Jurnal Sainstech Nusantara
https://nusantarajournal.id/sainstech
Vol. 2 No. 1 (2025) 12-23
ISSN: 3063-0657

Enhancing the Properties of Aluminum AA-1100: The Effect of Mg and Copper Additives with Heat Treatment

Bima Wahyu Saputra[1], Bambang Junipitoyo[1]

[1]Aircraft Engineering, Politeknik Penerbangan Surabaya, Jalan Jemur Andayani I No 73 Surabaya 60236, INDONESIA

Article Info

Article history:

Received 20 November, 2024
Revised 15 January, 2025
Accepted 5 February, 2025

Abstract

Aluminum alloys, renowned for their low density, high strength, and corrosion resistance, are widely utilized in industries such as aerospace. However, Aluminum 1100 is typically too soft, which necessitates the addition of alloying elements like magnesium (Mg) and copper (Cu) to improve its mechanical properties. This study examines the effects of adding 1.2% magnesium and varying copper concentrations (3.9%, 4.1%, and 4.3%) to Aluminum 1100, followed by heat treatment at 100°C, 200°C, 300°C, and 400°C for 120 minutes. The physical properties, including density, as well as mechanical properties—tensile strength and Vickers hardness—were evaluated. The results revealed that the highest density (3.408 g/cm³) occurred at 300°C with 1.2% Mg and 4.1% Cu. The maximum tensile strength (130.7948 MPa) was observed in the alloy with 4.3% Cu at 400°C, while the highest strain (0.03995%) was recorded at 300°C with 4.3% Cu. The lowest modulus of elasticity (2635.292 MPa) was measured at 100°C with 4.3% Cu, and the highest value (4162.763 MPa) was obtained at 200°C with 4.1% Cu. Additionally, the highest Vickers hardness (90.27 HVN) was achieved in the alloy containing 1.2% Mg and 4.3% Cu at 400°C.

Keywords: Aluminum 1100, Heat Treatment, Vickers Hardness Test, Tensile Test, Density

Corresponding Author:

Name: Bima Wahyu Saputra
Email: bimasaputra3103@gmail.com

1. Introduction

Aluminum alloys are widely recognized for their excellent combination of lightweight properties and high strength, making them ideal for a variety of industrial applications, particularly in the aerospace sector. In aircraft construction, aluminum is extensively used in fuselage components due to its low density, which contributes to reducing the overall weight of the aircraft, enhancing fuel efficiency, and improving performance. However, the aluminum alloys used in aerospace applications differ significantly from those encountered in everyday materials. To meet the stringent

DOI: https://doi.org/10.71225/jstn.v2i1.62

requirements of aerospace engineering, aluminum is often alloyed with other elements, such as copper, magnesium, zinc, and manganese. These alloying elements are incorporated to improve key mechanical properties, including strength, stiffness, and durability, while maintaining the inherent lightweight nature of the material [1] [2].

Recent advancements in the development of high-performance aluminum alloys have focused on optimizing the balance between mechanical strength, corrosion resistance, and weight reduction—properties that are essential for modern aircraft. Research has explored the use of various alloying elements, with particular emphasis on copper and magnesium. The addition of copper, for instance, significantly increases the tensile strength and hardness of aluminum alloys, making them more suitable for structural components that require high strength. On the other hand, magnesium enhances the material's resistance to corrosion and improves overall mechanical performance, particularly in challenging environments such as high humidity and exposure to saltwater [3] [4].

The development of these advanced aluminum alloys is driven by the need for materials that not only offer high strength but also exhibit long-term durability and resistance to fatigue and corrosion [4] [5]. Copper-based aluminum alloys have been extensively used in aircraft components, while magnesium alloys have shown great potential in improving environmental resistance. However, a challenge remains in optimizing the combination of these alloying elements, particularly in Aluminum 1100, to achieve the desired mechanical properties without compromising other important characteristics. Previous studies have demonstrated the benefits of incorporating copper and magnesium into aluminum alloys, but there is still a need for further research to explore the specific effects of varying concentrations of copper and magnesium on the properties of Aluminum 1100 [6] [7].

This study is essential for addressing the gaps in current understanding regarding the alloying of Aluminum 1100, particularly in terms of its corrosion resistance, tensile strength, and hardness. While Aluminum 1100 is widely recognized for its excellent corrosion resistance, its relatively low strength limits its application in more demanding environments [8] [9] . By investigating the effects of varying copper (Cu) and magnesium (Mg) concentrations, this research seeks to develop a more robust alloy with enhanced mechanical properties that are suitable for aerospace applications. Additionally, the study aims to optimize the heat treatment process to further enhance the overall performance of the alloy. The results of this research have the potential to contribute significantly to the development of advanced aluminum alloys with superior performance, leading to safer, more efficient, and longer-lasting aircraft structures [10] [11]. Furthermore, the findings could offer valuable insights for other industries that require high-strength, corrosion-resistant materials. Sanders (2001) states that in its pure form, aluminum is relatively soft, ductile, and lacks sufficient strength. Pure aluminum has a tensile strength of approximately 49 MPa. Initially, aluminum has a shiny silver color, but it gradually turns light gray when exposed to air due to the formation of oxides. This oxide layer is highly ductile and fire-resistant. The melting temperature of pure aluminum is 660°C, whereas the melting temperature of its alloys typically ranges between 520°C and 660°C. Pure aluminum is rarely used in its original form because of its low mechanical properties. To improve the mechanical properties of aluminum, elements such as copper, manganese, magnesium, silicon, and zinc are often added, leading to increased strength and hardness [12] [13] [14] [15] [16].

