

# Enhancing Weld Quality in Dissimilar Aluminum Alloys through Friction Stir Welding Parameter Optimization

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**Abstract:** This research focuses at the ways that various friction stir welding (FSW) settings affect the mechanical characteristics of two different aluminum alloys, AA5085 and AA6061. To find the best welding settings for increasing hardness and tensile strength, we used regression modeling, analysis of variance (ANOVA), and the Taguchi L9 orthogonal array. Welding speed mainly impacts hardness, although feed rate greatly impacts tensile strength, according to the results. The peak tensile strength was 125 MPa and the hardness was 62.4 HV, with the optimal settings being a welding axial force of 5 kN, feed rate of 10 mm/min, and speed of 900 RPM. Findings from this study highlight the significance of feed rate and welding speed for achieving strong, defect-free joints for use in the aviation, marine, and automobile sectors. Additional factors that could be investigated in future studies to improve FSW performance include tool geometry, rotational direction, and microstructural features.

**Keywords:** Friction Stir Welding of Aluminum Alloys, Taguchi Method, ANOVA, Tensile Strength, Hardness

## I. INTRODUCTION

The solid-state joining procedure known as Friction Stir Welding (FSW) is highly effective in producing defect-free welds with improved mechanical qualities, rendering it a favored option for welding aluminum alloys. The Welding Institute (TWI) developed FSW in 1991, and since then, it has been widely utilized in the aerospace, marine, and automotive sectors because to its remarkable strength and ability to weld incompatible materials with low distortion [1]. Unlike conventional fusion welding techniques, FSW eliminates issues related to solidification defects, making it highly suitable for aluminum alloys, which are prone to porosity and cracking in traditional welding processes [2].

Because of their different mechanical behaviors and thermal properties, welding dissimilar aluminum alloys like AA5083 and AA6061 is extremely difficult. AA5083 is a strain-hardened, corrosion-resistant alloy commonly used in marine applications, while AA6061 is a precipitation-hardened alloy known for its high strength and good machinability [3]. The joining of these alloys through FSW has been a subject of extensive research, with optimization of process parameters playing an essential factor in assessing the quality of the welds [4].

In order to improve the mechanical performance of welded joints, numerous research have concentrated on optimizing FSW parameters. These characteristics include tool rotation velocity, welding velocity, and axial force. In their study, Bhatnagar et al. [5] optimized FSW parameters for different Joints of AA7050 and AA6061 utilizing Response Surface Methodology (RSM). They found that the best combination of speed and force results in increased tensile strength. A similar vein of research by Verma et al. [6] examined how welding speed and tool design influenced the mechanical characteristics of AA6061 and AA5083 welds, highlighting the need of carefully selecting these parameters.

Taguchi and ANOVA statistical techniques have been widely applied to analyze and optimize FSW parameters. Elatharasan et al. [7] employed Grey Relation Analysis to identify the most influential factors affecting tensile strength and hardness in dissimilar aluminum welds. Moreover, regression analysis has been implemented to predict mechanical properties based on process parameters, aiding in real-time optimization of welding conditions [8].

Despite extensive research on FSW, further exploration is needed to enhance the understanding of microstructural evolution, fatigue behavior, and defect formation mechanisms in dissimilar aluminum welds. Additionally, the integration of machine learning algorithms for predictive modeling of weld quality is emerging as a promising approach [9]. This paper aims to analyze the influence of FSW process parameters on the mechanical properties of AA5083 and AA6061 joints using the Taguchi L9 orthogonal array method, ANOVA, and regression analysis, providing insights for optimizing welding conditions for industrial applications.

## II. METHODOLOGY

### 2.1 Material Selection and Preparation

In this paper, dissimilar aluminum alloys AA5083 and AA6061 were selected for Friction Stir Welding (FSW) due to their widespread industrial applications and distinct mechanical properties. AA5083, a strain-hardened alloy with excellent corrosion resistance, is commonly used in marine and structural applications, while AA6061, a precipitation-hardened alloy, is known for its high strength and machinability [1]. The workpieces were prepared as 150 mm × 75 mm × 6 mm plates, ensuring a uniform thickness to maintain consistency in the welding process [2].

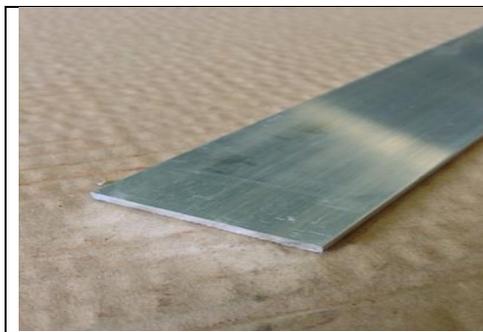


Figure 1. AA5083 Plate



Figure 2. AA6061 Plate

We removed oxides and impurities that potentially impact the weld quality from the surfaces of the aluminum alloys by mechanically cleaning them with acetone [3]. After that, we attached the edges that needed welding onto the fixture so they wouldn't move while we worked.

