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Effect of Alumina as Reinforcement on the Mechanical and Physical Properties of Recycled AA6061 Aluminium

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ABSTRACT

The utilisation of reinforcement materials in aluminium metal matrix composites is widely used in the manufacturing sector due to their lightweight nature, excellent strength-to-weight ratio, enhanced fracture toughness, and improved mechanical properties. The purpose of this study is to investigate the effect of reinforcing alumina in recycled AA6061 aluminium on the properties of the resulting aluminium matrix composite. Various compositions of recycled AA6061 aluminium reinforced with alumina were prepared and analysed using the cold compaction method. The results show that the addition of alumina composition increases the hardness properties of the composite by up to 5 wt.% at 32.91 Hv compared to the unreinforced sample at 30.63 Hv, but the hardness decreases as the alumina mass composition increases. According to the analysis of physical properties, in comparison to the unreinforced sample, the density decreases with increasing mass composition of alumina up to 10 wt.%, which is from 2.4636 g/cm^3 to 2.3014 g/cm^3, respectively. In relation to the microstructure of the samples, the addition of alumina results in irregular shapes with larger pores. An increasing in the mass composition of alumina results in increased porosity and water absorption.

1. Introduction

Engineering material encompasses six main types: metals, glass, ceramics, polymers, composites, and elastomers. The properties of composite materials can vary significantly depending on the type of components used and the manufacturing process employed [1]. Composite materials include polymer matrix composites, metal matrix composites, ceramic matrix composites, carbon matrix composites, and intermetallic composites [2]. The historical processing undergone by metals can influence their atomic structure, thus shaping their characteristics [3]. To achieve the desired properties, modifications can be made to the matrix alloy, reinforcement material, volume and shape of the reinforcement, reinforcement positioning, and production processes [4]. Recycling has

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become a well-established means of resource provision, particularly in countries that have industrialized their economies [5]. The addition of reinforcing components varies the mechanical properties of composites, making it crucial for individuals working with structural materials to understand this behavior [6,7]. Advanced matrix composites (AMCs) reinforced with particles have garnered interest for numerous applications in the aerospace, automotive, and transportation industries due to their unique properties [8]. When analyzing design criteria, several factors need to be considered, including the final product's shape, size, accuracy requirements, and the material it will be made from chips [9]. Powder metallurgy, abbreviated as PM, is a manufacturing technique used to produce metal parts from metal powders [10]. In the late 1990s, PM was used to manufacture tungsten filaments for electric lights and coins, and it is widely adopted in the aviation industry [11]. The starting porosity of the green compaction, sintering temperature, and duration of the process can all be considered in assessing the extent of porosity reduction during sintering process [12,13]. Inert gas, nitrogen-based, dissociated ammonia, hydrogen, and natural gas are all commonly sintering furnace atmospheres [14]. Aluminium can be recycled multiple times without any loss in quality, allowing for the recovery of its monetary value without compromising its excellence [15]. The significant economic motivation arising from the valuable market worth of aluminum scrap creates a compelling reason for its recycling [16-20].

The study aimed to investigate the reinforcement of alumina as a strengthening agent for recycling chips of aluminum AA6061 as metal matrix composites material. The analysis of metal matrix composites was conducted for physical and mechanical properties using simple recycling methods and the cold compaction process. Cold compression with the sintering process is an efficient method of recycling, and with the addition of alumina as reinforcement, it can improve the properties of aluminum composites. The study aimed to enhance the physical and mechanical properties of metal matrix composites to create a valuable material in the industrial field.

2. Methodology

2.1 Metal Matrix Composites Materials

Metal matrix material used was an AA6061 aluminium block with a theoretical density of 2.7 g/cm^3. Aluminium chips were produced using a CNC machine (SODICK - MC4301), as shown in Figure 1. A feed rate of 1100 mm/min, a depth of cut of 1.0 mm, and a cutting velocity of 345 m/min were used in the milling process. Following the milling, the recycled aluminium was cleaned in an ultrasonic bath apparatus, FRITSCH - ultrasonic cleaner Labarette 17. Material preparation was conducted at Universiti Tun Hussein Onn Malaysia. Each batch of recycled aluminium was cleaned for one hour with an acetone solution (CH_3COCH_3) to remove oil, grease, and any impurities. Following that, the drying process was carried out in a drying oven for one hour at 75°C, effectively removing residual acetone from the recycled aluminium. For the metal matrix composite samples, commercial alumina powder was used as a reinforcing agent.

