

# RECYCLING OF ALUMINUM-BASED COMPOSITES REINFORCED WITH FLY ASH AND ALUMINA VIA A STIR-SQUEEZE CASTING PROCESS

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## ABSTRACT

The stir-squeeze casting technique generally alters a material's physical and mechanical properties. This research investigates the effect of adding fly ash and alumina to the stir-squeeze casting of old aluminum cans. The stir-squeeze casting research parameters were carried out at a pouring temperature of 750°C with a stirring speed of 350 rpm for 3 minutes, with pressure variations ranging from 6 MPa, 8 MPa, and 10 MPa to fabricate Aluminum Matrix Composites (AMC) with an alumina weight fraction of 15% and fly ash of 12%. Aluminum Matrix Composites are metal matrix composites that use alumina and fly ash as reinforcing components. AMC development has also shown promise, owing to good mechanical qualities such as high hardness, impact strength, and relatively easy-to-find basic materials. On composites, X-Ray Fluorescence (XRF) testing or chemical composition testing, X-Ray Diffraction (XRD), impact strength Brinell hardness, and Scanning Electron Microscope (SEM) was performed; the test results obtained the highest value of the highest hardness at the bottom, and on composites were obtained at a pressure of 6 MPa at 1.577 gr/cm<sup>3</sup> and 0.577 percent, the highest impact value at

Keywords: Stir Squeeze Casting, Aluminum, Fly Ash, Alumina, Recycle

## 1 INTRODUCTION

The environment is currently facing a severe problem with organic and inorganic waste. Recycling is one approach to dealing with current waste. Recycling is turning waste materials into new ones to avoid creating garbage dumps that can pollute the environment continuously [1]. Various materials can be recycled, including drink cans, plastic, paper, glass, etc.

Recycling unwanted materials is not unusual in today's world of knowledge and technology, with composite recycling as an example. A composite is made up of different kinds of materials. Composites are made to combine the best qualities of their constituent parts. For instance, Aluminum Matrix Composite (AMC) has undergone extensive development. The automotive, aviation, building, food, and other industries use AMC extensively [2].

Aluminum, including beverage cans, is widely used in the food and automotive industries. Aluminum is thought to be more cost-effective, lightweight, resistant to extremes of temperature,

and non-toxic. However, consuming many canned drinks can result in many wasted cans. Therefore, these cans can be recycled into new materials to lessen the impact of garbage accumulation.

Fly ash is produced when coal is burned in a steam power plant. Hazardous waste includes fly ash. The production of fly ash may rise as there are more steam power plant developments operating as power plants. Fly ash waste will pollute the environment if it is not correctly used [3].

The stir casting method is frequently used in the production of composite materials. Because it is more affordable and convenient to use, the stirring way is more profitable. Reinforcing particle size, temperature, stirring time, and stirring speed are variables in the stir casting process. The wettability is made more wettable through mechanical stirring. While mixing in semi-solid conditions requires being reheated to reach the pouring temperature, which is intended to aid in the union between the matrix and the thickening agent, stirring in perfect liquid

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conditions causes the reinforcing particles to float on the surface of the matrix [4].

Stir casting is a casting technique that combines a pure metal (in this case, aluminum) with a reinforcing element. First, the pure metal is melted, and once it has cooled, it is continuously stirred until a vortex forms. Next, the reinforcing element (powder) is gradually incorporated through the edges of the vortex.

There are several drawbacks to adding particles while stirring, including the fact that the material will agglomerate in some areas due to the particles. The viscosity of the molten metal alloy will rise as a result. In addition, free air will enter the system as air pockets between the particles due to the accumulation of particles through the top.

The outcomes of the cast products will be better with the stir casting process. The defects caused by trapped air in the cast product can be reduced because it enables air bubbles trapped in the molten metal during the casting process to rise to the surface of the molten metal.

Squeeze Casting combines the benefits of casting and forging by applying pressure during freezing. Squeeze casting can enhance materials' mechanical and physical characteristics, particularly those with aluminum base alloys. Castings with properties akin to those of forging can be made by squeeze casting on aluminum base alloys [5].

In the casting process known as squeeze casting, molten metal is solidified between a mold and a closed hydraulic plate at high pressure. The benefits of casting and forging are essentially combined in this process [6].