The main objective of this study is to examine the effects of adding 1.2% magnesium and varying copper content (3.9%, 4.1%, and 4.3%) to Aluminum 1100, focusing on its mechanical properties, such as tensile strength, hardness, and density. Through heat treatment at various temperatures, this research aims to enhance the physical and mechanical properties of Aluminum 1100, thereby

DOI: https://doi.org/10.71225/jstn.v2i1.62

improving its suitability for demanding applications in aerospace and other industries requiring high-performance materials. The findings from this study will contribute to optimizing aluminum alloys, facilitating the development of more efficient and durable materials for use in structural components.

2. Materials and Method

The research design involves the preparation of Aluminum 1100 alloy samples with varying compositions of magnesium (1.2%, 4.1%, and 4.3%) and copper (3.9%, 4.1%, and 4.3%) to investigate the effects of different heat treatment temperatures (100°C, 200°C, 300°C, and 400°C) and quenching times (2 hours) on their mechanical properties. The samples are subjected to heat treatment, followed by quenching in water, and their hardness is measured using the Vickers Hardness Test (HVN), tensile strength is determined through tensile testing (MPa), and density is calculated (g/cm^3). The aim is to evaluate how the alloy's composition and heat treatment conditions affect its hardness, tensile strength, and density, providing insights into the optimal conditions for improving the material's performance in various applications.

Input			Heat Treatment		Output		
Magnesium (Mg)	Copper (Cu)	Aluminium 1100	Temperature (^{0}C)	Quenching (Time)	Hardness Vickers (HVN)	Tensile Strength (MPa)	Density (gr/cm3)
1,2%	3,9%	94,9%	400^{0}C	2 jam			
			300^{0}C	2 jam			
			200^{0}C	2 jam			
			100^{0}C	2 jam			
	4,1%	94,7%	400^{0}C	2 jam			
			300^{0}C	2 jam			
			200^{0}C	2 jam			
			100^{0}C	2 jam			
	4,3%	94,5%	400^{0}C	2 jam			
			300^{0}C	2 jam			
			200^{0}C	2 jam			
			100^{0}C	2 jam			

Figure 1. Research Design

2.1 Heat Treatment

The first step in the sample preparation process is solution annealing at various temperatures (100°C, 200°C, 300°C, 400°C) for a holding time of 2 hours. Following solution treatment, the samples undergo rapid cooling (quenching) in oil for 3 minutes. Next, the workpieces are placed in the heating furnace at temperatures of 100°C, 200°C, 300°C, and 400°C, also for a holding time of 2 hours. After the holding time, the workpieces are removed from the furnace using clamping pliers and quenched in water for 3 minutes at 26-27°C. The samples are left at room temperature in oil. After the solution heat treatment and quenching steps, the samples are ready for further tests, such as mechanical property analysis, microstructure examination, or other advanced treatments [17] [18].

2.2 Tensile Test Specimen

The material used for testing in this research is Aluminum 1100, alloyed with magnesium and copper. The material is initially in slab form and is then cut into test specimens using sheet metal cutting tools at the Sheet Metal Shop, Hangar AMTO 147D/010, Aviation Polytechnic Surabaya. The size of the test specimen adheres to the ASTM E8/E8M standard for tensile testing. The dimensions of the tensile test specimen are Gauge Length: 57 mm, Thickness: 10 mm, Width: 12.5 mm, Grip

DOI: https://doi.org/10.71225/jstn.v2i1.62

Section Length: 50 mm, Grip Section Width: 20 mm, Fillet Radius: 21.5 mm and Overall Length: 200 mm. The tensile strength test is conducted to evaluate the material's suitability for production purposes by determining the maximum weight and strain the material can withstand before failure. The test specimens are made according to ASTM E8 standards. The specimens are mounted on the testing equipment, and the lower cylinder is raised and lowered at a controlled speed. The specimen is stretched incrementally by 10 mm/deci increment until it breaks. The break is expected to occur at the gauge length of the specimen. Data recorded during the dynamic testing process include weight gain (P) and length gain (ε) at specified intervals. The maximum tensile load and tensile strength at failure are also recorded [19] [20].

