Experimental Study on Mechanical Properties of Aluminum Alloy

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ABSTRACT

In the present work, an experimental study is conducted to investigate the mechanical properties of an aluminum alloy. The study aimed to assess the tensile strength, hardness, and ductility of the alloy under various testing conditions. The aluminum alloy specimens were prepared and subjected to tensile testing, hardness testing, and microstructural analysis. The results showed that the tensile strength of the alloy varied with different heat treatments, revealing the influence of processing parameters on its mechanical behavior. Additionally, the hardness measurements indicated variations in material strength across different regions of the specimens. Overall, this experimental study sheds light on the mechanical properties of the aluminum alloy, providing valuable information for further optimization and application of the material in various engineering fields.

Keywords: - *Mechanical properties, Aluminum, Sand casting, Hardness.*

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1. Introduction

Aluminum has emerged as the most popular nonferrous metal and finds extensive use in various fields, including packaging, construction, transportation, and electrical materials [1]–[5]. This widespread adoption can be attributed to its abundant resources, lightweight nature, favorable mechanical properties, corrosion resistance, and excellent electrical conductivity. Enhancing both strength and plasticity in metallic materials is a crucial objective, and grain refinement, which involves altering the size of grain structures using various techniques, serves as a preferred method to achieve this goal. Consequently, grain refinement techniques hold significant importance in the aluminum processing industry [6]–[10].

Numerous techniques have been developed for grain refining of aluminum, which can be broadly classified into four categories: vibration and stirring during solidification, rapid solidification, addition of grain refiner, and severe plastic deformation [11]–[16]. Each technique possesses its own advantages, disadvantages, and specific applicability conditions. Nevertheless, there are ongoing debates regarding the underlying mechanisms of these techniques.

In this particular project, our focus lies on the grain refinement of aluminum alloy. To accomplish this, we utilize a grain refiner in the form of a master alloy. Grain refinement offers numerous benefits, the most notable being the attainment of a fine and uniform grain size [17]–[22]. This refinement leads to improved mechanical properties, including higher tensile strength, increased ductility, and enhanced fatigue resistance. Additionally, there may be effects on the physical properties of the material as well [23]–[30].

The development of aluminum grain refining aimed at enhancing the mechanical properties of cast products. In 1930, it was discovered that the addition of titanium to liquid aluminum resulted in the production of smaller and more equiaxed grains compared to when no titanium was added. Adding a small amount of titanium led to a reduction in grain size, while adding titanium beyond the solubility limit in the liquid (0.20 wt.%) resulted in a significant reduction in grain size. In 1949, the effectiveness of titanium diboride (TiB_2) particles as nucleating agents for heterogeneous nucleation in aluminum was demonstrated. Initially, titanium and boron-containing salts were directly added to the liquid aluminum intended for casting to introduce TiB_2 particles. Aluminum alloys, known for their lightweight nature and high deformability, find extensive applications in the automotive and aerospace industries. They are also commonly used in the food industry, as well as in automotive and chemical equipment [31]–[36].

These alloys possess high specific strengths and favorable mechanical properties, making them a preferred choice for ordinary sheet metal and marine applications. To further enhance the performance of aluminum alloys and their composition, the inclusion of reinforcing particles and additives has become increasingly necessary. The modification of aluminum alloys, particularly through the introduction of titanium (Ti), boron (B), and boron carbide (B_4C), has a significant impact on the microstructure and grain refinement. These modifiers play a crucial role in reducing grain size and altering the dendritic structure during the manufacturing process [37]. Elements such as titanium and boron have been widely employed as grain refiners in various aluminum alloy series. These modifiers improve the cast alloy through two key mechanisms: grain refinement and a reduction in porosity during the casting process.

2. Experimental Procedure

The preparation of a master alloy is a challenging experiment in our project, particularly due to the utilization of a muffle furnace for the melting process. In this work, we used an Al-5Ti master alloy, making it crucial to maintain the chemical composition of the master alloy during the melting procedure.