This research aims to fabricate and characterize aluminum composites-based waste beverage cans reinforced with fly ash and alumina through the stir-squeeze casting method. It also seeks to analyze the impact of variations in compaction pressure on physical, mechanical, and chemical properties.

## 2 METHODOLOGY

Beverages aluminum can is heated to its melting point temperature of 700°C during the casting process. The dross of the molten aluminum is removed when it melts at a temperature of 750°C. Reinforcement powder (fly ash and alumina) is preheated at 350°C and added immediately to the crucible. The stirring was run at a 350 rpm speed for 3 minutes, then poured into the mould once it

had reached the appropriate stir time. A jack with pressure variations of 6, 8, or 10 MPa, compaction pressure is applied after the composite liquid is poured into the mould. Figure 1 depicts the typical piston and mould used. Table 1 shows the sample weight fraction and squeezes pressure.

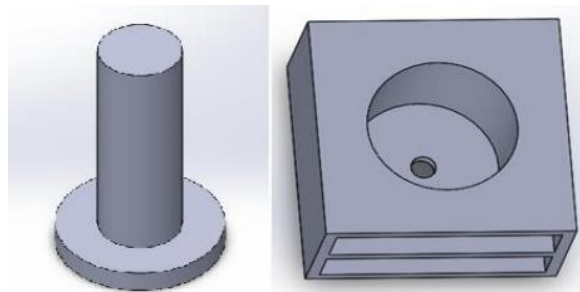


Figure 1 Piston and mould for squeeze casting

Table 1. Sample weight fraction and squeeze pressure

No.	Name	Weight fraction			Squeeze Pressure (MPa)
		Raw (%)	Fly Ash (%)	Alumina (%)	
1	Al-1	100	0	0	6
2	Al-2	100	0	0	8
3	Al-3	100	0	0	10
4	Al-FA-Al <sub>2</sub> O <sub>3</sub> -1	73	12	15	6
5	Al-FA-Al <sub>2</sub> O <sub>3</sub> -2	73	12	15	8
6	Al-FA-Al <sub>2</sub> O <sub>3</sub> -3	73	12	15	10

The Brinell Hardness Testing Machine is used to measure hardness. As seen in Figure 2, with a total of 15 points for each test specimen, 3 points were located at each 5 mm, 10 mm, 15 mm, 20 mm, and 25 mm from the top of the sample.

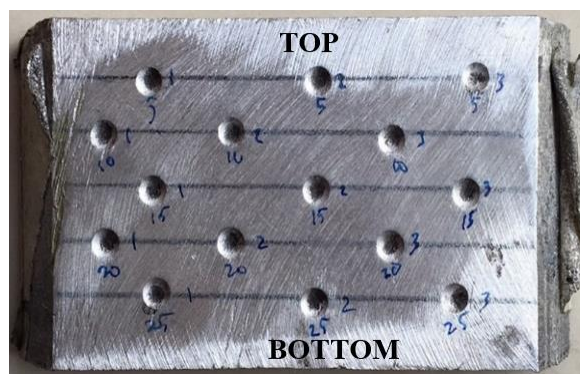


Figure 2 Hardness test point to sample height

The JIS Z 2202 standard is referred to as the Charpy impact test in this study. In addition, there are provisions for each specimen's dimensions, which are 55 mm long, 10 mm broad, and 10 mm thick. Nine specimens were used, each with three different compositions and pressure variations of 6 MPa, 8 MPa, and 10 MPa.

The PMI Niton Analyzer XL2 test apparatus is used to analyze the XRF chemical composition of aluminum composite casting. X-Ray Diffraction (XRD) analysis uses the Rigaku MiniFlex 600 equipment and the TESCAN VEGA3-EDS. Test machine for SEM evaluation.

### 3 RESULTS AND DISCUSSIONS

The XRF of Al-2 and Al-FA-Al<sub>2</sub>O<sub>3</sub>-2 can be seen in Table 2. It is demonstrated that the Al-2 raw sample consists of aluminum Al-Cu alloy with an Al 88.59 percent and Cu 5.66 percent composition. Further revealed that the composite sample of Al-FA-Al<sub>2</sub>O<sub>3</sub>-2 consisted of 95.51.1 percent Aluminum and 1.31 percent Zn.

