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Comparative Study on Mechanical and Microstructural Properties of Aluminium AA6061–Galvanized Steel Joints Using MIG and TIG Welding Techniques

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***Abstract* -- This paper will discuss the mechanical properties of dissimilar metals weld joints between aluminium alloy AA6061 and galvanized steel with different techniques and joint arrangements. The first aim of this experiment is to analyse and compare the quality of weld joints formed by Metal Inert Gas (MIG) welding technique and Tungsten Inert Gas (TIG) welding technique. Both butt joint and lap joint configurations were analysed. The experimental analysis was carried out by means of non-destructive test, Vickers hardness test, tensile test, and microstructure examination. The analysis of the experiment showed that the welding joints have some defects, including pores, cracks, and incomplete fusion. It should be noted that the best welding joint was formed by using the TIG butt joint technique. Microstructure analysis of TIG joints showed a thin layer of intermetallic compounds. The hardness analysis showed that TIG butt joints had higher hardness, equal to 114 HV. Results from tensile tests have also proven that butt joints offer more strength compared to lap joints, and that TIG butt joints yield the highest tensile strength of 107 MPa. Conclusively, the results show that TIG welding in combination with butt joint technique is the best way of joining aluminium and galvanized steel.**

***Keywords*-- MIG Welding, TIG Welding, Dissimilar Materials, Aluminium AA6061, Galvanized Steel, Mechanical Properties, Microstructure.**

I. INTRODUCTION

Increasing consumer demands for lighter cars that consume less fuel have prompted the automotive industry to seek out new materials and processes. Aluminium alloys have emerged due to their low weight and high resistance to corrosion. Combining aluminium with steel parts has resulted in hybrid structures whose primary goal is to improve car performance through the reduction in its overall mass.

One technology applied for creating hybrid structures is using Tailor Welded Blanks (TWB). With such a method, sheets made of dissimilar materials or with differing properties can be welded and subsequently formed.

There are numerous advantages of using TWB, which include weight reduction, better structural performance, and lower costs. Unfortunately, welding aluminium and steel plates brings up several difficulties, including material dissimilarity and brittleness caused by intermetallic compounds at the interface.

Choosing a proper welding technology depends on many factors. Some of the most commonly used welding techniques include Tungsten Inert Gas (TIG) welding and Metal Inert Gas (MIG) welding. These processes have certain benefits that make them popular within the industry. For example, TIG welding provides for high-quality and precise joints while MIG welding is considerably faster.

Although widely used, there is little research that compares the mechanical properties of aluminium-steel joints made by dissimilar welding processes. This research seeks to examine the effects of the two most commonly used welding processes, TIG and MIG, on the mechanical properties of dissimilar aluminum AA6061-galvanized steel joints.

II. LITERATURE REVIEW

The emergence of structures that are both lightweight and strong in the automotive industry has resulted in greater attention being paid to the joining of dissimilar metals, especially those with aluminium alloy and steel. TWB technology has proved to be an efficient means of joining different materials with unique characteristics into a single component. It should be noted that previous research has pointed out that it is difficult to weld aluminium and steel due to the difference in their melting point, thermal conductivity, and brittle intermetallic compounds (IMCs).

It has been established that TIG welding results in excellent quality welds and better control over heat input leading to minimum defects and increased strength in the weld joint. On the other hand, MIG welding allows for higher productivity and fast welding process; however, there may be some defects including porosity and excess heat input.

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Various researchers have conducted studies on the mechanical properties of the welds of dissimilar materials by applying different welding methods.

It has been observed that joint design is equally important since butt joint gives better load distribution and greater tensile strength than lap joint. Moreover, the microstructure study has found out that thinner IMC layers lead to better mechanical behaviour.

However, even after all these developments, there is a requirement for an integrated comparison between MIG and TIG welding processes combined with various joint designs. This paper intends to fulfill this research requirement through analysing the mechanical and microstructural properties of aluminium AA6061 and galvanized steel.

III. Methodology

A. Materials Selection

The study employed aluminium alloy AA6061 and galvanized steel as base materials due to their extensive use in automotive structural applications.

B. Welding Methods

Two types of welding were done in the process:

Tungsten Inert Gas (TIG) welding

Metal Inert Gas (MIG) welding

C. Types of Joints

There were two types of joints created during the experiment:

Butt joints

Lap joints

D. Experimentation Method

Samples were cut, welded, and polished in order. Welding conditions remained constant throughout the procedure.

