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# Comparative Assessment of Magnesium, Copper, and Zinc Addition to Aluminium Waste Casting for Improving Ship Material Behaviour

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ABSTRACT: The aluminium industry for ship materials produces waste material that can pollute the environment. To protect the environment from material pollution, the aluminium waste recycling process can be used to develop ship material. This study aims to analyze the physical and mechanical characteristics of aluminium with magnesium, copper, and zinc addition. Several tests, such as chemical composition, tensile, and impact tests, will be conducted to ascertain the mechanical properties of aluminium alloy. Adding alloy material in the range of 0-10% resulted in various alloy element compositions. It can be analyzed that the aluminium contents decreased with the increase of alloy elements. The highest rise in alloy elements can be found in the addition of magnesium than in copper and zinc addition. Moreover, the mechanical tests showed that aluminium casting with magnesium, copper, and zinc additions influenced the mechanical properties of the aluminium alloy. It can be found that tensile strength and modulus of elasticity values improved with the increase of alloy addition. The addition of magnesium has better tensile properties than the addition of copper and zinc. In contrast, the impact resistance decreased with the addition of magnesium, making the alloy more brittle.

## 1 INTRODUCTION

The growing material industry produces waste material that can pollute the surrounding environment. The industry sector in Indonesia produced around 250,000 - 260,000 tons of aluminium in 2017, and it is planned to 400,000 tons in 2024 predicted by Indonesia Asahan Aluminium Ltd. (INALUM) [1]. This industry frequently uses recycling technology to reduce material pollution and promote environmental friendliness [2]. This technique predictably reduces material waste more efficiently by using solid waste materials such as aluminium cans, used pans, etc.

It has been demonstrated that recycling aluminum alloys provides significant economic benefits. As a result, the aluminum industry as a whole should find, develop, and apply any and all technologies that will maximize the benefits of recycling [3]. One of the methods to utilize waste material is the casting method. The casting process and alloy composition choice greatly influence the microstructure and mechanical properties of aluminium alloy [4]. Many casting methods are used in manufacturing automotive components, such as the sand moulding method, metal moulding, high-pressure die casting, and lost foam casting method. The evaporative method is an exact casting method in producing automotive components made of aluminium alloy. The casting recycling method is simple, flexible, and strong [5, 6]. It can even replace primary aluminium material, potentially reaching about 95% usage [7]. Casting production is usually a combination of several metals and has recently had many applications in modern industry [8]. Shipping, aircraft, and other industries often use aluminium alloys because of their excellent characteristics, such as corrosion resistance, castability, and machinability [9, 10]. The shipping industry uses aluminium material for hull girder fabrication [11]. However, the 5000 and 6000 series alloys are typically employed for maritime applications. Aluminum alloys containing magnesium as the main alloying ingredient, the 5000 series alloys are corrosion-resistant aluminum alloys. They're employed in shipbuilding, automotive, and structural components. 6000 series alloys, with aluminum as the base metal and magnesium and silicon as main alloying constituents, balance strength, formability, and weldability. They're used in frames, heat sinks, structural components, and architecture. The 6000 series is strong and formable, whereas the 5000 series resists corrosion. These alloys are readily available, weldable, and have strong corrosion resistance. Examining the structural components made of aluminium that have the highest strength for marine applications, this study examines factors that influence the ultimate strength of aluminium ship hull girder elements, including the stress-strain relationship, initial defects, boundary conditions, and analytical scope [12].

Several alloys, including those that incorporate magnesium, copper, and zinc as extra materials in the casting process to strengthen material strength, are intriguing alternatives. Magnesium has a low density, excellent hardness, and strong corrosion resistance [13]. Copper is relatively soft and simple to fabricate, has a slow corrosion rate, and has good thermal and electrical conductivity [14]. Additionally, zinc has a low melting point and can boost the castability of aluminium, allowing it to be cast using various techniques [15]. Additionally, magnesium in alloys demonstrates how the element can impact tensile and impact strength. The findings demonstrate that adding more magnesium strengthens the alloy's tensile strength. The alloy becomes more ductile and durable due to magnesium [16–18]. However, the impact strength of the alloy decreases when more magnesium is added. The alloy becomes fragile and weak due to magnesium addition [19, 20].

According to a different study, adding copper to a casting can change its mechanical qualities. It has been discovered that the alloy's tensile and impact strength rises as the number of copper increases. The strain value has a decreasing trend. As a result, adding copper makes the alloy robust and ductile [21–23]. Zinc can change the mechanical characteristics of aluminium alloys. Numerous studies have demonstrated that differences in the expansion of zinc to aluminium alloys can strengthen the alloy and enhance the tensile strength due to the characteristics of the zinc [24, 25].

