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Effect of Groove Shape in GTAW Welding on Bending Strength of Aluminium 6061

Akbar Zulkarnain[1], Ajeng Tyas Damayanti[1], Roni Yanuar Saputro[1]

[1]Railway Mechanics Technology, Indonesian Railways Polytechnic Madiun Jl. Tirta Raya, Corner, Sambirejo, Subdistrict Jiwan, City of Madiun, East Java, Indonesia

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Abstract

The Aluminum alloy 6061 material is used to make components for light trains such as underframes, sidewalls, roofs, and endwalls. A joining process called welding is used to make train components. In the connection process using welding, many stages must be considered, such as the design stage starting from selecting the type of welding, to choosing the seam angle used. This research aims to determine the effect of the shape of the seam on GTAW welding on bending tests on aluminum alloy 6061 material. The shape of the seam used in this research is a variation of the shape of the seam square groove, V groove, and double V groove. The research method used is research by conducting tests, based on the treatment given to the test material, namely welding using GTAW welding on aluminum alloy 6061. To determine the strength of the joint, bending tests are carried out, and calculation of the bending strength and modulus of elasticity value so that the shape of the joint can be determined. Has a high elasticity value. After welding and bending tests were carried out, the highest average bending strength result was 94.83 MPa in the double V groove seam shape variation, and for the specimen that had the lowest bending strength it was 41.299 MPa in the square groove seam shape variation. The elastic modulus calculation was carried out showing that the largest elastic modulus value in the Double V groove seam shape was 295.929 MPa.

Keywords: Aluminum Alloy 6061, Seam Shape, GTAW Welding, Bending Test.

Corresponding Author:

Name: Akbar Zulkarnain
Email: akbar@ppi.ac.id

1. Introduction

Aluminum and its alloys are widely used in engineering and industrial applications due to their remarkable combination of properties, including lightweight, high tensile strength, and corrosion resistance. These alloys, which may incorporate elements such as copper, magnesium, manganese, silicon, zinc, and tin, are valued for their versatility and adaptability to various conditions. Mechanical properties of aluminum alloys can be enhanced through thermal treatments like heat aging and cold working, making them suitable for both structural and functional components. Aluminum's superior corrosion resistance and its high strength-to-weight ratio have positioned it as a material of choice in

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transportation, aerospace, and construction industries. Among the many aluminum alloys available, Aluminum 6061 stands out due to its excellent balance of mechanical properties, weldability, and corrosion resistance, particularly for applications in transportation sectors such as railway systems [1] [2].

Aluminum 6061, an Al-Mg-Si alloy, has become indispensable in industries requiring materials that combine lightweight with mechanical robustness. This alloy exhibits excellent extrusion characteristics, corrosion resistance, and machinability. Moreover, it can be strengthened through heat treatment, offering enhanced tensile and yield strength, which are critical for structural applications. Its thermal conductivity, corrosion resistance, and good fatigue strength make it a preferred material for manufacturing railway components such as frames and structural supports. Despite its lower initial strength compared to some other alloys, Aluminum 6061's ability to maintain formability at high and ambient temperatures while offering good weldability has made it highly sought after in the transportation and construction sectors [3] [4].

Welding is one of the primary methods used to fabricate Aluminum 6061 components, especially in the railway sector, where structural integrity is paramount. Gas Tungsten Arc Welding (GTAW), also known as Tungsten Inert Gas (TIG) welding, is the most commonly used welding technique for aluminum alloys due to its ability to produce precise and defect-free welds. GTAW involves creating an arc between a non-consumable tungsten electrode and the workpiece, with an inert shielding gas such as argon or helium protecting the weld area from atmospheric contamination. This process allows for precise control of the heat input, reducing the risks of distortion, porosity, and cracking that are often associated with aluminum welding. The choice of groove geometry in the joint preparation stage, however, has been identified as a critical factor influencing the quality and strength of the welded joint, necessitating further research into its impact on mechanical performance [5] [6].

