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To cite this article: Wahyono Suprpto 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **494** 012085

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# Effect recycled aluminium structures of metallurgical and melt efficiency

Wahyono Suprpto <sup>1\*</sup>

<sup>1</sup> Department of Mechanical Engineering, Universitas Brawijaya, Indonesia

\*Corresponding author; wahyos@ub.ac.id

**Abstract:** Generally, an expired structure aluminum is recycled into raw materials for the next casting process or component products. Slag and aluminum left in the ladle caused low melting efficiency. Microstructure formed in the castings components solidification process is often used to control mechanical properties and the castings fabrication. The purpose of this study is to improve structure aluminum recycling process quality. This recycling study used structure aluminum raw materials with recycling levels variations in the 1st, 2nd, 3rd, and 4th. In the first recycling, the structure aluminum pieces as melting raw materials weighing 2 kg were put in the induction furnace for melting. Let the aluminum pieces melted in the furnace and the temperature continued to rise to 700°C. Next, separated and took the floating slag on top of liquid aluminum, lifted the ladle from the furnace and poured the aluminum in the ingot mold from the permanent mold. After the ingots in the mold were being frozen and cooled, removed the ingots from the mold to be weighed and tested for microstructure. In the second recycling, the melted raw material was the first recycling ingot with the same procedure. In the third recycle, the melted raw material was the second recycling ingot with the same procedure; and the third recycling, the raw material that was melted was the third recycling ingot with the same procedure. Then the slag and ingot was weighed, and microstructure photos from the ingots were taken. From the microstructural photographs results, a calculation process can be performed to determine the grain size of each specimen. For smelting efficiency testing results at each recycling stages respectively 1st, 2nd, 3rd, and 4th were 76.23%, 82.64%, 85.17%, and 89.55%. The largest microstructure diameter at the first recycling for the surface part was 42,512  $\mu\text{m}$  and the center was 43,314  $\mu\text{m}$ . The smallest grain diameter of the 3rd recycling for the surface part was 42,164  $\mu\text{m}$  and the center was 42,346  $\mu\text{m}$ .

Keywords: structure aluminum, recycling, smelting efficiency, ingots, fabrication.

## 1. Introduction

Competitive product manufacturing processes, safe to produce and use, and environmentally friendly are modern industry main requirements. Metal Casting is one of the prospective manufacturing processes for the mass product of automotive and machinery components. The main advantages of Metal Casting is able to produce goods similar to the finished product (net shape) or near the net shape, using raw materials (ingots) and producing ingots from scrap metals so that pollution is



controlled. And the recycling process produces secondary aluminum to save lower melting energy than Bayer and Hall-Heroult process of which produces aluminum primary.

Castings product (cylinder blocks, pistons, permanent molds) generally produce segmental microstructure which can increase thermal resistance therefore distortion can be controlled. Graphite particles in compact graphite iron with a random and elongated orientation, but shorter, and thicker than other cast iron. Adding, these particles' end rounded, up to spheroidal nodules, the specificity of spheroidal graphite iron. The final properties of these casting materials depend on the alloy physical chemistry. Manasijevic (2013) declare, aluminum piston alloys are a special group of industrial aluminum alloys that have good mechanical properties at elevated temperatures (approximately up to 400 °C).

The Mg-5Al micro structure consists of primary Mg particles, separate Mg<sub>17</sub>Al<sub>12</sub> particles and segmental Mg<sub>17</sub>Al<sub>12</sub> deposits, all located at the grain boundary. Generally the addition of strontium improves as-cast microstructure, especially in the second phase. The coarse divorced eutectic phase turns into fine round particles and the distribution is more uniform than the Mg-5Al alloy. The spherical phase in the Mg-5Al-0.1Sr alloy contains small particles in it which act as nucleation sites for the Mg<sub>17</sub>Al<sub>12</sub> phase. The Mg<sub>17</sub>Al<sub>12</sub> phase core contains significant strontium, which indicates that strontium dissolves into the particles.

