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Analysis of Mechanical Properties of Recycled Aluminum Piston Castings

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ABSTRACT

The use of aluminum is increasing in the industrial sector, which is accompanied by an increase in aluminum waste if it is not handled quickly and appropriately, which will have a negative impact on the environment. Recycling is an alternative to overcome this problem. Recycling piston waste into pistons, data was obtained that there are insoluble aluminum elements, namely Cu, Fe, Si. The aim of this research is to determine the effect of recycling aluminum into pistons by tensile and impact testing with the addition of Cu 0.5%-1.5% & Fe 1%-1.5% with various tensile test speeds of 5mm/minute, 10mm/minute, and 15mm/min. The research uses independent variables, namely the addition of Cu & Fe to aluminum waste and the dependent variable is tensile strength testing and specific impact strength. The results of this research can determine how much Fe and Cu content is added in order to reach the standard piston content, increasing the hardness of aluminum without reducing the hardness and ductility too much, which is known from the strength values of recycled aluminum pistons through specific tensile and impact tests with average stress values. The highest was in Cu 1% - 1.5% & Fe 1% - 1.5% alloy with a tensile testing speed of 11 mm/minute of 196.19 MP, while the lowest stress value was obtained from Copper (Cu) 1% - 1.5 % & Iron (Fe) 0.5%-1% with a tensile testing speed of 8 mm/minute of 120.72 N/m2. The largest impact energy for aluminum piston specimens was obtained at 0.294 J in 1% - 1.5% Copper (Cu) and 1% - 1.5% Iron (Fe) alloys.

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INTRODUCTION

One of the metals that is most abundant in the earth's crust is aluminum. Aluminum is in third place after oxygen and silicon. Aluminum is widely used for structural components, transportation vehicles, food product packaging. and the aerospace industry (Susiana & Habibi, 2021). Aluminum can also be found in several motorbike spare parts, such as rims and pistons (Nugroho et al., 2022). The more vehicle uses increases, the greater the need for these vehicles to be repaired. One of the parts made of aluminum in vehicles, especially motorbikes, is the piston. The piston or piston is an important component in a motorized vehicle. functions as a cross-section tool to withstand pressure during the compression stroke and power stroke. The piston or piston works after an explosion occurs in the combustion chamber (Abdillah, 2010). The piston works continuously as long as the engine is running. On the piston, thermal and mechanical loads work (Solechan, 2010). The piston's resistance to thermal and mechanical loads limits the power of a combustion engine (Budiyanto et al., 2018). Pistons are made from aluminum alloy with a dominant composition of aluminum and silicon. The piston works with the piston handlebar (connecting rod) in an up and down movement of the cranksaft (Nurhadi, 2010). The piston is made from aluminum because the piston must be light, strong and resistant to high temperatures. The alloy used is usually with a eutectic composition, namely one with a silicon content of between 10-13%. Therefore, aluminum as a raw material for components is often obtained in the form of alloys with elements such as Cu, Zn, Si, Mg, Sn, and so on so that they can increase their mechanical strength (Nofri, 2019).

The increasing use of aluminum will produce aluminum waste which, if not handled quickly and appropriately, will have an increasingly bad impact on the environment. One solution that can be provided is by recycling. Recycling is an alternative for dealing with aluminum (Al) waste, overcoming the scarcity of raw materials and as an effort to save natural resources (Hadi et al., 2020). From an economic perspective, the utilization and processing of aluminum waste has much cheaper costs and can reduce energy consumption because it only requires 5% energy compared to bauxite primary aluminum production (Wong & Lavoie, 2019). If recycling of aluminum waste is carried out, the results can be used for household purposes or for making technical materials. In previous research, from recycling waste pistons into pistons, data was obtained that there were insoluble aluminum elements, namely Cu, Fe, Si. This is because previous research used LPG oxygas which could only reach a temperature of 750°. The smelting must be carried out using oxyacetylene gas to reach the melting point of the elements Cu and Fe. The smelting process is carried out through casting activities. Casting is carried out by filling the mold cavity with casting material that has been melted or melted at a certain temperature (Darianto, 2015). In this mold the liquid metal will freeze and shrink. The casting results can be used directly as final products, but most of them still require further processes such as cutting, joining, turning, or physical treatment or other finishing processes (Wisnujati & Sepriansyah, 2018a).

