Fabrication and characterization of aluminum based nano-micro hybrid metal matrix composites

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Abstract

A process for the development of nano-micro metal matrix composites by squeeze casting method is presented. This paper is reported the influence of nano-micro hybrid fiber preform for fabricating the metal matrix composites (MMCs). A356 aluminum alloy is reinforced by graphite nanofiber (GNF) and alumina short fiber hybrid preform. Based on the microstructure observations, it was found that a good dispersion of the alumna short fiber and graphite nanofiber in the developed MMCs. However, graphite nanofiber appeared densely packed structure due to the volume percentage of nanofiber and the mechanical stirring while preforming. In addition, a nano-indentation study of developed composite was carried out.

1. Introduction

Metal matrix composites (MMCs) reinforced by nano fibers and nano particles are enhanced properties at elevated temperatures and applied widely in aviation, automobiles and nuclear applications [1]. Currently, there are existing results reported on hybrid composites reinforced by short fibers and particulates [2,3,4]. Previously no attempts have been made to develop hybrid preform using alumina short fiber and graphite nanofiber. In addition, it is extremely difficult to disperse nano fibers uniformly into the molten melt due to high aspect ratio and poor wettability in the metal matrix [5]. However, the principle difficulty to develop a preform using nanofiber is its lager surface to volume ratio and it is difficult to handle. Therefore, that disintegrated when expelling from the mould during preforming. Hence, a hybrid preform in that the arrays of the short fibers could be used to disperse the nanofiber. The processing of hybrid preform were previously reported [6]. From the casting routes, squeeze-casting method is widely used for fabricating near net shaped nano composites [7].The preform will be required for squeeze infiltration for a well distribution of nanofibers or nanoparticles. In hybrid MMCs which has been shown that to enhanced mechanical properties. This is due to the reduction of meniscus penetration defects at fiber contact points. Also the reductions in the formation of intermetallic compound at interfaces due to increase in the interfacial area. However, nanofiber based hybrids differs from these MMCs. Since the short fiber network, that is interspace between the fibers also influences the properties of the MMCs. Presently, nanoindnetation have been widely used for investigate the mechanical properties of MMCs [8]. In this paper, A356/GNF-alumina fiber hybrid composites were fabricated by squeeze casting. The microstructure characterization and nano indentation behavior of the developed composite were investigated.

2. Processing methodology

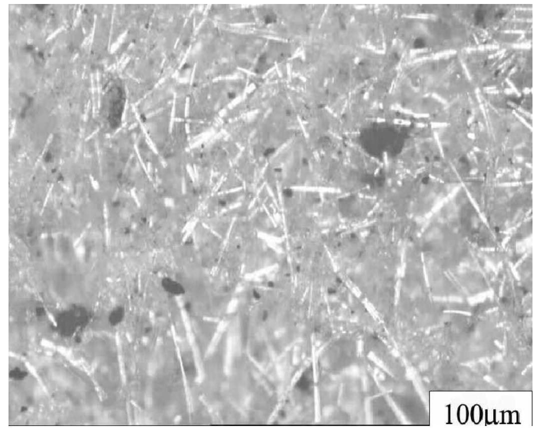
A356 aluminum alloy was used as matrix for this study.The melting temperature of aluminum alloy is in the range of 650^{o}C-680^{o}C.The preform is preheated to 400^{o}C and the die is at 300^{o}C. The developed hybrid preform was placed into the die and molten aluminum alloy was poured into the preform. The pressure applied was 10MPa. A356 aluminum alloy hybrid composites with 20Vol. % were fabricated. The composite microstructure study was carried for developed MMCs using optical microscope and SEM images analysis, which is used to observe the distribution of nanofiber and short fibers. The compositions of MMCs were examining using EDX analysis. The hardness and elastic hybrid composites were measured using nanoindentation.

