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Original Article

Investigating and Optimizing Friction Stir Welding Parameters of AA6082 and AA5052 by Response Surface Method

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Abstract - *Friction Stir Welding (FSW) is a promising strategy for joining unique aluminum combinations because of its capacity to create excellent welds with insignificant deformities. FSW is a pollution-free welding process used for joining similar or dissimilar alloys. AA6082 T6 and AA5052 aluminum combinations were chosen for FSW due to their unique properties and applications. Mostly these alloys are used in many applications such as automobile, aerospace, shipbuilding, etc. In this research, a plan of trial approach was utilized, with 15 exploratory runs differing in the FSW boundaries as per foreordained levels. The outcomes showed that the FSW boundaries fundamentally affected the elasticity and hardness of the welded tests. A factual investigation involving relapse conditions uncovered the ideal boundary settings for accomplishing wanted weld quality.*

Keywords - *Friction Stir Welding, Dissimilar aluminum alloys, AA6082 T6, AA5052, Optimization, Tensile strength, Hardness.*

1. Introduction

During the process of performing the weld, the Friction Stir Welding (FSW) technique is equipped with a rotating device that does not require any consumable materials. The turning device is comprised of a shoulder and a pin as its constituent pieces or components. Both the shape and size of the gear shoulder and stick add to an expansion in how much power is made, which thus prompts an improvement in the plastic stream that is available in the space of the workpiece that is being welded. To achieve changes in mechanical and microstructural characteristics, like tensile strength, the hardness of the weld, pliability, and disintegration lead, the weld joints go through plasticization and solidifying. The mix of these two processes achieves these progressions. The plastic deformation of the parent metal that happens during the welding process, which at last outcomes in a fine grain structure, is brought about by both the shearing action of the tuning pin and the assembling movement of the shoulder. Both exercises are answerable for the improvement of the fine-grain structure. By the main bending that happens in the welding locale, the microhardness of the friction stir zone is, on each occasion, lower than that of the base metal. This is the case no matter what the conditions. This was finished to develop the joint's mechanical properties further. The completion of this was accomplished to develop the joining procedure further. Through the utilization of friction stir welding, the evaluation is carried out on joints that are constructed out of AA6082 and AA5052, both of which are composed of a vast assortment of materials. It is the normal erosion resistance property of AA5052 (Al-Mg) that is the primary explanation for its widespread application in the marine industry, as well as in the construction industry and the food processing and manufacturing industries. The material AA6082 (Al-Mg-Si) is utilized in marine primary casings most of the time due to the excellent joint strength it possesses. Moreover, the FSW technique has the capability of improving the joint strength of aluminum alloys that are not identical to one another, specifically 6063 and 5052. Wan et al. had the option to build the solidness of aluminum compound AA6082 - T6 welded associations that FRP passed on to a level that was truly 69% better than that of the base metal.

This was achieved by utilizing Fiberglass-Reinforced Plastic (FRP). In the making outline that was presented previously, it was observed that mathematical models and observational relations were made in a combination of aluminum composites for friction stir welded joints to anticipate the mechanical properties of the joints. Another explanation is that the AA6082 aluminum compound was not assessed all through the friction stir handling action. This was because of the way that the movement was completed. Hence, the justification behind this assessment is to spread out a reasonable model and an exploratory relationship utilizing RSM to conclude the mechanical properties of the friction-stir-treated aluminum compound AA6082. Outrageous tensile strength and limited scope hardness (Hv) are two of the properties that include these characteristics [1].

The purpose of RSM is to determine the best process parameters that will result in the highest possible weld chunk hardness. This is the motive for RSM. The ideal process parameters are as follows, as indicated by RSM: An instrument rotational speed of 1100 cycles per moment, a welding velocity of 80 millimeters per moment, a pivotal power of 8 kilonewtons, and device parameters include a shoulder width of 15 millimeters, a pin measurement of 5 millimeters, and an apparatus hardness of 45 HRC. These parameters represent the ideal process parameters [2]. In addition, it is possible to improve the process settings to achieve a more significant joint strength for the friction stir welded 6082-T6 aluminum alloy. When it comes to FSW, the pivot of the instrument is a critical variable. During the process of increasing the instrument turn from 700 to 900 cycles per moment, the friction stir welded AA6082 joint demonstrates an increased level of strength. The strength of the joint gradually decreases as the process progresses, beginning with a speed increase that occurs somewhere in the region of 1100 to 1500 cycles per moment [3]. Every instant, 900 cycles are performed, which results in increased joint strength. If the shoulder infiltration of the hexagonal pin profile is 0.08 millimeters, the microhardness will be at its highest possible level.

