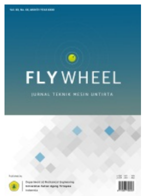
FLYWHEEL: JURNAL TEKNIK MESIN UNTIRTA

Home page journal: http://jurnal.untirta.ac.id/index.php/jwl



The Effect of Artificial Aging on Al 6061/SiC Composite Produced by Thixoforming

Shofiatul Ula[1], A. Ali Alhamid[1,2*], Sunardi Sunardi[1], Dhimas Satria[1], Yusvardi Yusuf[1], Ipick Setiawan[1], Narendra Putra Vendana[1]

[1] Departement of Mechanical Engineering, Faculty of Engineering, Universitas Sultan Ageng Tirtayasa, Cilegon, Indonesia.
[2] Departement of Mechanical Engineering, Faculty of Engineering, Universitas Jenderal Soedirman, Purwokerto, Indonesia.

*Corresponding author: alhamidi@untirta.ac.id;

ARTICLE INFO

Received 03/02/2025
Revision 24/03/2025
Accepted 19/04/2025
Available online 30/04/2025

ABSTRACT

Thixoforming improves material properties better than conventional methods through the formation of non-dendritic or rounded structures. This study aimed to optimize the mechanical properties of Al 6061/SiC composites by adding Mg as a wetting agent through stir casting, thixoforming, and artificial aging processes. The holding time during the artificial aging process was varied to investigate its effect on microstructure, hardness, and impact toughness. SEM analysis revealed a more uniform distribution of SiC particles with increasing holding time, indicating the effective formation of Mg_2Si precipitates. The maximum hardness of 48.5 HRB and the highest impact toughness of 0.022 J/mm^2 were obtained at the longest holding time of 3 hours. This indicates that the formation of homogeneous Mg_2Si precipitates during the artificial aging process significantly contributed to the improvement of the composite's mechanical properties.

Keywords: *6061/SiC Composite, Thixoforming, Artificial Aging, Hardness, Impact Test*

1. INTRODUCTION

Aluminum and its alloys are classified as non-ferrous metals and are widely used across various sectors including household, automotive, and aerospace. Aluminum and its alloys possess several advantages, such as being lightweight, having a high strength-to-weight ratio, resistance to corrosion, high thermal and electrical conductivity, ease of forming and machining, non-magnetic properties, reflectivity, and non-toxicity [1]. However, aluminum has mechanical properties below other metal materials such as iron and steel. Therefore, aluminum matrix composites are made and heat treated to improve their mechanical properties [2].

Al 6061 composite with SiC reinforcement which is added Mg as a wetting agent is formed by stir casting followed by a thixoforming process. thixoforming related to the compacting behavior of molten metal [3].

Thixoforming is a material formation process that exploits the rheological behavior of metals during the solidus and liquidus temperature ranges [4]. The purpose of forming within the temperature range between solidus and liquidus is to create a non-dendritic or rounded structure, which can result in better component properties compared to components formed by conventional casting [5].

After forming, the composite is heat treated with the aim of obtaining better and expected mechanical properties such as an increase in the hardness value of the composite [6].

Heat treatment is a combination of the heating and cooling process of a metal or its alloy in a solid state to obtain certain properties [7]. An example of heat treatment is artificial aging, which is by heating the composite to below the temperature solves and then holding it for a certain period of time then followed by slow cooling in the air [8].

2. METHODOLOGY

2.1 Sample Preparation

The main sample used in this study is Aluminium 6061 with the proportion of 90%. Following this, SiC and Mg with the proportion of 5% and 5%. Aluminum 6061 is cut into small pieces so that it can be arranged in the crucible. SiC serves as a reinforcing material in the composite with a specification of 1200 mesh. Whereas SiC serves as a solvent in the stir casting process, it falls under the Engineering grade category.

(a) (b) (c)

Figure 1. Sample (a) Al 6061, (b) SiC, and (c) Mg

2.2 Stir casting

The process began with inserting the crucible containing aluminum into the melting furnace and heating the melting furnace until the aluminum melted, which is at a temperature of 660°C for 45 minutes. Next, stirring is carried out using a stir casting tool, accompanied by the addition of supplementary materials, namely SiC and Mg, according to their respective proportions. The stirring is performed at a rotation speed of 1500 rpm for 3 × 5 minutes.

The mold that has been heated with a torch is then prepared. The mold has dimensions of 200 × 20 × 12 mm. The heating of the mold is intended to prevent excessive temperature differences between the composite melt and the dies used for molding.