3. Experimental results and discussion

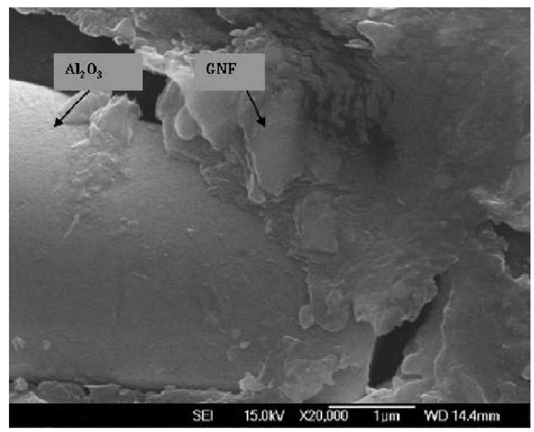
3.1 Microstructure characterization

Fig. 1(a). shows microstructure of hybrid fiber preform. GNF and alumina fiber is good bonding due to the silica colloidal used as a binder as shown in Fig.1 (b). Sodium dodecylbenzene sulfonate (NaDDBs) was used for disperses the graphite nanofiber in the alumina fiber network homogeneously, while the preform was processing [9]. It could be enhances this effect by increases the percentage of NaDDBs. Microstructure observations were carried out for developed MMCs using optical and scanning microscope, which shows that GNF and alumina fiber is uniformly distributed in the matrix alloy as in Fig.2. and Fig. 3. respectively. It can be seen that the aluminum alloy is well infiltrated into the hybrid preform. However, the GNF were densely packed in the short fiber network. This is due to the volume percentage of GNF and mechanical stirring while preforming. This results indicates that the volume percentage of GNF is less than 10% instead of 30% [10], so that it can be avoid the densely packed structure. It is expected that residual thermal stresses are created at the GNF/Al_2O_3 matrix interfaces during cooling from the casting temperature due to the thermal mismatch between the reinforcement and matrix In Fig. 4. shows the SEM image of GNF cluster. From the EDX analysis, it was revealed that even in the GNF cluster is infiltrated by aluminium alloy as shown in Fig. 5. Also, the SEM analysis shows that the graphite nanofibers are well bridged in the aluminium alloy. This will improve the mechanical properties of hybrid MMCs. By changing the Alumina/GNF percentage in the hybrid preform, the mechanical properties can be controlled. In addition, the micro pores are not seen in the SEM image, this indicates that aluminium matrix is also infiltrated in the pores of alumina and GNF in the hybrid preform. Moreover, alumina fiber and GNF are well bonded even after the aluminium alloy is infiltrated in the hybrid preform.

A TEM study is required to characterize the GNF and alumina fiber interfaces in developed MMC. It is clear that more characterization is needed in order to further understand the mechanics of nano-micro hybrid MMCs. In order to avoid the formation of GNF clusters (densely packed structure), a needs to high frequency ultrasonic agitation while preforming.



(a)



(b)

Fig.1. (a) Optical micrograph of GNF-Al_2O_3 -hybrid preform 20%V_f. (b) SEM image, bonding of alumina and GNF.

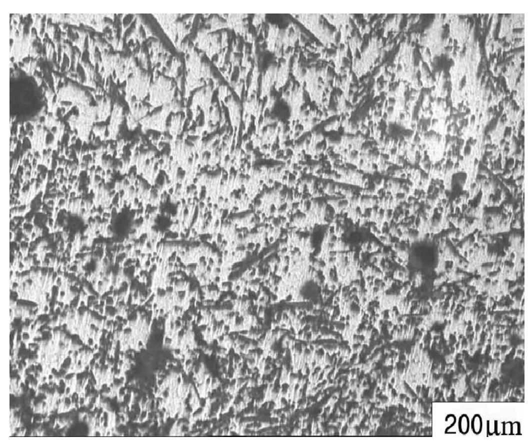


Fig. 2. Optical micrograph of GNF-Al_2O_3/A356 hybrid composite.

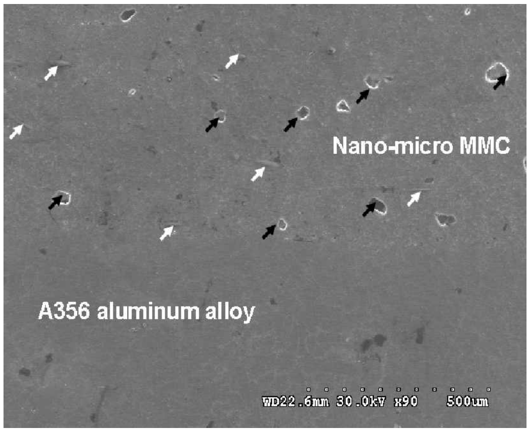


Fig. 3. SEM image of nano-micro MMCs. GNF/Al $_2O_3$ dispersion in A356 aluminum alloy, GNF (black arrows), Al $_2O_3$ (white arrows).

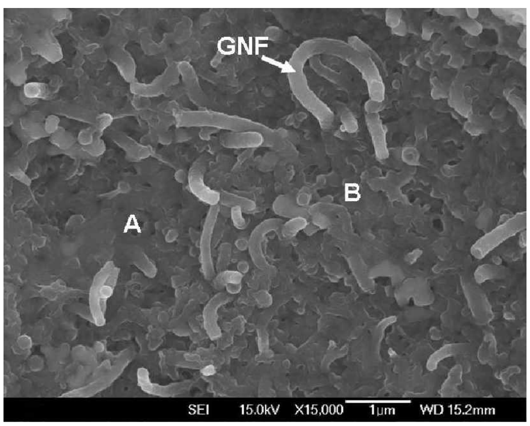


Fig. 4. SEM image observed on GNF cluster in hybrid MMC.