The groove geometry determines the heat distribution, penetration depth, and stress distribution in the welded joint, thereby significantly affecting its mechanical properties, including tensile and bending strength. While several studies have investigated the effect of groove geometry on the tensile strength of materials such as steel, limited research has focused on the influence of these parameters on aluminum alloys, particularly Aluminum 6061. For instance, prior research on ST 37 steel demonstrated that single U-groove welds exhibited higher yield stress and overall strength compared to single V-groove welds due to improved stress distribution and reduced heat-affected zone (HAZ) width. However, the specific impact of groove geometry on bending strength a critical parameter for structural components subjected to dynamic loads remains underexplored for aluminum alloys, motivating this study [7] [8] [9] [10].

This research investigates the effect of groove geometry on the bending strength of Aluminum 6061 joints produced using GTAW welding. The study aims to bridge the gap in the current literature by evaluating the mechanical performance of welded joints with varying groove shapes. Through detailed bending tests and analysis, this research seeks to provide insights into optimizing groove design for aluminum welding to enhance the structural integrity and reliability of components. The findings will be particularly relevant for industries where aluminum 6061 is extensively used, such as transportation and construction, offering practical recommendations for improving welding practices and joint performance [9] [11] [12].

2. Research Method

This study investigates the effect of groove geometry variation on the bending strength of Aluminum 6061 joints welded using Gas Tungsten Arc Welding (GTAW). The research involves several stages: material preparation, welding process, mechanical testing, and data analysis. The details of each stage are described below.

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2.1 Material and Sample Preparation

The material used in this study is Aluminum 6061, an Al-Mg-Si alloy with excellent mechanical properties such as tensile strength, corrosion resistance, and ductility. The raw material was cut into standard test specimens measuring 150 mm × 50 mm × 5 mm for the bending test. Surface cleaning was performed using a chemical etching solution to remove contaminants like oil, dust, and oxides, which could affect the welding quality. Three types of grooves were analyzed in this study: single V-groove, single U-groove, and square groove. The grooves were prepared with specific dimensions, including angles and depths, following welding standards such as ASME BPVC IX and ISO 9606. Precision measuring tools like digital calipers and micrometers were used to ensure accurate groove geometry.

Table 1. Specification Al 6061

Modulus elastisitas	68,9 GPa
Densitas	2700 Kg/m^3
Yield stress	276 MPa
Elongation	12%
Fatigue strength	96,5 MPa
Shear strength	207 MPa
Shear modulus	26 GPa
Ultimate tensile strength	310 MPa

2.2 Welding Process

The welding was conducted using the GTAW method. The welding machine employed was an inverter-type TIG welder with a maximum current capacity of 200 A. A 2.4 mm non-consumable tungsten electrode was used to ensure arc stability. Pure argon gas was supplied at a flow rate of 15 L/min to shield the weld area from atmospheric contamination. The welding parameters were selected based on literature and preliminary tests: welding current was set at 120 A, voltage at 15 V, and welding speed at 2.5 mm/s. No filler material was used to ensure that the weld joint characteristics relied solely on the Aluminum 6061 material. The welding process was carried out in a controlled environment to minimize the effects of temperature and humidity. in this study, the welding filler using type ER 4043 Table 2 [13] [14] [15].

Table 2. Filler Chemical Composition

Grade	Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
ER 4043	4,8	0,2	0.02	0.01	0.01	0,02	0,01	*balance*