Fig. 1. Aluminium chips are produced from CNC machines

2.2 Sample Preparation for Metal Matrix Composites

In the compaction process, a Carver type 3851-0 uniaxial hydraulic press machine was used. Table 1 shows the composition of recycled AA6061 aluminium mixed with alumina powders. The sample was then formed by pouring this mixture into the mould as shown in Figure 2. The compaction process was completed with a load setting of 9 tonnes and a holding time of 20 minutes [13,21]. The surface of the die was cleaned with a lubricant-saturated solution to facilitate sample removal. Following the compaction process, the samples were sintered to improve bonding. Sintering was done in a tube furnace with precise control over the heating rate, duration, and temperature. Argon gas was used as an inert medium to protect the samples from oxidation. The sintering process began at 552°C and lasted 60 minutes.

Table 1
Composition of aluminium matrix composites of recycled AA6061 aluminium and alumina powders addition [13]

Samples	Composition of samples
1	Recycled AA6061 aluminium
2	Recycled AA6061 aluminium + 2.5 wt.% of alumina
3	Recycled AA6061 aluminium + 5.0 wt.% of alumina
4	Recycled AA6061 aluminium + 7.5 wt.% of alumina
5	Recycled AA6061 aluminium + 10.0 wt.% of alumina
6	Recycled AA6061 aluminium + 12.5 wt.% of alumina

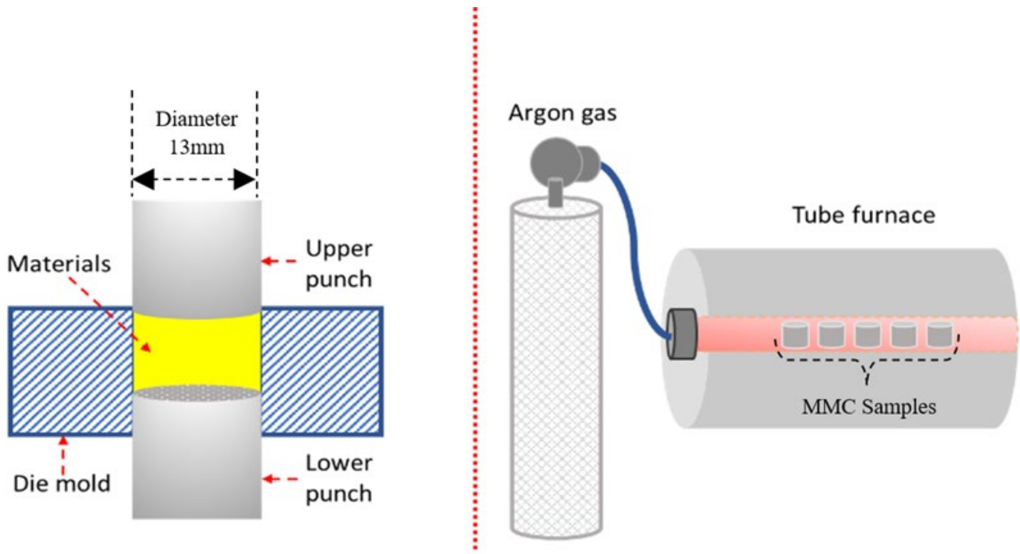

Fig. 2. Process of metal matrix composites samples

2.3 Metal Matrix Composites Analysis

A Vickers hardness apparatus was used to measure the hardness of the samples during the hardness test. In accordance with ASTM E384 standards, the test involved applying a load of 980.7mN for 10 seconds and repeating it eight times. The density, porosity, and water absorption of the metal matrix composites were determined using the Archimedes Principle and a Mettler Toledo Germany electronic balance during the physical testing. Following these analyses, the standard ASTM B328 density and ASTM B962-17 porosity methods were used. An optical microscope (OM) was used to observe particle bonding, shape forms, and sample composition to analyse the microstructure of the metal matrix composite.

3. Results and Discussion

The data reveals important findings regarding the relationship between alumina powders with the properties of metal matrix composites, as shown in Figure 3. Higher composition of alumina powders results in lower composite densities, as compared with unreinforced samples, the value of density decreases with increasing of alumina powders to 10 wt.%, 2.4636 g/cm^3 to 2.3014 g/cm^3, respectively. the trends show vice versa to the porosity and water absorption which are the increasing of alumina powders also increased the porosity and water absorption values up to 10 wt.%. Previous findings on the fabrication of Al_2O_3/SiC particle-reinforced aluminium-based metal matrix composites concluded that the presence of reinforcement particles can lead to increased porosity, which in turn can result in lower density [22]. Figure 4 presents the hardness of aluminium matrix composite samples, showing addition of alumina powders improves the samples up to 5 wt.%. The addition of more than 5 wt.% of alumina powders showing decreasing in hardness analysis.