To prepare the master alloy, we required pure aluminum and pure titanium in the form of chips. The Al-5Ti master alloy consists of 100g of pure aluminum and 5g of pure titanium. Based on our data, we prepared an alloy containing 800g of pure aluminum and 40g of titanium, resulting in the Al-5Ti master alloy.

Initially, we melted 99.9% pure aluminum in a crucible using the muffle furnace. The melting point of pure aluminum is 660°C, but during the preparation of the master alloy, additional heat was necessary. Therefore, the temperature was maintained between 750-800°C. The aluminum was left in the muffle furnace for 2 hours. After melting, we removed the slag using a graphite rod. Subsequently, we added 99.9% pure titanium in the form of chips to the molten aluminum. To facilitate the dissolution of titanium, a stirring action was required, which we accomplished using the graphite rod. Stirring was conducted every 2 hours. Titanium has a melting point of 1668°C, so a prolonged period of 24 hours was necessary for the complete dissolution of titanium in the pure aluminum within the muffle furnace. After the production of the molten master alloy, we removed the slag and poured it into a permanent mold, resulting in the master alloy taking the form of a bar or rod.

Sand casting plays a crucial role in our project as we aim to perform grain refinement of aluminum in its as-cast condition. For this project, we primarily utilize the green sand molding process. In sand casting, the molten metal is poured into a sand mold cavity, which is expendable, either by gravity or with the help of force. The metal solidifies within the mold, taking the shape of the cavity and resulting in the formation of a casting, which represents a three-dimensional object.

Sand casting requires several preparatory steps, including the preparation of sand and the creation of the mold cavity using a sample or pattern (shown in Figure 1). The selection of the sand-casting process is based on the fact that LM25 is commonly used for this purpose, making it a suitable choice for our project.

(A) Pouring of metal

(B) Shaking out of casting

(C) Final casting

Fig 1: Photographs of casting process.

3. Result and Discussions

The results obtained from the hardness testing of the aluminum alloy specimens are presented (Figure 2) and discussed in this section. The hardness values were measured using a standardized testing method, such as the Vickers hardness test, at various locations on the specimens. The obtained hardness is increased with increased in Ti content up to 0.20%. The hardness results indicated variations in material strength across different regions of the aluminum alloy. This suggests that the alloy's microstructure and composition influence its hardness characteristics. It was observed that certain regions exhibited higher hardness values, indicating increased material strength, while other regions showed relatively lower hardness values, indicating decreased material strength.

The variations in hardness can be attributed to several factors. One such factor is the presence of different phases within the aluminum alloy. Depending on the alloy composition and processing conditions, different phases such as alpha (α), beta (β), and intermetallic phases may be present. These phases can have varying hardness values, leading to localized variations in hardness across the alloy. Furthermore, the heat treatment process applied to the aluminum alloy can significantly affect its hardness. Heat treatments like solutionizing, quenching, and aging can modify the alloy's microstructure, resulting in changes in hardness. For instance, the precipitation of strengthening phases during the aging process can increase the alloy's hardness. The results also indicated that the hardness values were influenced by the presence of any defects or inclusions within the alloy. Inclusions or impurities can act as stress concentrators, leading to localized hardening or softening of the material.

