Utilization of Sic to Improve the Impact Strength of Aluminum Scrap and Its Microstructure with Sintering Method

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Abstract. This study aims to determine the effect of adding the Silicon Carbide (SiC) to aluminum scrap on impact strength and microstructure using powder metallurgy (sintering) method. The materials used in this research are aluminum scrap and silicon carbide (SiC). There are three variations of the mixture, namely the mold mixture of 0, 10 and 20% SiC, respectively. Heating was carried out for 3 h and a temperature of 500 Co. The tests carried out were impact testing and microstructure observations.

The results showed that the variation of the addition of SiC affects the value of the impact strength of the material. The addition of 20% SiC in this study resulted in the highest impact strength of 13.078 × 10^{-4} J/mm^2. Meanwhile, aluminum scrap without the addition of SiC is 11.98 × 10^{-4} J/mm^2.

Keywords: SiC · Al-scrap · Sintering · Impact Strength

1 Introduction

Please Aluminum (Al) is one of the non-ferrous metals that has several advantages, including having a light specific gravity, corrosion resistance, and good electrical conductivity. The basic nature of pure Al is to have good castability but low mechanical properties [1] and [2].

To improve the mechanical properties of Al metal, the number of studies were carried out by treating the metal or adding other alloys to the main material. Additional materials commonly used include: Al2O3, SiC, TiC, and ZrO2. Among the ceramic types, the hardest is SiC [3–5] and [6].

The compound of SiC is easy to bind and do not cause oxidation of Al metal. Meanwhile, oxide-type ceramic materials, such as Al_2O_3, and ZrO_2 are also relatively hard and strong, but the weakness is that it is difficult to bond with Al metal. In addition, the presence of oxygen (oxide) groups has the potential for oxidation to occur in Al metal composites [7]. Note that the first paragraph of a section or subsection is not indented. The first paragraphs that follows a table, figure, equation etc. does not have an indent, either.

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Indonesia has a large potential for bauxite minerals (source of Al). Meanwhile, SiC ceramics are not directly available in nature. SiC material can be made from a carbothermal mixing process between rice husk ash or silica sand as a Si source and a carbon (C) source from coconut shell charcoal or teak wood powder charcoal, through sintering and milling processes so that SiC nanoparticles can be produced [8].

In designing this composite, one of the most widely used methods is the powder metallurgy method. In this method, the ingredients that make up the alloy are mixed, compacted, and then heated below their melting point [9].

The research that will be carried out is improving the impact toughness and observing the shape of the microstructure of scrap aluminum material. In this case, the researchers tried to add SiC powder to the aluminum scrap obtained from the waste of the shop window production. The addition process is carried out by the sintering method (powder metallurgy) because the two materials are quite complicated when done with the casting process.

2 Method

The tools and materials needed in the research include impact test equipment with the following specifications:

Tool name: Charpy impact test equipment
Brand: RMU
Type: A052M
Capacity: 300 Joule

Tool Name: Grinder-polisher
Type: Digiset-2V
Brand: METKON,

Tool name: Microscope
Type: Inverted
Brand: Union
Capacity: 1000X magnification,

In addition, there are also heating ovens, Hung Ta Instruments, digital scales, sandpaper, and other supporting tools. While the main materials are aluminum scrap (Al-scrap), silicon carbide (SiC), resin and hardener.

2.1 Mold Making

Three square molds were made with the same size, with dimensions of 57 x 55 x 100 mm. The mold material uses an iron plate with a thickness of 8 mm. For the pressing part and the mold wall the thickness is 3 mm (see Fig. 1).

Fig. 1. Molding for specimens.

2.2 Preparation of Materials

The mixed material in this study was Al-scrap with silicon carbide which had been sifted beforehand with a particle size of 200 mesh. The mixture ratio used is based on the mass ratio.

2.3 Mixing Process

Mixing the reinforcing particles with the matrix is done by entering the two ingredi-ents into a container that has been prepared in the form of a bottle and then rotating it until the two ingredients are evenly mixed.

2.4 Pressing Processor

The pressing of the material was carried out with the Hung Ta Instrument machine with a large pressure used of 150 kN.

2.5 Testing

Sintering is heat treatment upon the metals to change the mechanical properties. In the heating process, an oven with a temperature of 500 °C is used with a holding time of 3 h. The mold containing the specimen material is placed in an oven with an initial temperature of 30 °C. Held for 30 min until the temperature is raised at 500 °C, the total heating time is 3.5 h. After the heating time is complete, the mold is removed from the open and cooled with air media until the temperature is in accordance with room temperature.