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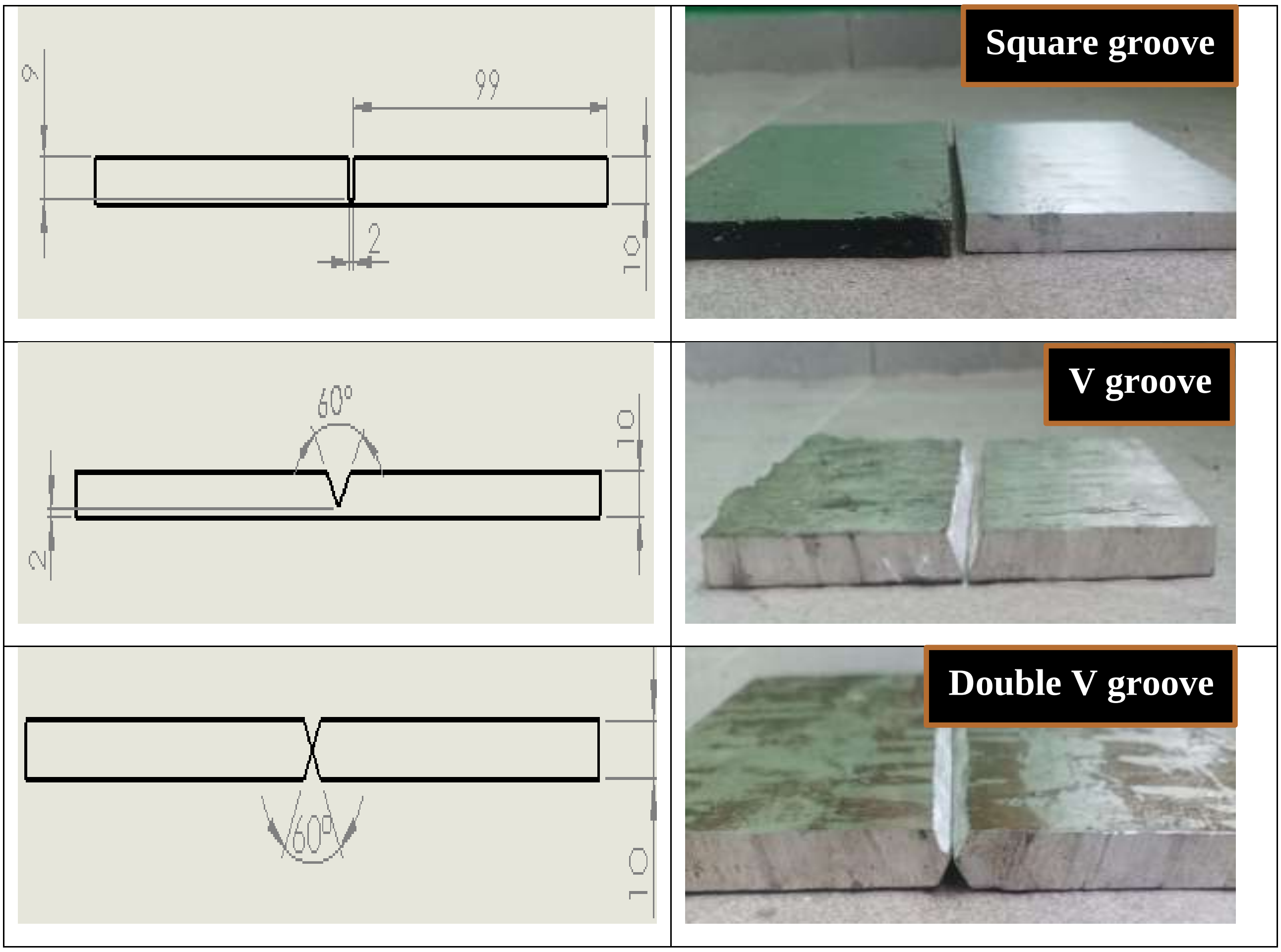

Figure 1. Specimen Test

2.3 Mechanical Testing

Mechanical testing focused on evaluating the bending strength of welded joints with different groove geometries. A three-point bending test was performed using a universal testing machine, following ASTM E290 standards. Each sample was placed on supports with a specified span, and a load was applied at the midpoint until deformation or fracture occurred.

$$\sigma = \frac{3.F.L}{2.b.d^2} \quad (1)$$

Where F is the maximum load, L is the span length between supports, b is the width, and h is the thickness of the specimen. Additionally, microstructural analysis was conducted using optical microscopy to observe the heat-affected zone (HAZ) and detect defects such as porosity or cracks [16] [17] [18].