The Al6061 alloy, which has been mixed with SiC and Mg, is then poured into a preheated mold to prevent excessive temperature drop that could cause cracking in the casting result. The composite melt is poured until the sample height exceeds that of the mold to assist in the subsequent process. If the temperature is close to room temperature, the sample is removed from the mold.

2.3 Thixoforming

In the Thixoforming process, the sample is reinserted into the mold, and the mold is placed into a muffle furnace set at a temperature of 750°C. From the initial temperature of the maffle furnace, such as room temperature, to the combustion chamber temperature of the maffle furnace at 750°C, it takes about 45 minutes. At this temperature, it can be observed that the composite is still in a semi-solid form or has not fully melted, as seen from the pressing results.

When the combustion chamber reaches a temperature of 750°C, the mold containing the composite is immediately removed from the muffle furnace and placed in a 4-ton press, then subjected to pressure and held under those conditions for 5 minutes. After the time is reached, the pressure can be released and the mold along with the sample can be cooled to room temperature.

2.5 Precipitation Hardening

In the precipitation hardening process, there are three heat treatments performed, namely solutioning, quenching, and artificial aging. A diagram illustrating these three heat treatments is presented in figure 2.

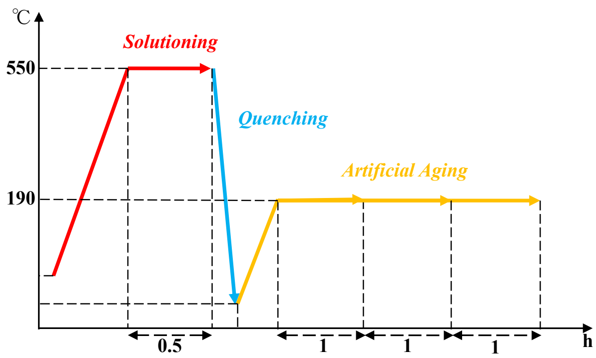


Figure 1. Precipitation hardening process

In the solutioning treatment, the temperature is raised to 550°C and held at that temperature for 30 minutes. This aims to reduce the grain size or undesirable phases in the material, improve homogeneity that can distribute reinforcements more evenly, help reduce internal stresses arising from the material manufacturing process, and serve as an initial process in subsequent heat treatment.

The next heat treatment process is quenching, where the material at a temperature of 550°C or higher is rapidly cooled using cold water media. This aims to accelerate the solidification of the metal, resulting in a harder microstructure and increased material hardness, preventing the formation of phases during slow cooling, and helping to maintain the dimensions of the material that has undergone the machining stage.

In this artificial aging process, a temperature of 190°C is used with a holding time at that temperature of 1 hour, 2 hours, and 3 hours. Artificial aging aims to improve the mechanical properties of the material by accelerating the formation and precipitation of the strengthening phase in the material and can also optimize the uniform distribution of the strengthening phase in the material.

2.5 Testing and characterization

To determine the distribution of reinforcements in the Al6061 matrix, observations were made on the cross-section using a Scanning Electron Microscope (SEM). The hardness test was conducted using the Rockwell method with a steel ball indenter and a load of 100 kgf. This testing complies with ASTM E18 standards with a test sample size of 40 mm x 20 mm x 12 mm.

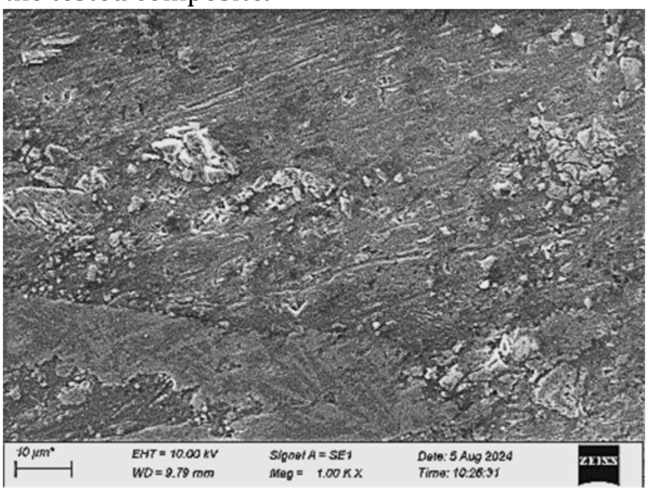
Next, the impact test is conducted using the Charpy method. The tested samples conform to ASTM E23 standards. The loading pendulum has a strength of 300 joules. The samples have dimensions of 55 mm x 10 mm x 10 mm.