The effect of Sr and the liquid metal resistance time to improve Mg-Al alloy grain combined with commercial Al-10Sr parent alloys are still need further discussion. In addition, the practice performed on Al-Sr alloys for aluminum alloys modification and improvemnet, a high solubility level f can be obtained for the Al<sub>4</sub>Sr phase which is better in Al-Sr parent alloys, so the modification efficiency increases.

Al<sub>4</sub>Sr phase smoothing can be achieved by deformation, solid solidification, or heat treatment. Until now, the Al-Sr parent alloy type was used to improve magnesium alloy Al-Sr alloys which are untreated. Effect observation of rolling, heat treatment, and remelting for Mg-Al alloy grains smoothing is rarely to be performed. So, it is necessary to do a research on the effect of Sr and molten metal holding time on the magnesium grains smoothing of untreated AZ31 alloy. In addition, the effect of Al-10Sr alloys dissolution, rolling and remelting on refined magnesium AZ31 grains.

Microstructure observation with the help of magnifying devices, such as lopes and optical microscopes. Microscope with sufficient magnification can be seen in its composition and can be determined photographically. By observing microstructure, it is very important to study castings crystallography so that they can know their physical and mechanical properties. This article explains the efforts to increase aluminum casting productivity by adding excess or reducing weaknesses in the metal casting types and their methods.

## 2. Research Methodology

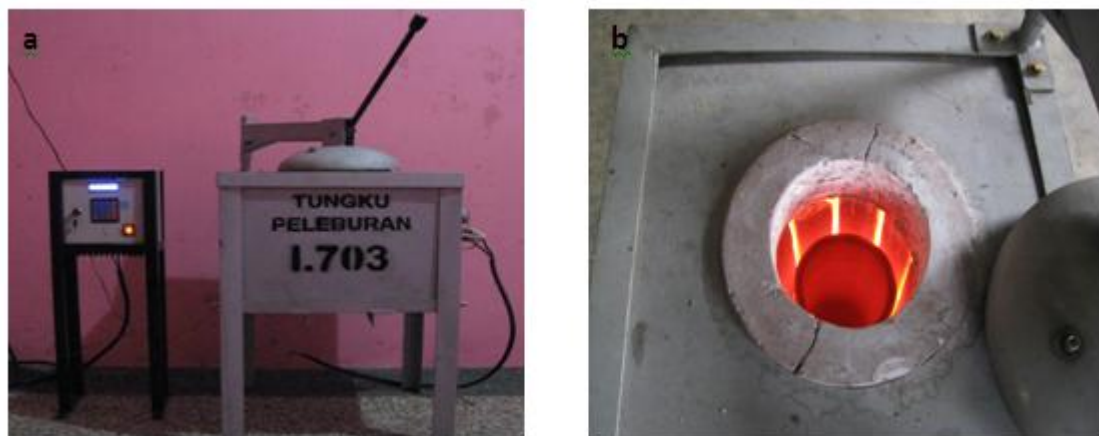
This study used aluminum structure materials, based on the optical emission spectrometry (OES) test of the two raw materials chemical elements as in Table 1. Structure aluminum was cleaned of impurities and followed-up, then the aluminum was cut and weighed 150 - 250 g.

**Table 1.** Spark spectrometry Research Materials testing results

Material	Elements [%]						
Aluminum Scrap (Raw material)	Cu	Mn	Si	Mg	Zn	Fe	Zr
	0.105	0.15	0.558	9.912	0.215	0.409	0.001
	Ti	Cr	Ni	Pb	Sn	Cd	Al
	-	0.112	0.005	0.009	0.055	0.015	Rem