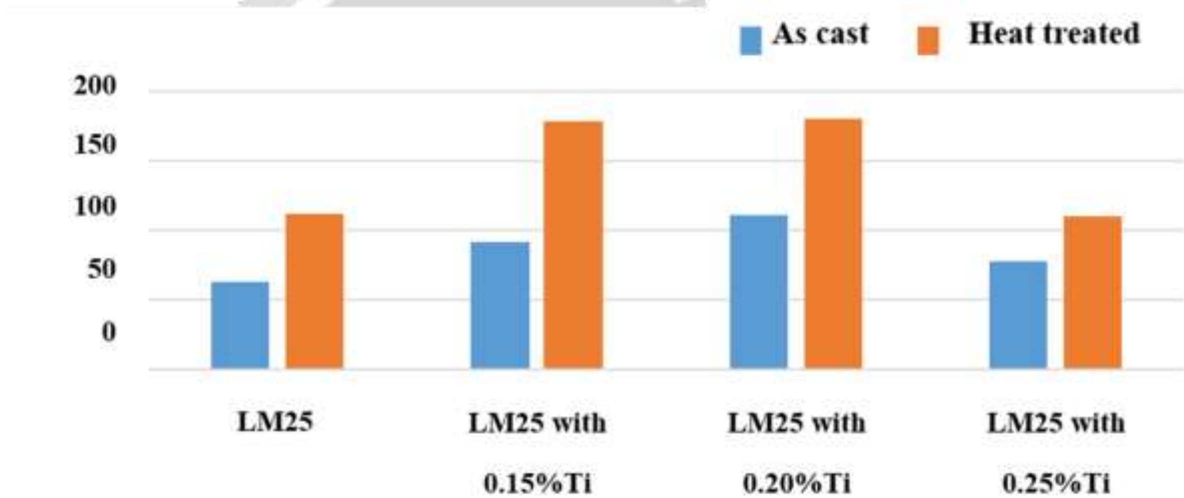

Fig 2: Hardness of prepared Aluminum Alloy specimens.

The ultimate tensile strength (UTS) is a measure of the maximum stress that a material can withstand before fracturing or breaking. It is an essential parameter for assessing the mechanical strength of the aluminum alloy. The UTS values obtained for the aluminum alloy specimens indicated their ability to withstand applied tensile forces (Table 1). During the tensile testing, the specimens were subjected to gradually increasing tensile loads until fracture occurred. The maximum load applied just before fracture was recorded as the ultimate tensile strength. The UTS values varied depending on factors such as alloy composition, heat treatment, and processing conditions. The maximum value of 173 ± 6 MPa is obtained for LM25 with 0.20%Ti.

Table 1. Results of tensile tests.

Sample	Ultimate Tensile Strength (MPa)	Load Applied (N)
LM25	135 ± 4	16 ± 1
LM25 with 0.15%Ti	169 ± 8	20 ± 1
LM25 with 0.20%Ti	173 ± 6	21 ± 1
LM25 with 0.25%Ti	143 ± 5	17 ± 1

4. Conclusion

In summary, the hardness testing of the aluminum alloy revealed variations in material strength across different regions. These variations can be attributed to factors such as the presence of different phases, the effect of heat treatment, and the influence of defects or inclusions. Understanding the hardness characteristics of the aluminum alloy is crucial for assessing its mechanical properties and optimizing its performance in various applications. The ultimate tensile strength testing provided insights into the mechanical strength of the aluminum alloy. The variations observed in UTS values were influenced by factors such as alloy composition, heat treatment, and processing conditions. Understanding the UTS characteristics of the aluminum alloy is vital for evaluating its structural integrity and determining its suitability for specific applications.

5. References

[1] A. S. Katarkar, B. Majumder, A. D. Pingale, S. U. Belgamwar, and S. Bhaumik, "A review on the effects of porous coating surfaces on boiling heat transfer," *Mater. Today Proc.*, vol. 44, pp. 362–367, 2021, doi: 10.1016/j.matpr.2020.09.744.

[2] B. Majumder, A. D. Pingale, A. S. Katarkar, S. U. Belgamwar, and S. Bhaumik, "Enhancement of Pool Boiling Heat Transfer Performance of R-134a on Microporous Al@GNPs Composite Coatings," *Int. J. Thermophys.*, vol. 43, no. 4, p. 49, Apr. 2022, doi: 10.1007/s10765-022-02973-7.

[3] A. S. Katarkar, A. D. Pingale, S. U. Belgamwar, and S. Bhaumik, "Experimental investigation of pool boiling heat transfer performance of refrigerant R-134a on differently roughened copper surfaces," *Mater. Today Proc.*, vol. 47, pp. 3269–3275, 2021, doi: 10.1016/j.matpr.2021.06.452.