- The process of removing the specimen from the mold.
  In this section, because the mold walls are swollen due to pressure, it will be difficult to remove the specimen normally, therefore removing must be done by splitting the mold.
- The process of forming the specimen in accordance with the test standards.
  In this section, researchers make cuts from materials that have been made according to each testing standard.

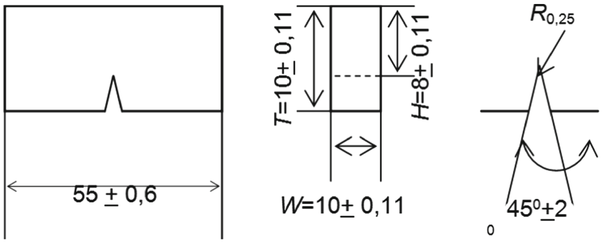

Fig. 2. Shape and size of specimen for impact test.

- Testing of specimens.
  Specimen testing is carried out by adjusting the respective test equipment used.
- Data collection and discussion.
  The data obtained from the test results are discussed and adjusted to the theoretical basis.

2.6 Testing

Impact Test. Impact testing was carried out with a Charpy impact test apparatus with the standard ASTM E23 specimen. The Charpy method uses a sample with a length of 55 mm, a width of 10 mm and a height of 10 mm with a notch 2 mm deep with an angle of 45o. For more details can be seen in Fig. 2.

Microstructure Test. In this observation, researchers used pieces of impact testing that were cut and mounted with resin mountings. Mounting size is adjusted to the needs to facilitate the polishing process.

After the mounting is complete, the specimen is polished with sandpaper 400, 800, 1200, 2000 and ending with 5000. To further smooth the surface to be tested, the surface is rubbed with a velvet cloth with the addition of sufficient autosol.

Data Analysis. To be able to see the effect of the variation of SiC on the strength of Aluminum, in this study, the data were analyzed using one-way ANOVA. But first, the hypothesis from the research is determined, namely.

- H0:$\mu 1 = \mu 2 = \mu 3$; There is no effect of the addition of SiC on the addition of aluminum strength.
- H1: $1 \neq \mu 2 \neq \mu 3$; There is an effect of adding SiC to the addition of aluminum strength.

The next step is to determine the value of F_{count} and F_{table}. Where after F_{table} is known, then F_{count} and F_{table} are then compared. If $F_{\text{count}} > \text{F}_{\text{table}}$, then there is a different average value between each variation. Or in other words, there is an effect of treatment variations on the value resulting from an experiment. On the other hand, if $F_{\text{count}} < F_{\text{Table}}$, then there is no effect of treatment variation on the resulting value.

Table 1. Impact test results data.

SiC (%)	*W* (mm)	*T* (mm)	*H* (mm)	α (°)	*β* (°)
0	10.05	10.10	8.10	15	13.5
	10.10	10.05	8.05		13.5
	10.00	09.95	7.95		13.7
10	10.10	10.10	8.05	15	13.4
	10.00	10.05	8.10		13.5
	09.95	09.95	7.90		13.6
20	10.00	10.05	8.10	15	13.4
	10.10	10.10	8.00		13.4
	09.90	10.05	8.05		13.5

3 Results and Discussion

Below are the results of the impact testing that has been carried out with the ASTM E23 standard specimen and the V-shaped notch. The energy absorbed (E) by the material is obtained by using Eq. (1):

$$E = m.g.L(\cos\ \beta - \cos\ \alpha) \tag{1}$$

where:

α = Initial angle of arm.

β = End angle of arm.

Pendulum mass (m) = 20 kg, arm length (L) = 0.8 m obtained from the impact testing machine used and the earth's gravity (g) = 9.8m/s^2. By knowing E and the cross-sectional area of the notch (A) it can be seen the value of the impact strength E_i of the material (see Table 1) by using Eq. (2):

$$E_i = E/A \tag{2}$$

Calculation of data without the addition of SiC.

Calculation result for specimen 1:

$$\begin{aligned} E &= m.g.L(\cos\ \beta\ -\ \cos\ \alpha) \\ &= 20\ \times 9.8 \times\ 0.8(\cos 13,5 - \cos 15) \\ &= 1.010 \text{ Joule} \end{aligned}$$

$$\begin{aligned} A &= LH \\ &= 10.05 \times 8.1 \\ &= 81.41\ \text{mm}^2 \end{aligned} \tag{3}$$

Table 2. Average impact toughness.