As a result of the discussions above, further research on recycled aluminium casting for ship material is required to lessen the harm caused by aluminium waste. Several mechanical tests, such as tensile and impact tests, will be conducted to ascertain the mechanical properties of the addition of magnesium (Mg), copper (Cu), and zinc (Zn). This study objective is anticipated to be used as an alternative material for ship structures. Traditional casting techniques are used in testing aluminium alloys by micro, small, and medium-sized businesses to help analyze the aluminium alloys that will be manufactured.

## 2 MATERIAL AND METHOD

### 2.1 *Materials selection and characteristic*

In this section, the material selection and material properties of each proposed material will be discussed. The specimen manufacture process of aluminium waste casting was conducted at Mukti Jaya workshop in Demak, Indonesia. The test specimens were made from an alloy of aluminium pan waste, powdered magnesium, copper, and zinc at specific compositions. The pan waste was collected from the used goods/waste bins in the Bangetayu area, Indonesia, as seen in Figure 1a. At the same time, the three alloy material powders were purchased at Justus Kimiaraya, Semarang, Indonesia. Based on the chemical composition test, the composition contained in the magnesium powder was 99.65% Mg and 0.05 Fe, the copper powder content was 99.5% Cu and 0.05% Pb, and the zinc powder content was 96% Zn and 0.02% Pb. Figure 1 shows waste aluminium pans and three different alloy additions. The chemical composition of the waste aluminium obtained from the chemical composition test pan can be seen in Table 1.

Figure 1. a) waste aluminium pan, b) magnesium powder, c) copper powder, d) zinc powder.

Table 1. Chemical composition of waste pan

| Element | Amount (%) | Element | Amount (%) |
|---|---|---|---|
| Si | 3.1100 | V | <0.0030 |
| Fe | <0.0010 | Sr | 0.0041 |
| Cu | 0.7761 | Zr | <0.0020 |
| Mn | 0.0452 | Cd | <0.0050 |
| Mg | 0.1674 | Co | <0.0030 |
| Ni | <0.0050 | Ag | <0.0010 |
| Zn | 0.7611 | Bi | <0.0060 |
| Ti | <0.0020 | Ca | 0.0013 |
| Pb | <0.0050 | Li | <0.3000 |
| Sn | <0.0050 | Al | 94.9124 |

## 2.2 *Manufacture of test specimen*

The tools used in specimen manufacture included wood mould, silica sand, a burning furnace, digital scales, casting mixers, clamping tools (pliers), a sand pounder, callipers, a grinding machine, a rubber pounder, and a thermocouple. The comprehensive steps of specimen manufacture are described in Figure 2. The first step involved gathering supplies from discarded aluminium pans, magnesium, copper, and zinc powder. Before placing the pan waste in the furnace, the specimen must be cleaned. The next step was conducted by creating sand moulds that match the test specimen's dimensions, each of which should take around 10 minutes to complete. The wood mould's dimensions were 27 x 10 cm in length and breadth, and its thickness was assumed to be about 5 cm. It took around 30 minutes to melt the pan scrap and the alloyed metal, measured in percentages in the furnace. Before pouring the melted casting into the mould, check the casting's temperature and swirl the liquid to disperse the casting uniformly. To prevent the initial freezing, the furnace temperature was raised to 67°C, higher than the temperature at which aluminium melts. Pour the uniformly melted metal alloy and used aluminium pan into the prepared mould as soon as it has melted. Allow the castings to cool in the mould for 30 to 60 minutes to prepare the moulds for removal. The last step was conducted by removing any last bits of sand that were stuck on the paper. The sample was ready for testing.

Figure 2. The step of test specimen manufacture.

The study used five different specimen variations with a different weight percentage of metal alloy addition. The Mg, Cu, and Zn additions were varied in the range of 0-10%, as described in Table 2. Each variation has five specimens for tensile and impact tests. For the composition test, only one specimen in each variation was tested.