[4] A. Owhal, A. D. Pingale, S. U. Belgamwar, and J. S. Rathore, "Preparation of novel Zn/Gr MMC using a modified electro-co-deposition method: Microstructural and tribo-mechanical properties," *Mater. Today Proc.*, vol. 44, pp. 222–228, Nov. 2021, doi: 10.1016/j.matpr.2020.09.459.

[5] A. D. Pingale, A. Owhal, S. U. Belgamwar, and J. S. Rathore, "Effect of Current on the Characteristics of CuNi-G Nanocomposite Coatings Developed by DC, PC and PRC Electrodeposition," *JOM*, vol. 73, no. 12, pp. 4299–4308, Dec. 2021, doi: 10.1007/s11837-021-04815-7.

[6] A. D. Pingale, A. Owhal, S. U. Belgamwar, and J. S. Rathore, "Electro-codeposition and properties of Cu–Ni-MWCNTs composite coatings," *Trans. IMF*, vol. 99, no. 3, pp. 126–132, May 2021, doi: 10.1080/00202967.2021.1861848.

[7] A. D. Pingale, C. M. Patil, and P. B. Marathe, "Experimental Investigation of Thermosyphon for Different Parameters," *IOSR J. Mech. Civ. Eng.*, vol. 14, no. 01, pp. 76–85, Feb. 2017, doi: 10.9790/1684-1401067685.

[8] A. D. Pingale, S. U. Belgamwar, and J. S. Rathore, "The influence of GNPs addition on the microstructure and mechanical properties of Cu-GNPs composites fabricated by electro-co-deposition and powder metallurgy," 2020.

[9] A. D. Pingale, "Synthesis and characterization of Cu-Ni / Gr nanocomposite coatings by electro-co-deposition method : Effect of current density," *Bull. Mater. Sci.*, 2019.

[10] A. S. Katarkar, A. D. Pingale, S. U. Belgamwar, and S. Bhaumik, "Experimental Study of Pool Boiling Enhancement Using a Two-Step Electrodeposited Cu–GNPs Nanocomposite Porous Surface With R-134a," *J. Heat Transfer*, vol. 143, no. 12, Dec. 2021, doi: 10.1115/1.4052116.

[11] C. M. Patil and A. D. Pingale, "Measurement of Gear Stiffness of Healthy and Cracked Spur Gear by Strain Gauge Technique," *Int. J. Mech. Eng.*, vol. 5, no. 7, pp. 9–15, Jul. 2018, doi: 10.14445/23488360/IJME-V5I7P102.

[12] A. S. Katarkar, A. D. Pingale, S. U. Belgamwar, and S. Bhaumik, "Effect of GNPs Concentration on the Pool Boiling Performance of R-134a on Cu-GNPs Nanocomposite Coatings Prepared by a Two-Step Electrodeposition Method," *Int. J. Thermophys.*, vol. 42, no. 8, p. 124, Aug. 2021, doi: 10.1007/s10765-021-02876-z.

[13] A. D. Pingale, C. M. Patil, and S. U. Belgamwar, "Structure Design and Development of Engine Crankshaft Damper," *Int. J. Mech. Eng.*, vol. 5, no. 7, pp. 1–8, Jul. 2018, doi: 10.14445/23488360/IJME-V5I7P101.

[14] A. Owhal, A. D. Pingale, S. Khan, S. U. Belgamwar, P. N. Jha, and J. S. Rathore, "Facile and Scalable Co-deposition of Anti-bacterial Zn-GNS Nanocomposite Coatings for Hospital Facilities: Tribo-Mechanical and Anti-corrosion Properties," *JOM*, vol. 73, no. 12, pp. 4270–4278, Dec. 2021, doi: 10.1007/s11837-021-04968-5.

[15] A. D. Pingale, S. U. Belgamwar, and J. S. Rathore, "Effect of Graphene Nanoplatelets Addition on the Mechanical, Tribological and Corrosion Properties of Cu–Ni/Gr Nanocomposite Coatings by Electro-co-

deposition Method," *Trans. Indian Inst. Met.*, vol. 73, no. 1, pp. 99–107, Jan. 2020, doi: 10.1007/s12666-019-01807-9.