This is the most significant level that can be possibly achieved. The weld chunk zone revealed a higher weld hardness than the base metals. This was discovered because of the intense recrystallization taking place in the metals. In the RSM approach, the Central Composite Design (CCD) technique is utilized to find the three reactions, which are UTS and hardness. Patel and Krishna tried to examine the impact of different tool profiles while fabricating joints using a workpiece of aluminum alloy with a constant thickness of 3 mm. Tensile strength is a metric used to describe the mechanical characteristics of welded materials.

Generate the specimen via Friction Stir Welding (FSW) with the assistance of a vertical milling machine. Tensile testing of the welded specimen was done utilizing universal testing equipment. Following that, experiments were conducted to forecast the tensile strength of the welded junction using the Design of the Experiment (DOE) principle. This conclusion is reached after comparing predicted and practical values of tensile strength [4]. Sabry, I., Gadallah, N., & Abu-Okail, M. developed a novel method for anticipating discontinuity development, location, and size during Friction Stir Welding (FSW) of aluminum alloy (AA6061). Via visual examination, hardness testing, and tensile testing of the friction stir welded joints, the technique's efficacy was shown. Power calculations were used to analyze the observed current. The energy consumption varies dramatically in each of the FSW stages, making it easy to discern the tool's penetration, revolution, traverse movement, and rate of metal removal. The results of monitoring energy usage show that welding quality is important when considering power consumption. The FSW has been conducted using two factors: two levels. A mathematical model is created using Response Surface Methodology (RSM).

The constructed mathematical model's suitability is evaluated using the Analysis of Variance (ANOVA) approach, which is used successfully with a 95% confidence level. On the other hand, testing for tensile strength and hardness also revealed that welds with significant power consumption consistently failed inside the welding zone because of the lower welding temperature and lack of penetration [5]. Ghaffarpour, Aziz, and Hejazi researched the practicality of friction stir welding slender sheets of 5083-H12 and 6061-T6 aluminum combination. Inspected is welding with a 1.5 mm thickness.

The results of the trial and advancement were then differentiated. A. Sasikumar conducted research. The 5052 and 6082 aluminum alloys are widely employed to provide lighter main components with better strength and resistance to consumption. In this evaluation, the filler materials that were utilized to increase disintegration security were powdered Magnesium (Mg) and Chromium (Cr). In the Friction Stir Welding (FSW) technique, the disintegration velocities of several FSW joints were examined, and mathematical models were created using the reaction surface approach, which is based on a central composite design [6].

Aluminium and its alloys, according to P. Kumar, are highly valued and widely used materials in a variety of modern applications, including shipbuilding, automobiles, airplanes, and buildings. They also prevent erosion. It is recommended that parts manufactured of different aluminum alloys, specifically AA6061 and AA7475, be linked in industries such as aviation, marine, and automobile [7]. Friction stir welding, or FSW is used in this study to fuse various aluminium alloy 6061 and 7475 plates. Regarding the tensile strength and rate of lengthening of the welded plates, the effects of varying the device pin shape, apparatus turning speed, instrument feed rate, and instrument slant point have been investigated [8].

Following the establishment of a precise correlation between the information parameters and the reaction outcomes, it was determined that the optimal values for miniature hardness, UTS, and strain rate at SZ were 81.05 HV, 16.43%, and 205.23 MPa, respectively [9].For TS, TRS, and slant point, the best values were, respectively, 0.48 and 783.92 fire up/m. The author also noticed uneven particle formation and an irregular division of temperatures around the area [10].