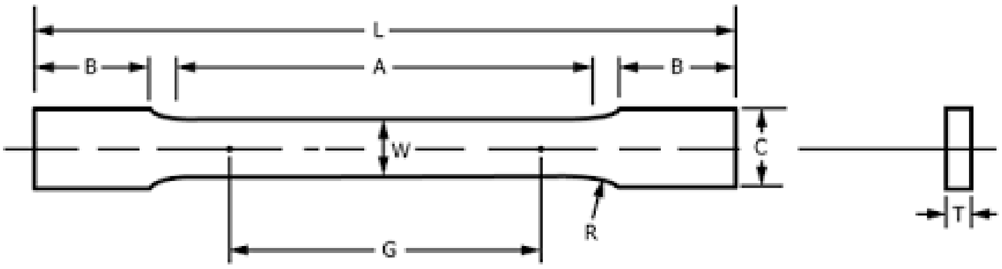


Figure 1. ASTM E8 standard

2.3 Hardness Vickers Test

The test material used for the Vickers hardness test is Aluminum 1100 alloyed with magnesium as a reinforcing agent through a melting and heating process. The material is cut into three specimens using a sheet metal cutting tool at the Sheet Metal Shop, Hangar AMTO 147D/010, Aviation Polytechnic Surabaya. The hardness test specimen follows the guidelines outlined in ASTM International E384, which specifies the Standard Vickers Hardness Test Method for Metallic Materials. The dimensions for the Vickers hardness test specimen are as Length: 30 mm, Width: 30 mm and Thickness: 8 mm. The Vickers hardness test aims to determine the hardness value and mechanical properties of each specimen to identify which alloy has the best hardness characteristics. The process involves preparing the specimen by grinding and polishing to achieve the best possible surface finish. A diamond pyramid indenter with a 136-degree angle is used, applying a load of 50 kgf for 10-20 seconds [21] [22].

2.4 Density Test

The density test aims to measure the density variation among the samples and estimate the purity of the aluminum metal used. The procedure is as follows: First, prepare a measuring cup, the sample, and a digital scale with an accuracy of 0.01 grams. Add water to the measuring cup until it reaches the desired volume, then immerse the weighed sample in the cup. Record the new total volume after the sample is added [23] [24] [25].

3. Results And Discussion

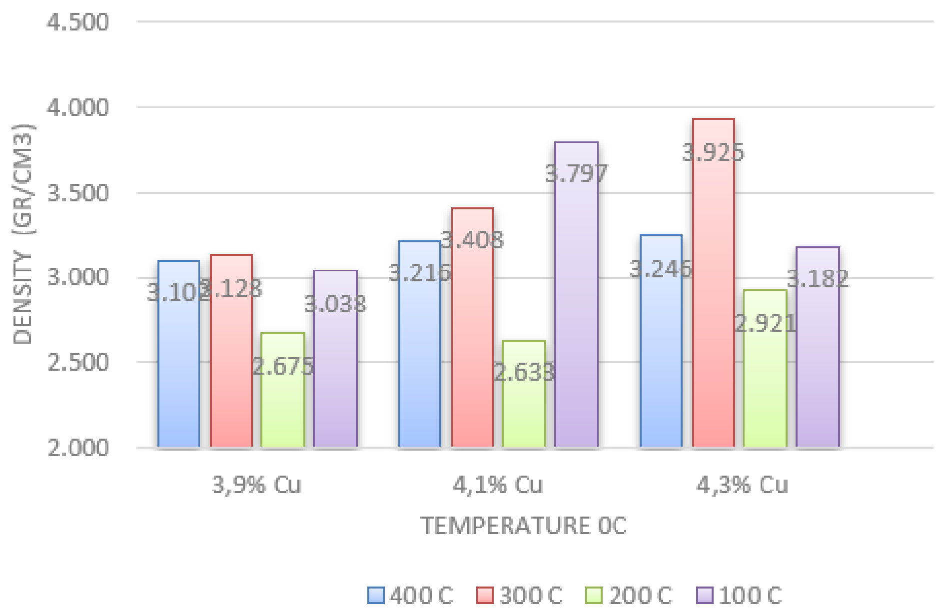
Based on the previously described research methodology, the author presents the results of the specimen tests, including density testing, tensile testing, and Vickers hardness testing. These tests aim to assess the mechanical properties of Al-Mg alloys with varying copper (Cu) additions and applied treatments. Additionally, the test results provide data on the distribution of physical

DOI: https://doi.org/10.71225/jstn.v2i1.62

properties, tensile strength, and Vickers hardness values in each specimen, which underwent Solution Heat Treatment at temperatures of 100°C, 200°C, 300°C, and 400°C for an aging time of 2 hours, followed by quenching.

3.1 Density

This test aims to identify differences in density between each specimen and to compare the density values of pure 1100 aluminum and 1100 aluminum alloy, which has been alloyed with 1.2% magnesium. Copper variations of 3.9%, 4.1%, and 4.3% were applied, and heat treatment was carried out at temperatures of 100°C, 200°C, 300°C, and 400°C. The results of these tests are shown in the following figure 2.