### 2.2 Friction Stir Welding Process

Using a high-speed steel (HSS) non-consumable tool and a CNC-controlled FSW machine, the FSW procedure was carried out. The material flow was improved and defect formation was minimized by choosing a cylindrical threaded pin profile [4]. To make sure the two alloys mixed well at the interface, the welding was done in a butt joint arrangement.

To optimize the welding parameters, three key process variables were considered:

- ❖ Tool Rotational Speed (RPM): 900, 1100, and 1300 RPM
- ❖ Welding Speed (mm/min): 30, 45, and 60 mm/min
- ❖ Axial Force (kN): 4, 5, and 6 Kn



Figure 3. Friction Stir Welding Process



Figure 4. L9 FSW Samples

These parameters were selected based on prior studies indicating their significant influence on weld strength, microstructure, and defect formation [5]. The experimental design followed the Taguchi L9 orthogonal array to systematically analyze the influence of these parameters on the mechanical characteristics of the welds [6].

### 2.3 Mechanical Testing and Analysis

#### Tensile Testing

A Universal Testing Machine (UTM) was employed to evaluate the tensile strength of the welded joints in accordance with ASTM E8M standards. A strain rate of 2 mm/min was utilized for the tensile testing, and the specimens were machined into a dog-bone shape [7]. For each circumstance, an average of three specimens was utilized to ascertain the ultimate tensile strength (UTS) of the weld.



Figure 5. Tensile testing

#### Microhardness Testing

Employing a Vickers hardness tester with a 100g load 15-second dwell time, microhardness measurements were taken. In order to assess the alterations in material characteristics induced by thermal cycling during Friction Stir Welding (FSW), the hardness profile was taken over the weld zone, the heat-affected zone (HAZ), and the base metal areas [8].

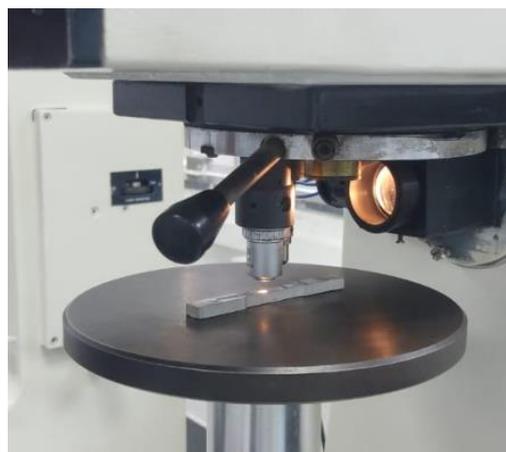


Figure 6. Hardness testing

#### Statistical Analysis

The experimental data underwent Analysis of Variance (ANOVA) in order to identify the process factors that had the greatest impact. To evaluate the robustness of the weld quality, the signal-to-noise (S/N) ratio derived from the Taguchi methodology was utilized. Additionally, regression analysis was applied to develop a predictive model correlating process parameters with tensile strength and hardness values [10].

Table: 1. Table of Tensile result for all samples

<i>Tensile Testing sample</i>	<i>Ultimate Tensile Strength (Mpa)</i>
T1	125
T2	107
T3	90
T4	76
T5	102
T6	93
T7	96
T8	73
T9	89

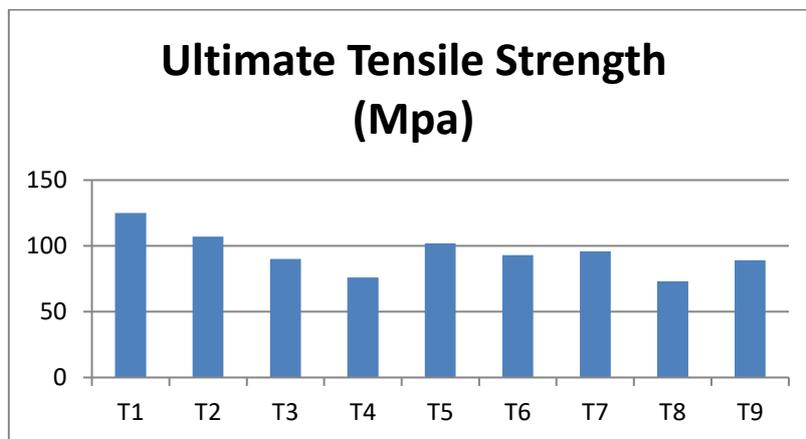


Figure 7. Comparison for tensile

Table: 2. Orthogonal Array L9 Formation

<i>S.NO</i>	<i>Speed (RPM)</i>	<i>Feed (mm/min)</i>	<i>Axial Force (KN)</i>
1.	900	10	5
2.	900	12	6
3.	900	14	7
4.	1000	10	6
5.	1000	12	7
6.	1000	14	5
7.	1100	10	7
8.	1100	12	5
9.	1100	14	6