3. RESULTS AND DISCUSSION

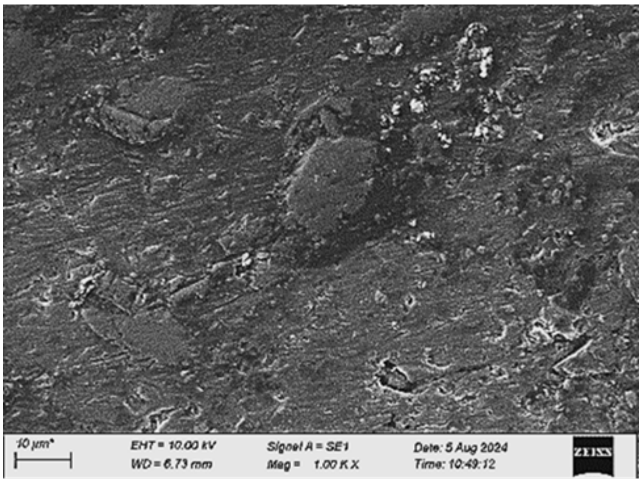
3.1 Microstucture analysis

The samples in this study are Al 6061 that have undergone artificial aging using the thixoforming method with holding times of 1 hour, 2 hours, and 3 hours. Microstructure observation on the samples was conducted using a device called the Zeiss EVO 10 Scanning Electron Microscope (SEM). The results obtained from the tests include images from the Scanning Electron Microscope (SEM) and Energy Dispersive X-Ray Spectroscopy (EDS) on the cross-section. Figure 3 display the SEM test images with a magnification of 1000× for samples with artificial aging holding times of 1 hour, 2 hours, and 3 hours.

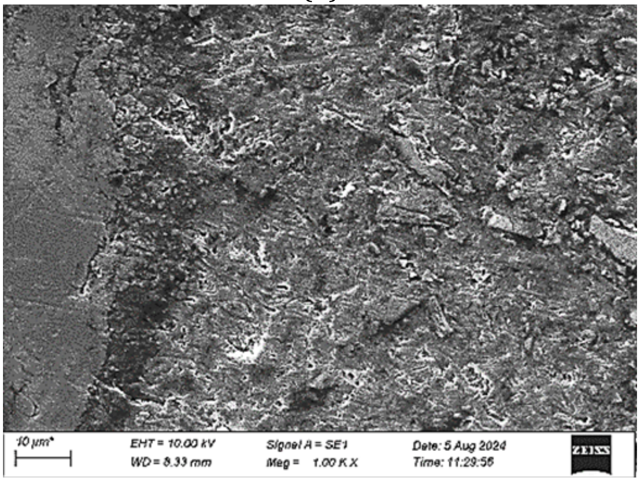
In the SEM test results with the three holding times during artificial aging, it can be seen that Al 6061 serves as the background of the test result images. This proves that Al 6061 is the main component or matrix (having the highest content) in the tested composite.



(a)



(2)



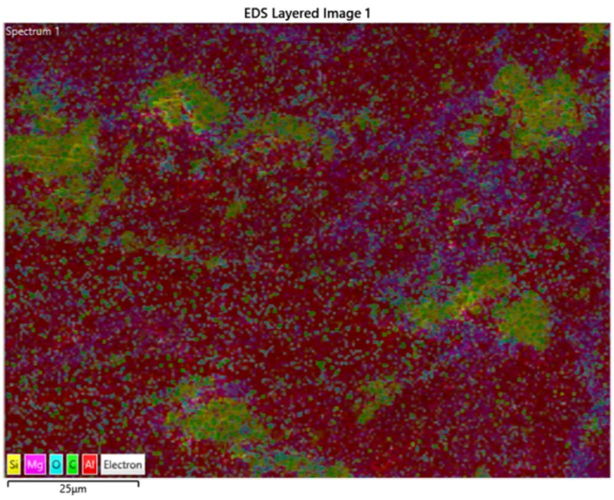
(3)

