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Effect of Zinc (Zn) Addition on Impact and Hardness Properties of Aluminum (Al) Scrap

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Abstract: The aim of this study is to investigate the effect of zinc (Zn) material added to used aluminum (Al), which should affect its strength and hardness. In this current study, zinc material (Zn) was applied as an additional material to aluminum scrap, by mass percentages of Al 100% Zn 0%, Al 95% Zn 5%, Al 94.5% Zn 5.5%, and Al 94% Zn 6%, respectively. The results showed that the addition of zinc (Zn) had indeed affected the impact value and hardness properties of aluminum-zinc alloy (Al-Zn). The addition of zinc (Zn) at 6% yielded the highest effective strength value of 0.24 J/mm^2, and the lowest effective strength value of 0.14 J/mm^2. Although the highest hardness value was found by addition of 6% zinc (Zn), the average hardness was 73.76 HRB and the lowest hardness was 29.23 HRB. In conclusion, as the addition of Zinc (Zn) into the material composition increases, the impact and toughness properties of the material increases.

Keywords: Aluminum (Al), zinc (Zn), impact, hardness, mechanical properties.

1. Introduction

Aluminum, the most common alternative metal element in the country, did not become a profitable competitor in the machine industry until the late 19th century. The existence of important artificial developments whose material properties matched the unique proportions of aluminum and its alloys contributed greatly to product growth and the use of this new metal.

Aluminum is readily available, affordable, and non-ferrous, thus extensively used in foundry processes. Pure aluminum has poor mechanical properties; therefore, it is necessary to add other alloying rudiments to ameliorate its mechanical properties [1]. Used aluminum is everywhere around us, such as beverage scrap, cans, auto parts, airplanes, trains, and household furniture. Wasted or unused aluminum is reusable, thus various experiments have been carried out to find solutions for the reutilization of aluminum [2].

Aluminum has several types, namely aluminum ingots, aluminum billets, and aluminum alloys. Pure aluminum ingot used to make aluminum alloy (mixture), usually has purity of 99.70% to 99.90%. Recycled aluminum, usually finalised into the shape of metal bars, will have content mixture of aluminum scrap, cans, or others. Ingot are cast shapes produced with a cross-section to ease consequent fabrication processing such as rolling, extrusion, and forging. About 100 years ago, the industry began to use ingot-casting techniques commonly employed for the well-established steel and copper industries [3]. Over time, the heat treatment process was modified by changing the melting temperature to obtain desirable mechanical properties. Casting is a manufacturing process in which molten metal is poured into a casting pattern to produce objects resembling the original product [4]. Casting method is either by metal mould casting and sand casting. Metal mould casting is done using readily made metal mould, and the cavity is made according to the product to be produced. Comparatively, sand casting needs to be shaped according to the product it should produce.

In this study, beach casting process was applied to shape aluminum scrap mixed with zinc, which is commonly used to make propeller, nuts, rings, simple parts, etc. Zinc (Zn) is a bluish-white, shiny, and diamagnetic metal. However, highly marketable zinc lacks luster. Zinc is slightly thicker than iron and has a hexagonal demitasse structure. The metal is hard but brittle at maximum temperatures; nonetheless, malleable at 100-150ºC. Compared to other metals, the melting point of zinc is quite low, at 420ºC, and its boiling point is 900º C. The main function of zinc is for galvanization, to prevent corrosion [5, 6]. This metal can form alloys with aluminum. The melting point of aluminum is 660.3º C. The purpose of this work is to obtain the mechanical properties of aluminum (Al) and zinc (Zn) alloy. The process of melting was done in a shed often used to make traditional boat propellers from scrap aluminum for "ketek ship" in Palembang, Indonesia.

2. Methods

This study was conducted to determine the mechanical properties after adding zinc (Zn) to scrap aluminum (Al) as the base material for the production of propellers. Processes included material assemblies, test sample fabrication, hardness testing, and impact testing.