Table 2. Total of specimens used for different tests.

| Test type | Material variations |
|---|---|
| 1 | 100% Al |
| 2 | 97.5% Al + 2.5% alloy addition |
| 3 | 95% Al + 5% alloy addition |
| 4 | 92.5% Al + 7.5% alloy addition |
| 5 | 90% Al + 10% alloy addition |

| Test type | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Tensile test (repetition) | 5 | 5 | 5 | 5 | 5 |
| Impact test (repetition) | 5 | 5 | 5 | 5 | 5 |
| Composition (repetition) | 1 | 1 | 1 | 1 | 1 |

## 2.3 *Testing specimen and procedure*

To explore the mechanical behavior of materials under varying weight compositions of alloy additions, several mechanical experiments, including tensile and Charpy impact tests, were performed. Tensile and impact testing were performed at the Materials and Construction Laboratory, Department of Naval Architecture, Diponegoro University, Indonesia. A tensile test was performed to determine the tensile strength of materials using ASTM B557 [26] for cast aluminum material. The Nanjing T-Bota Scietech Instruments & Equipment Co., Ltd (TBT) WE-1000B Universal Testing Machine (UTM) with a maximum capacity of 1000 kN was employed. The test specimen's bottom side was fastened on a testing machine, and the loading was gradually increased to a specific load until the test object broke. Tensile testing was carried out using a tensile testing machine with a grasp on the device to clamp the specimen and a computer linked to the test equipment to collect test results. The strain value was then calculated by measuring the length of the broken sample at gauge length. Tensile test results included specimen tensile strength, strain, and modulus elasticity. Five specimens were tested, and the average tensile values were given. Figure 3 depicts the testing machine and the standard dimensions of the tensile test specimen.

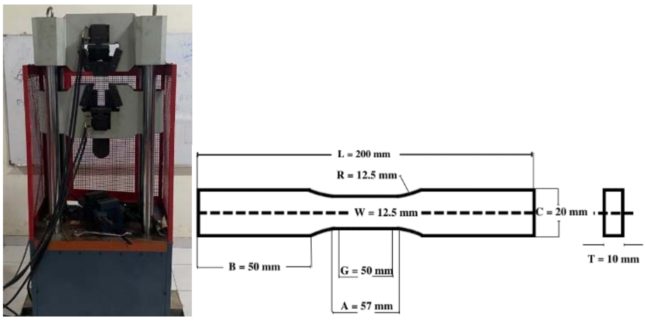


Figure 3. Dimensions of tensile test specimen based on ASTM D557.

The ultimate and tensile strength were calculated at each required data point using Eq. 1 and Eq. 2, respectively.

$$\sigma_{max} = \frac{P_{max}}{A_0} \tag{1}$$

$$\sigma_i = \frac{P_i}{A} \tag{2}$$

where $\sigma_{max}$ is the ultimate tensile strength (MPa), $P_{max}$ is the maximum load before failure (N), $\sigma_i$ is the tensile stress at $i_{th}$ data point (MPa), $P_i$ is the load at $i_{th}$ data point (N), and $A$ is the average cross-sectional area (mm²). Tensile strain from the indicated displacement at each required data point can be calculated using Eq. 3.

$$\varepsilon_i = \frac{\delta_i}{L_g} \tag{3}$$

where $\varepsilon_i$ is the tensile strain at $i_{th}$ data point, $\delta_i$ is the extensometer displacement at $i_{th}$ data point (mm), and $L_g$ is the extensometer gauge length (mm).

Modulus of elasticity (MOE) is a property of a material that tells how easily it can stretch and deform and is defined as the ratio of tensile stress ($\sigma$) to tensile strain.

Besides the tensile test, the Charpy impact test aimed to assess the brittle performances of the aluminium alloy material when subjected to an impact load. Impact testing aims to determine the tendency of the toughness properties of ductile materials. The primary measurement of the impact test is the energy absorbed in breaking the specimen, and the result is expressed in joules [27]. The Charpy impact machine Model DB-300A, Dongguan Hongtuo Instrument Co., Ltd, Dongguan, China, as depicted in Figure 4a, determined the amount of energy absorbed by a standard notched specimen when it broke under an impact load. The Charpy device is a dynamic three-point bending experiment that employs an experimental setup that includes the specimen, anvils on which the specimen is freely supported, and a pendulum with a defined mass coupled to a rotating arm pinned to the machine body. The pendulum falls in a circular path, striking the test specimen at the span's center and delivering kinetic energy. Total correction energy ($E_{TC}$) was calculated using Eq. 4.

$$E_{TC} = \left[E_A - \left(\frac{E_B}{2}\right)\right] \cdot \left(\frac{\beta}{\beta_{max}}\right) + \left(\frac{E_B}{2}\right) \tag{4}$$

where $E_{TC}$ is the total correction energy for the breaking energy of a specimen (J), $E_B$is the energy correction for windage of the pendulum (J), and $E_A$ is the energy correction for windage of the pendulum plus friction in dial (J). Impact resistance $I_S$ can be calculated using Eq. 5.

$$I_S = \frac{(E_S - E_{TC})}{t} \tag{5}$$

where $I_S$ is the impact resistance of the specimen (J/m), $E_S$ is the dial reading breaking energy for a specimen (J), and $t$ is the width of the specimen or width of the notch (m).