Table 1. Title of table 6082 and 5052 aluminum alloy's chemical composition

Alloy	Fe	Si	Mn	Cu	Zn	Ti	Cr	Al
AA6082	0.5-0.8	0-0.2	0.2	0.42	0.2	0.1	0.2	-
AA5052	0.1-0.3	0.2	0.5	0.1	0.1	0.3	0.1	-

2. Materials and Methods

2.1. Selection of Materials

The aluminum alloys AA6082 T6 and AA5052 were chosen for the investigation. AA6082 T6, measuring 400 mm by 2440 mm and having a thickness of 3 mm, is widely used in structural applications, automotive parts, and maritime settings because of its superior weldability, strong corrosion resistance, and great formability.

Conversely, AA5052, which has a 3 mm thickness but a smaller 400 x 1220 mm dimension, is ideal for sheet metal work, fuel tanks, and appliances because of its strong strength and exceptional corrosion resistance [11].

2.2. Selection of Materials

In the experimental details, the dissimilar materials AA6082 and AA5052 are to be joined by optimizing the Friction Stir Welding (FSW) parameters. Tool Rotational Speed (A) in rpm, Traverse Speed (B) in mm/min, and Tool Offset (C) in mm are the three input parameters that are considered. The values for Tool Rotational Speed (A) are 840 rpm, 1045 rpm, and 1300 rpm. There are three different settings for the Traverse Speed (B): 25, 45, and 65 mm/min. One can set the Tool Offset (C) to 0.6 mm, 1 mm, or 1.2 mm [12].

Table 2. Input parameters and their levels as a function of degrees of freedom

Sr. No.	Input Parameter	Code	Unit	Levels		
				-1	0	1
1	Tool Rotational Speed	A	rpm	800	1045	1300
2	Transverse Speed	B	mm/ min	25	45	65
3	Tool Effect	C	mm	0.6	1	1.2

The values will adjust these variables indicated (-1, 0, 1) to ascertain their impact on the FSW procedure and the final weld quality [13].

For the FSW process, there are 15 experimental runs in the Design of the Experiment (DOE), with different Tool Rotational Speed (A), Traverse Speed (B), and Tool Offset (C) parameters.

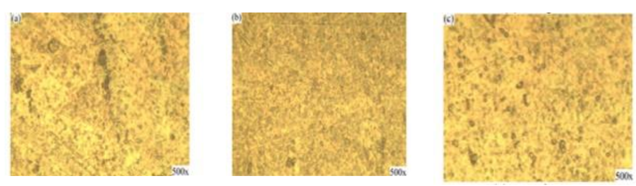
Each run, which has a number between 1 and 15, indicates a different combination of parameter values. For instance, in Run 1, all parameters are set to the midway (0 levels), however in Run 2, Tool Rotational Speed (A) stays at the midpoint (0), Traverse Speed (B) is set to the high level (1), and Tool Offset (C) is set to the low level (-1) [14].

To comprehend the individual and combined impacts of various parameter combinations on the FSW process and the final weld quality, the DOE enables the methodical investigation of these combinations. This method assists in determining the ideal parameter values to attain the intended results during welding [15].

2.3. Experimental Procedure

The AA6082 and AA5052 plates are prepared for the experiment by cutting them to a thickness of 3 mm and cleaning them to get rid of any impurities. After that, the FSW apparatus is assembled, and a suitable tool is chosen to combine the aluminum alloys.

Before firmly gluing the plates together, safety measures are taken. With the Tool Rotational Speed (A), Traverse Speed (B), and Tool Offset (C) set to the predefined settings, the experimental parameters are chosen based on the Design of Experiment (DOE) design. The FSW procedure is carried out with great care, and it is closely watched to guarantee that the components are properly mixed and bonded [16].



(a) Sample A (b) Sample B (c) Sample C

Fig. 1 Microstructure of AA6082 and AA5052 joints

The weld is visually examined for flaws, including voids, fractures, or insufficient bonding after every pass. The welded samples undergo mechanical testing, such as tensile, hardness, and impact tests, to assess their strength and quality. To investigate the weld microstructure, optical or electron microscopy is also used for microstructural study. Every experimental run generates a set of data, which includes test results, welding results, and parameter values.

The impact of the FSW parameters on the weld quality is then ascertained by analyzing the data [17]. To determine the ideal parameter values for merging AA6082 and AA5052, the outcomes are compared with the DOE. To thoroughly explore the parameter space and verify the findings, the experiment is repeated for each DOE run. Based on the experimental results, conclusions are developed, and suggestions are given for the best FSW parameters to link AA6082 and AA5052 to achieve the intended application [18].