2.4 Validation and Error Control

A factorial experimental design was employed to identify interactions between groove geometry and welding parameters on the bending strength of the material. The independent variable was groove

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type, while the dependent variable was bending strength. Controlled variables included material type, specimen thickness, and welding parameters. To ensure data validity, each test was repeated three times. Measurements with deviations exceeding 5% from the mean were considered outliers and excluded. Testing equipment was calibrated before each use to minimize instrument error.

Figure 2. Welding and Speciment Testing

3. Results And Discussion

Bending testing was carried out in the laboratory of PT Detech Profesional Indonesia. A total of 9 specimens will be tested for bending. Bending testing is carried out using the direction of the load on the surface of the weld (face bend). After bending testing, the output of the test results for each specimen is obtained. The output obtained from the test results is the maximum load.

Table 3. Bending Load

No. Spesimen	Beban Maksimum (N)
Square groove.1	1442
Square groove.2	1284
Square groove.3	1464
V groove.1	2016
V groove.2	2106
V groove.3	2039
Double V groove.1	3297
Double V groove.2	3170

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Double V groove.3	3116

Based on the results of the calculations that have been carried out, the largest average result in the bending strength test is obtained in the variation of the double V groove shape with an average bending strength of 94.834 MPa. After obtaining the test results, the data is presented in tabular form. The following is a table of the average amount of strength of the welded joints of each variation used.