The rectangular test specimen used in the impact test had dimensions of 55 x 10 x 10 mm and a notch angle of 45°/-45°, as shown in Figure 4b. The ASTM E23 [28] impact test was carried out at the Materials and Construction Laboratory, Department of Naval Architecture, Diponegoro University, Indonesia. The impact energy was 150 J with a small hammer, the impact speed was 5.2 m/s, and the pendulum angle was 150°. An average of five test specimens was used to calculate the impact strength for each variation.

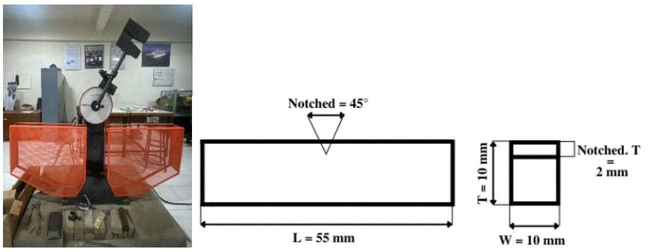


Figure 4. Impact test instrument a) testing machine, b) specimen dimension

Besides the mechanical test, a chemical composition test was conducted at the Laboratory of Manufacture, Polytechnic State of Semarang, using a universal chemical composition spectrum test (spectrometer) of the Bruker Q2 ION type produced by Bruker Corporation, as seen in Figure 5a. Because the alloy contains specific components that determine its qualities, the test seeks to ascertain its composition [29]. Preparing composition test specimens were under ASTM E1251-17a [30]. Use a grinder to chop and ground the specimen before running the test. After being sliced and mashed, the specimens were laid on a bed and heated with electrodes until they melted or crystallized. The diameter of the specimen is 30 mm with a thickness of 10 mm, as seen in Figure 5b. When the test object was recrystallized, the device used a light sensor to capture the colour and then transmitted it to a computer for analysis.

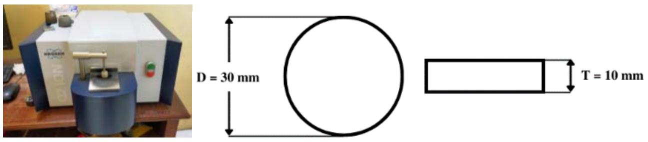
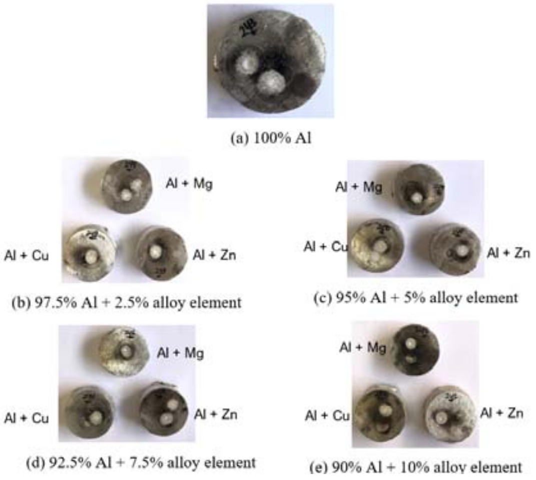


Figure 5. Chemical composition test a) Bruker Q2 ION spectrometer, b) composition test dimension.

## 3 RESULTS AND DISCUSSION

### 3.1 *Result of chemical composition test*

A composition test was carried out to determine the element compositions contained in the alloy to determine the mechanical properties of the alloy. Each test was coded to show five specimen variations of 0-10% alloy element addition. As a reference specimen, Specimen A comprised 100% waste aluminium pans without adding alloy material. Specimen B comprised 97.5% waste aluminium pans and 2.5% alloy elements, Specimen C consisted of 95% waste aluminium pans and 5% alloy elements, and Specimen D comprised 92.5% waste aluminium pans and 7.5% alloy elements. Specimen E contained 90% waste aluminium pans with 10% alloy elements. Specimen of chemical composition test with different alloy element addition is depicted in Figure 6.



(a) 100% Al

(b) 97.5% Al + 2.5% alloy element

(c) 95% Al + 5% alloy element

(d) 92.5% Al + 7.5% alloy element

(e) 90% Al + 10% alloy element

Figure 6. Specimen of chemical composition test with different alloy element addition.

