Physical Characteristics of Solid State Recycled Aluminum Chip AA6061 Reinforced with Silicon Carbide (SiC) by using Hot Extrusion Technique.

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Abstract. Solid state recycling is a current approach technique on recycled chip without needed to remelting waste chips and increases the green production productivities. This study defined the effect of preheating temperature and preheating time on aluminium extruded characteristics reinforced with silicon carbide, SiC. AA6061 chips were cold pressed and extruded through round die using preheating temperature of 450, 500 and 550°C for 1, 2 and 3 hours of preheating time. The physical properties and microstructure of aluminium extruded characteristics were analyzed. The density result shown at 550°C with 1h preheating time and added with SiC 5 wt.% value higher than the theoretical value at 2.7333 g/cm³ and 2.7267 g/cm³ respectively.

Keyword: Aluminium chips, aa6061, recycled, hot extrusion, physical characteristic.

1. Introduction
Solid state recycling is a direct recycling process that changes aluminium waste to final product without remelting process. In addition, conventional method consume high energy process, operating costs and several operations involved compared with direct convention where only needed 5% of energy process [1]. Gronostajski et al. [2][3] also investigated the new method in chip recycling by using cold press and hot extrusion method to produce aluminium metal matrix composite (MMC). The optimization of perfect reinforcement composition was difficult to achieve. On the other hand, the reinforcement particles in MMC have bigger influence on mechanical and physical properties [4] where metal matrix and reinforcement particles distribution becomes uniformly after trough deformation diffusion process.

Hot extrusion process is commonly shaping material process used widely in manufacturing industries. Extrusion process used to transform aluminium alloy into final product with definitive cross-sectional profile for generally uses such as automotive parts and household appliance [5]. Tekkaya et al. [6] state, due to high strains occur, pressure and temperature assumed to become an effect factor during conventional extrusion. Thus, in this research paper focus on investigated an acceptable composition of silicon carbide reinforcement and suitable preheating temperature and time for aluminium chip AA6061 recycling using hot extrusion process.
2. Experimental setup

The materials used in this study were aluminium block AA6061 as the metal matrix material considering the theoretical density as 2.7 g/cm³ and Silicon Carbide, SiC with particle 150 µm used as reinforcement material. The aluminium chips were prepared by mill aluminium block using CNC milling machine with the constant set up cutting parameters used were the feed rate at 1100 mm/min, depth of cut at 1.0 mm and cutting velocity at 345.4 m/min. The milled aluminium chips was treated with acetone solution then cleaned by ultrasonic bath for 30 minutes to remove any impurities. After that, the aluminium chips will be dried in conventional oven at 80°C for 60 minutes [7].

The composition of mixture aluminium chips and silicon carbide were loaded in a cylindrical container and compacted by cold press to make a billet shape of diameter 30 mm and height 90 mm at maximum force 30 tons. The chip preprocessing is shown in Figure 1.

![Chip preprocessing](image)

Figure 1. Chip preprocessing

After chip compacted process, the billet were extruded trough the designated parameter as shown in Table 1. The range of temperature and preheating between 400 and 550°C and 1 and 3 hours respectively were selected in this study. Samples with different composition setting for extrusion are present in Table 2.

| Parameter setting of hot extrusion |
|-----------------------------------|
| Parameter                     | Value/type |
| Extrusion die                  | Round      |
| Extrusion ratio, R             | 5.3        |
| Billet, Θ (mm)                 | 30         |
| Extrude size                   | 13         |
| Extrusion speed (mm/s)         | 1          |
| Container temp. (°C)           | 300        |
| Die temp. (°C)                 | 300        |
| Preheating temp. (°C)          | 450, 500, 550 |
| Preheating duration (h/s)      | 1-3        |

| Sample | Preheating temperature (°C) | Preheating time (h/s) | Silicon carbide, SiC (wt.%) | G no. | Average dia. (µm) |
|--------|-----------------------------|-----------------------|----------------------------|-------|------------------|
| S1     | 450                         | 1                     | 5                          | 6.18  | 42.34            |
| S2     | 550                         | 1                     | 5                          | 6.37  | 39.65            |
| S3     | 450                         | 3                     | 5                          | 6.24  | 41.49            |
| S4     | 550                         | 3                     | 5                          | 6.17  | 42.49            |
| S5     | 500                         | 2                     | 10                         | 5.77  | 48.81            |
| S6     | 450                         | 1                     | 15                         | 6.32  | 40.36            |
| S7     | 550                         | 1                     | 15                         | 6.29  | 40.78            |
| S8     | 450                         | 3                     | 15                         | 6.05  | 44.19            |
| S9     | 550                         | 3                     | 15                         | 6.19  | 42.20            |
| S10    | As-received                 |                       |                            |       |                  |
3. Result and Discussion

3.1. Physical properties
As described in Table 2, have three different temperature used in preheating process to produce extruded sample of round cross section. The extruded and as-received samples were cut into size 1mm length for density balance measurement and were identified using Archimedes' water immersion technique.

![Figure 2. Measured density of sample](image)

The density of different composition of silicon carbide and extruded at different temperature and preheating times shown noticeable decreasing for sample S5 at 500°C with 2 hour preheating time and 10 wt.% of silicon carbide as illustrate in Figure 2. This results shown that the void still occur during extrusion process even though added silicon carbide as reinforcement material to fill up the cavities between the chips [6]. While, most of extruded sample result value almost closet to the theoretical value.

3.2. Microstructure analysis
The extruded sample were observed trough on optical microstructure (OM). The sample preparation firstly, grind using SiC paper of grits 240, 600 and 1200 in wet condition and polished with polycrystalline diamond solution. After that, polished sample were electrolytic etching using Barker’s reagent with voltage of U=12V for 120s to reveal the grain size and grain boundary [8]. The average grain size measured using linear intercept method by following ASTM E112-13 standard [9].

Based on Figure 3, the extruded sample at 450°C shown almost small chip boundaries and grain size present. While, there have no observable crack or porosity can be seen in this extruded sample including with the high temperature, preheating and different composition of silicon carbide still no significant crack or void occur. The aluminium chips and silicon carbide bonding uniformly were continues boundary have been observed between chip interface especially sample S2 at 550°C where sample reveal very dense microstructure and crack or void difficult to identified. In Table 2, the grain size measurement result state for supported the microstructural result.
Figure 3. Optical Microstructure of extruded sample
4. Conclusion

In this study, the effect of silicon carbide, preheating temperature and preheating time on recycled aluminium chips was investigated by using hot extrusion technique. Based on finding, we can see that sample S2 shown the equal relative density with theoretical value at 2.73 g/cm$^3$. With addition, S2 sample also shown the dense microstructure during the observant in microstructural analysis and has lower grain size measurement.

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