



# Mechanical Properties of Direct Recycling Metal Matrix Composite (MMC-AIR) AA7075 Aircraft Aluminium Alloy

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**Abstract:** Recycling of aluminium aerospace alloys represents a major challenge to both the aluminium and aerospace industries. Ecological manageability in assembling is these days is a dire and exceptional issue and the principle concerns are identified with increasingly proficient utilization of energy and materials. Recycling allowed saving large amount greenhouse gas emission, particularly in the case of aluminium. Metal matrix composites spur the possibility of advancing typical monolithic material properties. Offering great strength, lightweight and being able to withstand high temperatures are the main behaviours of the metal matrix composite. To that extent, many practitioners in either automotive or aerospace industries employed metal matrix composite in most of the critical parts. Forming metal matrix composite via solid state processing is considered innovative, as most of the metal matrix composite forming process took place either in liquid or gaseous processing. An experimental investigation was conducted to investigate the mechanical properties of a recycled aluminium shifting alumina sum from 1 to 5 wt. % that had been presented to recycled aluminium chip employing hot press forging. Aluminium chip was obtained by milling AA7075-T1 bulk to a certain parameter. The medium size chips were cleaned, dried and mixed with alumina particles before being poured into a closed-die mould. The main responses investigated were ultimate tensile strength and elongation to failure and microstructure analysis. Out of all fractions, 4 wt. % of alumina shows the highest Ultimate tensile strength when the value increased from 155.214 MPa (1 wt. %) to 187.183 MPa. Further addition of alumina would enhance the composite strength, but in contrary, it also could prone the material performance.

**Keywords:** Sustainable direct recycling, metal recycling, hot press forging, aluminium recycling, aluminium AA6061, reinforced particles, metal matrix composite

## 1. Introduction

Metal matrix composites (MMCs) have been a subject of specific investigation and applied research for about two decades but only in the past few years these advanced materials became realistic candidates in engineering components. The applications of aluminium matrix composite materials are growing continuously in the field of automotive and aerospace because of their superior physical, mechanical and tribological properties as compared to base alloy. The main benefits exhibited by MMCs such as lower density, increased specific strength and stiffness, increased high-temperature performance limits, and improved wear-abrasion resistance, are dependent on the properties of the matrix alloy and of the reinforcing phase [1][2][3]. Aluminium is the most favourable matrix due to its low density, excellent strength, and also high resistance to corrosion. Furthermore, properties of aluminium matrix composite can be tailored

by varying the nature of constituents and their fraction [4]. The other constituent is embedded in this aluminium/aluminium alloy matrix and serves as reinforcement, which is usually non-metallic and common ceramic such as SiC and Al<sub>2</sub>O<sub>3</sub> [1]. Reinforcement material for MMC can be produced in the form of continuous fibres, short fibres, whisker or particles. In comparison with the unreinforced alloy, all reinforcement forms were able to presents significantly better retention of anisotropic properties and specific properties at room and high temperatures [5]–[8]. Despite encouraging results of these reinforcement forms, there were still flaws hidden in each of the forms. For instant, whisker do not have uniform dimensions or properties which then leads to extremely large variability in its properties [9]. Continuous fibre which used extensively in industrial application has been hindered by high manufacturing costs associated with the high costs of the reinforcement fibres [10], [11]. In addition, the processing methods for short fibre reinforced MMC allow only limited control over the arrangement of the fibre in the matrix [12]. While for the particulate reinforced MMCs, it was elucidated that the reinforcement were more critical toward damage [13]. On contrary, particle reinforced constituent however, fascinated substantial devotion as a result of: (a) inexpensive costs, (b) good promising manufacturing process for MMCs development and (c) convenience metal working methods to form particulate MMCs [11].

