Effect of preheat and post heat on mechanical properties of 6061 aluminium tungsten inert gas welded joints

A Hamsi*, T B Sitorus and R K Sinaga
Mechanical Engineering Department, Universitas Sumatera Utara, Medan Indonesia

*E-mail: alfian.hamsi@usu.ac.id

Abstract. Tungsten inert gas (TIG) welded joints of 6061 aluminium are often used in the fuel tanks of large launch vehicles, because of the massive loads these vehicles carry, dealing with weld reinforcement on TIG joints represents an important issue in their preheat and post heat on mechanical properties. Experimental and calculation methods were used to investigate the effect of weld preheat and post heat on the mechanical properties of these joints. The purpose of this study was to determine the effect of preheat and post heat on mechanical properties of 6061 aluminium. The experimental result indicated that mechanical properties of Al 6061 of the welding changed. The hardness of weld metal increase in temperature 130°C = 68.72 BHN, in 160°C = 70.51 BHN, and in 190°C = 76.26 BHN. Tensile strength also increase in temperature 130°C = 158.57 N/mm², in 160°C = 169.85 N/mm², in 190°C = 174.50 N/mm².

1. Introduction
Aluminium 6061 is a nonferrous metal with excellent cryogenic properties, high fracture toughness, and stress corrosion resistance. It is often used in manufacturing fuel tanks for large launch vehicles such as the Thor and Delta rockets [1][2][3]. Under heat treatment. It has excellent stress corrosion cracking resistance and can be applied as covering for supersonic aircraft [4]. Variable polarity tungsten inert gas (VPTIG) arc welding is an appropriate process for welding aluminium and it has wide application in various industries, especially aviation and aerospace [5]. The weld metal generally has less hardness and strength than other parts of the joint due to its solidification microstructure. In practical welding structures, the strength shortage in the weld metal is often offset by weld reinforcement. However, the weld reinforcement can induce stress concentration around the weld toe, impairing its reinforcing effects. Furthermore, a partially melted zone exists adjacent to the weld [6][7][8][9], in which there in near-continuous θ phase along the α(Al) grain boundary that cause serious deterioration of the PMZ’s plasticity. In addition to these two regions of weakness, an over-aged zone (OAZ) exists in joints because of the effects of the thermal welding cycle, and the most seriously OAIZ. Consequently, the joint consists of different zones with different mechanical properties and geometric shapes. In other words. The joint is heterogeneous in both properties and geometry, such that the joint’s tensile behavior becomes very complicated. Researchers investigated the geometrical and microstructural effect on tensile behavior of 2219 aluminium alloy fusion welded joints [10][11]. However, insufficient research has been conducted on the effect of the reinforcement’s shape on the welded joint’s tensile behavior. In this study, the effect of preheat dan post heat TIG welded joint on mechanical properties were investigated through experimental methods and calculation. Various tensile test and hardness test were conducted on joints with preheat and post heat on welded joint.
2. Experiment
As base material, this experimental used 6061 aluminium alloy plate with preheat and post heat. The composition of 6061 Al shown below.

|    | Al | Si | Fe | Cu | Mn | Mg | Mn | Cr | Zn | Ti | Etc. |
|----|----|----|----|----|----|----|----|----|----|----|------|
|    | 97.32 | 0.69 | 0.5 | 0.22 | 0.11 | 0.86 | 0.15 | 0.15 | 0.11 | 0.05 | 0.02 |

The joint was created with tungsten inert gas welding and the filler metal ER5356, the current 80 ampere. The hardness test used standart ASTM E-10, ASTM E-8 dimensions are listed below figure 1.

![Figure 1](image)

Figure 1. (a) Specimen ASTM E-10. (b) Specimen ASTM E-8.