Table 3. Test of Tensil Strength

<i>S.NO</i>	<i>Speed (RPM)</i>	<i>Feed (mm/min)</i>	<i>Axial Force (KN)</i>	<i>Tensile Strength</i>
1.	900	10	5	125
2.	900	12	6	100
3.	900	14	7	90
4.	1000	10	6	96
5.	1000	12	7	102
6.	1000	14	5	93
7.	1100	10	7	96
8.	1100	12	5	93
9.	1100	14	6	89

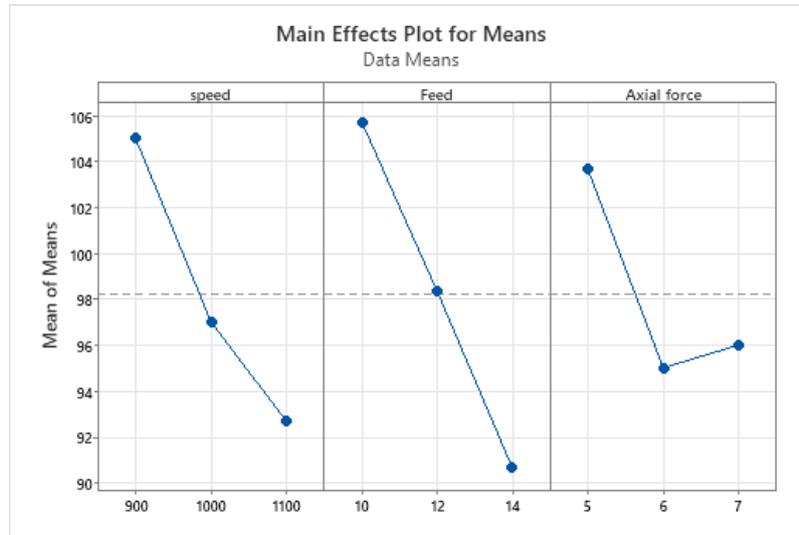


Figure 8. Tensile Main Effects Plot for Means

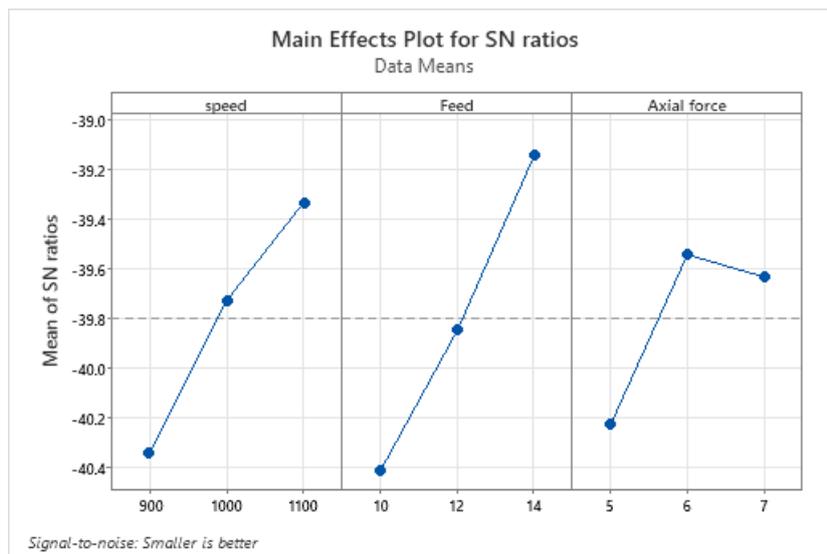


Figure 9. Tensile Main Effects Plot for SN Ratios

Table: 4. Test Result of Hardness strength

<i>Hardness Testing</i>	<i>Vickers Strength HV 10</i>			
	<i>ID 1</i>	<i>ID 2</i>	<i>ID 3</i>	<i>Average</i>
H1	63	61.5	62.7	62.4
H2	62.6	61.1	63.2	62.3
H3	60.7	59.9	61.5	60.7
H4	59.8	58.7	60.5	59.7
H5	61.8	60.2	62.3	61.4
H6	62.4	59.6	60.9	60.9
H7	61.2	60.3	62.1	61.2
H8	58.9	57.6	59.8	58.7
H9	60.1	59.4	61	60.2