3. Result and Discussion

3.1. Tensile Strength Analysis in Friction Stir Welding of Different Aluminum Alloys

Friction stir welding is utilized for the welding of different aluminum alloys. The quantity of preliminaries is resolved utilizing the RSM strategy, and the info and result reactions are inspected utilizing a Regression [19, 20]. For every test, Table 3 shows the estimated reaction tensile strength of the welded example.

Different rigidity levels are shown in the information concurring on the blend of elements. For example, preliminary attempt 5 created the best elasticity in the dataset, 168 MPa, utilizing a device rotational speed of 1045 rpm, navigate speed of 25 mm/min, and apparatus offset of 0.6 mm. Preliminary attempt 7, then again, showed the least elasticity of 132 MPa with a device rotational speed of 840 rpm, a crossing rate of 45 mm/min, and an instrument offset of 1.2 mm [20]. These discoveries propose that the rigidity of the welded tests is profoundly affected by the blend of cycle factors. At the point when friction stirs welding aluminum compounds, extra assessment and correlation of the discoveries could shed light on the ideal boundary values for acquiring the expected elasticity [21, 22].

Table 3. The tensile strength of the example with different process parameter blends

Trial Run	Tool Rotational speed (RPM)	Transverse speed (mm/min)	Tool Offset (mm)	Tensile Strength (Mpa)
1	1045	45	0.9	160
2	1045	65	0.6	149
3	1300	65	0.9	152
4	1045	45	0.9	162
5	1045	25	0.6	168
6	1045	65	1.2	146
7	840	45	1.2	132
8	840	45	0.6	138
9	1300	45	1.2	162
10	840	25	0.9	142
11	1045	45	1.2	154
12	1300	45	0.6	166
13	1300	25	0.9	180
14	1045	25	1.2	160
15	840	65	0.9	132