2.1 Materials

In this study, the materials used for the fabrication was aluminum waste or also known as aluminum scrap. The aluminum scrap is a commonly found waste, which is recyclable and should be recycled. Figure 1(a) shows scrap aluminum to be processed into aluminum ingots. Scrap aluminum waste is often used for the manufacture of ship propellers in small cottage industries. The process started by melting the aluminum with addition of zinc, and finally transformed into aluminum alloy ingots. Figure 1(b) shows aluminum ingots that have been melted into aluminum bars leftover from smelting recyclable propeller manufacturing materials. Figure 1(c) shows an aluminum alloy material in the form of zinc (Zn) ingot.

2.1.1 Sample preparation

Five test specimens as ASTM E18 were prepared for each four variations. The samples were set to be having 38 mm of diameter and 15 mm of thickness [7]. For the impact test, three test specimens as ASTM E23 for each four variations. The samples were set to be having 55 mm of length, 10 mm of width, and 10 mm of thickness. Figure 2 illustrate the size for both hardness and impact test.

Figure 1. (a) *Scrap aluminum waste,* ***(b)*** *Scrap aluminum that has been processed into aluminum ingots,* ***(c)*** *Zinc ingot.*

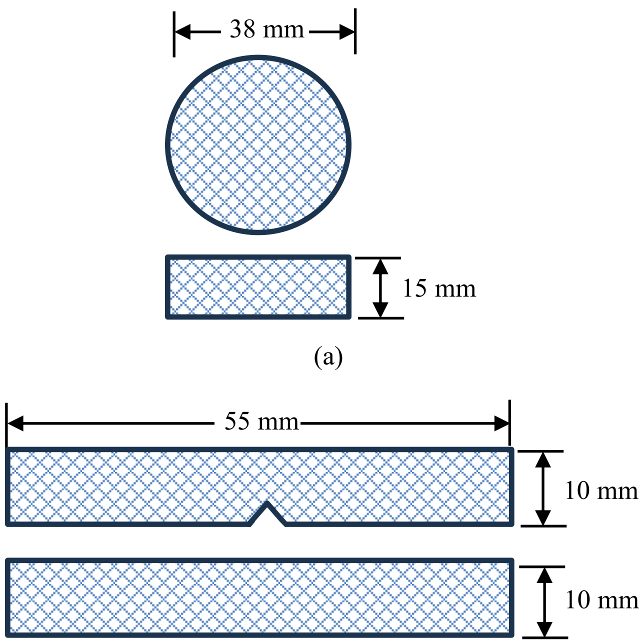

Figure 2. (a) *Sample geometry for hardness test,* ***(b)*** *Sample geometry for impact test.*

2.2 Mechanical Test

There are two mechanical tests were carried out which are hardness test and impact test to obtain the mechanical properties of the materials.

2.2.1 Hardness Test

Hardness test were carried out using Rockwell method where a 1/16" steel ball indenter was used. Rockwell scale B was employed in this material test, because in the first hardness testing, it was found that the material was soft, which was below B100. As for the C scale, it is used to test materials with high hardness, using diamond cone indenter.

Figure 3. *Rockwell hardness test machine*

Figure 3 shows Rockwell hardness test being performed by pressing the surface of the sample with an indenter. The Rockwell hardness test is the most commonly used hardness test because it is simple, quick, does not require a microscope to measure marks, and is relatively non-destructive.

2.2.2 Impact Test

Next, impact test was performed to determine the impact resistance and also another method to obtain the hardness properties of the material.

To obtain the impact result, the specimen will receive a sudden shock load from a pendulum. In this test, a rectangular test rod was used, in compliance with ASTM E23 test standard with the Charpy method. The Charpy method is used to determine material properties based on how many nerves are required to break a test bar with a single blow [7].

To perform the impact test, the batting pendulum was raised to a certain height and were then released. It will swing freely, to hit the test rod until it breaks. The difference between the initial energy and the final energy is the energy used to break a test object. The Charpy method were chosen to perform the impact test, where the test specimen was placed horizontally, with the test standard as the initial angle parameter [8, 9].