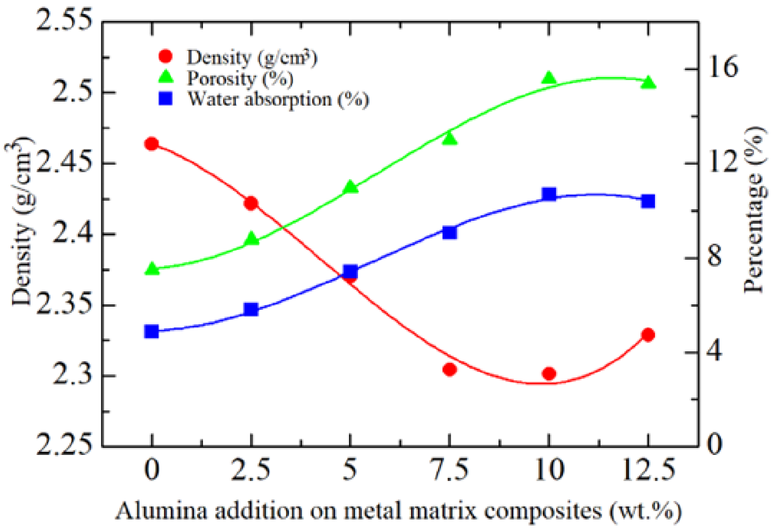

Fig. 3. Physical properties of aluminium matrix composite reinforced alumina powders

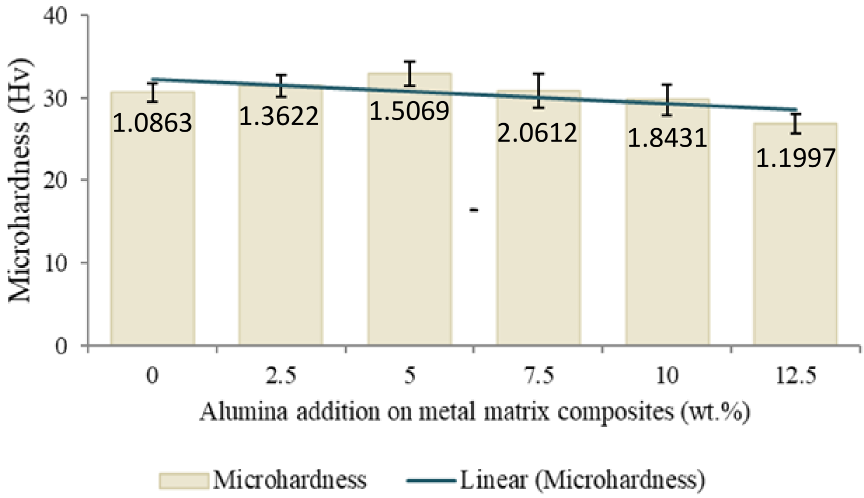

Fig. 4. Microhardness of aluminium matrix composite reinforced alumina powders

Optical microscopy analysis of metal matrix composites provided valuable insights into their microstructure, particularly in relation to alumina content (Figure 5). A pure aluminium microstructure was observed in the absence of alumina, featuring uniform aluminium grain distribution and minimal porosity. However, as the alumina content increased, clusters of alumina particles appeared within the aluminium matrix, but their dispersion was uneven, potentially compromising composite strength. Higher alumina content also led to the presence of more gaps or empty spaces in the microstructure, which could weaken the composite and increase susceptibility to fractures. Porosity in the composites primarily resulted from the weak interface between the matrix and reinforcement, especially with greater amounts of hard ceramic particles. Additionally, there was a correlation between pore size, irregularity, and porosity levels, suggesting that the formation of porosity is influenced by interface quality and structural irregularities, impacting overall porosity levels and pore shape characteristics.