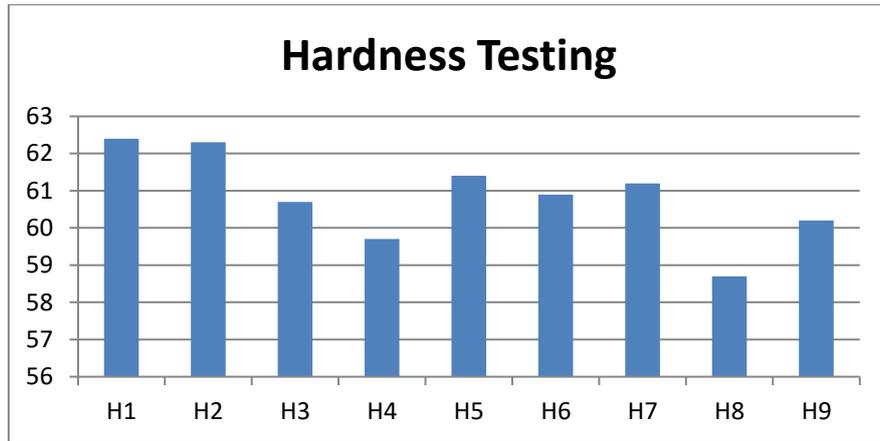


Figure 10. Comparison for Hardness

Table: 5. Test of Hardness Strength

S.NO	Speed (RPM)	Feed (mm/min)	Axial Force (KN)	Hardness
1.	900	10	5	62.4
2.	900	12	6	62.3
3.	900	14	7	60.7
4.	1000	10	6	59.7
5.	1000	12	7	61.4
6.	1000	14	5	60.9
7.	1100	10	7	61.2
8.	1100	12	5	58.7
9.	1100	14	6	60.2