E. Testing and Analysis

Both mechanical and microstructural characteristics of the weld joints tested were evaluated through proper test methods as discussed below:

1.Non-Destructive Test (NDT)

Non-Destructive test was done using visual examination and dye penetrant test

Test specification used: ASTM E165

Defects identified include:

Porosity

Surface cracks

Incomplete penetration

Table I
Ndt Defect Analysis Of Welded Samples

Sample Type	Welding Process	Porosity	Surface Cracks	Incomplete Penetration	Overall Quality
TBAG (Butt)	TIG	Low	None	None	Excellent
TLAG (Lap)	TIG	Low	Minor	Low	Good
MBAG (Butt)	MIG	Medium	Minor	Medium	Moderate
MLAG (Lap)	MIG	High	Present	High	Poor

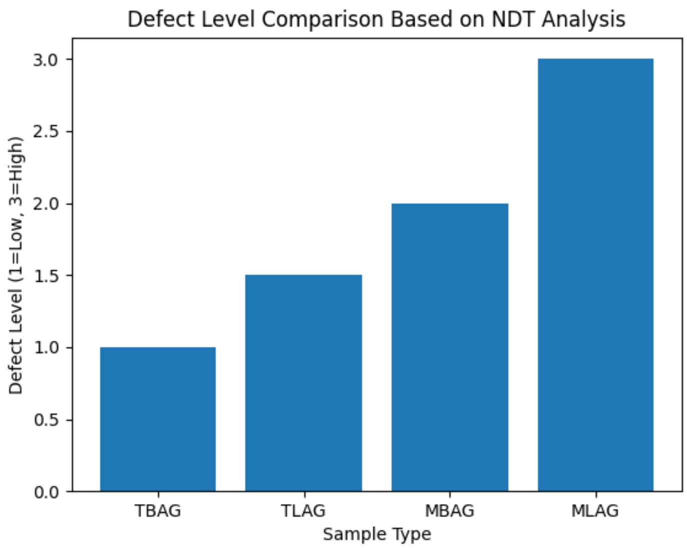

Fig. 1. Comparison of defect levels in welded samples based on NDT analysis

The defect distribution acquired using the non-destructive testing technique is illustrated quantitatively in Fig. 1 below. From Fig. 1, it can be observed that the TIG welded specimens have comparatively lesser defects than the MIG welded specimens. The TBAG specimen possesses the minimum defect level, demonstrating that it has the best weld quality, whereas the MLAG specimen has the maximum defects because of higher porosity and incomplete penetration.

This study demonstrates that the TIG welding technique offers better control during the welding process, leading to minimal defects.

2. Tensile Test

The tensile test was conducted to determine the ultimate tensile strength of the welds.

- Testing method: ASTM E8/E8M
- Tensile machine: Universal Tensile Machine (UTM)
- Test specimens: Rectangular weld specimens
- Test speed: 2 mm/min

Table II:
Tensile Strength of Aluminum-Steel Joints for Different Welding Processes and Joint Configurations

Sample Type	Welding Process	Tensile Strength (MPa)
TBAG (Butt Joint)	TIG	**107 MPa**
TLAG (Lap Joint)	TIG	85 MPa
MBAG (Butt Joint)	MIG	65 MPa
MLAG (Lap Joint)	MIG	**42 MPa**

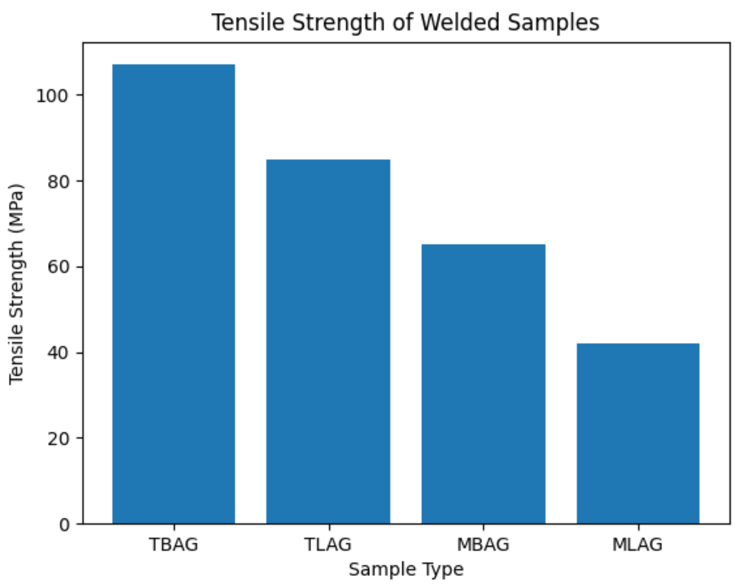

Fig. 2. Tensile strength of different welded joint configurations

Tensile strength differences among various welds are displayed graphically in Fig. 2. It can be seen that the highest tensile strength is 107 MPa for the TIG butt weld (TBAG), and the minimum value of tensile strength is 42 MPa for the MIG lap weld (MLAG).

3. Vickers Hardness Test

The hardness of the welded joints was measured using the Vickers hardness method.