Magnesium (Mg)	Copper (Cu)	Aluminium 1100	Temperature (^{0}C)	Quenching (Time)	Weight of Castings (gr)	Volume Addition (Cm^3)	Density (gr/cm^3)
1,2%	3,9%	94,9%	400^{0}C	2 Jam	15,51	5	3,102
			300^{0}C	2 Jam	15,64	5	3,128
			200^{0}C	2 Jam	16,05	6	2,675
			100^{0}C	2 Jam	15,19	5	3,038
	4,1 %	94,7%	400^{0}C	2 Jam	16,08	5	3,216
			300^{0}C	2 Jam	17,04	5	3,408
			200^{0}C	2 Jam	15,80	6	2,633
			100^{0}C	2 Jam	15,19	4	3,797
	4,3%	94,5%	400^{0}C	2 Jam	16,23	5	3,246
			300^{0}C	2 Jam	15,71	4	3,925
			200^{0}C	2 Jam	17,53	6	2,921
			100^{0}C	2 Jam	15,91	5	3,182

Figure 2. Density Test Results for Heat Treatment

DOI: https://doi.org/10.71225/jstn.v2i1.62

Figure 2. illustrates an increase in the density of specimens with copper variations of 3.9%, 4.1%, and 4.3% when heat-treated at 300°C. The best result was observed with the 4.3% copper variation, yielding a density of 3.925 g/cm³. This demonstrates that as the percentage of copper increases and heat treatment is applied, the specimen density also increases. The varying percentages of magnesium, copper, and heat treatment conditions result in different specimen densities. Among the mixed specimens of aluminum 1100, magnesium (Mg), and copper (Cu) with heat treatment, the highest density value of 3.925 g/cm³ was observed in the mixture with 1.2% magnesium and 4.3% copper. According to the article by Yizeng Manufacturing (2021), the density of 2024 aluminum is 2.77 g/cm³. Therefore, it can be concluded that the density of aluminum 1100 with magnesium, copper, and heat treatment is comparable to or even exceeds that of aluminum 2024. This suggests that additional alloying elements and heat treatment may further enhance the material properties

3.2 Tensile Strength

The tensile strength and strain test was performed on specimens containing 1.2% magnesium with varying copper content of 3.9%, 4.1%, and 4.3%, which were subjected to heat treatment for 2 hours at different temperatures: 100°C, 200°C, 300°C, and 400°C. The results of this test indicate that copper content and heat treatment temperature significantly influence the tensile properties of the material. From the graphs in Figure 3, it is clear that the three copper variations lead to distinct tensile properties. For instance, the 3.9% Cu alloy shows slightly lower strain compared to the 4.1% Cu alloy at 300°C, but the 4.3% Cu alloy exhibits a notably higher stress and strain after the 2-hour aging process. The highest tensile strength was recorded in the 4.3% Cu alloy at 400°C, reaching a peak stress of 130.79 MPa. At 200°C, the 4.1% Cu alloy demonstrated relatively low strain of 0.02195%, while the 4.3% Cu alloy exhibited the highest strain of 0.03995% at 300°C. This increase in strain can be attributed to the higher copper and magnesium content, which enhances the alloy's ductility and strain capacity. The significant increase in tensile strength of the 4.3% Cu alloy at 400°C demonstrates that both the addition of copper and the heat treatment process contribute to improving the material's strength. Furthermore, these findings suggest that the alloy exhibits an excellent balance of strength-to-weight ratio, heat resistance, and chemical corrosion resistance, particularly when heat-treated under optimal conditions. In terms of elasticity, the results also indicate that the addition of copper and heat treatment can enhance the material's flexibility and extend its strain capacity [26] [27] [28]. For example, the 4.3% Cu alloy at 300°C exhibited the highest strain value, indicating an improved capacity for deformation without failure. The tensile strength values were highest in the 4.3% Cu mixture at 400°C (130.79 MPa), while the 4.1% Cu alloy at 200°C displayed the highest elastic modulus of 4162.76 MPa, suggesting better resistance to deformation. The lowest elastic modulus was found in the 4.3% Cu alloy at 100°C (2635.29 MPa), indicating a trade-off between strength and stiffness at lower temperatures. These results highlight the importance of carefully selecting the composition of magnesium and copper, along with the proper heat treatment temperature, to achieve the desired mechanical properties such as optimal tensile strength, strain capacity, and elasticity. In conclusion, the combination of higher copper content and heat treatment plays a crucial role in enhancing the tensile strength, strain capacity, and elasticity of the alloy. These findings suggest that the 4.3% Cu mixture, when heat-treated at 400°C, is the most optimal for achieving high strength and good ductility, making it a promising candidate for applications requiring high-performance materials with excellent strength-to-weight ratios [29] [30].