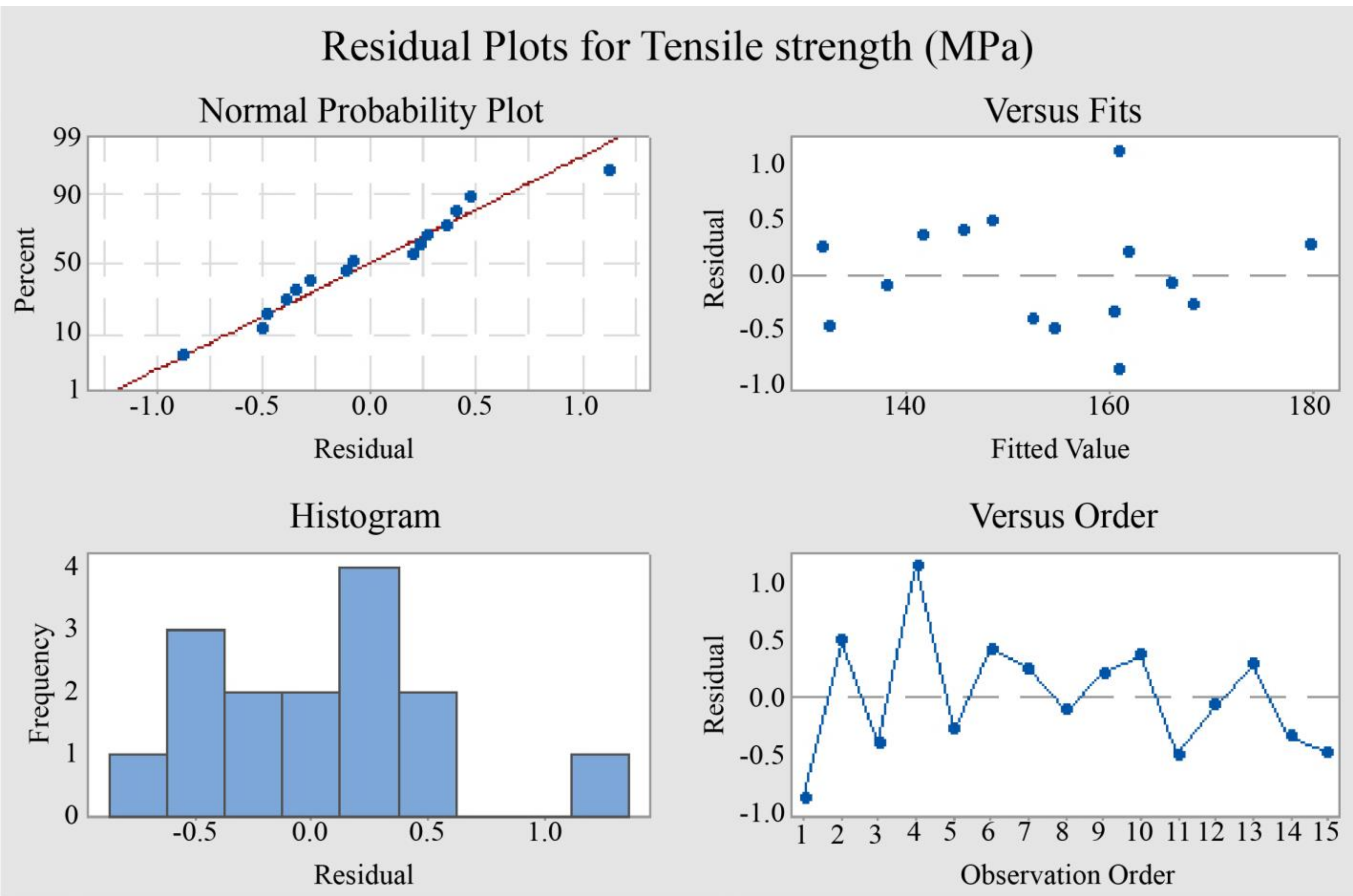


Fig. 2 Data testing for tensile strength

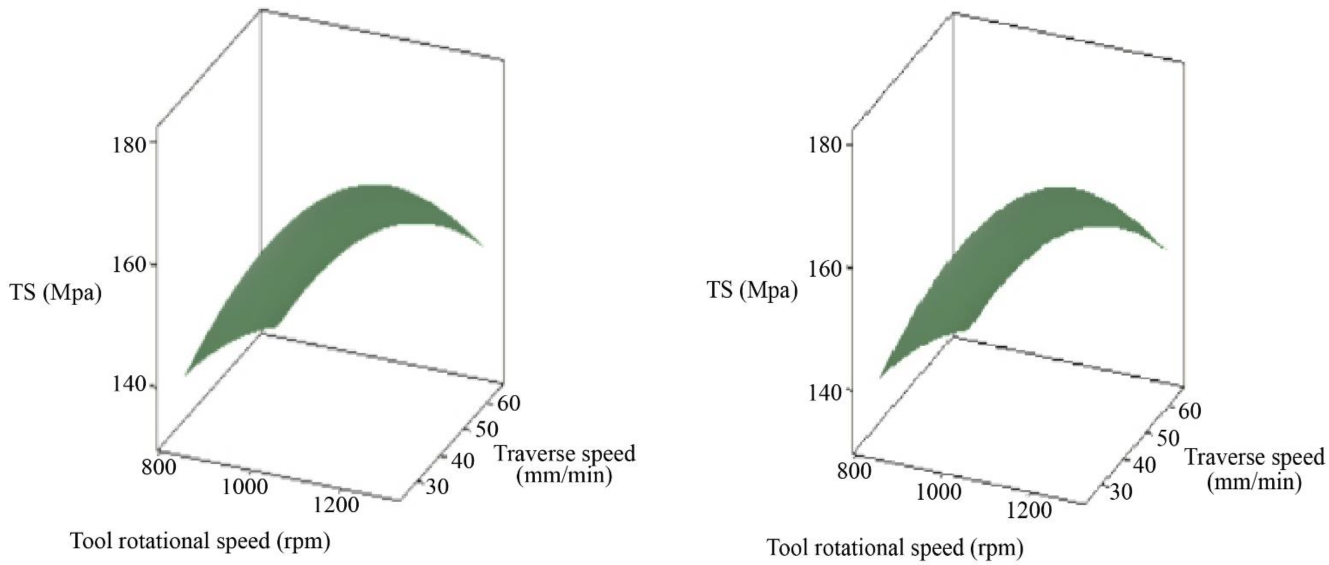


Fig. 3 Surface plot of tensile strength

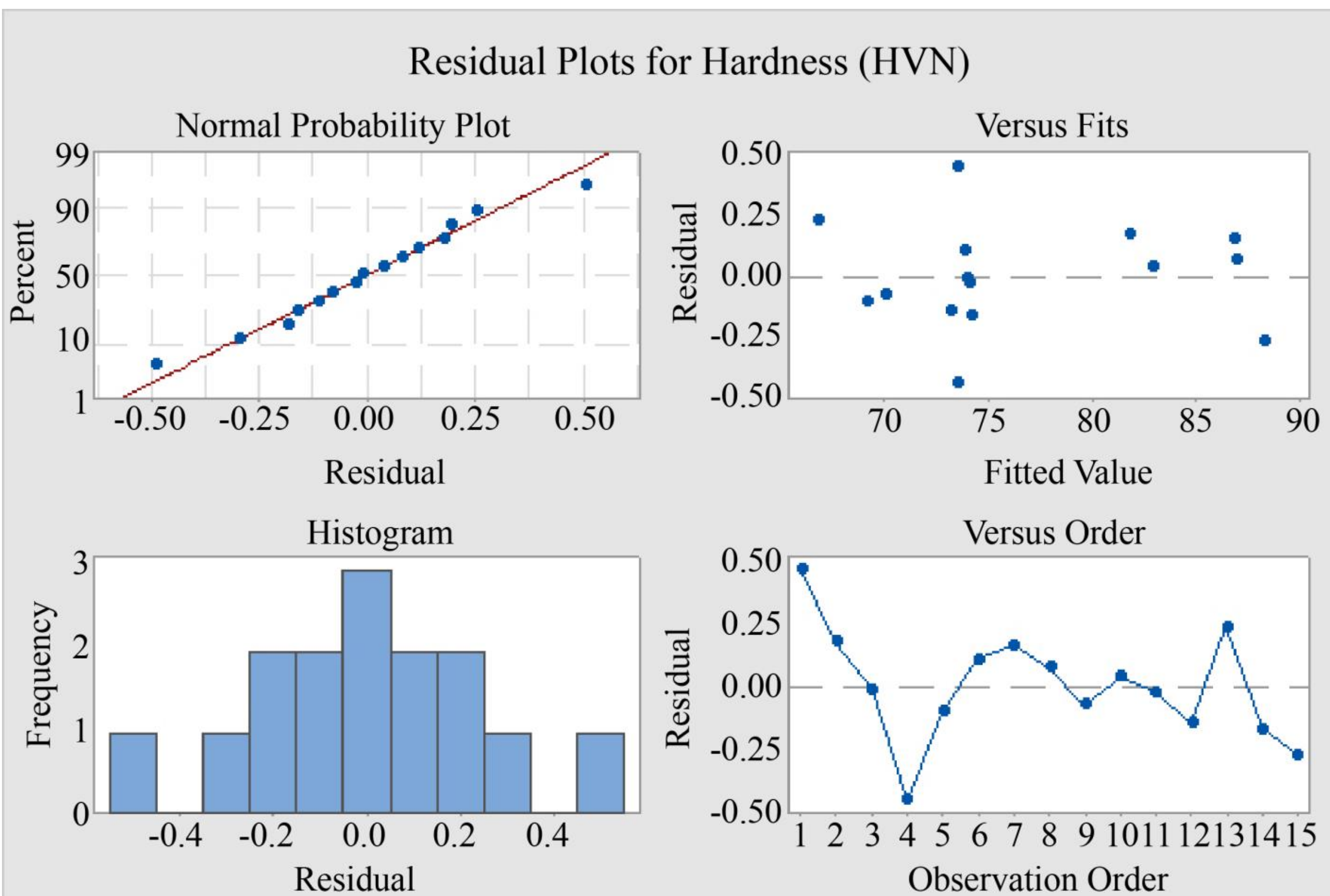


Fig. 4 Data testing for hardness

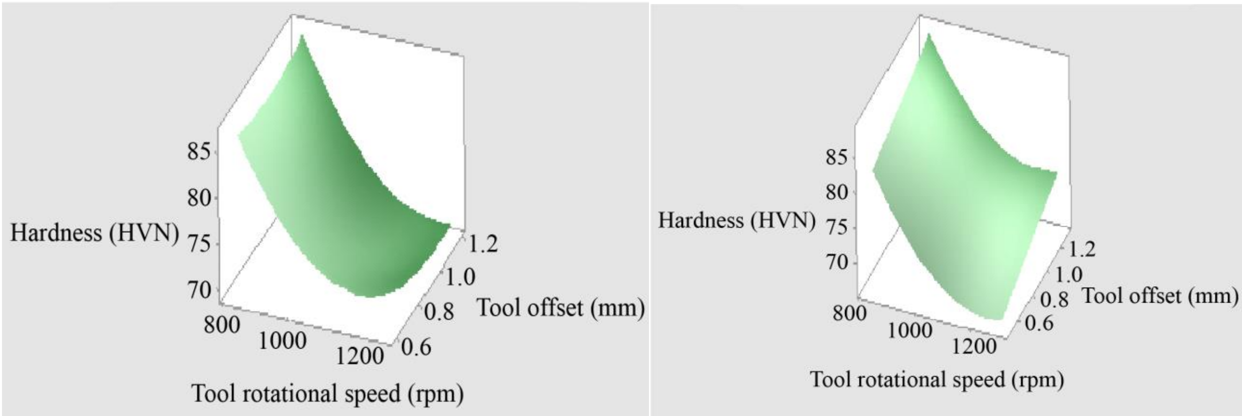


Fig. 5 Surface plot of hardness

Table 4. The hardness of the example with different process parameter blends

Trial Run	Tool Rotational Speed (RPM)	Transverse Speed (mm/min)	Tool Offset (mm)	Hardness (HVN)
1	1045	45	0.9	74
2	1045	65	0.6	82
3	1300	65	0.9	74
4	1045	45	0.9	73
5	1045	25	0.6	69
6	1045	65	1.2	74
7	840	45	1.2	87
8	840	45	0.6	87
9	1300	45	1.2	70
10	840	25	0.9	83
11	1045	45	1.2	74
12	1300	45	0.6	73
13	1300	25	0.9	67
14	1045	25	1.2	74
15	840	65	0.9	88

3.2. Hardness Strength Analysis in Friction Stir Welding of Different Aluminum Alloys

Friction stir welding is utilized for the welding of different aluminum alloys. The quantity of preliminaries is resolved utilizing the RSM strategy, and the info and result reactions are inspected utilizing a Regression. For every test, Table 4 shows the estimated reaction hardness of the welded example.