In spite various advanced have been made over the years regarding the fabrication of the MMCs, there were limited application which required such advanced process. This matter had been contributed by the difficulties with satisfactorily forming the final component, where the machining process could cause surface damage and it can lead to detrimental to properties such as fatigue and corrosion resistance [14]. Hence, it is a privileged to employ hot press forging process, in order to achieve near-net-shape components, without acquiring such damage. Furthermore, forging offers the prospect of improving anisotropic properties by work hardening the matrix and modifying microstructural features such as porosity [9], [14].

In direct recycling method average metal loss during the re-melting phase could be avoided approximately 20% by preventing intensive oxidation on the molten metal surface, burning and mixture with the slag removed from the surface of the ladle [15][16]. This is due to material being recycled directly from the chips by hot press forging, resulting in a more cost effective process. The study that utilized direct recycling using hot forging process shows that recycled aluminium exhibits good strength and plasticity potential, proving that the solid-state technique with hot forging is a viable alternative for recycling aluminium alloy chips. A method of solid-state recycling aluminium alloy using hot press forging process was studied as well as the possibility of the recycled chip to be used as secondary resources [17], [18], [19], [20], [21], [22], [23], [24]. Hence, this study aimed to investigate the mechanical properties on the effects of alumina reinforced particle percentage in Direct Recycling Metal Matrix Composite (MMC-AlR) AA7075 Aircraft Aluminium Alloy.

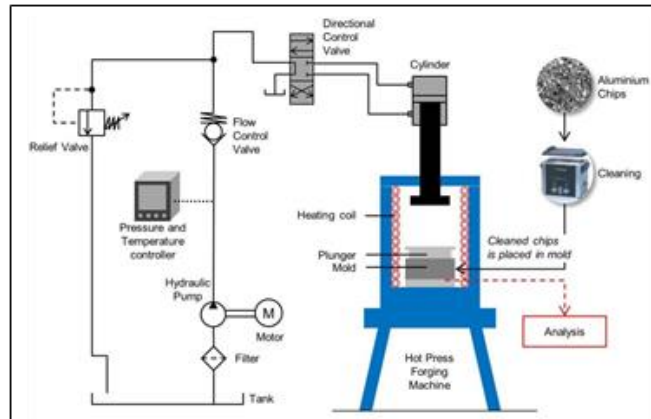
## 2. Methodology

As-cast aluminium (AA7075-T6) and alumina powder sized <1 mm with 99.9 % purity were obtained from IAC Manufacturing Malaysia Sdn. Bhd. and commercial vendors respectively. The chips were then being clean by using Elmasonic S 60H ultrasonic bath by applying acetone (C<sub>3</sub>H<sub>6</sub>O) solution [25]. The chip is then will be dried in the furnace at 60 °C. Aluminium AA7075 were then mixed with alumina powder in the SYL 3 Dimensional Mixer with the speed of 50 rpm. 1, 2, 4, and 5 wt % of alumina powder was loaded into the mixing chamber, whereas the aluminium chips should take the rest of the total composite weight. After mixed, the precomposite blend was poured into a close-die hot press forging mould, followed by plunge which was fixed accordingly. The hot press forging process was executed in a closed hot furnace, which being heated to 530 °C, Fig. 1. The mixtures were then pressed-forge with the pressure of 35 tonnes for the period of 120 minutes. The forming procedure for arrangement for tensile testing in this paper abide by the following standard of Standard Test Methods for Tension Testing of Metallic Material [26], and the dimensions are shown in Fig. 2. Tensile tests were performed utilizing universal testing machine GOTECH Testing Machines using a 25 kN load cell with gauge length 25 mm was used to record the strain. Tensile tests were performed at speeds 5 mm/min. The microstructure analysis followed the Standard Guide for Preparation of Metallographic Specimens and Standard Test Method for Macroetching Metals and Alloys. Light optical microscope Nikon Eclipse LV150 was used to quantify the microstructural of the recycled samples. The samples were prepared for metallographic observations by grinding the sample consecutively with 60, 240, 400, 600 and 1200 SiC papers, and then polishing with 6 and 1 µm DIAMAT Polycrystalline Diamond cloths. Then, 0.02 µm SIAMAT Noncrystalline Colloidal Silica was used for finishing. The samples were etched with Barker's reagent to show the grain boundary developed by dynamic recovery or recrystallization.

