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Aluminum-Carbon Metal Matrix Composites: Effect of Carbon Fiber and Aspect Ratio on the Mechanical Properties

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Abstract. Aluminum-Carbon composites with different weight ratio of carbon fiber were fabricated using powder metallurgy route. The mixture powders were consolidated using heat induction furnace under vacuum at temperature of 600°C and pressure 50 MPa. Two different aspect ratio of carbon fiber were used in this study; namely 12 and 20. The mechanical properties of composites were evaluated by compression and hardness tests. The SEM was used to analyze the structure of the composites which showed a very good dispersion.

Introduction

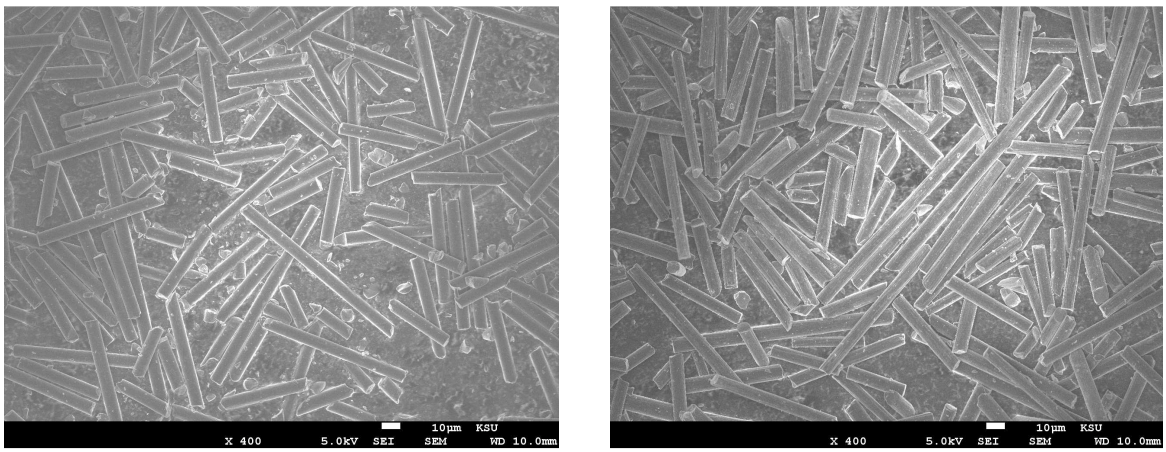
Aluminum and al-alloys have been extensively used in industrial applications. Having high strength to weight ratio made Aluminum a great candidate in advanced industry such as aerospace where weight is critical [1]. Aluminum-based composite have received great interest in recent years. Reinforcing aluminum alloy with graphite fibers have captured attention due to the increase in mechanical properties that have been observed [2,3]. The dispersion of graphite fiber in aluminum increases the tribological properties of the composites [4,5]. The strengthening mechanism of inclusions in the base materials result from the dislocation interaction between the inclusion and the base materials. This effect of the inclusion in the dislocation motion is dependent on the inclusion size and morphology [6]. Al-based composites can be processed via different techniques. Powder Metallurgy (P/M) is one of the most popular techniques to process metal matrix composites [7]. Powder Metallurgy technique provides more homogenous microstructure and well dispersed fillers [7]. It requires less energy input than the conventional ingot metallurgy processes. The P/M steps are mixing, compacting, and then sintering. Mixing is considered a critical step as the dispersion of the filler will control the performance of the composites.

The objective of this study is to investigate the effect of the addition of carbon fibers on aluminum matrix. The study includes two fold; 1) effect of weight percent of carbon fiber and 2) effect of fiber aspect ratio. Different percentages of graphite are used, namely 1, 2, and 4%. Two fiber aspect ratios were selected for this study, 12 and 20. The fiber diameter is of 7-9 micron. The study is focused on the mechanical properties of the composites such as strength and hardness. SEM is used to examine the dispersion of the fillers in the metal matrix.

Materials and Processing

Aluminum powder with purity of 99% with an average of 20μm particle size used in this study was supplied by Riedel-De Haen Ag Seelze-Hannover, Germany. The carbon fibers were supplied by Asbury Graphite Mills, USA. Two types of carbon fiber were supplied. The first type of carbon fiber is AGM94MF090C with 7-9μm diameter and 90μm length. The second type of carbon fiber is AGM94MF0150 with 7-9μm diameter and 150μm length. The aspect ratio of the fibers are 12 and 20 respectively. SEM graphs of the carbon fiber are shown in Fig. 1. The carbon fibers were

dispersed in acetone media under ultrasonic waves at a frequency of 50 kHz for 1 h. The Al powder was then added into the solution with various contents of carbon fibers, namely 1, 2 and 4% by weight. The aluminum-carbon mixture was sonicated for 1 hour to disperse the fibers in the aluminum matrix. The mixtures were then dried at 60°C to produce composite powder. The aluminum-carbon powder is pressed in the heat induction furnace at temperature of 600ºC and a pressure of 50 MPa to produce a bulk sample.