Contingent upon the blend of variables, the information shows contrasts in hardness. Preliminary attempt 7, for instance, had the best hardness worth of 87 HVN with a device rotational speed of 840 rpm, a crossing rate of 45 mm/min, and an instrument offset of 1.2 mm. Then again, Preliminary attempt 13 had the most reduced hardness worth of 67 HVN with a device rotational speed of 1300 rpm, a crossing pace of 25 mm/min, and an instrument offset of 0.9 mm. These discoveries propose that different blends of cycle factors might cause the welded tests' hardness levels to vary. Extra assessment and differences in the results could offer significant viewpoints on the best boundary arrangements to achieve the planned hardness in friction stir welding of aluminum combinations.

4. Conclusion

The objective of the review was to improve the Friction Stir Welding (FSW) settings to accomplish the ideal weld quality. The aluminum composites AA6082 T6 and AA5052 were read up for their difference. The best FSW settings for upgrading the elasticity and hardness of the welded tests were tracked down by measurable examination and a plan of investigation strategy. The discoveries showed that the rigidity and hardness of the welded tests were significantly influenced by the FSW boundaries, which included apparatus rotational speed, cross speed, and instrument offset. Considering the FSW attributes, the relapse examination created numerical models to appraise the rigidity and hardness. The results of the research showed that some combinations of parameters resulted in increased tensile strength and hardness, highlighting the significance of parameter optimization in obtaining excellent weld quality. The study adds to our knowledge of the FSW process parameters for fusing different aluminum alloys and offers suggestions for enhancing the efficacy and efficiency of aluminum welding procedures. The study emphasizes parameter optimization's critical role in producing high-quality welds and demonstrates the potential of FSW as a workable approach for combining different aluminum alloys. More investigation may delve into more facets of FSW process optimization and broaden the scope of FSW's application to diverse materials and industries.

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