in the mixing zone are the key difference between butt and T joint setups in terms of parameter values. Depending on the joint type, a good AA6262-T6 aluminium alloy flow is achievable by using rotating speeds ranging from 1100 to 1600 revolutions per minute and welding speeds ranging from 220 to 310 millimetres per minute as well as penetration of the probe and a shoulder of 15 mm. There are a number of variables that must be kept constant for these findings to hold up. For example, the tool geometry and joint configurations.

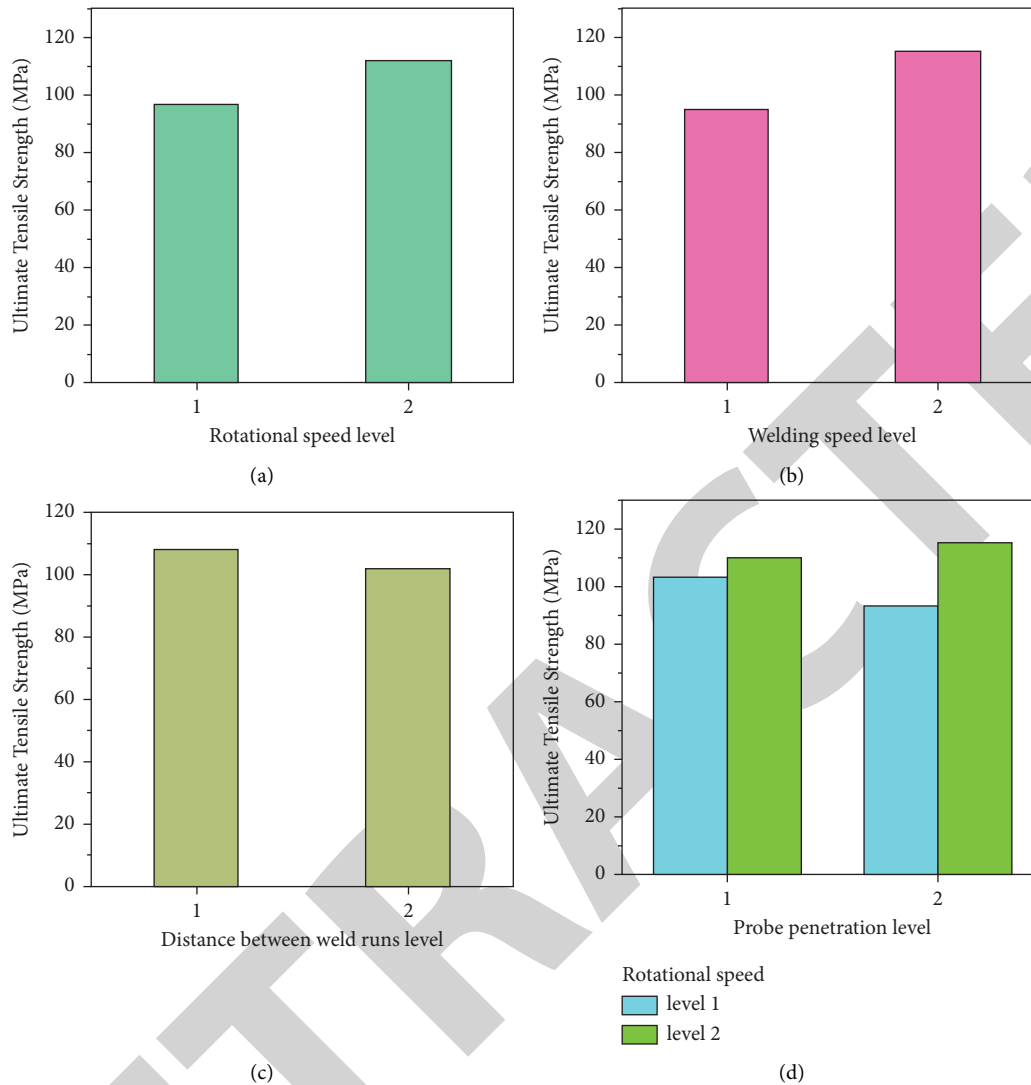


FIGURE 5: (a-d) Lap joint trend analysis of the mean main effect of the different parameters.