a) AR = 12 b) AR = 20

Fig. 1 SEM graph of the carbon fiber. a) aspect ratio, AR = 12, b) aspect ratio AR = 20

Results and Discussion

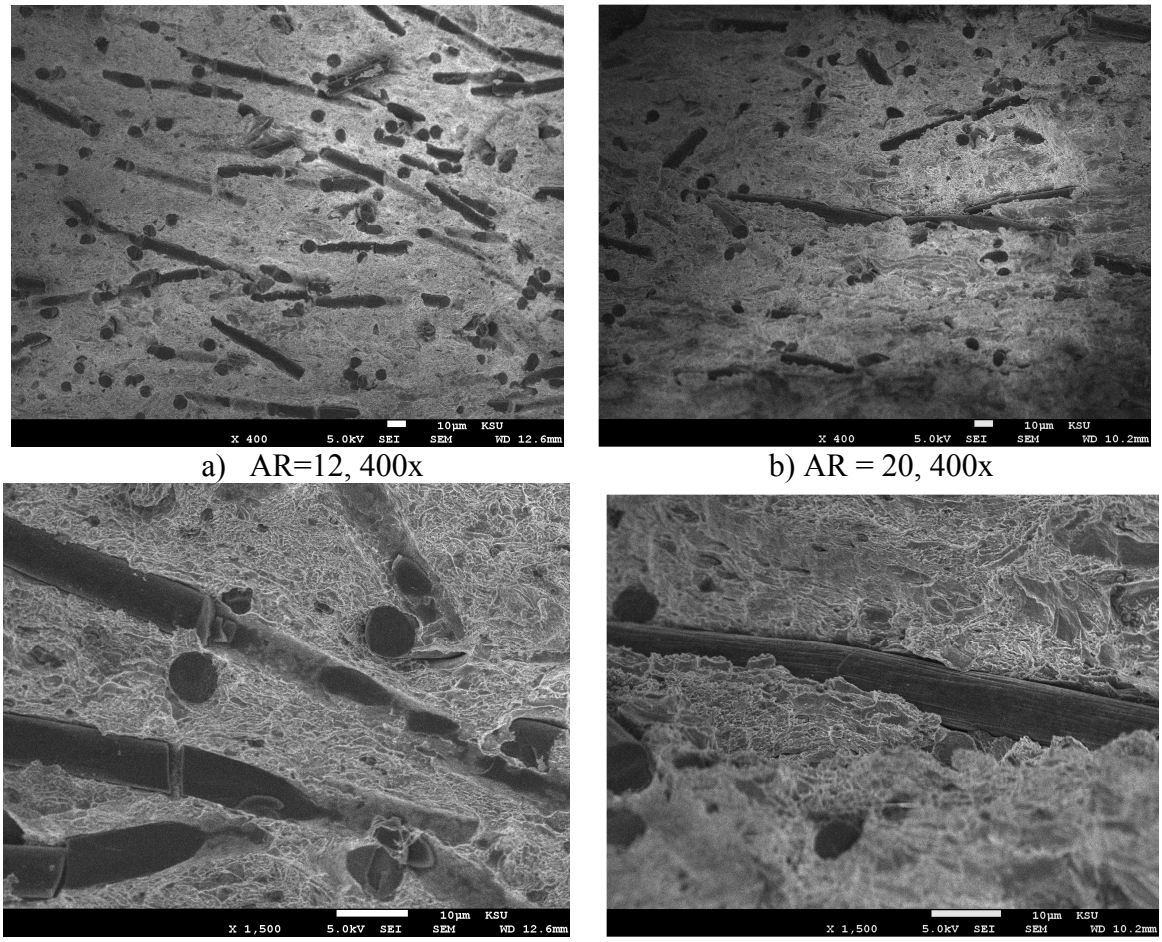
Once the materials are processed using the induction heat furnace, density measurement was then conducted. Table 1 shows the density measurement for the parent aluminum as well as aluminum-fiber composites. Using induction heat furnace, the materials have reached more than 96% density. Fig. 2 shows SEM picture of the Al-carbon composites at 4 wt. % of carbon fiber for aspect ratio of fiber of 12 and 20, respectively. It is clear from the pictures that the carbon fiber were well dispersed in the matrix and randomly oriented in all direction. It was very difficult to have a clear observation of the fiber orientation in the lower weight ratio, namely; 1 and 2%.