DOI: https://doi.org/10.71225/jstn.v2i1.62

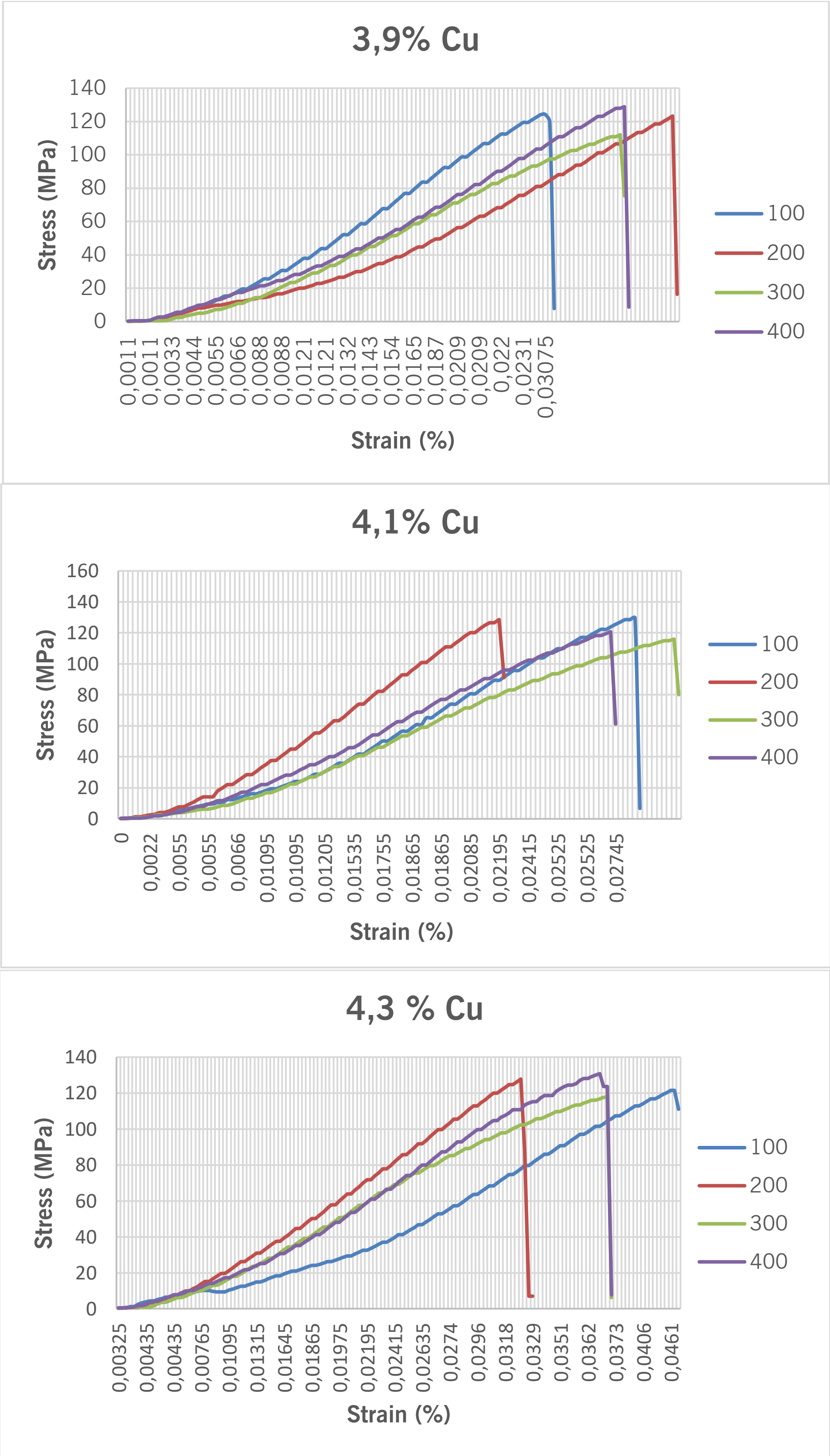


Figure 3. Tensile Strength

DOI: https://doi.org/10.71225/jstn.v2i1.62

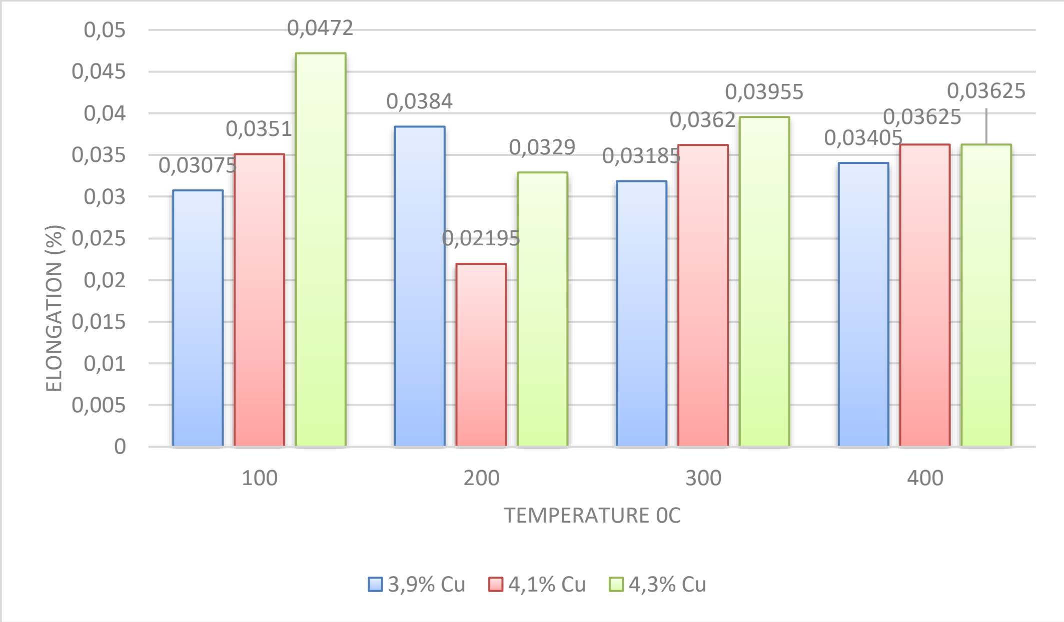


Figure 4. Elongation

Figure 4 illustrates the strain values for the specimens, which differ from the tensile stress results. While the maximum tensile strength was observed in the 4.3% Cu mixture at 400°C, the highest strain occurred in the 4.3% Cu specimen at 100°C. This specimen exhibited a strain value of 0.0472%, demonstrating that copper enhances both the elastic and tensile properties of the material. However, the 4.1% Cu specimen at 400°C, despite its high tensile strength, could not support the strain value as effectively as the 4.3% Cu specimens [31].