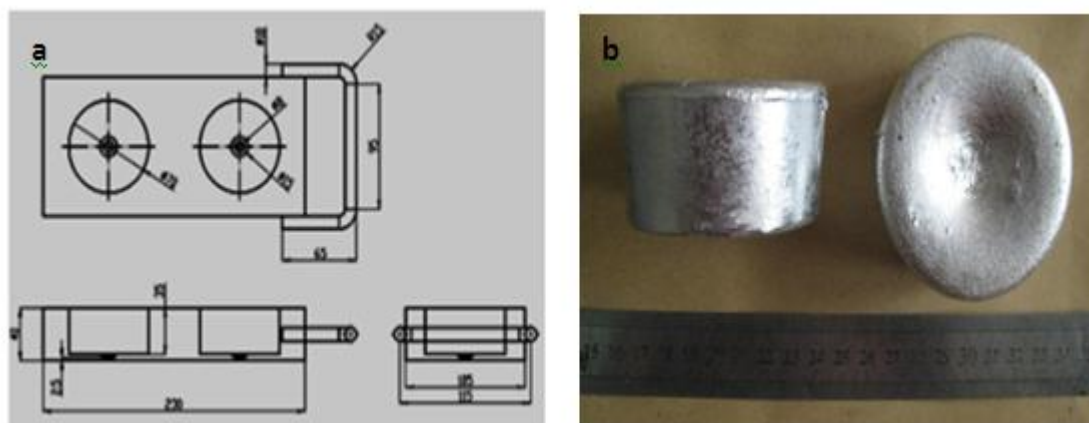
The melting of aluminum structure pieces in this study used electrical induction furnace (EIF) as in Fig. 1. The smelting operation was started with heating ladle up to 450°C and preheated

aluminum pieces at 250 °C were put in the ladle. At EIF temperatures reaching 600°C, aluminum in the ladle melted, let the furnace temperature to rise to 700°C. Took out or separated slag from melt aluminum, lifted the ladle from the furnace and poured the melt aluminum by gravity into the permanent mold (ingot) which has preheated 250°C. After the melted aluminum in the mold has frozen, removed the ingots from the mold. In the second recycling, melted the ingots from the first recycled just like the the aluminum casting structure operation process. In the third recycling, used the second recycled ingot. As raw material for 4th recycling was the 3rd recycling ingot. Fig. 2a shows the permanent ingot mold and ingot specimens used in this study.



**Figure 1.** Electrical induction furnace in research  
a). Over view of EIF, b). Melt Duralumin in EIF ladle

EIF specification: Capacity of aluminum melt 3 kg, maximum temperature operation 1000 °C, electric current and voltage; 12 – 14 Ampere and  $\pm 220$  volt.



**Figure 2.** Permanent ingot mold in research  
a). Design of permanent ingot mold, b). Ingot of duralumin

After the recycling smelting process completed, the next step was testing the scrap weight and dependent variable ingots from the smelting efficiency. The dependent variable of the microstructure was observed by ingot pieces with optical microscopy. Preparation and testing include: a). chemical elements, b). mass weigh of raw material, slag and ingot products, c). each micro structure of ingot uses OES, Optical Microscopy. Specifications of instrument test in research are:

1. *Optical emission spectrometry (OES)*

The ingredients of raw materials (aluminum and copper) and duralumin ingots can be known by the OES tool. The working principle of the OES apparatus is to burn specimens with electrodes so that the family of flame will then describe the flame in the light spectrum ( ) and the intensity of each type, and percentage of the element weight.

2. *Optic microscopy*

- OM : Magnification; 50x, 100x, 200x, 500x, and 1000x

Model BX41RF-LED

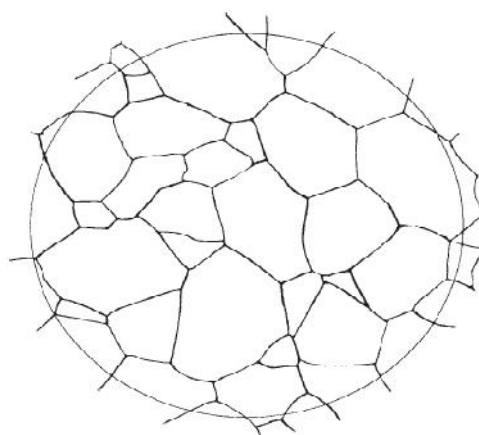
100-120/220-240V~, 0.12/0.08A 50/60Hz

Brand; Olympus, Made in Japan

Etza which was used to obtain the geometry (size and shape) of the grain and porosity morphology of each used 1%NaOH+4%KMnO<sub>4</sub>+95%H<sub>2</sub>O [10] and 5% HF + 95%H<sub>2</sub>O.