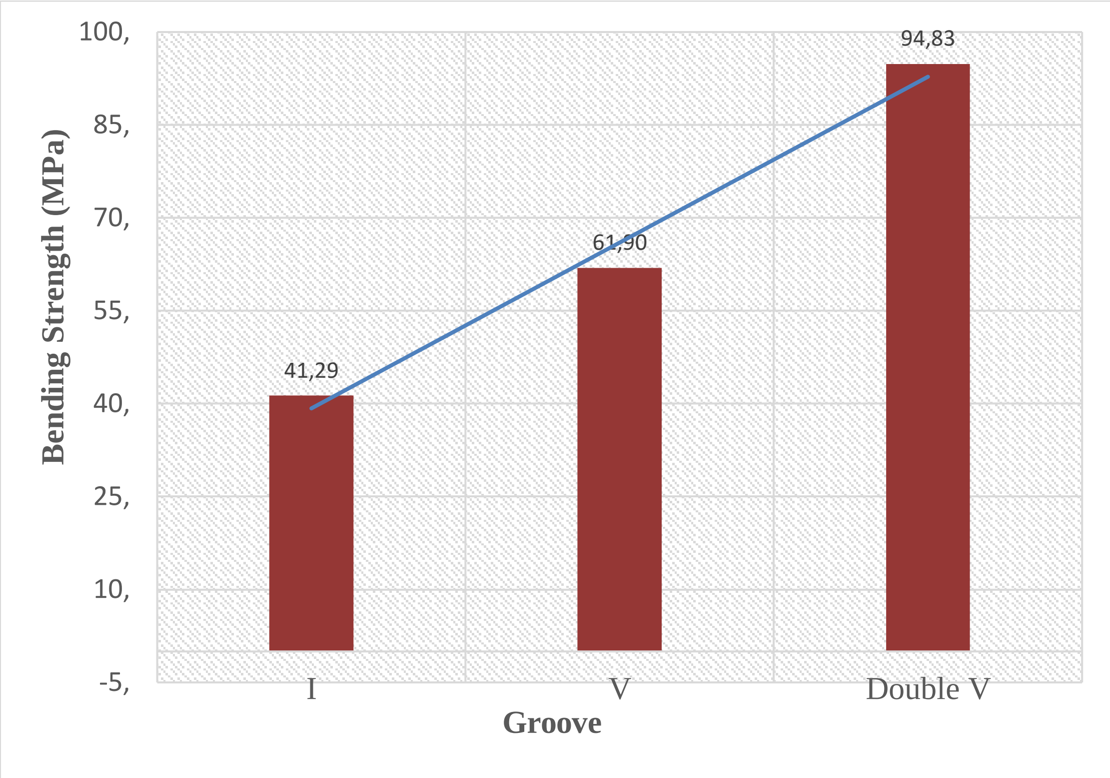

Figure 3. Bending Strength

In the results of bending tests with variations in the shape of the camphor from the diagram above, it can be seen that the variation in the shape of the double V groove camphor gets the highest average value of maximum bending strength of 94.83 MPa, the variation in the shape of the V groove camphor gets an average value of bending strength of 61.90 MPa, and the shape of the square groove camphor gets the lowest average value of maximum bending strength of 41.29 MPa. With the average value of the highest maximum bending strength of 94.83 MPa, the double V groove based on the test results that have been carried out has physical characteristics that are not broken because the welding fluid fills the entire specimen. Then the result of the maximum bending strength of the double V groove is still below the yield stress value of Aluminium Alloy 6061 material of 276 MPa and is declared to be suitable for use with the maximum bending strength value in the form of a double V groove after calculation of 94.83 MPa. The recommended variation based on the test results that have the highest average value of maximum bending strength is the variation of the double V groove shape [19] [20] [21] [22].

The results presented in the image demonstrate the significant influence of groove shape variation on the bending strength of Aluminum 6061 welds produced using the Gas Tungsten Arc Welding (GTAW) method. Based on the bending test data, it is evident that the groove shape variation (V, U, and square) has different impacts on the bending strength of the welded material. For welding with a single V groove, the test results show that the bending strength is higher compared to the other groove types, namely U groove and square groove. The V groove creates a higher concentration of stress in a narrower area,

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allowing for deeper penetration and more focused heat distribution, which ultimately enhances the weld joint strength. This finding aligns with previous research, which suggests that groove shapes with higher stress concentration, such as the V groove, generally provide better bending strength. On the other hand, with a U groove, although the groove is wider and deeper, the stress distribution is more uniform, which may reduce bending strength since more energy is required to achieve optimal penetration, resulting in a weaker weld joint. Additionally, the U groove tends to create a wider Heat Affected Zone (HAZ), which affects the microstructure of the surrounding material, leading to a reduction in strength in that area. A similar trend is observed with the square groove, where, despite the more uniform heat distribution, the resulting bending strength is not as strong as with the V groove, and the sample experiences higher deflection before fracture, indicating that the square groove welds are more prone to deformation. Microstructural analysis also supports these findings, where the V groove results in a narrower HAZ, limiting the potential for phase changes or recrystallization that could weaken the weld joint. In contrast, the U and square grooves result in a wider HAZ, which can compromise the weld strength due to the higher temperatures affecting the surrounding material. Furthermore, the stress distribution along the weld joint was analyzed, and it was found that stress in the V groove is concentrated at specific points, allowing the weld to resist loading for a longer period before failure. In contrast, the U groove, with more evenly distributed stress, provides lower bending strength, although it may be more resistant to fatigue and cracking in the weld. This research underscores the importance of selecting the appropriate groove shape for welding Aluminum 6061, depending on the application requirements for the weld joint, whether it is for structural applications requiring high bending strength or for applications that demand better fatigue resistance and environmental durability. In industrial contexts, such as in the railway or aerospace industries, the choice of groove shape can significantly impact the design and efficiency of weld joints, ensuring that the welds meet not only strength requirements but also long-term durability against environmental factors that could affect the material's integrity. Therefore, the results of this study provide valuable guidelines for welding Aluminum 6061, considering groove geometry, stress distribution, and the effects of the HAZ on weld performance in real-world applications [23].

Based on the calculations that have been performed, it can be concluded that the elastic modulus value of double V groove 1 is 288.730 MPa, double V groove 2 has an elastic modulus value of 300.863 MPa, double V groove 3 has an elastic modulus value of 298.194 MPa. The average value of the modulus of elasticity in the variation of the shape of the double V groove resulting from the welding connection of 6061 aluminium using GTAW (Gas Tungsten Arc Welding) welding with calculations obtained a value of 295.929 MPa.