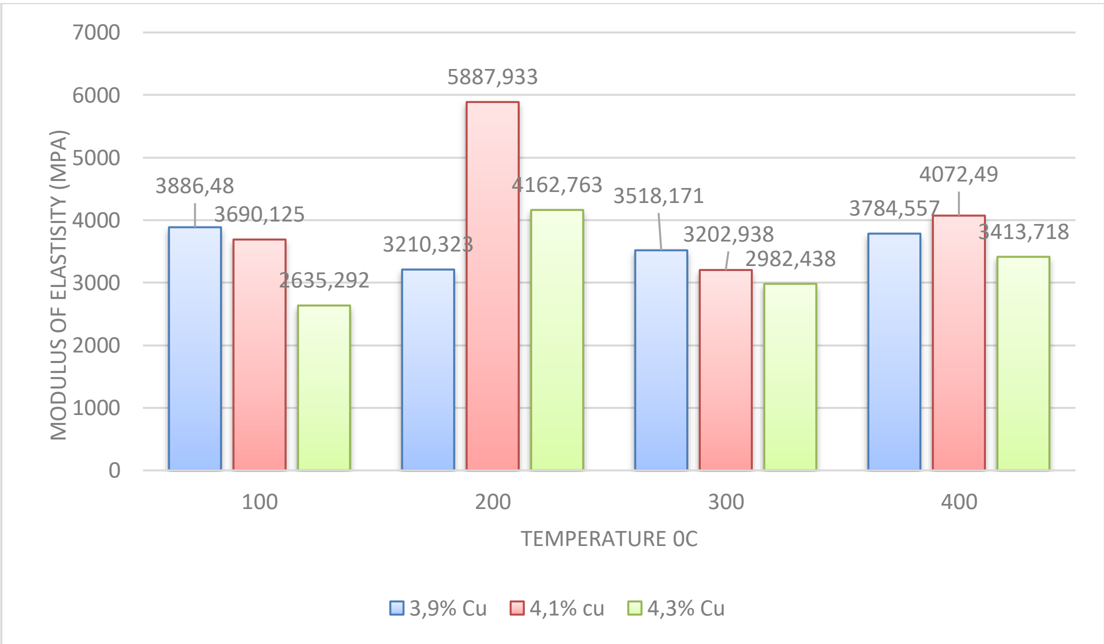


Figure 5. Modulus Elasticity

Figure 5. presents the elastic modulus for each copper variation and heat treatment condition. Notable differences were observed across the variations. For instance, the 3.9% Cu specimen at 200°C exhibited a minimum value of 3210.32 MPa, while the 4.1% Cu specimen at 300°C showed

DOI: https://doi.org/10.71225/jstn.v2i1.62

a minimum of 2982.44 MPa, and the 4.3% Cu specimen at 100°C had a minimum of 2635.29 MPa. These findings suggest that the 4.3% Cu specimen at 100°C is the most elastic, whereas the 4.1% Cu specimen at 200°C is the most plastic. Therefore, adding magnesium, copper, and varying heat treatment temperatures increases the material's elasticity [28] [29].

3.2 Hardness

This test evaluates the hardness of specimens with a predetermined shape and size, in accordance with the applicable standards. In this study, specimens were fabricated by melting 1100 aluminum with magnesium and copper alloys, followed by heat treatment at temperatures of 100°C, 200°C, 300°C, and 400°C. The specimens contained 1.2% magnesium, with copper variations of 3.9%, 4.1%, and 4.3%. The Vickers hardness test results are presented in Figure 6, which serves as a visual representation of the observed hardness values. These results were systematically analyzed to assess the influence of magnesium and copper additions on the hardness properties of aluminum alloys. The Vickers hardness test data were collected at various stages, and the findings were analyzed to investigate the impact of magnesium and copper additions on aluminum alloys in terms of their mechanical properties. The results, presented in histograms and graphs, reveal significant changes in hardness values due to the incorporation of magnesium and copper elements, particularly when combined with heat treatment [18] [20] [31].

Figure 6. Vickers Hardness

Figure 6 shows that specimens with 1.2% magnesium and copper variations of 3.9%, 4.1%, and 4.3%, subjected to heat treatment at temperatures ranging from 100°C to 400°C, demonstrated a noticeable increase in hardness compared to the base 1100 aluminum specimen. The specimen with 1.2% magnesium and 4.3% copper at 400°C exhibited the highest hardness value of 90.27 HVN, which signifies an enhancement in material strength. In contrast, the lowest hardness value of 74.90 HVN was observed in the specimen with 1.2% magnesium and 3.9% copper, suggesting that the copper content directly influences the hardness characteristics.