### ***Calculation of Grain Diameter***

Characterization is the activity of identifying material properties based on crystal structure, microstructure and macrostructure geometry. Observation of aluminum ingot microstructure requires a series of steps carried out carefully based on scientific understanding and practical experience. Figure 3 shows the schematic of microstructural photographs with optical microscopy that can be analyzed using grain size calculations using the planimetric method.



**Figure 3.** Grain Size Calculation

Calculation of grain size with mathematical formula as follows:

$$N_A = f(N_{inside} + \frac{1}{2}N_{intercepted}) \quad \text{and} \quad G = \{3,322 (\log N_A) - 2,954\}$$

In which:

$N_A$  : number of grains in the area (grain /mm<sup>2</sup>),  $N_{inside}$  : number of grains in the circle

$N_{intercept}$  : the number of items that intersect with a circle

$f$  : Jeffries multiplier factor (Jeffries multiplier ASTM E 112-96 2004)

$G$  : ASTM grain size number [3]

### 3. Results and Discussions

The test results in this study were grouped into a). Elements in ingots, b). smelting efficiency, c). microstructure, which is explained as follows:

#### a). Elements in recycling (ingots)

Comparing Table 1 and Table 2 shows the Iron content that increases from the beginning to the end of recycling. In some aluminum Fe alloys is one of the most important alloy elements, because Fe is the main impurity and is usually detrimental in aluminum alloy castings. Fe impurities in recycled cast alloys are mainly from the use of steel scrap material. Fe solubility in aluminum alloys so that most of the iron forms the intermetallic phase. Iron impurities in aluminum alloys form coarse needle-shaped intermetallic compounds during freezing and inhibit the recycling process. Yoshiaki et al (2007) states that the formation of nuclei from intermetallic compounds at liquid temperatures is difficult, large supercooling can initiate nucleation at once, which serves as the driving force to promote the formation of rough plates.

**Table 2.** Spark spectrometry testing result of research materials

Material	Elements [%]						
	Cu	Mn	Si	Mg	Zn	Fe	Zr
Ingot of first recycle	0.114	0.056	0.56	9.803	0.205	0.430	0.001
	Ti	Cr	Ni	Pb	Sn	Cd	Al
	-	0.115	0.005	0.005	0.050	0.015	Rem
Ingot of second recycle	Cu	Mn	Si	Mg	Zn	Fe	Zr
	0.143	0.056	0.39	9.054	0.195	0.435	0.001
	Ti	Cr	Ni	Pb	Sn	Cd	Al
Ingot of third recycle	-	0.115	0.005	0.004	0.045	0.010	Rem
	Cu	Mn	Si	Mg	Zn	Fe	Zr
	0.163	0.056	0.529	8.975	0.187	0.406	0.001
Ingot of fourth recycle	Ti	Cr	Ni	Pb	Sn	Cd	Al
	-	0.115	0.005	0.004	0.040	0.005	Rem
	Cu	Mn	Si	Mg	Zn	Fe	Zr
Ingot of fourth recycle	0.197	0.056	0.409	8.756	0.167	0.411	0.001
	Ti	Cr	Ni	Pb	Sn	Cd	Al
	-	0.115	0.005	0.004	0.035	0.005	Rem

Using aluminum structures that contain large amounts of iron, it accelerates the formation of intermetallic compounds nucleation in Al-Si-Fe alloys freezing. Thus, aluminum alloys containing high iron impurities can be used as raw materials if the iron intermetallic compounds are finely dispersed by several solidification processes. In Al-Mg-Si based alloys that can provide super tenacity in casting, iron is a common impurity element but is unavoidable during the smelting and casting process, and especially in the recycling process. Iron levels above the critical level for the silicon content of the alloy should be avoided as these can cause serious loss of ductility in the final cast product and decreased casting productivity through increased rejects due to shrinkage porosity, John (2012). In Al-Mg-Si alloys with the addition of Mn, Fe-rich intermetallic forms two first and secondary solidifications, usually labeled as 'Fe<sub>1</sub>' and 'Fe<sub>2</sub>' respectively. Fe<sub>1</sub> which usually rich

Intermetallic is associated with the primary  $\alpha$ -Al phase and shows the compact morphology of the coars, which are tetragonal, pentagonal, hexagonal. Other fine intermetallic (labeled Fe<sub>2</sub>) is associated with the  $\beta$ -Al phase and is separated in the primary  $\alpha$ -Al grain boundary.