The chemical composition due to the addition of Mg, Cu, and Zn elements into waste aluminium alloys was evaluated. Table 3 and Figure 7 show the percentage of the alloy content measured by the universal chemical composition spectrum test under 5 testing specimens. It can be found from the result that specimen A as a base material, contained 0.167% Mg, 0.776% Cu, and 0.761% Zn. The magnesium component in the specimen was higher than zinc and copper. The addition of alloy material in the range of 0-10% resulted in different alloy element contents. The highest alloy additions can be found in Specimen E due to adding 10% alloy element, which contained 2.039% Mg, 2.174% Cu, and 0.921% Zn. As shown, the highest percentage increase can be found in the addition of magnesium. To a certain extent, changes in chemical composition that occur in an alloy can change the desired mechanical properties.

Table 3. Percentage of alloy element content in specimens.

| Compound element | Specimen variation<br>A (%) | B (%) | C (%) | D (%) | E (%) |
|---|---|---|---|---|---|
| Mg | 0.167 | 0.694 | 0.845 | 1.064 | 2.039 |
| Cu | 0.776 | 0.832 | 1.352 | 1.985 | 2.174 |
| Zn | 0.761 | 0.802 | 0.881 | 0.893 | 0.921 |

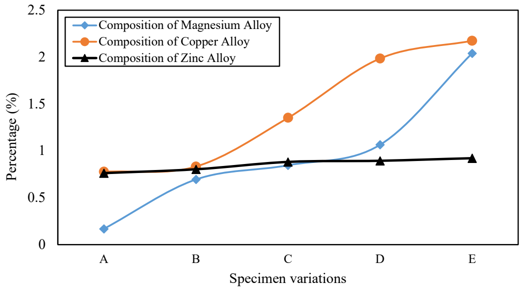


Figure 7. Content percentage of different alloy elements addition at five specimen variations.

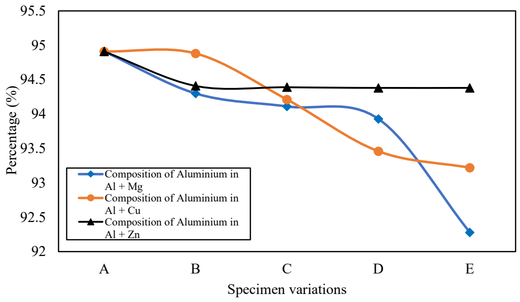


Figure 8. Percentage of aluminium content in different specimen compositions.

Table 4 shows the percentage of aluminium content at five specimen variations. The highest percentage of aluminium content was found in specimen A as base material, which was about 94.91%. The result showed that the aluminium contents in the specimen had different percentages due to adding the same percentage of alloy element. It can be analyzed that the aluminium contents decreased with the increase of alloy elements. In specimen E, it can be found that the addition of 10% Mg contained 92.28% Al, 10% Cu contained 93.22% Al, and 10% Zn contained 94.38 % Al. Moreover, Figure 8 shows the highest aluminium decrease in the specimen with magnesium addition. In contrast, the specimen with zinc addition has the lowest decreasing trend compared to magnesium and copper additions.

Table 4. Percentage of aluminium contents in five different specimen compositions.

| Compound element | A (%) | B (%) | C (%) | D (%) | E (%) |
|---|---|---|---|---|---|
| Al + Mg | 94.91 | 94.30 | 94.11 | 93.93 | 92.28 |
| Al + Cu | 94.91 | 94.88 | 94.21 | 93.46 | 93.22 |
| Al + Zn | 94.91 | 94.41 | 94.39 | 94.38 | 94.37 |

### 3.2 *Result of uniaxial tensile test*

Tensile strength/ultimate tensile strength is the highest stress that a composite can sustain before it breaks when stretched. Tensile strength is typically determined by running a tensile test and recording the strain and stress value changes. The ultimate tensile strength is the highest point on the stress-strain curve. The strength value is determined by the type of material rather than its size. Table 3 shows the average tensile strength and standard deviation (STDEV) results from five specimens under different alloy additions. STDEV is a popular measure of variability because it returns to the original units of measure of the data set. From the result in Table 5, it can be analyzed the result from 5 specimens in each variation has a low standard deviation, which indicates that data points are close to the mean.