[16] A. D. Pingale, S. U. Belgamwar, and J. S. Rathore, "Synthesis and characterization of Cu–Ni/Gr nanocomposite coatings by electro-co-deposition method: effect of current density," *Bull. Mater. Sci.*, vol. 43, no. 1, p. 66, Dec. 2020, doi: 10.1007/s12034-019-2031-x.

[17] A. S. Katarkar, A. D. Pingale, S. U. Belgamwar, and S. Bhaumik, "Fabrication of Cu@G composite coatings and their pool boiling performance with R-134a and R-1234yf," *Adv. Mater. Process. Technol.*, vol. 8, no. sup4, pp. 2044–2056, Nov. 2022, doi: 10.1080/2374068X.2022.2033046.

[18] A. Owhal, A. Pingale, and S. Belgamwar, "Developing sustainable Zn-MWCNTs composite coatings using electrochemical co-deposition method: Tribological and surface wetting behavior," *Adv. Mater. Process. Technol.*, vol. 8, no. sup4, pp. 2142–2155, Nov. 2022, doi: 10.1080/2374068X.2022.2035968.

[19] A. S. Katarkar, B. Majumder, A. D. Pingale, S. U. Belgamwar, and S. Bhaumik, "A review on the effects of porous coating surfaces on boiling heat transfer," *Mater. Today Proc.*, vol. 44, pp. 362–367, Nov. 2021, doi: 10.1016/j.matpr.2020.09.744.

[20] B. Majumder, A. D. Pingale, A. S. Katarkar, S. U. Belgamwar, and S. Bhaumik, "Pool Boiling Heat Transfer Performance of R-134a on Microporous Al Surfaces Electrodeposited from AlCl3/Urea Ionic Liquid," *J. Eng. Thermophys.*, vol. 31, no. 4, pp. 720–736, Dec. 2022, doi: 10.1134/S1810232822040166.

[21] A. R. Shelke, J. Balwada, S. Sharma, A. D. Pingale, S. U. Belgamwar, and J. S. Rathore, "Development and characterization of Cu-Gr composite coatings by electro-co-deposition technique," *Mater. Today Proc.*, 2020.

[22] B. Majumder, A. D. Pingale, A. S. Katarkar, S. U. Belgamwar, and S. Bhaumik, "Pool Boiling Heat Transfer Performance of R-134a on Microporous Al Surfaces Electrodeposited from AlCl 3 / Urea Ionic Liquid," vol. 31, no. 4, pp. 720–736, 2022, doi: 10.1134/S1810232822040166.

[23] A. D. Pingale, S. U. Belgamwar, and J. S. Rathore, "Synthesis and characterization of Cu–Ni/Gr nanocomposite coatings by electro-co-deposition method: effect of current density," *Bull. Mater. Sci.*, vol. 43, no. 1, p. 66, Dec. 2020, doi: 10.1007/s12034-019-2031-x.

[24] B. Majumder, A. Pingale, A. Katarkar, S. Belgamwar, and S. Bhaumik, "Developing Al@GNPs composite coating for pool boiling applications by combining mechanical milling, screen printing and sintering methods," *Adv. Mater. Process. Technol.*, vol. 8, no. sup4, pp. 2110–2121, Nov. 2022, doi: 10.1080/2374068X.2022.2036037.

[25] A. D. Pingale, A. Owhal, A. S. Katarkar, and S. U. Belgamwar, "Fabrication and tribo-mechanical performance of Cu@Al2O3 composite," *Mater. Today Proc.*, vol. 64, pp. 1175–1181, 2022, doi: 10.1016/j.matpr.2022.03.425.