Based on the background above in the case of a large amount of motorbike piston waste resulting from motorbike damage, it is necessary to recycle it into products other than pistons after testing their strength, including tensile strength and impact strength, therefore this research aims to determine the effect of recycling aluminum into pistons. with tensile and punch testing with the addition of Cu 0.5%-1.5% and Fe 1%-1.5% with various tensile test speeds of 5 mm/minute, 10mm/minute and 15mm/minute.

METHOD

This type of research uses quantitative or experimental research. Researchers analyzed and presented facts from experimental trials with free parameters, namely the addition of Cu of 1% and 1.5% and Fe of 0.5% and 1.5% in aluminum waste processing. The data collection methods used include observation and experimentation. The data obtained is in the form of tensile test stress results on 27 tensile test specimens and impact energy on 12 specimens.

The research steps carried out are (1) starting with the preparation of tools and materials to be used. (2) The next process is setting the test parameters with punch testing and tensile testing. Research using aluminum waste. Testing was carried out with replication 3 times. The number of specimen samples from each parameter variation was 27 tensile test specimens and 12 punch test specimens. (3) Tensile and impact tests were carried out on the 16 specimen samples using a Tensile Test Machine and a Charpy punch test machine. The testing process uses a tensile test tool using the ASTM E8 standard as seen in Figure 1 and Figure 2 for the ASTM23 standard for impact testing.

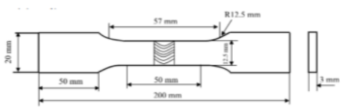

Figure 1. Tensile test specimen. Source: (ASTM E8)

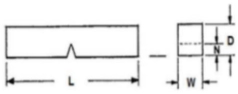

Figure 2. Strike test specimen. Source: (ASTM E23)

RESULTS AND DISCUSSION

Tensile Test Results

Tensile testing is useful for finding out how long a specimen can survive after being pulled. The specimens used in this experiment had variations of copper (Cu) of 0.5%, 1% and 1.5%. As well as iron (Fe) 0.5%, 1% and 1.5%. Tensile testing was carried out with tensile testing speeds of 8 mm/minute, 10 mm/minute and 15 mm/minute. Tensile testing generally produces two strength parameters, namely tensile strength and yield strength (Purnawan et al., 2016). Next, tensile testing of the specimens was carried out at the POLINEMA Materials Laboratory and the results of the specimens for tensile strength testing were obtained in Figure 3 as follows:

Figure 3. Specimen for tensile test.

Tensile testing with a brittle fracture type can be done by calculating the stress by dividing the load (kg) by the cross-sectional area (mm^2) via the following equation.

$$\sigma = \frac{F}{A} \tag{1}$$

Information: σ = stress (N/m^2), F = load (N), and A = cross-sectional area of the specimen (m^2). For a circular cross section, $A=\frac{1}{4}\pi d^2$. Next, the specimens were tested for tensile strength and the tensile test results were obtained according to Table 1 as follows.

Table 1. Tensile Strength Testing

No.	Alloy in Aluminum	Tensile Testing Speed	Replication	Voltage (MPa)	Average (MPa)
1	Copper (With) 1% - 1.5% Iron (Fe) 0.5%-1%	5 mm/min	1	124.15	125.45
			2	120.72	
			3	131.48	
		8mm/min	1	143.69	142.99
			2	148.29	
			3	136.98	
		11 mm/min	1	144.02	148.12
			2	148.66	
			3	151.68	
2	Copper (With) 0.5%-1% Iron (Fe) 1% - 1.5%	5mm/min	1	153.98	141.06
			2	133.37	
			3	135.83	
		8 mm/min	1	178.48	165.89
			2	147.86	
			3	171.31	
		11 mm/min	1	180.33	178.37
			2	186.27	
			3	168.51	
3	Copper (With) 1% - 1.5% Iron (Fe) 1% - 1.5%	5mm/min	1	164.85	168.67
			2	171.44	
			3	169.71	
		8 mm/min	1	152.74	168.22
			2	175.96	
			3	175.96	
		11 mm/min	1	193.21	190.70
			2	196.19	
			3	182.69	