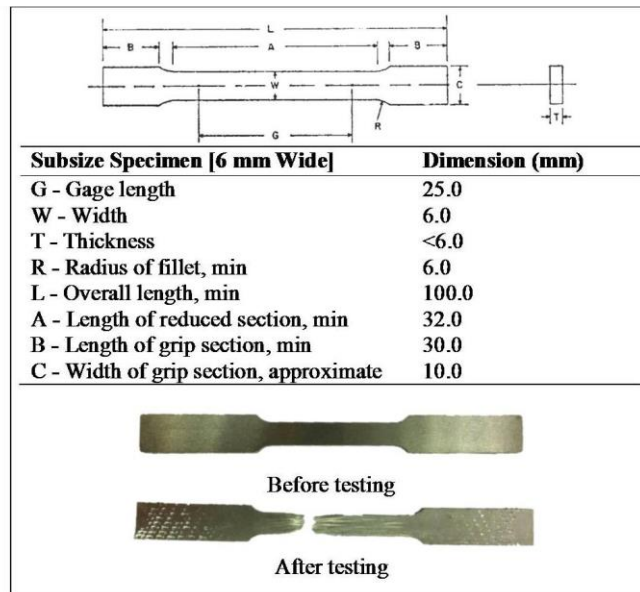
## 3. Results

Fig. 3 shows Ultimate Tensile Strength increase with increment of wt. % of alumina and then decrease for 5 wt. % specimen. The tendency trend in Figure 3 is depicted as the wt. % of alumina at 1 %, the Ultimate Tensile Strength are 155.214 MPa was surged up to 169.391 MPa at 2 wt. % of alumina. Next, for 4 wt. % sample, it had reached higher Ultimate Tensile Strength, 187.183 MPa. From the previous study, Alumina also responsible for increasing matrix strength and a significant decrease in ductility and elongations which summed that the ceramic particle

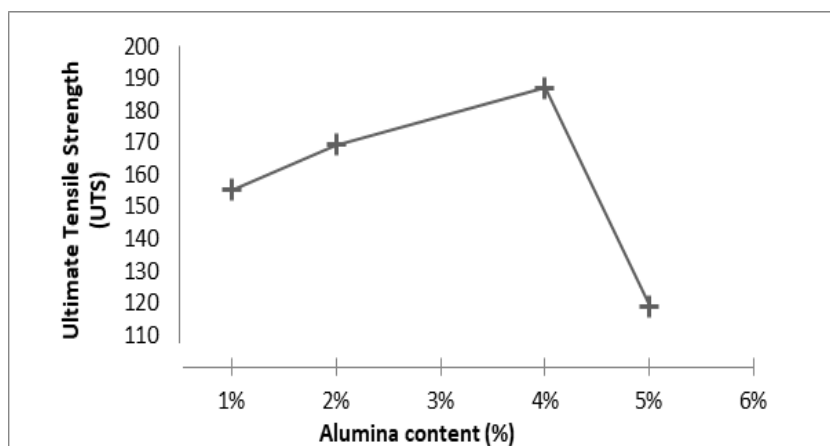
encouraging the specimen fracture as soon as necking occurs [4]. Then, the trend changes its direction at 5 wt. % of alumina with Ultimate Tensile Strength dropped to 118.869 MPa. Strength declined due to the increment of particle agglomeration, thus impairing the tensile ductility of the composite. Furthermore, increasing of alumina amount will raise the possibility of clustering and finally initiates the formation of weak regions in the compact [4][21].