Figure 3. SEM 1000× Artificial Aging (a) 1 hour, (b) 2 hours ; (c). 3 hours

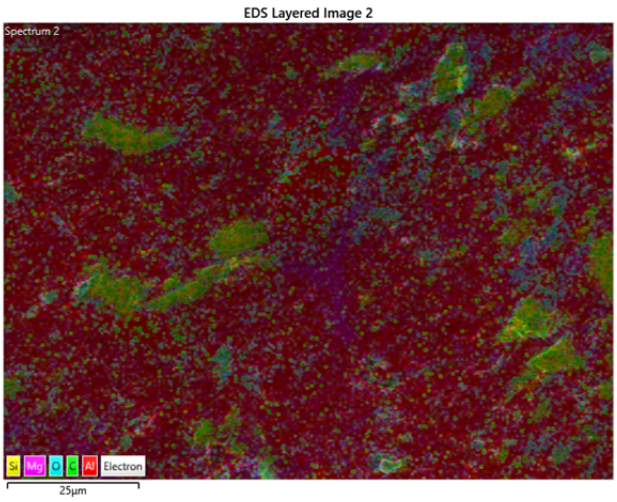
Meanwhile, the Mg reinforcement can precipitate with Si to form Mg_2Si (Magnesium Silicide), which is suspected to be visible in the image as small particles dispersed in the Al 6061 matrix. And in all three images, no indications of porosity were found in the samples, which are usually marked by a tendency towards a blackish color. This proves that the goal of thixoforming can be considered achieved because the porosity resulting from the casting process is not visible in the SEM images.

If compared to the three SEM images, it can be seen that as the holding time during artificial aging increases, the particle grains become smaller, or in other words, the particles break into several parts that then move away from their parent with the aim of evenly distributing the reinforcement in the Al 6061 matrix. This is in accordance with the function of the precipitation hardening process, which is to optimize the distribution of the existing reinforcements, and can form a new phase from the two reinforcements, namely SiC and Mg, which becomes Mg_2Si. This precipitate plays an important role in increasing the strength and hardness of the sample to be tested.

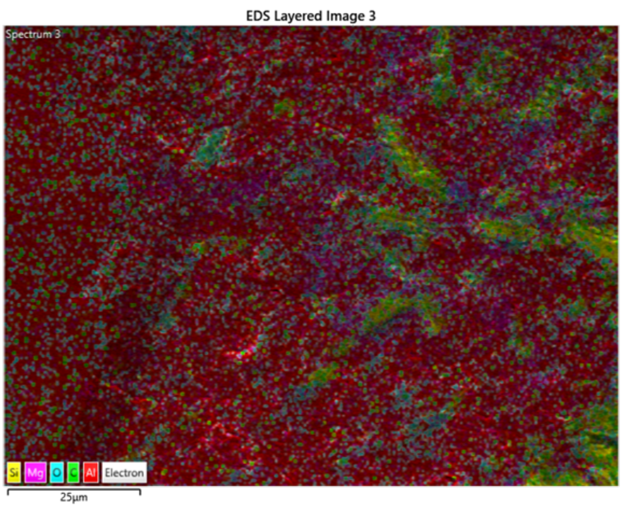
For a clearer depiction of the dispersed particles, The EDS mapping image shown in figure 4.



(a)



(b)



(c)

Figure 4. EDS Mapping Artificial Aging (a) 1 hour, (b) 2 hours, and (c) 3 hours

The image results from the EDS mapping are similar to the SEM image results at 1000× magnification, but in the EDS, all the constituent elements of the test sample are detected. According to the analysis results in the SEM image, the Mg and SiC reinforcements present in the sample are increasingly dispersed and broken down into smaller grains.

It can be seen in the three EDS mapping images that the indication of the most numerous precipitates is found in the sample with an artificial aging holding time of 3 hours. This indication can occur because, in that sample, the small-sized grains of the precipitate-forming elements Mg2Si, namely Mg and Si, have become more numerous and dispersed, appearing to merge when viewed in the EDS mapping images. This is the reason for the formation of a new phase from these two elements.

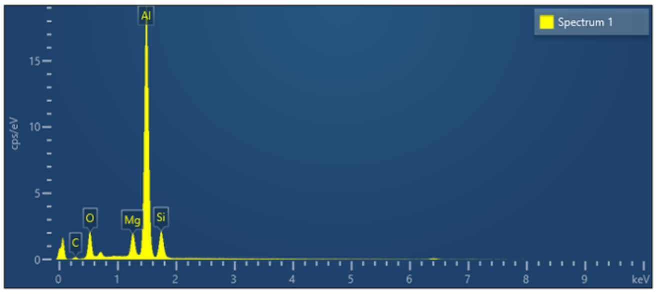


Figure 5. Spectrum of EDS Artificial Aging 1 hour

Table 1. Compositition of EDS Artificial Aging 1 hour

Element	Line Type	Weight (%)	Weight (%)	Atomic(%)
C	K Series	5.98	0.35	11.58
O	K Series	12.31	0.15	17.89
Mg	K Series	5.08	0.07	4.86
Al	K Series	65.95	0.29	56.83
Si	K Series	10.68	0.12	8.85
Total		100.00		100.00