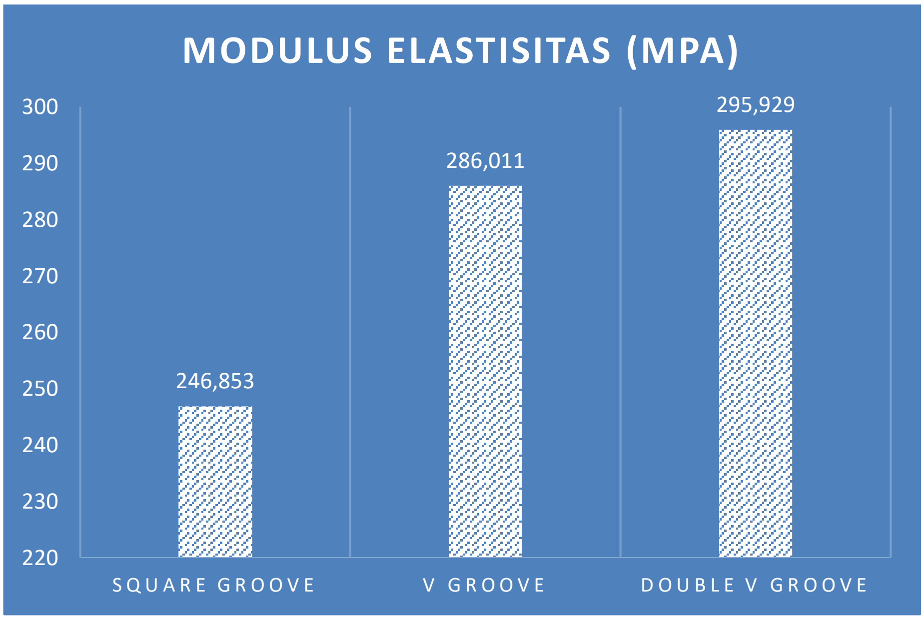

Figure 4. Modulus Elastisity

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The difference in cross-sectional area in the aluminium bending test specimen material causes the magnitude of the elastic modulus value of each specimen that has a different shape. The Double V groove shape has the largest elastic modulus value of 295.929 MPa, the V groove shape has an elastic modulus value of 286.011 MPa, and the square groove shape has an elastic modulus value of 246.853 MPa. It can be assumed that the Double V groove has a larger cross-sectional area than the V groove and square groove. So it can be analysed that the larger the cross-sectional area of the welding seam, the smaller the stress applied to the specimen and the greater the force required.

Figure 5. Fracture

Based on the bending test results shown in the image, the fracture patterns in the I, V, and double V groove weld specimens differ, influenced by the joint geometry and stress distribution during testing. For the I groove weld, the fracture tends to occur at the center of the weld joint, where the material experiences maximum deflection before failure. This suggests a relatively uniform stress distribution but is susceptible to higher loads. The V groove weld, on the other hand, shows failure more concentrated at the weld's corners, with cracks initiating at the joint interface due to the higher stress concentration at the point where the two sides of the weld meet. This leads to a faster fracture at this point, indicating that the V groove weld has lower bending strength compared to the I groove. Meanwhile, the double V groove weld often fails at the center of the joint or along the Heat Affected Zone (HAZ), where the material undergoes higher plastic deformation due to the elevated heat during welding. In the double V weld, failure is more likely to occur in the wider HAZ, where the material properties are altered due to the high temperatures experienced during welding. Overall, these fracture patterns suggest that the I groove weld is more resistant to bending loads than the V or double V grooves, though the double V weld tends to be more stable in terms of stress distribution across a wider area [19] [20] [21] [24].

4. Conclusion

Specimens that use variations in the form of square groove seams have a bending strength of 42.29 MPa, specimens that use variations in the form of V groove seams have a bending strength of 61.90 MPa, and specimens that use variations in the shape of double V groove seams have bending strengths of 94.83 MPa. Specimens with variations in the shape of the square groove seam have a modulus of elasticity value of 246.853 MPa, specimens using variations in the shape of the V groove seam have a value of the modulus of elasticity of 286.011 MPa, and specimens using variations in the shape of the double V groove seam have a modulus value of 286.011 MPa. Elasticity of 295.929 MPa.

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So it can be stated that the shape of the double V seam is better in the test results compared to other forms.

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