Table 2 Chemical composition analysis

No.	Element	Sample	
		Al-2 (%)	Al-FA-Al <sub>2</sub> O <sub>3</sub> -2 (%)
1	Aluminum ( Al )	88.59	95.51
2.	Mangan ( Mn )	0.821	0.64
3.	Iron ( Fe )	1.54	1.10
4.	Copper ( Cu )	5.66	1.27
5.	Zinc ( Zn )	2.89	1.31
6.	Lead ( Pb )	0.309	0.11

The existence of alumina, which also includes aluminum, is assumed to be responsible for the increase in aluminum concentration. The chemical composition data revealed a few impurities during the casting process, resulting in the formation of various chemical compositions. In the chemical composition test, the percentage of aluminum in the aluminum composite increased compared to pure aluminum's composition.

The increase in aluminum composition from pure aluminum to aluminum composites is assumed to be impacted by alumina, which also contains aluminum composition, increasing the percentage of aluminum in aluminum composites. In addition, the presence of copper and lead components is also induced by the casting furnace, which is utilized not only for aluminum melting but also for other elements such as copper casting.

In Figure 3, the XRD results of the sample demonstrate that an aluminum phase owns each peak. The peaks intensities and 2-theta are 1865, 70, 62, 7033, 334 and 38,789, 40,483, 42.65, 44,958, and 78.62, respectively. No other 2-theta values were observed. However, there are six peaks in the XRD powder test findings for sample

Al-FA-Al<sub>2</sub>O<sub>3</sub>-2 (Figure 4) with four peaks of aluminum phase at 2-theta respectively, 38,479, 44,687, 65,035, and 78,186, and two other phase peaks at 2-theta 41.90 and 82.35 with intensities 61 and 231.

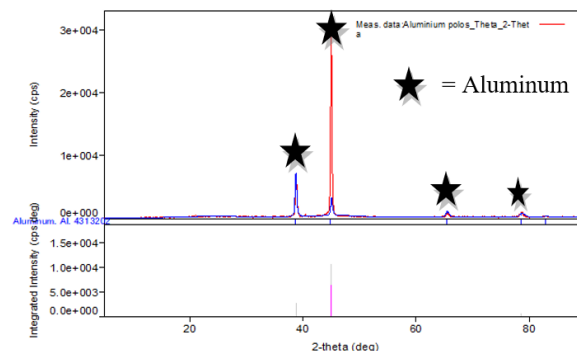


Figure 3 XRD result of Al-2 raw sample

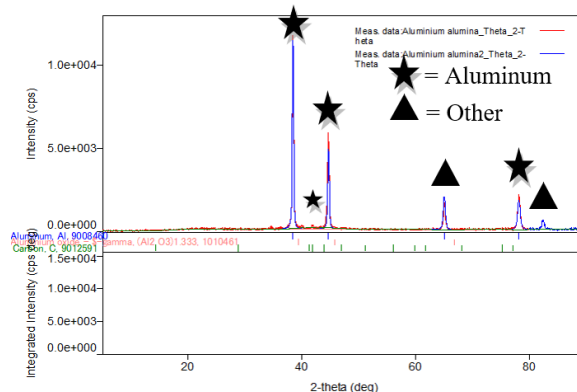


Figure 4 XRD result of Al-FA-Al<sub>2</sub>O<sub>3</sub>-2 sample

The impact test findings are used to measure the ductility or brittleness of the casting material. The energy of impact raw material composites is shown in Figure 5 Al-2 raw sample has the most significant average impact strength value of 17.421, and Al-FA-Al<sub>2</sub>O<sub>3</sub>-1 has a moderate impact strength value of 14.771 J.