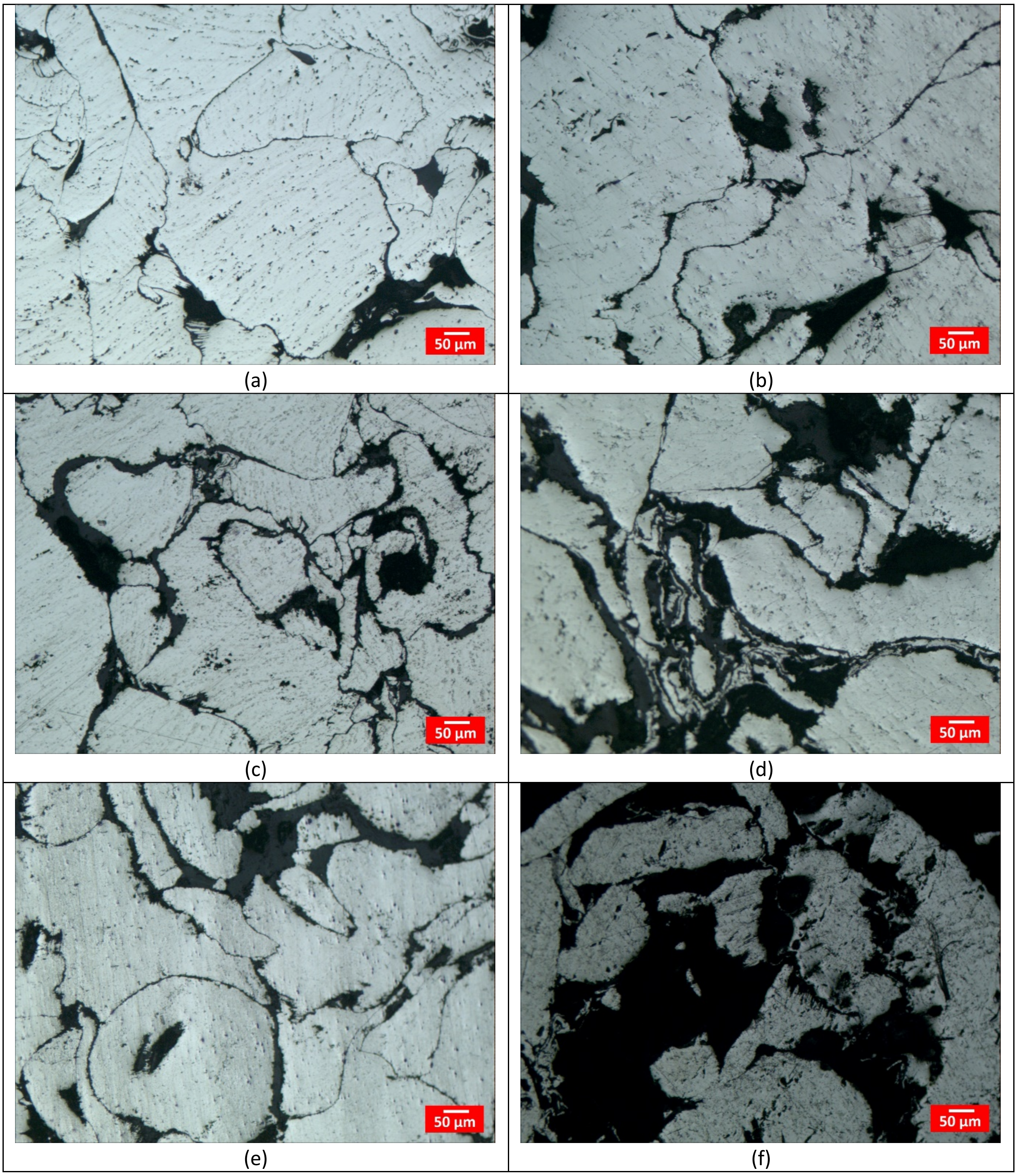

Fig. 5. Microstructure of compositions of metal matrix composites samples; (a) Unreinforced samples, (b) 2.5 wt.% alumina, (c) 5.0 wt.% alumina, (d) 7.5 wt.% alumina, (e) 10.0 wt.% alumina, (f) 12.5 wt.% alumina

4. Conclusions

A novel solid-state recycling method was investigated, involving the consolidation of machined aluminum chips into blocks, followed by cold compaction and sintering. This approach eliminates the need for remelting, reducing energy consumption. Incorporating alumina into the composite led to a favorable microstructure with fewer large surface pores. The density of samples with alumina powders approached the theoretical density of AA6061, while those without alumina had lower density due to increased porosity. The hardness value increased with the addition of alumina powders, reaching its highest in the sample with 5 wt.% alumina with 32.91 Hv compared to the unreinforced samples with hardness of 30.63 Hv. The immediate cold compaction of aluminum chips with alumina allowed for the formation of recycled AA6061/alumina composites, exhibiting non-uniform distribution of microstructures with spiral and uneven shapes with the addition of alumina powders. Overall, the optimal composition was AA6061/5 wt.% alumina, showing improved hardness and lower density compared to other compositions.

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