Based on Figure 9, the tensile strength increased with the increase of alloy additions. The same phenomena were found in the increase in tensile strength experienced by adding magnesium, copper, and zinc. It can be seen that specimen E, with the highest alloy addition, experienced the highest tensile strength. Compared to three different alloy additions, the addition of magnesium showed the most dominant contribution in increasing tensile strength compared to zinc and copper additions. The tensile strength value increased about 16-33% with the addition of zinc, with the highest average tensile strength value of 211.61 MPa at specimen E with 90% Al and 10% Zn variation. Moreover, adding magnesium increased the tensile stress value by about 25-31%, with the highest average value at 90% Al 10% Mg variation of 208.10 MPa. The addition of copper increased the tensile stress value by about 4-32%, with the highest average value at 90% Al and 10% Cu at 209.45 MPa.

Table 6 and Figure 10 shows the fracture strain at different specimen compositions. It can be analyzed that the tensile strain values obtained by statistical analysis of standard deviations did not experience high variations. The addition of alloy materials caused a decreasing trend in fracture strain value. The addition of copper had a lower effect on the contribution of fracture strain decrease than magnesium and zinc additions. The addition of magnesium experienced the highest decrease trend of the strain value in the range of 46-82%, with the lowest strain value can be found in specimen E with 90% Al and 10% Mg variation. Moreover, the addition of zinc decreased in the 62-71% range, with the lowest average value at specimen E with 90% Al and 10% Zn. Moreover, adding copper slightly decreased the strain by about 10-43%.

Table 5. Tensile strength value at five different specimens.

| Content additions | A (MPa) | STDEV | B (MPa) | STDEV | C (MPa) | STDEV | D (MPa) | STDEV | E (MPa) | STDEV |
|---|---|---|---|---|---|---|---|---|---|---|
| Mg | 157.9 | 5.7 | 197.63 | 4.8 | 201.10 | 4.5 | 204.47 | 4.7 | 208.10 | 8.2 |
| Cu | 157.9 | 4.9 | 164.62 | 6.7 | 175.14 | 8.9 | 189.65 | 6.9 | 209.45 | 11.2 |
| Zn | 157.99 | 4.6 | 183.82 | 9.2 | 189.29 | 6.6 | 197.42 | 8.9 | 211.61 | 9.2 |

Table 6. Tensile strain at different specimen compositions.

| Alloy additions | Strain at different specimen codes | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | A | STDEV | B | STDEV | C | STDEV | D | STDEV | E | STDEV |
| Mg | 23.93 | 0.00073 | 12.88 | 0.00062 | 9.20 | 0.00064 | 6.73 | 0.00066 | 4.29 | 0.00068 |
| Cu | 23.93 | 0.00073 | 21.47 | 0.00079 | 19.14 | 0.00071 | 16.57 | 0.00072 | 13.5 | 0.0001 |
| Zn | 23.93 | 0.00073 | 9.06 | 0.00063 | 8.75 | 0.00102 | 7.19 | 0.00063 | 6.88 | 0.00072 |

Table 7. Modulus of elasticity in different specimen compositions.

| Alloy additions | Modulus of elasticity at different specimen codes | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | A (GPa) | STDEV | B (GPa) | STDEV | C (GPa) | STDEV | D (GPa) | STDEV | E (GPa) | STDEV |
| Mg | 6.6 | 0.7 | 15.3 | 0.8 | 21.9 | 1.8 | 30.4 | 1.2 | 48.5 | 3.9 |
| Cu | 6.6 | 0.7 | 7.7 | 0.3 | 9.2 | 0.4 | 11.4 | 0.5 | 15.5 | 0.4 |
| Zn | 6.6 | 0.7 | 20.3 | 1.2 | 21.6 | 2.6 | 27.5 | 2.6 | 30.8 | 3.3 |

Table 8. Impact resistance value in different specimen compositions.

| | A (J/mm$^2$) | STDEV | B (J/mm$^2$) | STDEV | C (J/mm$^2$) | STDEV | D (J/mm$^2$) | STDEV | E (J/mm$^2$) | STDEV |
|---|---|---|---|---|---|---|---|---|---|---|
| Mg | 0.57 | 0.04 | 0.56 | 0.02 | 0.48 | 0.05 | 0.43 | 0.03 | 0.26 | 0.02 |
| Cu | 0.57 | 0.04 | 0.60 | 0.05 | 0.63 | 0.02 | 0.66 | 0.03 | 0.71 | 0.03 |
| Zn | 0.57 | 0.04 | 0.58 | 0.02 | 0.62 | 0.01 | 0.64 | 0.01 | 0.70 | 0.03 |

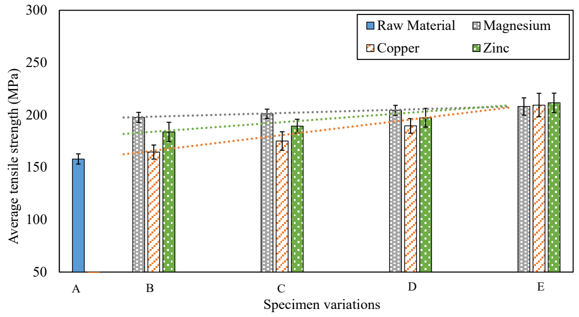


Figure 9. Comparison of tensile strength at different specimen compositions.