5. Conclusions

In three configurations, the Taguchi design of the experiment (DOE) was suitable for optimizing FSW aluminium welding joints. The contribution of each parameter was calculated, and the major and minor parameters were found. The influence on UTS was calculated using the mean main effects and interactions for each parameter. As far as welding parameters, the most critical factors are spindle speed, arc voltage, and shoulder diameters. Under these conditions, butt joints can reach the maximum UTS at 1100 rpm (300 millimetres per minute), 15-millimetre shoulder, and 3.75-millimetre probe penetration. Higher UTS can be achieved by welding T joints at rates ranging from 79 to 220 mm/min at a rotational speed of 1100 rpm, with a shoulder diameter of 15 mm and a penetration depth of 3.5 mm. 1600 rpm, 310 mm/min provides the best UTS in lap joints. Welding with different joint configurations requires varied parameter values to meet the area's thermal and material flow requirements.

Data Availability

The data used to support the findings of this study are included in the article. Should further data or information be required, these are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

The authors thank Arba Minch University, Ethiopia, for the research and preparation of the manuscript to complete this work. The authors also thank the MVJ College of Engineering, Agni College of Technology, Madras Institute of Technology, Anna University, and Noida Institute of Engineering and Technology for the support in completing the work.

References

- [1] K. S. A. Ali, V. Mohanavel, S. A. Vendan et al., "Mechanical and microstructural characterization of friction stir welded SiC and B4C reinforced aluminium alloy AA6061 metal matrix composites," *Materials*, vol. 14, no. 11, p. 3110, 2021.
- [2] T. Sathish, A. R. R. Kaladgi, V. Mohanavel et al., "Experimental investigation of the friction stir weldability of AA8006 with zirconia particle reinforcement and optimized process parameters," *Materials*, vol. 14, no. 11, p. 2782, 2021.
- [3] R. Ramesh, S. Suresh Kumar, V. Sivaraman, and R. Mohan, "Finite element analysis and simulation of Al 7075 alloy joints produced by friction stir welding," *Applied Mechanics and Materials*, vol. 766-767, pp. 1116–1120, 2015.
- [4] M. A. S. Miranda, G. M. D. Almaraz, J. J. V. López, and J. A. R. Vilchez, "Dissimilar joining of ABS and PP using friction stir welding (FSW) and mechanical properties evaluation," *Procedia Structural Integrity*, vol. 39, no. 2022, pp. 161–172, 2022.
- [5] S. Murali, A. Chockalingam, S. Suresh Kumar, and M. Remanan, "Production, characterization and friction stir processing of AA6063-T6/Al₃Tip in-situ composites," *International Journal of Mechanical and Production Engineering Research and Development*, pp. 399–406, 2018.
- [6] V. P. Singh, S. K. Patel, A. Ranjan, and B. Kuriachen, "Recent research progress in solid state friction-stir welding of aluminium-magnesium alloys: a critical review," *Journal of Materials Research and Technology*, vol. 9, no. 3, pp. 6217–6256, 2020.
- [7] R. Jabraeili, H. R. Jafarian, R. Khajeh et al., "Effect of FSW process parameters on microstructure and mechanical properties of the dissimilar AA2024 Al alloy and 304 stainless steel joints," *Materials Science and Engineering: A*, vol. 814, Article ID 140981, 2021.