Figure 4. *Impact test machine*

Figure 4 shows a pendulum used to pound the test specimens and two scale arc needles that serve as angular displacement instructions [10, 11]. The impact energy and impact force required to break the test specimen can be calculated using equations (1) and (2), where W_c is the impact energy, mp is the mass of the pendulum, g is the gravity of the Earth, L_p is the length of the arm, α_o is the starting angle of the pendulum, α_r is the end angle of the pendulum, acu is the impact strength, b is the width of the test specimen, and h is the thickness of test specimen [12].

$$W_c = m_p.g.L_p(cos\alpha_r - cos\alpha_o) \tag{1}$$

$$a_c u = \frac{W_c}{b.h} \tag{2}$$

3. Result and Discussions

3.1 Hardness Test

Material selection for critical applications, such as machining and structures, relies significantly on mechanical properties such as hardness and impact strength. The hardness test was performed by pressing five different points on the specimen surface to obtain specific comparison on the surface hardness of the specimens. Figure 5 shows the samples after being tested under Rockwell hardness test.

Figure 5. *Rockwell hardness testing speciment*

Table 1. Hardness test results.

Materials	P (Kg)	Hardness value (HRB)					Average (HRB)
		1	2	3	4	5	
Al 100% + Zn 0%	100	30.6	30.2	34.9	28.6	22.2	29.3
Al 95% + Zn 5%	100	51.7	65.4	62.2	44.6	23.0	49.38
Al 94.5% + Zn 5.5%	100	72	62.8	70.0	68.9	70.5	68.84
Al 94% + Zn 6%	100	70.9	71.8	76.1	77.6	72.4	73.76

The hardness test result for four (4) samples with different composition is presented in Table 1. Based on the Table 1, the sample variations were differentiated by different percentages of zinc (Zn) and aluminum (Al) content and five (5) different pressure points on each test specimens. The different results were due to the fact that the pressure points tested were different on each specimen surface. The hardness value obtained for Al 100% + Zn 0%, Al 95% + Zn 5%, Al 94.5% + Zn 5.5%, and Al 94% + Zn 6% was 29.3 HRB, 49.38 HRB, 68.84 HRB, and 73.76 HRB, respectively.

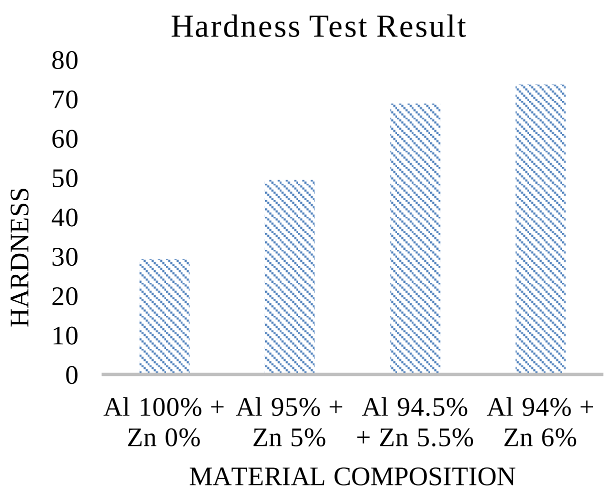

Figure 6. Graph of the relationship between hardness value and alloy composition.

Figure 6 shows the graph of comparison between the highest hardness test values with the lowest hardness test values, where materials with 0% Zinc (Zn) have the lowest hardness level compared to aluminum casts with the addition of Zinc (Zn) of 5%, 5.5%, and 6%. Based on the Figure 6, the hardness test results shows that specimen containing 100% Al 0% Zn had the lowest hardness value of 29.3 HRB followed by Al 95% + Zn 5% (49.38 HRB), Al 94.5% + Zn 5.5% (68.84 HRB), and the material with highest hardness was Al 94% + Zn 6% (73.76 HRB).

It can be seen that the value of the hardness increases when the amount of the Zinc (Zn) added into the Aluminum (Al) increases.

3.2 Impact Test

The impact result from the impact test was discussed in this section. Figure 7 shows the specimens that had been tested under impact test. As shown in the figure, fractures were proved in the tested specimens. The fibrous fracture can witnessed, characterized by a dimple-shaped fracture surface that has an opaque appearance.