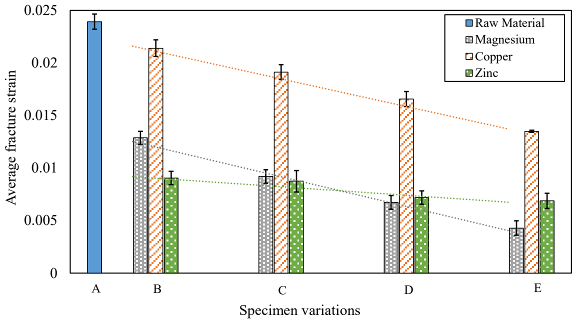
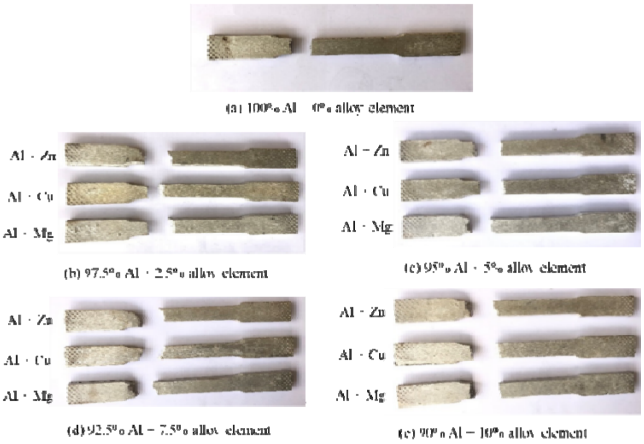


Figure 10. The result of fracture strain results in different specimen compositions.

The test results showed the macro photograph of the surface fracture of the specimen that could be seen directly using visual observation in Figure 11. The middle part of the length of span of the specimen was the part that received constant stress and receives loading. The part will experience strain and eventually break during the tensile test. Similar fracture phenomena were seen in all specimen variations.



(a) 100% Al – 0% alloy element

(b) 97.5% Al + 2.5% alloy element

(c) 95% Al + 5% alloy element

(d) 92.5% Al – 7.5% alloy element

(e) 90% Al – 10% alloy element

Figure 11. Tensile test specimen fracture under different specimen compositions

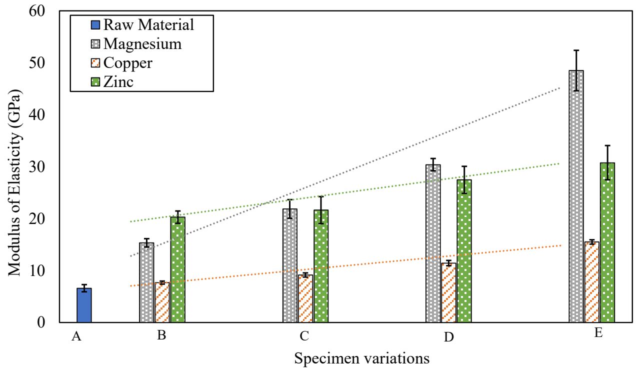
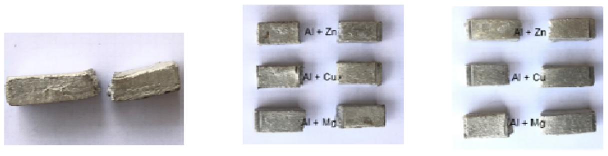


Figure 12. Elasticity modulus in different specimen compositions.

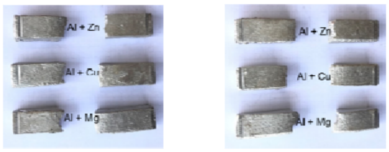
Modulus of elasticity was used to measure a material's resistance to elastic deformation when a force was applied to the specimen. The modulus of elasticity of a specimen was defined as the slope of the stress–strain curve in the elastic deformation region. Table 7 and Figure 12 shows the modulus of elasticity value obtained by statistical standard deviation analysis did not experience high deviations. It can be found that adding the alloy materials can increase the modulus of elasticity. The higher the additional percentage of alloy material, the higher the modulus of elasticity. The result shows that the addition of magnesium alloy experienced the highest increase percentage compared to copper and zinc. In contrast, the addition of copper has the lowest elastic modulus increase. In further analysis, adding magnesium increased the value by about 96-560%, with the highest value at specimen E (90% Al and 10% Mg) with a value of 48.5 GPa. Moreover, adding zinc and copper increased the value by about 207-369% and 16-134%.