SiC (%)	A (mm^2)	E (J)	E_i x10^{-3} (J/mm^2)	$E_{i\ average}$ x 10^{-3} (J/mm^2)
0	81.41	1.010	12.40	11.98
	81.31	1.010	11.24	
	79.50	0.882	11.11	
10	81.31	1.074	13.21	12.03
	81.00	1.010	12.47	
	78.61	0.946	12.03	
20	81.00	1.074	13.26	13.08
	80.80	1.074	13.29	
	79.70	1.010	39.22	

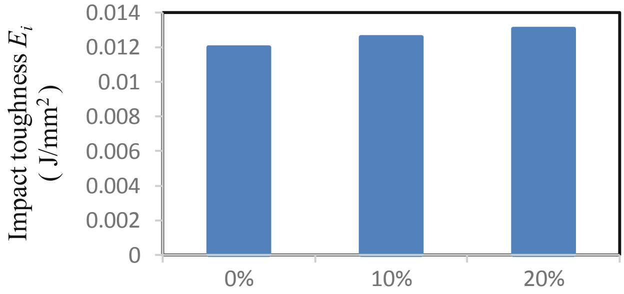

Fig. 3. The average Ei value of the impact test results.

$$E_i = E/A$$
$$= (1.010)/(81.41) = 12.41 \times 10 - 4\ \text{J/mm}^2$$

Furthermore, by using the same data processing method, the calculation results for each specimen are shown in Table 2.

The relationship between E_i and the percentage of SiC mixture from the tests that have been carried out is shown in Fig. 3.

It can be seen that the lowest E_i was obtained at 0% SiC addition of 11.98 x 10–4 J/mm^2 and the highest was obtained at 20% SiC addition of 13.08 × 10–4 J/mm^2. Thus, the addition of 20% SiC gives an increase in E_i of 9.24%. The impact energy of this material is relatively low, this is due to the condensation process and the less-than-optimal sintering temperature.

Fig. 4. Fracture of 0% SiC.

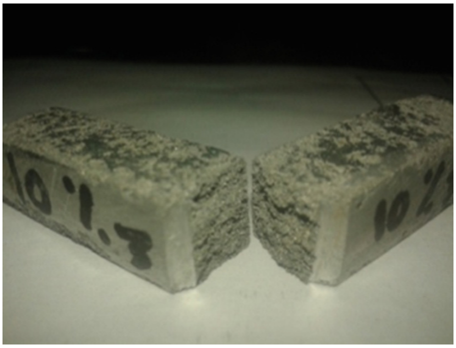

Fig. 5. Fracture of 10% SiC.

Fig. 6. Fracture of 20% SiC.

3.1 Failure Shape

From the observation of the fracture shape of each mixed variation, namely in Fig. 4, 5 and 6. It can be seen that the fracture shape becomes more ductile as the percentage of SiC increases.

3.2 Analysis Using ANOVA

In this study, the hypotheses used are (see Table 3).

- H0: μ1 = μ2 = μ3; There is no effect of the addition of SiC on the addition of aluminum strength.
- H0: 1 2 μ3; There is an effect of the addition of SiC on the addition of aluminum strength.

Note: X1: 0% SiC, X2: 10% SiC, X3: 20% SiC.
N = 9, k = 3.
Total Squared Sum (TSS)

$$TSS = \sum_{i=1}^{k}\sum_{j=1}^{n} X_{ij} - \frac{T^2}{N}$$
$$= 0,00142 - \frac{0,112889}{9} = 0,0000039$$

.
Number of Squares of Columns (NSC)

$$NSC = \sum_{i=1}^{k} \frac{T_k^2}{N_k} - \frac{T^2}{N}$$
$$= 0,001418 - \frac{0,112889}{9} = 0,0000018$$

Total Squared Error (TSE)

$$TSE = TSS - NSC$$
$$= 0,0000039 - 0,0000018 = 0,0000021$$

Center Square of Column (CEC)

$$CEC = \frac{NSC}{k-1} = \frac{0,0000018}{3-1}$$
$$= 0,0000009$$

Center Square Error (CSE)

$$CSE = \frac{TSS}{N-k} = \frac{0,0000039}{9-3}$$
$$= 0,0000004$$

Table 3. Variations in addition of SiC to Aluminum.