Figure 7. Impact test specimens.

Table 2. Impact Test Results.

Test materials	Charpy Test Specimens	Impact Energy (W_c)	Width (b)	Thickness (h)	Impact Toughness ($a_c u$)	Impact Toughness Average ($a_c u$)
Al 100% + Zn 0%	1	11.2	10	8	0.14	0.14
	2	10.34			0.12	
	3	15.3			0.18	
Al 95% + Zn 5%	1	13.31	10	8	0.16	0.15
	2	14.2			0.17	
	3	11.43			0.14	
Al 94.5% + Zn 5.5%	1	17.8	10	8	0.22	0.20
	2	15.29			0.19	
	3	16.32			0.20	
Al 94% + Zn 6%	1	19.9	10	8	0.24	0.24
	2	21.3			0.26	
	3	19.39			0.24	

The results of impact test for four (4) samples with different composition of zinc (Zn) and aluminum (Al) were summarized in Table 2. Based on the Table 2, the impact toughness (a_cu) for Al 100% + Zn 0%, Al 95% + Zn 5%, Al 94.5% + Zn 5.5%, and Al 94% + Zn 6% was 0.14 J/mm^2, 0.15 J/mm^2, 0.20 J/mm^2, and 0.24 J/mm^2, respectively.

The results obtained were different from each other due to the vibrational phenomenon of the atoms in the material at different temperatures. With higher vibration, the dislocation movement will be relatively difficult; hence, greater energy is needed to break the test object. Conversely, at temperatures below zero degrees Celsius, the atomic vibrations are relatively small; therefore, when the material is deformed, the movement of dislocation becomes very easy and the specimen will be more breakable with relatively low energy.

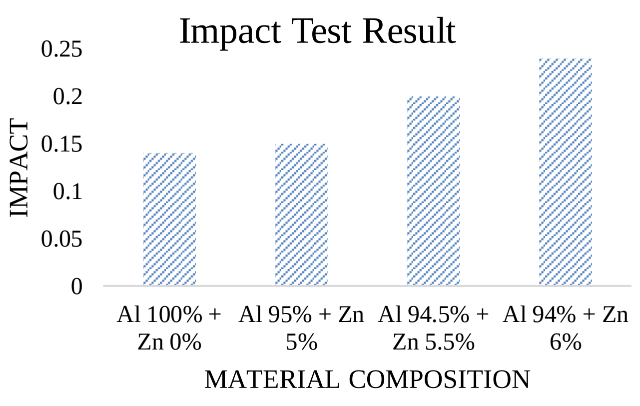

Figure 8. Graph the relationship between impact strength and alloy composition.

Figure 8 shows the average impact value from the Charpy method test. The highest impact value was obtained from specimen containing 6% Zinc (Zn) with value of 0.24 J/mm^2 while the lowest impact value was pure Aluminum (Al) with value of 0.14 J/mm^2. The second and third impact value was Al 95% + Zn 5% and Al 94.5% + Zn 5.5%, respectively. Based on the Figure 7, the impact toughness value increases when the amount of the Zinc (Zn) added into the Aluminum (Al) increases. It is believed that composite material will enhance the mechanical properties of the materials due to the bonding created [13]. Moreover, other than composite material, treatment of material also influences the mechanical properties of the material as proved from previous research [14, 15].

4. Conclusion

It is concluded that the addition of Zinc (Zn) in Aluminum (Al) shows an increment in both hardness and impact toughness value. The more addition of zinc (Zn) leads to higher hardness level of aluminum-zinc alloy (Al-Zn). In this study, the highest hardness value was obtained by specimen added with 6% zinc, with a hardness value of 73.76 HRB. In addition, more addition of zinc (Zn) leads higher level of impact toughness of aluminum-zinc alloy (Al-Zn). In this test, the highest impact toughness value was obtained by specimen added with 6% zinc, with an impact value of 0.24 J/mm^2. The results obtained shows that material composition influence the mechanical properties of materials. The more composition contained in the used material, the more impact it will have.

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