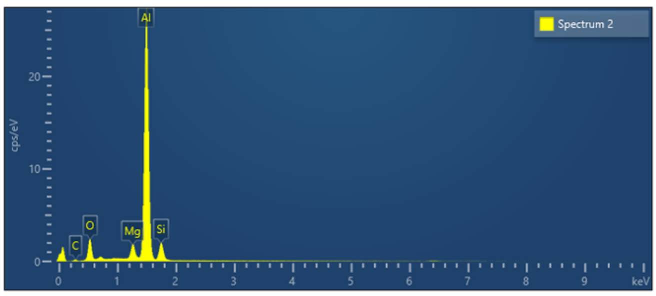


Figure 6. Spectrum of EDS Artificial Aging 2 hours

Table 2. Compositition of EDS Artificial Aging 2 hours

Element	Line Type	Weight (%)	Weight (%)	Atomic(%)
C	K Series	4.87	0.30	9.26
O	K Series	11.09	0.12	16.44
Mg	K Series	3.47	0.06	3.39
Al	K Series	72.66	0.26	63.87
Si	K Series	7.90	0.10	6.68
Total		100.00		100.00

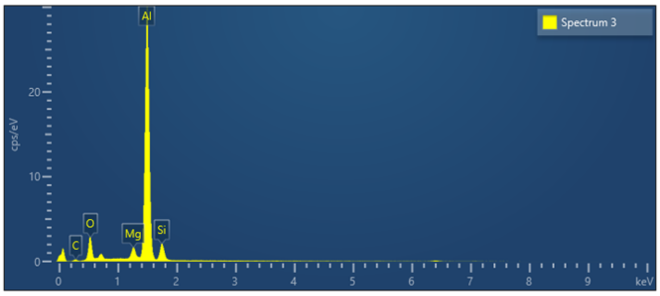


Figure 7. Spectrum of EDS Artificial Aging 3 hours

Table 3. Compositition of EDS Artificial Aging 3 hours

Element	Line Type	Weight (%)	Weight (%)	Atomic (%)
C	K Series	5.48	0.42	10.70
O	K Series	11.99	0.18	17.57
Mg	K Series	2.65	0.07	2.55
Al	K Series	72.34	0.37	62.88
Si	K Series	7.54	0.13	6.30
Total		100.00		100.00

The composition of the elements in the composite can be seen in the graph or table above, where it can be observed that each test sample has varying contents despite originating from the same casting process. This is the result of uneven mixing during the stir casting process. With the presence of that data, the suspicion of the presence of a precipitate is stronger because it contains the constituent elements of the Mg_2Si precipitate.

For types of elements that have a larger composition compared to the weighing process during stir casting, this can occur because Al 6061 consists of several other constituent elements besides aluminum itself. There is a higher value of oxygen compared to the reinforcing value, which proves that oxidation occurred during the treatment process, supported by the darkening of the sample surface that has undergone the entire treatment.

3.2 *Hardness testing analysis result*

This hardness test uses the ASTM E18 standard with a Rockwell Type Hardness Tester FR-X Series, which employs a steel ball indenter with a load of 100 kgf. The unit produced from this test is HRB. In this hardness test, there are 3 samples with different variables, as well as 1 sample of Al6061 from casting with 3 test points on each sample.

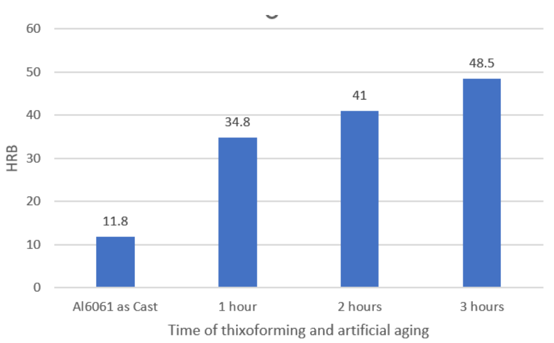


Figure 8. hardness level

From figure 8, it can be seen that there is an increase in hardness in each sample variable. This proves that artificial aging can form a new phase, namely the Mg_2Si precipitate, which, according to microstructure observations, indicates that the longer the holding time during artificial aging, the more precipitates are formed. This is directly proportional to the hardness value produced by each variable because increasing the strength and hardness of the sample is a result of the presence of precipitate. Meanwhile, the difference in values at each testing point on the sample with the same variable can occur due to the imperfect distribution of the reinforcement. Besides precipitation, oxidation can also be one of the factors contributing to the increase in hardness of the test sample.