Repetition	$X_1.10^{-3}$	$X_2.10^{-3}$	$X_3.10^{-3}$	Total
1	12.41	13.21	13.26	
2	12.43	12.48	13.29	
3	11.09	12.04	12.68	
Total	35.93	37.73	39.23	0.11289
Repetition	$X_1{}^2.10^{-5}$	$X_2{}^2.10^{-5}$	$X_3{}^2.10^{-5}$	Total
1	15.40	17.50	17.60	
2	15.44	15.60	17.70	
3	12.30	14.50	16.10	
Total	43.15	47.50	51.30	0.00142

#F_{hitung}

$$F_{hitung} = \frac{CEC}{CSE} = \frac{0,0000009}{0,0000004}$$
$$= 2,58$$

#F_{tabel}

$$df_1 = k - 1 = 3 - 1 = 2$$
$$df_2 = N - k = 9 - 3 = 6$$

By using the degree of confidence α = 0.05, then the resulting F_{table} is = 5.14. Because $F_{\text{count}} < F_{\text{table}}$, then H0 is accepted, which means there is no significant effect between each variation of the experiment.

3.3 Microstructure

Observations on the microstructure of the test material was using a metallurgical microscope with 1000x magnification.

Compared to Fig. 7, it can be seen that in Fig. 8 the Al-scrap powder granules began to decrease because 10% SiC was added to this specimen. With the reduction of the Al-scrap powder grains the bonds of the powders begin to form which gives an increase in the impact energy.

In Fig. 9 the bond between the powder particles begins to form well in this specimen there is a content of 20% SiC.

The results of the observation of the microstructure can be seen that the percentage of SiC addition helps the binding process of adjacent powder particles. This is because the material from SiC is a material that has good thermal properties.

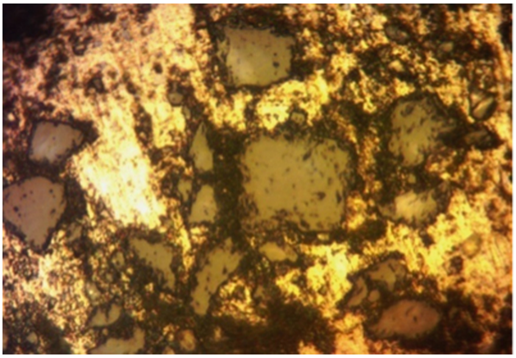

Fig. 7. Sample with 0% SiC at 1000X magnification.

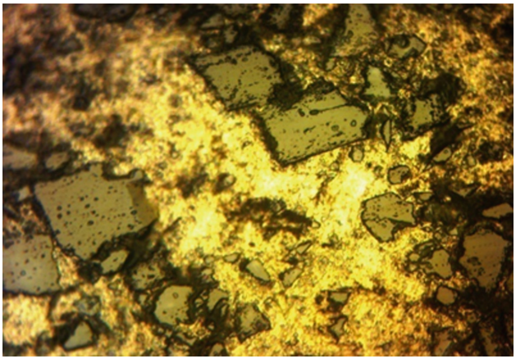

Fig. 8. Sample with 10% SiC at 1000X magnification.

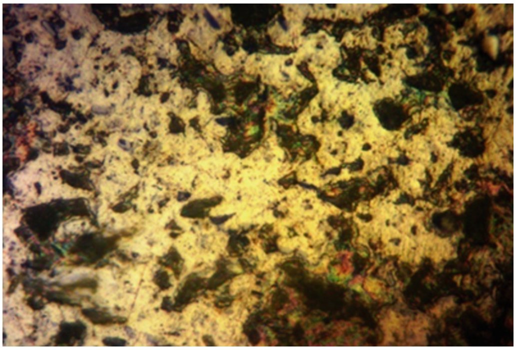

Fig. 9. Sample with 20% SiC at 1000X magnification.

4 Conclusions

Based on the results of the research that has been done, the following conclusions can be drawn:

The addition of silicon carbide (SiC) to aluminum scrap (Al-scrap) can affect the impact toughness. The highest value of impact strength (Ei) is found in the variation of the addition of 20% SiC with an Ei value of 13.08 x 10–4 J/mm^2.

From the observation of the microstructure, at a low SiC percentage (below 20%) there are still un-crystallized Al-scrap powder particles which result in incomplete bonding of the powder to the specimen. Therefore, the value of impact strength is also low.

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