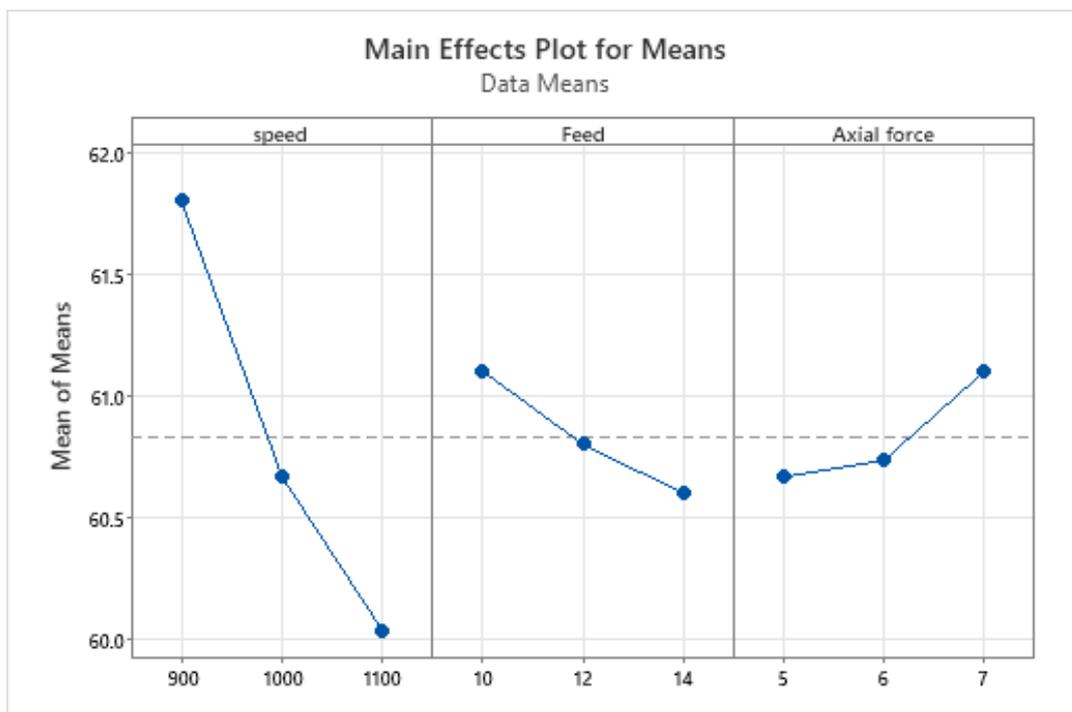


Figure 11. Hardness Main Effects Plot for Means

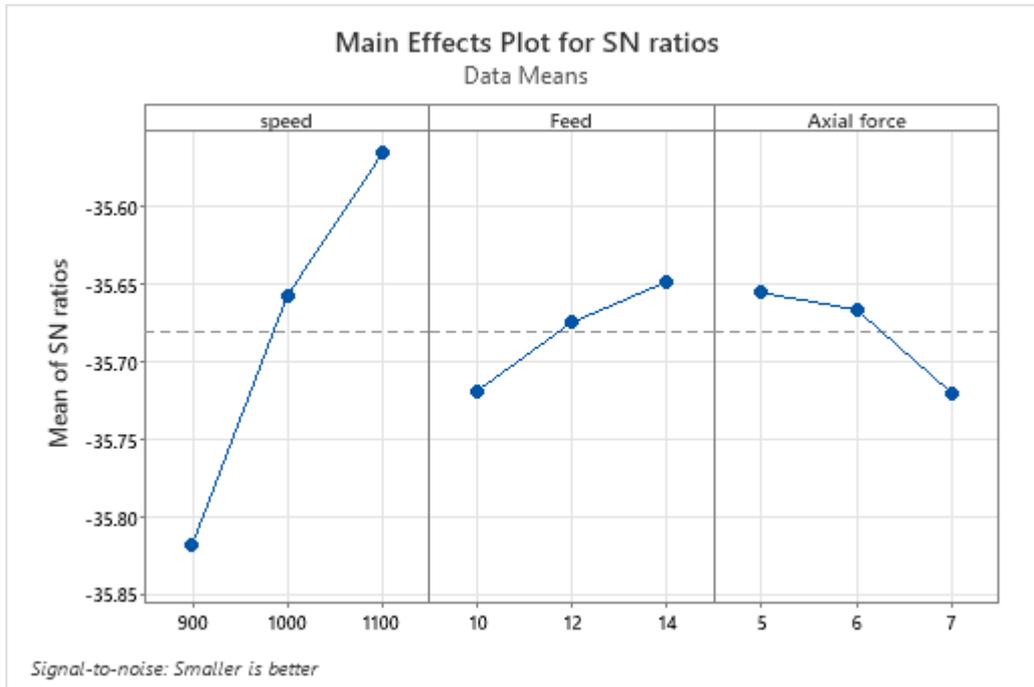


Figure 12. Hardness Main Effects Plot for SN ratios

### III. RESULT AND DISCUSSION

This research takes a look at the mechanical characteristics of two distinct aluminum alloys, AA5085 and AA6061, and how they are affected by the parameters involved in the friction stir welding (FSW) process. The tensile strength and hardness have been investigated with the help of the Taguchi L9 orthogonal array. The most important factors impacting tensile strength, which ranged from 89 MPa to 125 MPa, were feed rate, welding speed, and axial force. The most important element, other from welding speed, was hardness value, which varied from 58.7 HV to 62.4 HV. The optimal welding parameters were determined to be 900 RPM, axial force of 5 kN and a feed rate of 10 mm/min, according to the optimization results, which also indicated the highest tensile strength and hardness. Consistent with earlier research, faster welding speeds increase grains, increasing hardness, and appropriate feed rates increase tensile strength by decreasing flaws. The results presented in this study have practical implications for the aerospace, marine, and automobile industries. To further improve process efficiency, future studies should investigate further elements including tool geometry and predictive models based on machine learning.

### IV. CONCLUSION

This study utilizes the Taguchi L9 orthogonal array, ANOVA, and regression analysis to examine the effect of friction stir welding (FSW) factors on the mechanical properties of two different aluminum alloys, AA5085 and AA6061. Results show that feed rate is most important for tensile strength and that welding speed is most important for hardness. Maximum tensile strength of 125 MPa and hardness of 62.4 HV were achieved using the optimal welding conditions of 900 RPM speed, 5 kN of axial force and a feed rate of 10 mm/min.

For aerospace, marine, and automotive applications in particular, our findings highlight the significance of maximizing weld integrity by optimizing feed rate and welding speed. In addition, the study confirms previous findings that show how controlled feed rates decrease flaws and increase tensile strength, as well as increased welding speeds refine grains to enhance hardness.

To further optimize, future studies could take into account additional aspects including tool shape, rotational direction, and tilt angle. In addition, machine learning models could help with predictive optimization for real-time applications, and microstructural analysis and fatigue testing could tell us more about how long welds last. In order to guarantee better mechanical performance in industrial welding applications, this research adds to the advancement of FSW parameter optimization.

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