In an aluminum alloy with 1% - 1.5% Copper (Cu) and 0.5% - 1% Iron (Fe) with a varying tensile testing speed of 5 mm/minute, an average stress of 125.45 MPa, 8 mm/minute was obtained. The average stress was obtained at 142.99 MPa and at 11 mm/minute the average stress was obtained at 148.12 MPa. In an aluminum alloy with 0.5% - 1% Copper (Cu) and 1% - 1.5% Iron (Fe) with a varying tensile testing speed of 5 mm/minute, an average stress of 141.06 MPa, 8 mm/minute was obtained. The average stress was obtained at 165.89 MPa and at 11 mm/minute the average stress was 178.37 MPa. In an aluminum alloy with Copper (Cu) 1% - 1.5% and Iron (Fe) 1% - 1.5% with a varying tensile testing speed of 5 mm/minute, an average stress of 168.67 MPa, 8 mm/minute was obtained. The average stress was obtained at 190.70 MPa and at 11 mm/minute the average stress was 168.22 MPa. It can be concluded that the increasing percentage of Cu and Fe alloy added to aluminum piston castings will result in a greater tensile test stress and the increasing tensile test speed given to aluminum piston castings will also result in an increasing tensile stress. The greatest stress value was obtained from an alloy of copper (Cu) 1% - 1.5% and iron (Fe) 1% - 1.5% with a tensile testing speed of 11 mm/minute of 196.19 MPa.

Next, there is a Factorial Plot graph of the effect of the interaction between speed and the addition of Cu and Fe on the tensile test stress in Figure 4 below. It can be seen that a good tensile speed to obtain good tension is 190.699 MPa, namely 11 mm/minute with an aluminum alloy of 1% - 1.5% copper (Cu) and 1% - 1.5% iron (Fe). The results of the research carried out are also presented in a Factorial plot which illustrates the effect of adding Cu and Fe elements as well as variations in tensile testing speed on the tensile stress. The graph is presented in Figure 5 below.

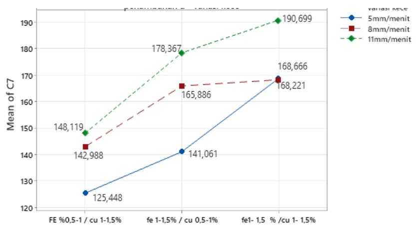

Figure 4. Factorial Plot Graph of the influence of the interaction between speed and alloy addition of Cu and Fe on the magnitude of the tensile test stress.

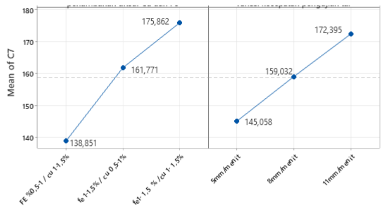

Figure 5. Factorial Plot Graph of the Effect of Adding Cu and Fe Elements and Varying Tensile Testing Speed on Tensile Stress.

From Figure 5 it can be seen that the greater the tensile testing speed given to aluminum alloy, the greater the tensile test stress value will be. The faster the tensile testing speed and the more Cu and Fe elements added to the aluminum alloy, the better the resulting tensile test stress. The relationship between tensile test speed and the percentage of Cu and Fe alloy in aluminum is directly proportional. This is in line with research whose results show that the higher the hardness value, the higher the tensile strength value (Saefuloh et al., 2018). Cu concentration (%) with tensile strength, where the tensile strength of the alloy is directly proportional to its hardness value. Cu concentration will increase the tensile strength of the alloy higher than the tensile strength of the original material (S. Slamet & Suyitno, 2013). Utama (2009) shows that the addition of copper (Cu) can increase the tensile strength of an aluminum-silicon alloy after being treated with dissolution and natural aging. The addition of Cu (1%, 3%, and 5%) will provide an increase in the average tensile strength, namely at 1% Cu the average tensile strength is 176.428 MPa, at 3% Cu the average tensile strength is 203.659 MPa and at the addition of 5% Cu the average tensile strength is 226.64 MPa.

These results are also in line with research results from Adinata et al (2021) that the tensile strength of the material gets better as the rotational speed of the centrifugal casting increases with the highest tensile strength value being at a rotational speed of 1500 rpm, namely 103.569 MPa. The faster the mold rotation, the faster the specimen solidifies and becomes harder, resulting in the tensile strength value also increasing with the results of a rotational speed of 2000 rpm resulting in a tensile strength of 156.88 MPa and at a rotational speed of 2500 rpm a tensile strength of 162.86 MPa is obtained. When the centrifugal casting machine rotates rapidly, the alloy will fill the outermost side first and come into direct contact with the mold, causing the specimen to solidify more quickly (Prakoso et al., 2021). The piston specimen that had been subjected to a tensile test broke, so the specimen indicated that the casting could not be formed or plastically deformed (Wisnujati & Sepriansyah, 2018). Aluminum obtained from an alloy with an Fe content greater than 0.6% affects the tensile strength of the aluminum alloy according to Ji *et al* (2013) (As Ari et al., 2023).