### b). Slag weight, ingot weight, and smelting efficiency

Recycling variation in this study resulted in different slag and ingot weights as shown in **Table 3**. The difference in slag was caused by different types of melted raw materials, and differences in ingot weight due to differences in the properties of melted aluminum by elements lost due to evaporation (low melting points such as; Mg and Zn), bound by ladle walls (reactive like Fe). These elements affect the melted and solid aluminum properties which ultimately affect physical properties (specific gravity) and metallographic properties (phase and microstructural). Li (2001) states that in the melting condition the element Fe in duralumin accelerates the dissolution of the copper phase. Wahyono et. al in 2012 to declare are 1). In liquid, aluminum and magnesium, including metal are easy to absorb hydrogen gas from its surroundings such as air moisture, grease and oil, furnace water content, and others. 2). In solid of Al-Mg alloys it has a combination of high strength and high temperature. Besides that, elements with low melting temperature (Mg, Zn, and other elements) evaporate as a result of the % of the elements Mg and Zn decrease. Referring to the mass balance system in a mixture or alloy system, a decrease in % of the elements will cause an increase in % of the other elements.

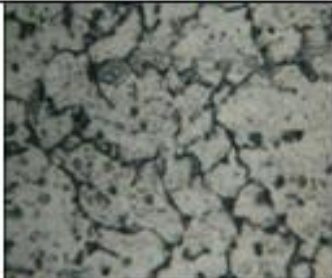

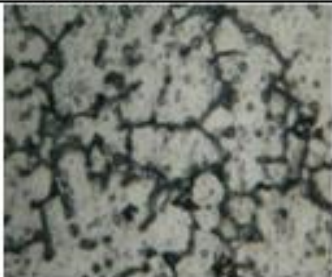

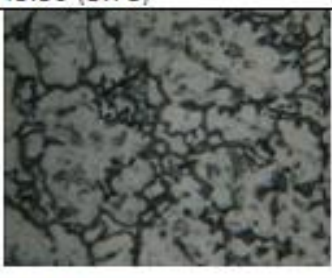

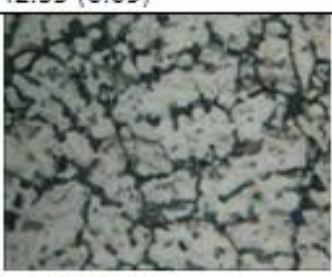
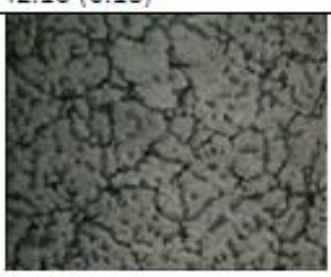
**Table 3.** Experimental results of recycling aluminum structures

Degree of Recycling	Kinds of	Weigh of [g]			Melted efficiency [%]
	Raw Materials	Raw Material	Slag	Ingot	
1	Structure aluminum	2000	145	1790	89.50
2	Ingot of first recycling	2000	105	1775	88.75
3	Ingot of second recycling	2000	90	1760	88.00
4	Ingot of third recycling	2000	75	1755	87.75