3.3 *Impact testing analysis*

In this impact test, the Charpy method was used with the ASTM E23 standard. The dimensions of the impact test sample were 10 × 10 × 5.5 mm with an energy input of 300 joules. In this test, the value of the energy absorbed by the sample was obtained, which was then calculated to find the impact value produced for each sample.

$$\text{Cross sectional area} = \text{p (mm)} \times \text{l (mm)} \ \dots\dots\dots\dots\dots (1)$$

$$\text{Impact value} = \frac{\text{Absorbed energy (Joule)}}{\text{Cross sectional area (mm}^2\text{)}} \ \dots\dots\dots (2)$$

The average impact value of the samples is presented in Figure 8.

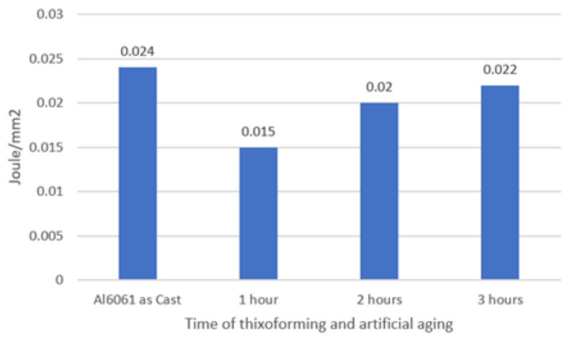


Figure 8. Impact values

As seen in the graph of impact values, the impact value of the cast Al6061 sample is higher than the three variable samples resulting from artificial aging. This can occur due to the heat treatment performed on the sample, which increases the hardness value of the sample but sacrifices the energy absorption value. However, when compared with other results from artificial aging, the impact value increases with the addition of holding time. Compared to the increase in hardness value, the increase in impact value is relatively small.

4. CONCLUSION

The longer the holding time of artificial aging at a temperature of 190°C, the more uniformly the strengthening particles are distributed, the size of the strengthening grains decreases, and there are more indications of Mg2Si precipitate formation. Meanwhile, the hardness test results at an artificial aging temperature of 190°C with holding times of 1 hour, 2 hours, and 3 hours are 34.8 HRB, 41 HRB, and 48.5 HRB, respectively. The impact test results at the same aging temperature and holding times are 0.015 J/mm^2, 0.02 J/mm^2, and 0.022 J/mm^2, respectively.

REFERENCES

1. Widyantoro EK. Pengaruh Variasi Temperatur Aging Pada Aluminium 6061 Terhadap Uji Impak, Kekerasan, Dan Struktur Mikro. Institut Teknologi Sepuluh Nopember, Surabaya. 2018.
2. Tsamroh DI, Sasongko MIN, Yazirin C. Analisis Sifat Mekanik Dan Sifat Fisik Paduan Aluminium Pada Perlakuan Penuaan Buatan. TRANSMISI. 2022: 26-33.
3. Husain NH, Ahmad AH, Rashidi MM. An Overview of Thixoforming Process. In IOP Conference Series: Materials Science and Engineering. 2017; 257.
4. Hirt G, Kopp R. Thixoforming: Semi-Solid Metal Processing, New York: John Wiley & Sons. 2009.
5. Lu Y, Li M, Huang W, Jiang H. Deformation Behavior And Microstructural During The Semi-Solid Compression Of Al-4Cu-Mg Alloy. Materials Characterization. 2005; 54: 423-430.
6. Pandu P. Pengaruh Post Weld Heat Treatment (PWHT) Terhadap Struktur Mikro Dan Sifat Mekanik Pegas Daun Yang Dilas Dengan Pengelasan SMAW. Universitas Islam Riau, Pekanbaru. 2020.
7. Budi H. Peningkatan Sifat Mekanis Propeler Perahu Motor Dengan Aging Treatment. Universitas Islam Riau, Pekanbaru. 2019.
8. Polat A, Avsar M, Ozturk F. Effects of The Artificial-Aging Temperature and Time on Mechanical Properties and Springback Behavior of AA6061. Materials and Technology. 2015: 487-493.