- Testing standard: ASTM E384
- Load applied: 500 g (HV0.5)
- Dwell time: 10–15 seconds

Table III.
Average Hardness of Aluminium-Steel Joints for Different Welding Processes

Welding Process	**Average Hardness (HV)**
TIG Welding	**114 HV**
MIG Welding	**82 HV**

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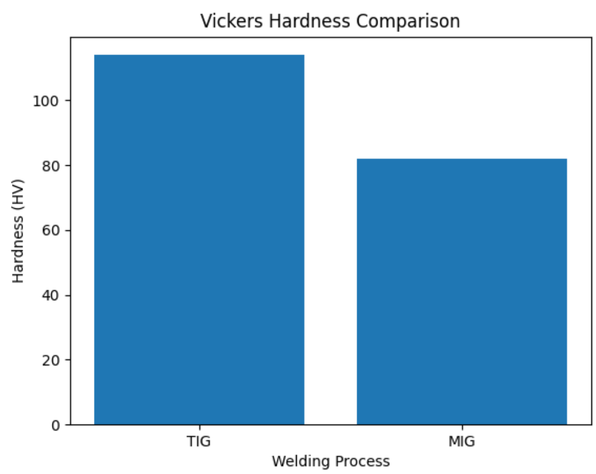

Fig. 3. Comparison of Vickers hardness between TIG and MIG welding

Figure 3 indicates the difference between the hardness values of TIG and MIG welding techniques. The hardness value of the TIG weld is greater, at 114 HV, than that of MIG welding, which is 82 HV.

4. Microstructural Analysis

Microstructure of the weld was examined using an optical microscope in order to examine the weld region, heat affected zone (HAZ) and the base metal. The sample had been polished and etched using Keller's reagent, which is specifically used for aluminium alloys. Magnifications used in the study were 100× – 500×

Table IV.
Microstructural Analysis

Parameter	Details
Microscope Type	Optical Microscope
Magnification	100× – 500×
Etching Solution	Keller's Reagent (for aluminium)
Focus Areas	Weld zone, HAZ, Base metal
Observed Feature	Intermetallic Compound (IMC) layer
TIG Weld IMC Layer	~2–5 µm (thin)
MIG Weld IMC Layer	~5–10 µm (thick)

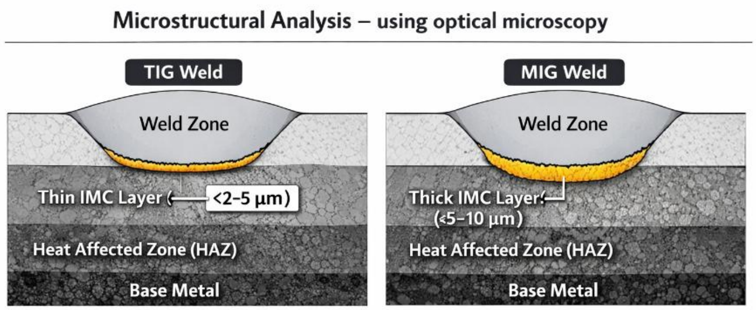

Table: Methodology

Weld Type	IMC Layer Thickness	Joint Strength
TIG Weld	**2~5 µm** (Thin)	Better Strength
MIG Weld	5–10 µm (Thick)	Brittle Joint

Figure 4: Optical micrographs of aluminium welds.

IV. Results And Discussion

A. Weld Appearance and Defects

Defects seen in the weld specimens included porosity, cracks, and lack of fusion. The TIG welds had superior surface quality and fewer defects than MIG welds because of better control of heat input.

B. Microstructural Analysis

The microstructure results showed the presence of intermetallic compound (IMC) layers on the surface where aluminum and steel meet. The IMC layer was found to be relatively thin in the TIG welds, while it was thicker in the MIG welds.

C. Hardness Analysis

According to the readings obtained through Vickers Hardness Tests, it was evident that TIG welding produced a greater value of hardness (114HV) than the MIG welding (82HV). The increased level of hardness may be credited to better weld quality.

D. Tensile Strength Analysis

Tensile testing revealed that butt joints were more effective than lap joints owing to even distribution of stresses. In terms of all samples, the best tensile strength was recorded by the TBAG sample (107 MPa), whereas the lowest was obtained from the MLAG sample (42 MPa).

E. Discussion

The findings suggest that the welding method and joint design play crucial roles in affecting the mechanical characteristics of the dissimilar welds. The TIG welding process outperforms other methods because it allows for more controlled heat input and less defects, as well as the formation of thin intermetallic compound layer.

V. Conclusion

In this study, an investigation on the comparative study of MIG and TIG welding was carried out to join aluminium AA6061 and galvanized steel. Results from the experiment show that welding process and joint design have significant effects on the mechanical properties of dissimilar joints.

In terms of weld quality, hardness, and tensile strength, TIG welding was shown to yield better results than MIG welding. Moreover, butt joints performed better mechanically than lap joints.One of the crucial elements affecting the joint strength was the formation of intermetallic compounds, where thin IMC formation yielded better mechanical properties.

It can be concluded that TIG welding and butt joint design should be considered as the optimal method of dissimilar aluminium-steel joints formation. Further research should concentrate on finding optimal parameters for the welding process and using other welding techniques.

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