Impact Test Results

The impact test functions to measure the toughness of cast aluminum materials with variations in the addition of Cu and Fe of 0.5%, 1% and 1.5% for impact or shock loading, where the impact test has been standardized by Charpy and Izod. Next, the specimen hitting test was carried out at the POLINEMA Materials Laboratory and the melting results were obtained in Figure 6 as follows:

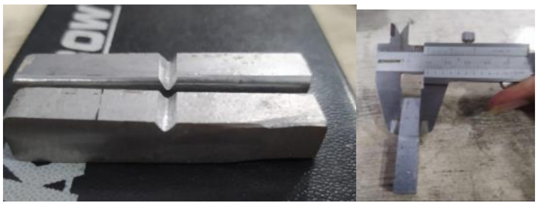

Figure 6. Specimen for punch test.

Next, the specimens were tested for strength using a UTM (Universal Testing Machine) machine and the tensile test results were obtained according to Table 2.

Table 2. Impact Speed Testing

No	Alloy in Aluminum	Replication	Hitting Speed Value (J/mm^2)
1.	Copper (Cu) 0.5% - 1% Iron (Fe) 1% - 1.5%	1	0.178
		2	0.157
		3	0.178
		4	0.210
2.	Copper (Cu) 1% - 1.5% Iron (Fe) 0,5% - 1%	1	0.262
		2	0.241
		3	0.241
		4	0.262
3.	Copper (Cu) 1% -1.5% Iron (Fe) 1% 1.5%	1	0.326
		2	0.379
		3	0.400
		4	0.369

Based on table 2, it can be seen that in aluminum alloys with the elements Copper (Cu) 1% - 1.5% and Iron (Fe) 0.5% - 1% (pure) an average impact energy of 0.178 J is obtained. The second aluminum (mixture A) with the elements Copper (Cu) 0.5% - 1% and Iron (Fe) 1% - 1.5% obtained an average impact energy of 0.231 J. Meanwhile for the third aluminum alloy (Mixture B) with the elements Copper (Cu) 1% - 1.5% and Iron (Fe) 1% - 1.5% obtained an average impact energy of 0.273 J. Based on these results, the largest impact energy was obtained in the third alloy with a percentage of Copper (Cu) 1% - 1.5% and Iron (Fe) 1% - 1.5% and the smallest impact energy is obtained in pure aluminum alloy with a percentage of Copper (Cu) 1% - 1.5% and Iron (Fe) 0.5% - 1%. This can also be observed in Figure 7 containing a graph of the impact values of 12 test specimens with 3 different types of alloys.

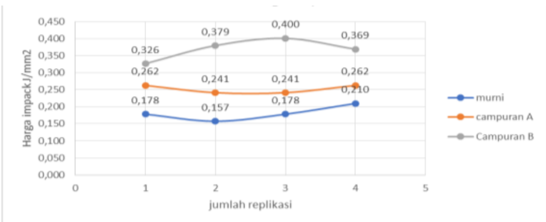

Figure 7. Impact price graph of the specimen.

Based on Figure 7, it is known that pure aluminum alloy (Copper (Cu) 0.5% - 1% and Iron (Fe) 1% - 1.5%) shows an average hitting speed of 0.18075 J. The graph shows that there is a decrease of 0.178 J/mm^2 to 0.152 in replication 2. In replications 3 and 4 it increased to 0.178 J/mm^2 and 0.210 J/mm^2. In the alloy (mix A), namely Copper (Cu) 1% - 1.5% and Iron (Fe) 0.5% - 1%, it shows an average hitting speed of 0.341 J. The graph shows a decrease until replication 3 of 0.262 J/mm^2, 0.241 J/mm^2, and 0.241 J/mm^2, while in replication 4 there was an increase of 0.262 J/mm^2. In the alloy (mixture B), namely Copper (Cu) 1% -1.5% and Iron (Fe) 1% 1.5% shows an average hitting speed of 0.3685 J. The graph shows an increase up to replication 3 of 0.326 J/mm^2, 0.379 J/mm^2 and 0.400