2.1. Numerical Method
The formula used in the experimental Tensile Test.

The formulation for determine tensile strength as:

$$\sigma = \frac{P}{A}$$

(1)

And the formulation for determine percentage of strain as:

$$\varepsilon = \frac{\Delta l}{L_0} \times 100\%$$

(2)

Modulus of elasticity formulation as:

$$E = \frac{\sigma}{\varepsilon}$$

(3)

Hardness test

Calculating the hardness number, the formulation as:

$$BHN = \frac{P}{\frac{\pi D}{2} (D^2 - d^2)}$$

(4)

Hardness test was used Brinnel test to identify the effect of preheat and post heat on joint welded of 6061 aluminium and the results shown in table 2.
| Specimens                      | Number test | Indentation Diameter (mm) | Hardness number (BHN) |
|-------------------------------|-------------|---------------------------|-----------------------|
|                               |             | Weld point | HAZ | Weld point | HAZ |
| Without *preheat* and *post* heat | i           | 3          | 3.2 | 63.69      | 55.00 |
|                               | ii          | 3          | 3   | 63.69      | 63.69 |
|                               | iii         | 2.9        | 3.1 | 68.72      | 59.14 |
| Average                       |             | 2.97       | 3.10 | 65.31      | 59.14 |
| *Preheat and post heat*       |             |            |     |            |     |
| 130°C                         | i           | 2.9        | 3   | 68.72      | 63.69 |
|                               | ii          | 2.9        | 3   | 68.72      | 63.69 |
|                               | iii         | 2.9        | 3.1 | 68.72      | 59.14 |
| Average                       |             | 2.93       | 3.03 | 68.72      | 62.13 |
| 160°C                         | i           | 2.8        | 2.9 | 74.28      | 68.72 |
|                               | ii          | 2.9        | 3   | 68.72      | 63.69 |
|                               | iii         | 2.9        | 3   | 68.72      | 63.69 |
| Average                       |             | 2.87       | 2.97 | 70.51      | 65.31 |
| 190°C                         | i           | 2.8        | 2.9 | 74.28      | 68.72 |
|                               | ii          | 3.8        | 2.9 | 74.28      | 68.72 |
|                               | iii         | 3.7        | 2.8 | 80.46      | 74.28 |
| Average                       |             | 2.77       | 2.87 | 76.26      | 70.51 |
| Base metal                    | i           |            | 2.5 |            | 95.08 |
|                               | ii          |            | 2.5 |            | 95.08 |
|                               | iii         |            | 2.4 |            | 103.79 |
| Average                       |             | 2.47       |       | 97.87      |     |
After testing the hardness it shows that hardness increase because of preheat and post heat of 6061 aluminium joint welded. The diagram shown in figure 2.

![Hardness Number Diagram](image)

**Figure 2.** Hardness Number Diagram.

2.2. Tensile test

Tensile test was conducted on the joint according to the standard procedure (6B/T 228.1-2010) with a cross head speed of 2mm/min. The dimensions of the tensile sample shown fig.3 the sample length was 50 mm.

![Dimension of tensile specimen](image)

**Figure 3.** Dimension of tensile specimen.

The results of the tensile test as shown in table 3.

| Specimens                        | Do (mm) | Lo (mm) | Li (mm) | Ao (mm²) | Fu (N)  | σ (N/mm²) | e (%)  | E       |
|----------------------------------|---------|---------|---------|----------|---------|-----------|--------|---------|
| Without preheat and post heat   | i       | 8       | 48      | 53.48    | 50.24   | 8000      | 159.24 | 11.42   | 13.95   |
|                                  | ii      | 8       | 48      | 53.11    | 50.24   | 7200      | 143.31 | 10.65   | 13.46   |
|                                  | iii     | 8       | 48      | 52.89    | 50.24   | 8200      | 163.22 | 10.19   | 16.02   |
| Average                          | 8.00    | 48.00   | 53.16   | 50.24    | 7800    | 155.25    | 10.75  | 14.44   |
| preheat and post heat 130°C     | i       | 8       | 48      | 53.62    | 50.24   | 7900      | 157.25 | 11.71   | 13.43   |
|                                  | ii      | 8       | 48      | 53.54    | 50.24   | 7500      | 149.28 | 11.54   | 12.93   |
|                                  | iii     | 8       | 48      | 53.24    | 50.24   | 8500      | 169.19 | 10.92   | 15.50   |
| Average                          | 8.00    | 48      | 53.46   | 50.24    | 7966.67 | 158.57    | 11.39  | 13.92   |

Table 3. Results of the tensile test.
The result diagram of tensile test was shown in figure 4.