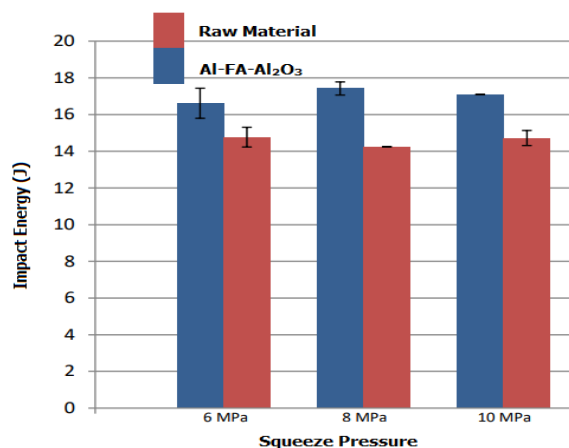


Figure 5 Impact test result

According to the impact energy results presented, the impact strength value decreases with adding alumina and fly ash, indicating that the aluminum matrix bond with alumina and fly ash as reinforcement is limited. It is consistent with the previous report [1] when alumina and silicon carbide are used as reinforcement in aluminum matrix composite materials. The impact value decreases, most likely due to imperfections in the smelting and casting processes, where silicon carbide particles or fly ash are challenging to mix with aluminum and alumina.

Figure 5 shows a decrease in the value of the hardness distribution of raw samples compared to the hardness distribution of composites. The hardness value decreases due to a failure of the link between the matrix and the reinforcing element.

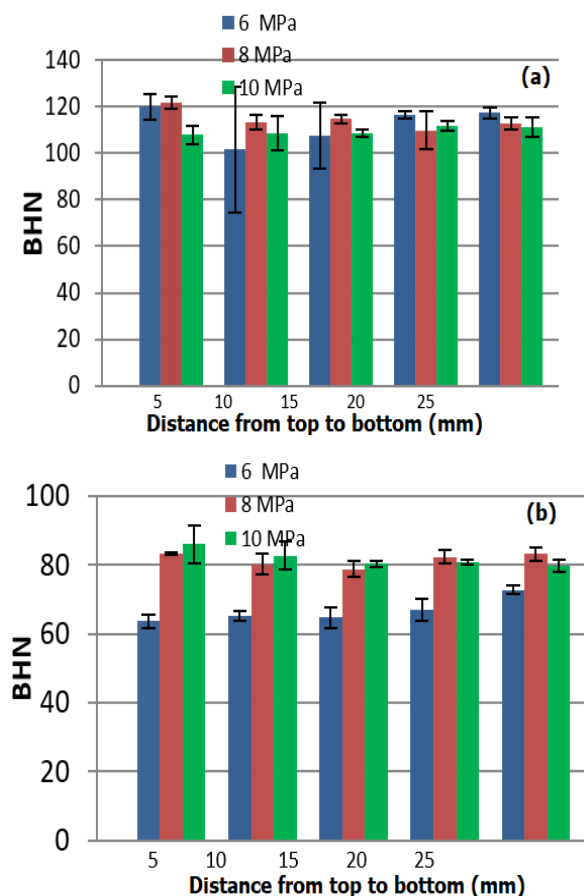


Figure 5 The hardness of test results from: (a) raw; and (b) composite samples

Another possible explanation for the inconsistency in hardness distribution values with the addition of fly ash and alumina powder is that

there is still air trapped in the casting material that is not eliminated during the squeezing process.

According to Ramnath's [7] research, the maximum hardness of the material was measured at 52.80 BHN, while Bharathi's [8] research found that the material had a hardness of 60.28 BHN. The current study demonstrates that increasing the compaction pressure of a casting product can increase its hardness to 85.954 BHN, which is obtained in the Al-FA-Al<sub>2</sub>O<sub>3</sub>-3.

SEM observation was performed on both raw and composite impact samples. The SEM test samples are labelled with Al-3, Al-FA-Al<sub>2</sub>O<sub>3</sub>-1, and Al-FA-Al<sub>2</sub>O<sub>3</sub>-3. The findings of SEM testing at low magnification are shown in Figures 6a-c. The SEM test results at low magnification are general appearances that indicate the results of the fractures that occur in the impact test so that it can detect what type of fault develops. There is also a gap between aluminum, alumina, and fly ash. It can also be seen that the type of fault that occurs is generally a malleable type of fracture because of the number of dimples or concave surfaces on the fault surface or, in other words, the presence of residual material that is left behind is attracted to the grains. It is considered to occur due to temperature differences during the freezing process, which causes some of the material to freeze faster, and no unification between the matrix and other reinforcement occurs. The fissures are said to have occurred due to the high temperature.