Table 1. Theoretical and measured densities for Al-Carbon composites

Materials	% Carbon Fiber	Measured Density [g/cm^3]	Theoretical Density [g/cm^3]	% Density
Pure Al	0,0	2,679	2.71	99
Al+1% CF 90	1,0	2,681	2.6989	99
Al+2% CF 90	2,0	2,648	2.6878	98
Al+4% CF 90	4,0	2,640	2.6656	97
Al+1% CF 150	1,0	2,665	2.6989	98
Al+2% CF 150	2,0	2,639	2.6878	97
Al+4% CF 150	4,0	2,597	2.6656	96

The mechanical properties for the pure aluminum as well as the al-carbon composites were investigated. Hardness and compression experiment were conducted to observe the effect of carbon fiber on the aluminum composites. Fig. 3 shows a bar diagram on the effect of the carbon fiber on the hardness of the composites. The hardness increases with the increase of carbon fiber. For an aspect ratio of 12, the hardness increased from 74 to 83 which is about 12% increase in hardness. Carbon fiber with aspect ratio of 20 has shown a similar trend in hardness but it increased to 10%. Fig. 4 shows the effect of fiber composition and aspect ratio in the strength of the composites. The fiber with aspect ratio of 12 reaches maximum strength of 402 MPa (10% increase in strength) at 1 wt. % ratio of fiber and then the strength remain almost constant. While the fiber of aspect ratio of 20 reaches maximum strength of 388 MPa (6% increase in strength) at 2 wt. % ratio of fiber and then the strength dropped beyond that point. Weak bonding is observed on the interface between

Aluminum and Carbon fiber as shown on Fig. 2a and 2b. The more fiber loaded to aluminum, e.g. 4%, reduces the distance between fibers and tend to align. This can lead to stress concentration that weakening the strength of composites. On the other hand, fibers with perpendicular orientation to the fracture surface strengthening the composite. Higher aspect ratio of fiber increases the area of contact and creates more stress concentration.



a) AR=12, 400x b) AR = 20, 400x

c) AR=12, 1500x d) AR = 20, 1500x

Fig. 2. SEM graphs of the Al-Carbon composites. a) AR=12, 400x, b) AR=12, 400x, c) AR=12, 1500x, d) AR=20, 1500x

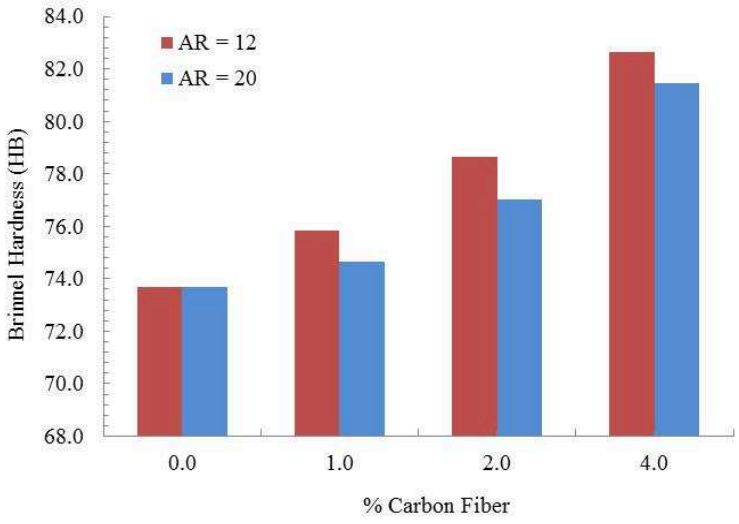


Fig. 3 Hardness measurement for Al-carbon composites.

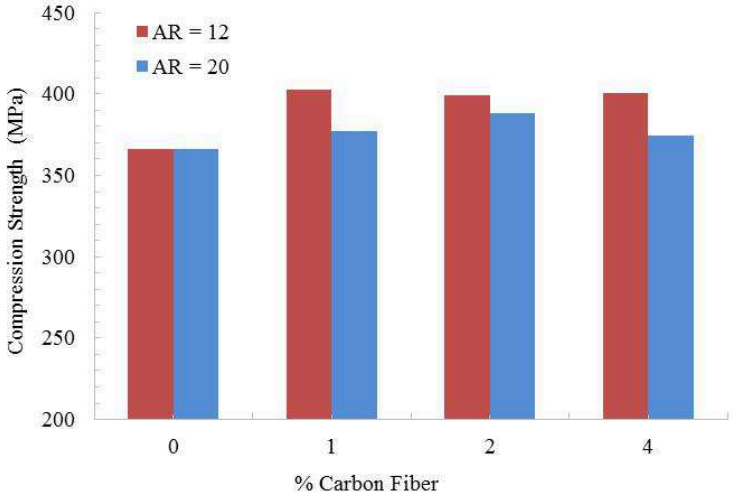


Fig. 4 Compression strength for Al-carbon fiber composites

Conclusion

Al-Carbon composites were processed via powder metallurgy technique. The hardness and compression strength have shown the positive effect of the fiber to strengthen the materials. The effect of the fiber length was not effective on the hardness while it has a diverse effect on the strength. At aspect ratio of 20, the Al-Carbon fiber composites reach maximum value at a weight ratio of 2%. Meanwhile the effect of the carbon fiber ratio did not influence the strength of the composite above 1 wt. % ratio of fiber.

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