### Table 3. Results of the tensile test.

|                  |   |   |   |   |   |   |
|------------------|---|---|---|---|---|---|
|                  | i | ii | iii | Average |   |   |
| preheat and post heat | 8 | 8 | 8 | 8 | 48 | 48 |
| 160°C             | 54.31 | 53.74 | 53.83 | 53.96 | 50.24 | 50.24 |
|                  | 9100 | 8000 | 8500 | 8533.33 |   |   |
|                  | 181.13 | 159.24 | 169.19 | 169.85 |   |   |
|                  | 13.15 | 11.96 | 12.15 | 12.42 |   |   |
|                  | 13.78 | 13.32 | 13.93 | 13.68 |   |   |
|                  |   |   |   |   |   |   |
| preheat and post heat | 8 | 8 | 8 | 8 | 48 | 48 |
| 190°C             | 54.77 | 53.85 | 54.54 | 54.39 | 50.24 | 50.24 |
|                  | 8600 | 8700 | 9000 | 8766.67 |   |   |
|                  | 171.18 | 173.17 | 179.14 | 174.50 |   |   |
|                  | 14.10 | 12.19 | 13.63 | 13.31 |   |   |
|                  | 12.14 | 14.21 | 13.15 | 13.11 |   |   |

### Stress Diagram

**Figure 4.a. Stress Diagram.**

### Strain Diagram

**Figure 4.b. Strain Diagram.**
2.3. Microstructure

Microstructure test conducted by using Reflected Metallurgical Microscopic Type Rax Vision No 545491, MM-10A, 230V, 230Hz. The specimen is 6061 Aluminium alloy which has joint welded by TIG and the figure of micro structure as shown in Figure 5.

6061 Aluminium alloy gives two phase and one carbide, phase of carbide from 6061 aluminium is \(\beta\)-AlFeSi, \(\alpha\)-Al(FeSi) and Mg\(_2\)Si. Base metal influence the heat will release Mg, which compound with Si as filler material. Influence shows the black ones is Mg and Si. The compound increase hardness of material.
3. Conclusions

Used heat treatment as preheat and post heat on 6061 aluminium used TIG joints increase the hardness and increase tensile strength. The highest in 190°C preheat and post heat, and the strain increase but decrease elasticity modulus, then decrease the toughness of material. Preheat and post heat treatment increase solubility of Mg2Si, as a result increase hardness of specimen. The microstructure of weld point and HAZ look different due to weld point influenced by ER5356 as a filler.

References

[1] Xu Wei-feng, LIU Jin-he, LUAN Gou-hong and DONG Chun-lin 2009 Microstructure mechanical properties of friction stir welded joints in 2219-T6 aluminium alloy J. Material & Design 30 (9) pp 3460-3467.
[2] A Hamsi and R Dinzi 2017 IOP Conf. Ser.: Mater. Sci. Eng. 180 012006
[3] Venkata N G, Sharma V M J, Diwakar V, Sree Kuma K, and Prasad R C 2004. Fracture behavior of aluminium alloy 2219-T87 welded plate J. Science and Technology of Welding and Joining 9(2): pp 121-130
[4] Wang Zhu-tang, Tian Rong-zhang. Aluminium alloy and its manufacturing M. 2nd ed. Changsha pp 200: 221. (Chinese : Central South University Press)
[5] Li Quan, Wu Ai-ping, Zhao Yue, Wang Gou-qing, Yan Dong-yang and Wu Hui-qiang 2015 Fracture behavior of double-pass TIG welded 2219-T8 aluminium alloy joints under transverse tensile test J. Transactions of Nonferrous Metal Society of China 25(6): 1794-1803.
[6] A Pintoro et al 2019 IOP Conf. Ser.: Mater. Sci. Eng. 505 012059
[7] Huang C, Kou S 2001 Partially melted zone in aluminium welds: Solute segregation and mechanical behavior J. Welding Journal 80 (9): pp 9-17.
[8] Z Lubis et al 2019 IOP Conf. Ser.: Mater. Sci. Eng. 505 012091
[9] Li Quan, Wu Ai-ping, Li Yan-jun, Wang Gou-qing, Yan Dong-yang, and Liu Juan 2015. Influence of temperature cycle on the microstructure and mechanical properties of the partially melted zone in the fusion weld joints of 2219 aluminium alloy J. Materials Science and Engineering A, 623 pp 38-48
[10] T.U.H.S. Ginting Manik et al 2018 IOP Conf. Ser.: Mater. Sci. Eng. 420 012026
[11] Nunes A C Jr, Novak H L 1981. Weld geometry strength effect in 2219-T87 aluminium R. (Washington, D.C.: NASA Marshall Space Flight Center).