[26] A. D. Pingale, S. U. Belgamwar, and J. S. Rathore, "The influence of graphene nanoplatelets (GNPs) addition on the microstructure and mechanical properties of Cu-GNPs composites fabricated by electro-co-deposition and powder metallurgy," *Mater. Today Proc.*, vol. 28, pp. 2062–2067, 2020, doi: 10.1016/j.matpr.2020.02.728.

[27] A. D. Pingale, A. B. Gaikwad, and A. N. Patil, "Engine Crankshaft Damper failure Investigation and Redesign," *Am. Int. J. Res. Sci. Technol. Eng. Math.*, vol. 1, no. 1, pp. 1–5, 2017.

[28] A. D. Pingale, A. Owhal, A. S. Katarkar, S. U. Belgamwar, and J. S. Rathore, "Recent researches on Cu-Ni alloy matrix composites through electrodeposition and powder metallurgy methods: A review," *Mater. Today Proc.*, vol. 47, pp. 3301–3308, Jul. 2021, doi: 10.1016/j.matpr.2021.07.145.

[29] A. D. Pingale, A. Owhal, A. S. Katarkar, S. U. Belgamwar, and J. S. Rathore, "Facile synthesis of graphene by ultrasonic-assisted electrochemical exfoliation of graphite," *Mater. Today Proc.*, vol. 44, pp. 467–472, Nov. 2021, doi: 10.1016/j.matpr.2020.10.045.

[30] A. D. Pingale, A. Owhal, S. U. Belgamwar, and J. S. Rathore, "Co-deposited CuNi@MWCNTs nanocomposites for structural applications: tribo-mechanical and anti-corrosion performances," *Trans. IMF*, pp. 1–8, Oct. 2022, doi: 10.1080/00202967.2022.2127512.

[31] A. R. Shelke, J. Balwada, S. Sharma, A. D. Pingale, S. U. Belgamwar, and J. S. Rathore, "Development and characterization of Cu-Gr composite coatings by electro-co-deposition technique," *Mater. Today Proc.*, vol. 28, pp. 2090–2095, 2020, doi: 10.1016/j.matpr.2020.03.244.

[32] A. S. Katarkar, A. D. Pingale, S. U. Belgamwar, and S. Bhaumik, "Experimental Study of Pool Boiling Enhancement Using a Two-Step Electrodeposited Cu-GNPs Nanocomposite Porous Surface with R-134a," *J. Heat Transfer*, Aug. 2021, doi: 10.1115/1.4052116.

[33] A. D. Pingale, S. U. Belgamwar, and J. S. Rathore, "Effect of Graphene Nanoplatelets Addition on the Mechanical, Tribological and Corrosion Properties of Cu–Ni/Gr Nanocomposite Coatings by Electro-co-

deposition Method," *Trans. Indian Inst. Met.*, Sep. 2019, doi: 10.1007/s12666-019-01807-9.

[34] A. Owhal, A. D. Pingale, S. U. Belgamwar, and J. S. Rathore, "A brief manifestation of anti-bacterial nanofiller reinforced coatings against the microbial growth based novel engineering problems," *Mater. Today Proc.*, vol. 47, pp. 3320–3330, 2021, doi: 10.1016/j.matpr.2021.07.151.

[35] S. U. Belgamwar, A. D. Pingale, and N. Nipun Sharma, "Investigation on electrical properties of Cu matrix composite reinforced by multi-walled carbon nanotubes," *Mater. Today Proc.*, vol. 18, pp. 3201–3208, 2019, doi: 10.1016/j.matpr.2019.07.196.

[36] A. S. Katarkar, A. D. Pingale, S. U. Belgamwar, and S. Bhaumik, "An experimental study on pool boiling of R-600a on Cu@Gr composite-coated patterned surfaces," *J. Brazilian Soc. Mech. Sci. Eng.*, vol. 45, no. 1, p. 40, Jan. 2023, doi: 10.1007/s40430-022-03936-7.

[37] P. Kachare and A. D. Pingale, "Passive Vibration Damping – A Review," *J. Xidian Univ.*, vol. 16, no. 3, pp. 235–247, Mar. 2022, doi: 10.37896/jxu16.3/026.