J/mm^2. Based on these results, it can be concluded that the fracture strength value for aluminum specimens can decrease due to several things, including the number of points that produce *void* or vacancies in aluminum which in this study obtained the lowest value in a mixture of pure Cu 0.5% - 1% and Fe 1% - 1.5% of 0.157 J/mm^2 with a number of replications of 2. The presence of a coarse grain arrangement in aluminum recycling causes rapid cracking (Budiyono, 2012). Meanwhile, the highest value of hitting power was obtained from a combination of (Cu) 1% -1.5% and (Fe) 1% 1.5% with replication 3 of 0.400 J/mm^2. The increase in the strike test value can be caused by the presence of evenly distributed dendrites on each side of the aluminum matrix (Budiyono, 2012). Anderson et al (2018) state that the optimal copper (Cu) content to be added to aluminum is 1% wt. A. S. Setiawan (2018) states that the greater the additional percentage of copper (Cu), the impact value will increase as well. The higher the impact value, the fracture of the specimen becomes ductile and vice versa, if the impact value is low the fracture of the specimen becomes brittle.

The amount of impact energy or impact energy (E) of a material shows the amount of energy absorbed by the test object or specimen (E) so that it breaks using the Charpy test method which can be written using the following calculations;

$$E = m \times g \times r(\cos\cos b - \cos\cos a) \quad (2)$$

E = impact energy (Joule).

m =massa pendulum (kg).

g =gravitational acceleration (m/s^2) = 9.8 = 10 m/s^2.

r = pendulum arm length = distance between the swing point and the notch point (m).

cosα = initial angle before the pendulum swings, position of point A.

cosβ = deviation angle after the pendulum hits the specimen, position of point B.

Given: m = 8.3 kg. r = 0.6 meter. g = 9.8 m/s^2.

$\alpha = 120^O$ $\beta = 102^O$

$$E = m \times g \times r(\cos\cos\beta \ - \cos\cos\alpha)$$
$$E = 8.3\,kg \times 9.8\,\frac{m}{s^2} \times 0{,}6\,m\,(\cos\cos 102 \ - \cos\cos 120)$$
$$E = 8.3\,kg \times 9.8\,\frac{m}{s^2} \times 0{,}6\,m\,((-0{,}207) - (-0{,}5))$$
$$E = 8.3\,kg \times 9.8\,\frac{m}{s^2} \times 0{,}6\,m\,(0{,}293)$$
$$E = 14{,}299\,J$$

Based on these calculations, the impact energy obtained is 14.299 Joules at a temperature of 1093^{O}C. Next, to calculate the impact value (HI) from this impact test, it is known by dividing the impact energy or impact energy (E) by the cross-sectional area of the specimen impact area (A). The surface area of the strike test area has dimensions of 10 x 8 mm, so the surface area of the strike area is obtained using the equation: $A = p \times l = 10\,mm \times 8\,mm = 80\,mm^2$. After getting the results of the surface area calculation (A), then calculations are carried out to determine the impact value (HI) of the specimen. To find the impact price, use the following equation.

$$HI = \frac{AND}{A} \quad (3)$$

HI= Impact Value (Joule/mm^2).

E = Energy absorbed (Joules).

A = Cross-sectional area under the notch (mm^2).

Known: E = 14.299 Joules A = 80 mm^2

$$HI = \frac{AND}{A} = \frac{14{,}299\,J}{80mm^2} = 0{,}178\ Kj$$

Based on the impact price calculation, it is known that the impact price obtained is 0.178 kJ.

CONCLUSION

The durability of recycled aluminum pistons based on tensile test results has the highest average stress values obtained for copper (Cu) 1% - 1.5% and iron (Fe) 1% - 1.5% alloys with a tensile testing speed of 11 mm/minute amounted to 196.19 MPa, while the smallest stress value was obtained from Copper (Cu) 1% - 1.5% and Iron (Fe) 0.5% - 1% with a tensile testing speed of 8 mm/minute amounting to 120.72 MPa. The greater the percentage of aluminum alloy and the tensile speed, the greater the tensile stress. The strength of the recycled aluminum piston added with Cu and Fe is quite good based on the impact test results. The largest impact energy was obtained in the third alloy with a percentage of Copper (Cu) 1% - 1.5% and Iron (Fe) 1% - 1.5 % of 0.294 J.

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