### 3.3 *Result of Charpy impact test*

In this case, the impact strength was used to measure the material's capability to withstand a suddenly applied load and was expressed in terms of energy. Impact testing aimed to determine the brittle nature of the test specimen against impact load. Impact testing requires energy to break the specimen with one hit using a hammer with a specific weight that is dropped by releasing it from a certain angle. The addition of alloy materials strongly influenced the impact strength value in the developed aluminium alloy materials. Figure 13 compares the specimen fracture due to the impact test. From the result, the specimen damage showed a brittle fracture pattern in the middle of the specimen.



(a) 100% Al + 0% alloy element (b) 97.5% Al – 2.5% alloy element (c) 95% Al – 5% alloy element



(d) 92.5% Al 7.5% alloy element (e) 90% Al + 10% alloy element

Figure 13. Specimen fracture due to impact test in different specimen combinations.

Based on Table 8, the impact test results obtained by statistical analysis of standard deviations do not experience high variations. The result in Figure 14 showed that adding copper and zinc has increased the impact resistance, while adding magnesium has a decreasing trend. The addition of zinc increased the impact resistance by about 1-22%, with the highest value can be found in specimen E with 90% Al and 10% Zn with a value of 0.7 J/mm². The same phenomenon was experienced with the addition of copper with the value increased up to 5-24%. In contrast, the addition of magnesium decreased to 1-54%, with the lowest value at specimen E with 90% Al and 10% Mg. The impact resistance decreased with the addition of magnesium, making the alloy more brittle [19]. The impact resistance value decreased in the results, with the most significant value at 1% Mg and the lowest at 7% Mg. As magnesium was added to the alloy, the porosity increased. Magnesium increased the strength and hardness of the alloys, especially in the casting method. It is accompanied by a decrease in impact resistance [31]. The previous study [32] shows that numerous design or casting geometry parameters can influence mechanical characteristics. The resulting alloy's mechanical qualities result in improved sand casting strength. However, this behaviour may change with age while increasing yield strength and porosity.

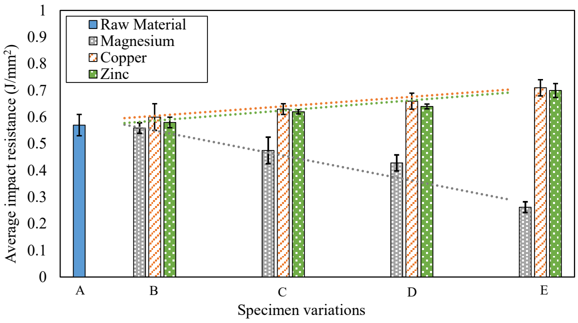


Figure 14. Result of impact resistance in different specimen combinations.

## 4 CONCLUSION

Several chemical composition and mechanical tests have been conducted to investigate the effect of alloy addition such as magnesium, copper, and zinc on the mechanical behaviour of the aluminium alloy. The casting method developed a total of five specimens with 0-10% alloy addition.

According to the findings, adding alloy material in the range of 0-10% resulted in different alloy element contents. The highest alloy additions can be found in Specimen E due to adding 10% alloy element, which contained 2.039% Mg, 2.174% Cu, and 0.921% Zn. As shown, the highest percentage increase can be found in the addition of magnesium. Moreover, aluminium casting with magnesium, copper, and zinc additions influenced the mechanical properties of the aluminium alloy. Tensile strength values improved by adding alloy components such as zinc, copper, and magnesium. The higher the alloy content, the greater the material's tensile strength and modulus of elasticity. It has been discovered that the addition of magnesium improved tensile strength performance over the addition of copper and zinc. In contrast, the result of the impact test showed the addition of zinc and copper increased the impact strength. However, the addition of magnesium decreased because magnesium made the alloy brittle.

Studying the effects of these alloying additives to aluminum waste casting may be used in shipbuilding to choose and create aluminum alloys with the appropriate qualities. These alloys improve corrosion resistance, strength, and weldability in ship components such hulls, superstructures, decks, and others. The insights may also optimize shipbuilding materials and procedures for performance, lifespan, and cost effectiveness.

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