In general, the chemical content of aluminum products can be controlled by selecting the aluminum scrap type that is included in the smelting process. This causes difficulties in controlling the process to get the recycling process efficiency. But on the basis of mass equilibrium and recycling efficient energy can be predicted. Slag produced from the recycling rate shows a decrease but the smelting efficiency decreases due to the large amount of molten metal left in the ladle. The low manganese content in aluminum scrap and the high element of Fe causes the formation of an intermetallic phase and lowers the flow of molten aluminum due to aluminum being left in the ladle. Besides Si in aluminum scrap is also low which can reduce the fluidity of melt aluminum. In as-cast microstructure, some of the rich intermetallic Fe develops into more complex morphologies with star shapes such as those associated with the primary  $\alpha$ -Al phase. This Fe-rich intermetallic has been found in castings with an experimental composition of Fe > 0.6% by weight. According to Hurtalova et al (2013), the magnitude of the Si element in the AlSi<sub>9</sub>CuX casting alloy improves the casting characteristics and mechanical properties. The elimination combine rearrange simplify (ECSR) technique can be used to increase aluminum scrap recycling so that the average cycle time can be reduced from 25.91 hours to 20.13 hours. In addition, human and machine efficiency can be increased from 34.12% and 59.46% to 50.68% and 61.95%, Sittipong and Viboon (2015).



**Table 4.** Metallographic Observation Results

Recycling rate	Metallurgical test	at Center	at Surface
1	Microstructure		
	Grains size in $\mu\text{m}$ (G)	43.31 (5.72)	42.51 (5.94)
2	Microstructure		
	Grains size in $\mu\text{m}$ (G)	43.30 (5.78)	42.35 (6.09)
3	Microstructure		
	Grains size in $\mu\text{m}$ (G)	42.35 (6.09)	42.16 (6.18)
4	Microstructure		
	Grains size in $\mu\text{m}$ (G)	42.36 (6.04)	42.18 (6.13)

Microstructures of aluminum structure recycling samples were characterized using optical microscopy (OM). Microstructure examples illustrate the formation of grain size on the surface and center of ingots due to changes in elements when the Aluminum structure is recycled. **Table 4** shows the shape of equiaxed dendritic grain size getting smaller with increasing recycling stage. In the recycling process the grain was initially dendritically shaped and the arms were released from the main stem. This happens because of the reduction in slag forming elements in molten aluminum and the increase in ferro elements in molten aluminum. With the increasing rate of recycling of major dendritic arm development



slower than the second dendrite arm. According to Shaymaa (2013) microstructural networks consist of particles of several intermetallic compounds formed by combinations of alloying elements which dissolve in compounds to form circular grains.

Dendrites freezing observation leads to the dendrites growth with columnar granules parallel to the heat flow direction. In this area, very large supercooling can occur in a liquid near the ingot center. Here are two main causes, first; the solution concentration in the liquid only in front of the interface tends to increase by increasing the growth of the grain columnar area, which needs are small and the temperature low on the interface for further solidification. The results research by Gan et.al (2015), section thickness increasing, microstructure of the alloy gets coarse due to a reduction in cooling rate, and the mechanical properties decrease monotonously. Second; the ingot central temperature tends to match its interface like a shared cover. Effect of flatness contour on temperature-distance curves in liquids. If the equiaxed central region is seen in ingots, it means that supercooling changes in this area and can progress to the liquidation point of the casting center. In this area crystallization occurs, followed by the growth of new crystals and its growth is not continued by crystals extending in the columnar area.

Dendritic equiaxed particles (spheroidized) began to grow on recycling 1 and the growth of Mg particles took place by holding time until the particles grow to reach a static state of spheroidized size. The microstructure at Al-5,25% Mg cast alloy without Ti and with a recycling rate of 1 to 4, respectively, appeared to consist of two phases, the primary (- Al and eutectic Mg. Increasing recycling levels seen modifying dendritic equiaxed morphology producing fine dendritic structures, this phenomenon is considered better for the recycling role in reducing the main dendrite arm length resulting in a higher chance for Primary nucleation (Al relative to Mg-eutectic, this in turn purifies the main phase) and inhibits growth of the main dendrite. Changes in microstructure by recycling revealed five stages: nucleation, fragmentation, spherodization, growth, and finally stabilization, Mustafa et al (2015).

#### 4. Conclusion

The impurity element (Fe) in ingot (as-cast) increases and elements with a melting point decrease along with the level of the recycling process. Increased recycling aluminum structure levels reduce the amount of slags produced but recycling efficiency also decreases. Recycling rates can be used to control microstructure. In this study the first recycling produced an equivalent grain diameter of 43.31  $\mu\text{m}$  and 42.36  $\mu\text{m}$  in the fourth recycling

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