DOI: https://doi.org/10.71225/jstn.v2i1.62

The increased hardness in these specimens can be attributed to several factors. The addition of copper contributes to the formation of solid solution alloys, which typically exhibit improved strength due to the atomic size mismatch and subsequent dislocation pinning effect. Copper also promotes the precipitation of strengthening phases when the material undergoes heat treatment, particularly at elevated temperatures. In this study, the highest hardness was obtained in the specimen with 4.3% copper, which is consistent with previous research on the effects of copper on aluminum alloys [17] [20] [25] [29].

Moreover, the heat treatment process plays a crucial role in enhancing the material's hardness. Heat treatment at higher temperatures facilitates the formation of intermetallic compounds and precipitates, which significantly increase the alloy's strength. Specifically, the combination of magnesium and copper with heat treatment at 400°C likely leads to the formation of finely dispersed precipitates that obstruct dislocation motion, thereby improving hardness. This effect is similar to the process of age hardening observed in many aluminum alloys [7] [13] [25].

The findings from this study align with those reported by Hatta Chess (2018), who observed that increasing the temperature in the heat treatment process significantly enhances the hardness of S45C steel. This improvement is attributed to the transformation of austenite into martensite at higher temperatures, which strengthens the material. Although this study focuses on aluminum alloys, a similar mechanism may occur, where heat treatment at higher temperatures leads to the formation of strengthening phases and increases hardness. In conclusion, the results from this Vickers hardness test underscore the importance of alloying elements like copper and magnesium, as well as the heat treatment process, in improving the mechanical properties of aluminum alloys. By carefully controlling the composition and heat treatment parameters, it is possible to tailor the hardness and strength of aluminum alloys for specific applications, providing enhanced performance in various engineering and manufacturing contexts.

4. Conclusion

The heat treatment process on aluminum alloys significantly improves their mechanical properties by altering the microstructure and phase distribution, leading to the formation of martensite structures with larger particles compared to pure aluminum or non-heat-treated alloys. The study revealed that as the percentage of magnesium and copper increased, along with heat treatment at temperatures of 100°C, 200°C, 300°C, and 400°C (with aging time of 2 hours and quenching), the density values of the specimens increased, with the highest density of 3.925 g/cm^3 found in the 1.2% magnesium and 4.3% copper mixture at 300°C. Furthermore, heat-treated aluminum alloys demonstrated higher tensile strength compared to pure aluminum, with the maximum tensile strength of 130.79 MPa observed in the 4.3% copper mixture at 400°C, and the highest strain value of 0.03995% at 300°C. The lowest elastic modulus was recorded at 2,635.29 MPa for the 4.3% copper mixture at 100°C, while the highest value was 4,162.76 MPa at 200°C for the 4.1% copper mixture. Additionally, hardness testing showed an increase in mechanical properties, with the hardness of pure aluminum at 39.79 HVN, and the highest hardness of 90.27 HVN observed in the specimen with 1.2% magnesium and 4.3% copper at 400°C. This demonstrates that the combination of alloying elements and heat treatment significantly enhances the density, tensile strength, and hardness of aluminum alloys.

DOI: https://doi.org/10.71225/jstn.v2i1.62

Acknowledgements

The author would like to express sincere gratitude to all those who contributed to the success of this research. Special thanks to the institutions and individuals who provided valuable support, guidance, and resources throughout the study. Appreciation is also extended to the research participants and colleagues for their cooperation and feedback. Without their dedication and assistance, this work would not have been possible.

References

[1] Afrah Hassoon Oraibi, (2021). Effective Of Heat Treatment On Physical Properties.(University Of Kufa,2021).

[2] Agus Adipura, (2022). Analisa Pengaruh Heat Treatment Temperring Dengan Variasi Waktu Tahan Dan Media Pendingin Terhadap Sifat Mekanik Baja Karbon Rendah.

[3] Ahmad Dahlan Dan Rusiyanto, (2021). Pengaruh Penambahan Unsur Aluminium Murni Pada Bahan Aluminium Scrap Terhadap Ketangguhan Impak Dan Struktur Mikro Hasil Pengecoran Velg Motor Honda. (Universitas Negeri Semarang,2021).

[4] A Zayadi, E. S. (2022). Pengaruh Waktu Tempering terhadap Karakter Baja s45c Pasca Quenching pada 950oc dan Tempering 500 C.

[5] A Zayadi, E. S. (2022). Pengaruh Waktu Tempering terhadap Karakter Baja s45c Pasca Quenching pada 950oc dan Tempering 500 C.

[6] Adya Aghastya, H. B. (2023). The Effect Of Heating Surface Treatment By Oxy-Acetylene Gas On The Microstructure And Hardness Of The UIC R42 Rail.

[7] Budiarto, D. A. (2020). Analisis Pengaruh Waktu Artificial Age Terhadap Kekerasan, Densitas Dan Struktur Kristal Paduan Alumunium (7075) Untuk Bahan Sirip Roket,

[8] Bambang Junipitoyo Dan Mochammad Farid Anfasa,(2020). Pengaruh Variasi Suhu Dan Waktu Heat Treatment Pada Aluminium Alloy 2024-T3 Terhadap Sifat Fisis Dan Mekanis Dengan Media Pendingin Oli. (Politeknik Penerbangan Surabaya,2020).