- [8] S. M. O. Tavares, R. A. S. Castro, V. Richter-Trummer, P. Vilaça, P. M. G. P. Moreira, and P. M. S. T. de Castro, "Friction stir welding of T-joints with dissimilar aluminium alloys: mechanical joint characterisation," *Science and Technology of Welding & Joining*, vol. 15, no. 4, pp. 312–318, 2010.
- [9] Z. M. Liang, G. Y. Wang, Z. B. Sun, D. L. Wang, L. W. Wang, and Y. M. Liang, "Rapidly improved tensile strength of 6N01 Al alloy FSW joints by electropulsing and artificial aging treatment," *Materials Science and Engineering: A*, vol. 841, Article ID 143056, 2022.
- [10] G. Buffa, L. Fratini, F. Micari, and R. Shivpuri, "Material flow in FSW of T-joints: experimental and numerical analysis," *International Journal of Material Forming*, vol. 1, no. 1, pp. 1283–1286, 2008.
- [11] K. Erbslöh, C. Dalle Donne, and D. Lohwasser, "Friction stir welding of T-joints," *Materials Science Forum*, vol. 426, pp. 2965–2970, 2003.
- [12] F. Acerra, G. Buffa, L. Fratini, and G. Troiano, "On the FSW of AA2024-T4 and AA7075-T6 T-joints: an industrial case study," *International Journal of Advanced Manufacturing Technology*, vol. 48, no. 9–12, pp. 1149–1157, 2010.
- [13] M. Papadopoulos, S. Tavares, M. Pacchione, and S. Pantelakis, "Mechanical behaviour of AA 2024 friction stir overlap welds," *Int. J. Struct. Integr.*, 2013.
- [14] G.-F. Zhang, W. Su, J. Zhang, Z.-X. Wei, and J.-X. Zhang, "Effects of shoulder on interfacial bonding during friction stir lap welding of aluminum thin sheets using tool without pin," *Transactions of Nonferrous Metals Society of China*, vol. 20, no. 12, pp. 2223–2228, 2010.
- [15] S. Yazdanian and Z. W. Chen, "Effect of friction stir lap welding conditions on joint strength of aluminium alloy 6060," *IOP Conference Series: Materials Science and Engineering*, vol. 4, no. 1, p. 12021, 2009.
- [16] J. E. R. Dhas and S. J. H. Dhas, "A review on optimization of welding process," *Procedia Engineering*, vol. 38, pp. 544–554, 2012.
- [17] S. Rajakumar and V. Balasubramanian, "Establishing relationships between mechanical properties of aluminium alloys and optimised friction stir welding process parameters," *Materials & Design*, vol. 40, pp. 17–35, 2012.
- [18] L. Cui, X. Yang, G. Zhou, X. Xu, and Z. Shen, "Characteristics of defects and tensile behaviors on friction stir welded AA6061-T4 T-joints," *Materials Science and Engineering: A*, vol. 543, pp. 58–68, 2012.
- [19] A. Heidarzadeh, H. Khodaverdizadeh, A. Mahmoudi, and E. Nazari, "Tensile behavior of friction stir welded AA 6061-T4 aluminum alloy joints," *Materials & Design*, vol. 37, pp. 166–173, 2012.
- [20] C.-Y. Lee, W.-B. Lee, J.-W. Kim, D.-H. Choi, Y.-M. Yeon, and S.-B. Jung, "Lap joint properties of FSWed dissimilar formed 5052 Al and 6061 Al alloys with different thickness," *Journal of Materials Science*, vol. 43, no. 9, pp. 3296–3304, 2008.
- [21] A. C. F. Silva, D. F. O. Braga, M. A. V. de Figueiredo, and P. Moreira, "Ultimate tensile strength optimization of different FSW aluminium alloy joints," *International Journal of Advanced Manufacturing Technology*, vol. 79, no. 5, pp. 805–814, 2015.
- [22] A. K. Lakshminarayanan and V. Balasubramanian, "Process parameters optimization for friction stir welding of RDE-40 aluminium alloy using Taguchi technique," *Transactions of Nonferrous Metals Society of China*, vol. 18, no. 3, pp. 548–554, 2008.
- [23] K. Mariyappan, K. Praveen, S. Suresh Kumar, K. Kadambanathan, S. Rajamanickam, and R. Vignesh, "Characterization of brass/steel plates joined by friction stir welding," *International Journal of Engineering & Technology*, vol. 7, no. 334, pp. 366–368, 2018.