Figure 7 showing porosity caused by local melting at the grain boundaries because the mould temperature parameter is not included in this test. Low squeezing pressure can also increase porosity, which depicts a loosely packed arrangement of grains. Figures 7a and b show the grain arrangement seems denser, indicating that the occurrence of porosity is smaller than the sample with SEM code Al-FA-Al<sub>2</sub>O<sub>3</sub>-1. As a result, it is possible to conclude that increasing the squeeze pressure reduces the quantity of porosity. Figures 7 also show that the sort of fault that occurs is a transgranular fault. A transgranular fault is a fracture defined by cracks impacting the grains rather than cracks splitting along the grain line (intergranular) [9]. This argument is bolstered by leftover material (debris) on the aluminum grains.

Reinforcements of the matrix are mainly in the centre of the image and aluminum molecules at the edges, indicating uneven distribution. Poor



stirring during sample manufacturing causes uneven matrix and reinforcement distribution. The specimen has ductile fractures and surface shearing.

Figure 6 Low magnification SEM observation of a) Al-3, b) Al-FA-Al<sub>2</sub>O<sub>3</sub>-1, and c) Al-FA-Al<sub>2</sub>O<sub>3</sub>-3

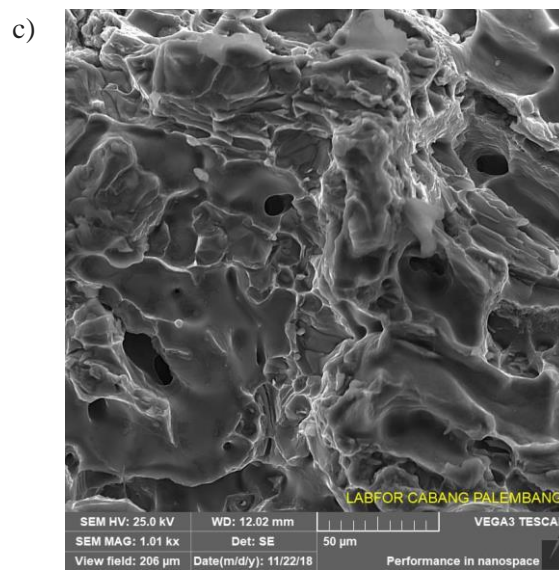
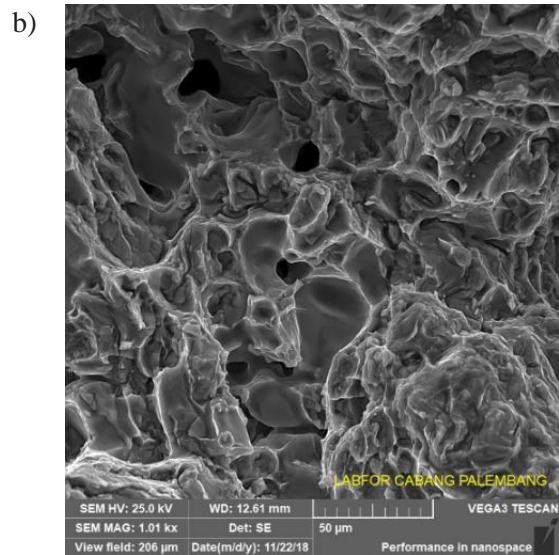
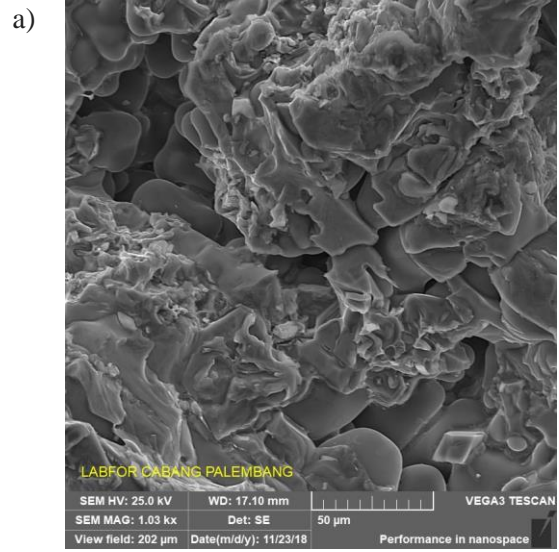
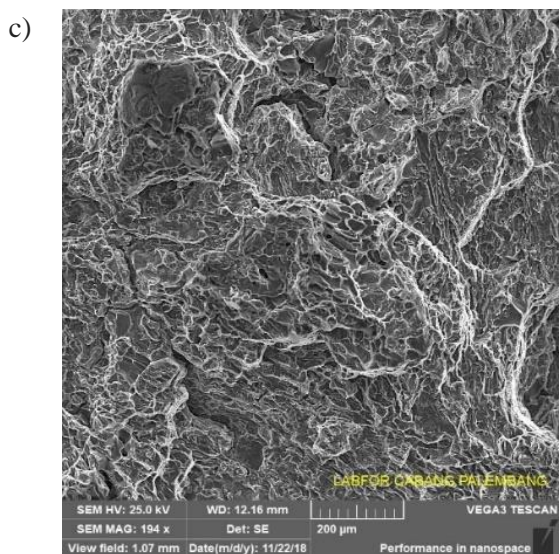
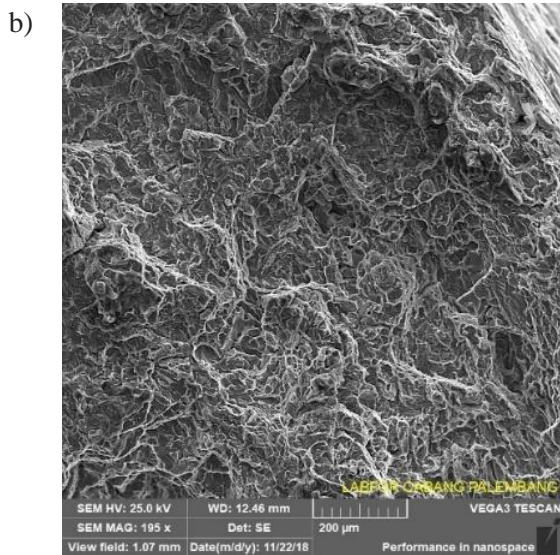
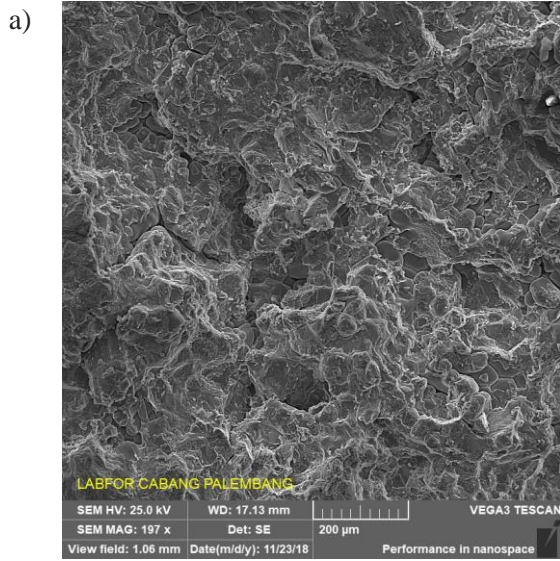


Figure 7 High magnification SEM observation of a) Al-3, b) Al-FA-Al<sub>2</sub>O<sub>3</sub>-1, and c) Al-FA-Al<sub>2</sub>O<sub>3</sub>-3

#### 4 CONCLUSIONS

The following conclusions can be derived from the findings of this study:

1. The fabrication of the usage of canned beverage waste was completed successfully by employing the stir-squeeze casting method and making a new aluminum composite while knowing the physical, chemical, and mechanical properties of the composite.
2. While the stir-squeeze casting method successfully increased the hardness and impact strength of pure aluminum, the pressure variation parameters used in this study were still relatively small to increase the hardness and impact energy of aluminum composites with a mixture of fly ash and alumina.
3. The scanning electron microscope (SEM) test results show that applying more pressure during the stir-squeeze casting process resulted in a denser grain arrangement.

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