[9] Deny Nur Setiawan, (2021). Meneliti Pengaruh Variasi Suhu Dan Waktu Heat Treatment Terhadap Struktur Aluminium 1100 Dengan Media Pendingin Minyak Nabati.

[10] Efendi, M. E. (2019). Aluminium Alloy 6061 Analysis Reinforced Iron Powder With Cooling Media Variations And Aging Temperature To The Hardness And Strength Of Tensile Material After T6 Heating Process.

[11] Faruq, U. (2019). Effects Of Temperature Variations And Withdrawal Rates On Microstructure And Flow Stress Of Aluminum 2075 Composite Plates With Reinforcement Off Bottom Ash.

[12] Fatoni, R. F. (2019). Experimental Study Of The Effect Of Aging Temperatures And Aging Time Variations In The Process Of Aluminum 2024 Heat Treatment On Mechanical Properties And Micro Structures.

[13] FAA, 2008. Aviation Maintenance Technician Handbook General Chapter 5.

[14] FAA, 2018. Aviation Maintenance Technician Handbook-General (Faa-H-8083-30a) Chapter 7: Aluminium Alloy, (Hal. 7-6). Oklahoma City, United State American.

[15] He Yin, Kai Wen, (2023). Meneliti Effect Of Zn/Mg Ratio On The Microstructure And Mechanical Properties Of As-Cast Ai-Zn-Mg-Cu Alloys And The Phase Transformation During Homogenization.

[16] Hera Setiawan, (2021). Pengaruh Proses Heat Treatment Pada Kekerasan Material Special K (K100). (Universitas Muria Kudus,2021).

DOI: https://doi.org/10.71225/jstn.v2i1.62

[17] Hera Setiawan, (2021). Pengaruh Proses Heat Treatment Pada Kekerasan Material Special K (K100). (Universitas Muria Kudus,2021).
[18] Julmansyah, (2020). Pengaruh Penambahan Unsur Magnesium Terhadap Sifat Mekanik Pada Pengecoran Paduan Aluminium (Piston Bekas). (Universitas Mataram,2020)
[19] Lin Yang, (2021). Effect Of Heat Treatment On The Physic-Mechanical.(Nanjing Forestry University,2021).
[20] Muhammad Abdus Shomad Dan Aulia Adam, (2020). Pengaruh Penambahan Unsur Magnesium Pada Paduan Aluminium Dari Bahan Piston Bekas. (Universitas Muhammadiyah Yogyakarta,2021)
[21] Muhammad Pristian Adinata Dan Mochammad Arif Irfa'i, (2021). Pengaruh Kecepatan Putar Terhadap Kekuatan Tarik Dan Analisis Patahan Pada Pengecoran Al-4% Mg Menggunakan Metode Centrifugal Casting. (Universitas Diponegoro,2021).
[22] Piktor Abadi Hutagaol, (2021). Analisa Heat Treatment Terhadap Kekuatan Uji Impact Aluminium 5083 Tahun 2021. (Universitas Harapan Medan,2021).
[23] Renita Wurdhani, (2021). Pengaruh Perlakuan Panas (Heat Treatment) Normalizing Terhadap Kekuatan Impak Aluminium 6061 Pengelasan Mig Dengan Variasi Posisi Dan Bentuk Kampuh. (Universitas Diponegoro,2021).
[24] Rudi Siswanto, (2021). Hardness Test Of Al-6,7% Cu Alloys With Variation Of Pouring Temperature And Pressure Results Of Squeeze Casting Process.(Universitas Lambung Mangkurat,2021).
[25] Rui Wang, Q. Z. (2023). The Control Of As-Cast Structure Of 2024 Aluminium Alloy With Intensive Melt Shearing And Its Effect On Microstructure And Mechanical Properties After T4 Treatment.
[26] Rui-Dong Fu, J.-F. Z.-J.-I.-C. (2013). Effect Of welding Heat Input And Post-Welding Natural Aging On Hardness Of Stir Zone For Friction Stir-Welded 2024-T3 Aluminium Alloy Thin-Sheet.
[27] Sholechuddin, P. (2023). Effect of Heat Treatment and Anodizing of Aluminum 2024 on Hardness Test and Impact Test.
[28] Willy Artha Wirawan, A. Z. (2023). Investigation Of Mechanical And Physical Properties Of Continue Drive Welding On Aluminium Alloy (AA6061).
[29] Yeong Seong Eom, (2021). Heat Treatment Effect On Physical Properties Of Stainless Steel / Inconel Bonded.
[30] B. Junipitoyo, D. Said, and D. Dwiyanto, "Effect of Heat Treatment and 1,5% Magnesium Addition on Density, Hardness, and Tensile Strength of Al-Cu-Mg Alloys", *JSTN*, vol. 1, no. 3, pp. 49–61, Aug. 2024.
[31] Yida Xiong, J. D. (2023). Effects Of Heat Treatments On The Microstructure And Localized Corrosion Behaviors Of AA7075 Aluminium Alloy.

DOI: https://doi.org/10.71225/jstn.v2i1.62