**Fig. 1 - Direct recycling hot press process [18]**



**Fig. 2 - Tensile specimen dimension after recycled process**



**Fig. 3 - Results of ultimate tensile strength on different wt. % of alumina**

Whereas, Fig. 4 shows the trends of uprising Elongation to failure were influenced by the variations of wt. % of alumina from 1 to 5 wt. %. By increasing percentage of alumina content, the percentage of material elongation increases since the materials were consented for good bonding. The Elongation to failure of the composite mildly increase from 5.179 % to 5.539 % when the amount of alumina increase from 1 to 4 wt. %. Then, the trend of Elongation to failure slightly dropped to 4.504 % at 5 wt. %. The increasing of ETF might be due to the constraints imposed on the deformation caused by the presence of hard and brittle alumina particle in the soft aluminium, which in turn required higher applied stress to initiate plastic deformation in the composite [27]. However, for the declination of elongation to failure is due to the weak network of the composite as alumina had allocated more inside the composite. As alumina content increased, the distances between the hard phases become closed. The dislocation movement is hindered which response in declination of elongation to failure. It is strongly believed that alumina be the contributing factor in decreasing the flexibility and elongation [28].

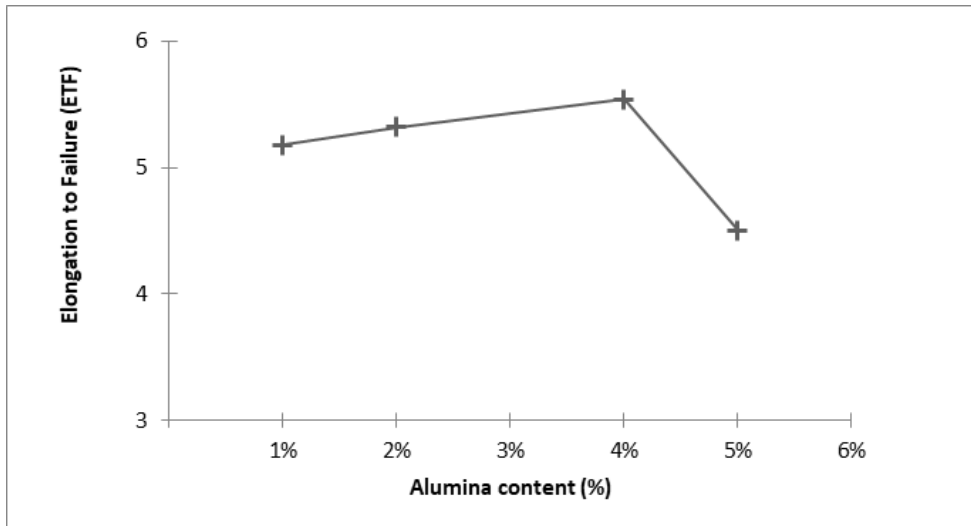


Fig. 4 - Elongation to failure responses with respect to different content of alumina

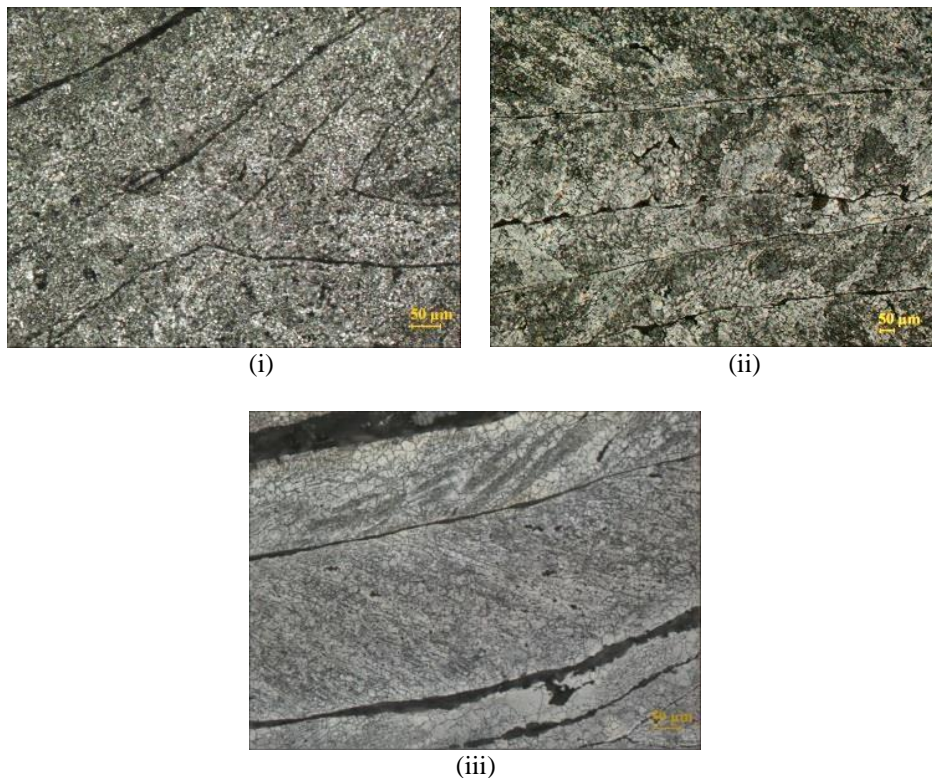


Fig. 5 - Microstructure on the effect of percentage of alumina reinforce particle at 20x for (i) 1 wt. %; (ii) 4 wt. %; (iii) 5 wt. %

Fig. 5 shows the microstructure evidence on the effect of percentage of alumina reinforce particle at 1 to 5 wt. %. At 1 wt. % of alumina, the porosity between the chips are more observable as shown in Fig. 5. (i) where consolidation of the boundary is closer between the chip due to presence of alumina particles. It can be observed that the increasing the amount of alumina leads to a finer grain sizes. This is because alumina particles act as an obstacle against the grain boundary movement at the time of the sintering [28]. Moreover, Fig. 5. (ii) shows the microstructure analysis of 4 wt. % alumina content. The porosity between the chips is much less observable compared to microstructure of 1 wt. % alumina. The porosity between the chip decrease due to the presence of alumina that lead to a finer grain size. Furthermore, as the amount of the reinforcement increases or the size of the reinforcement particles decreases, a finer grain size in the microstructure is produced. Based on result obtained, the value of Ultimate tensile strength for 5 wt. % alumina is slightly dropped and Fig. 5. (iii) shows that the porosity between the chips clearly seen. Therefore, strength decline as a result of reduction in relative density and a rise in pore number [28]. The porosity looking at the specimens are led to the tensile strength compare with the less porosity specimen. This is proven by the results obtained during tensile tests shows that the structure of every specimen affects the mechanical properties.

#### 4. Conclusions

Based on the present work, a method of effects of alumina reinforced particle percentage on Direct Recycling Metal Matrix Composite Aluminium chip AA7075 was studied. From the investigation, the following shows conclusions could be drawn:

- Results on the effects of alumina reinforced particle percentage gives high impact to the forging process. The Ultimate tensile strength surged up from 155.214 MPa to 187.183 MPa as the percentage of alumina content increased from 1 wt. % to 4 wt. %.
- The ultimate tensile strength increased when alumina particle was added up to 4 wt. %, but then reduce the strength as the amount increase further. The same responses were also recorded for the elongation to failure. The ceramic behaviour of alumina presents significantly better retention of mechanical properties. Hard and brittle properties of alumina, however, do provide some weakness to the composite. The brittle nature of its, makes the possibility of fracture event to happen early and unexpected.
- 4 wt. % of alumina, resulted in high and most reliable responses. It exerted highest ultimate tensile strength as well as highest ability to elongate before failure. To that extent, 4 wt. % of alumina attribute promising mechanical properties when being composed of recycled aluminium through hot press forging process.
- It is show that the surface porosity for 1 wt. % alumina is looking bigger than the 4 wt. % alumina. The porosity is easy to observe when the chip is just interlocking by itself. Different with the 4 wt. % specimen, the porosity is hard to observe, it is because the grain boundary became closer to the chips.

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