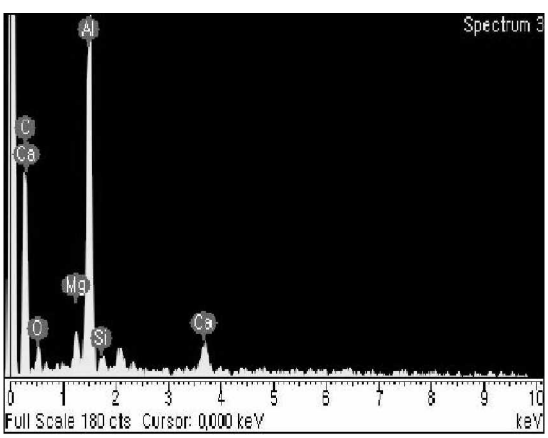


Fig. 5. EDX analysis of hybrid MMC, Position A in Fig 4.

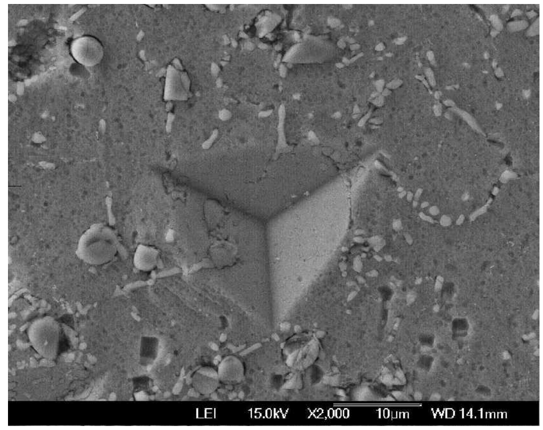
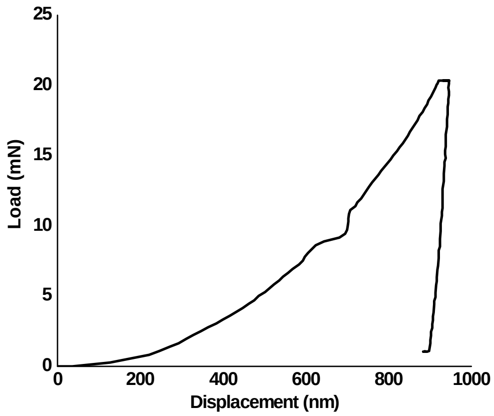


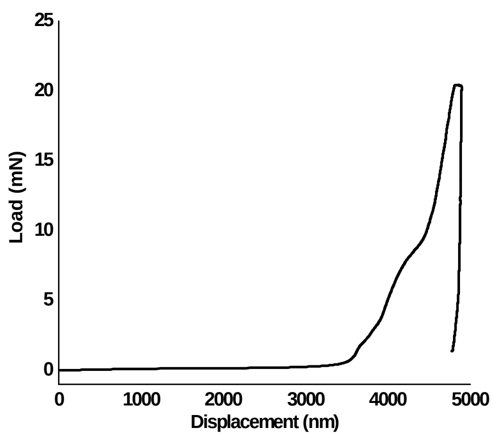
Fig.6. SEM image of nanoindentaion observed on hybrid MMC.

3.2 Nanoindnetation

The hardness and elastic modulus of hybrid MMCs measured using nano indentation method. SEM image obtained after nano indentation is as shown in Fig. 6. The load displacement curve for 20mN is shown in Fig. 7.(a), (b) and (c). From the load displacement curve it could be observed that the load apply on the specimen was initiated from the beginning itself, when the indentation is near the interface of alumina and GNF as shown in Fig.7 (a). However, the indentation is on GNF, the load displacement curve starts after some displacement of the indentation only. This may due to the GNF cluster. From the nanoindentation results, the elastic modulus of hybrid composite was determined to 101GPa at 20mN, which is higher than A356 aluminum alloy i.e.72GPa, as shown in Fig 8(a). However, the elastic modulus is 20GPa, where the indentation is on GNF. This may due to the agglomerates of GNF. The hardness is observed 1GPa, at the load of 20mN.However, the indentation is on GNF cluster the hardness is 0.35GPa. This is due to some of the week vander waals bond between the graphite nanofiber can be easily sheared which is allow to enhances the plastic deformation of the matrix. A small pileup is observed at the edge of indentation, this is due to the plastic deformation of aluminum alloy. Fig 8(b) shows the hardness and elastic modulus measured for the number of times to load is three. Hardness is increases when the number of times to load increases. This is due to the formation of Al_4C_3 in the interface of matrix and GNF. However, the elastic modulus is increases in the initial load steps after that it decreases. This may due to the debonding of matrix and graphite nanofiber.



(a)



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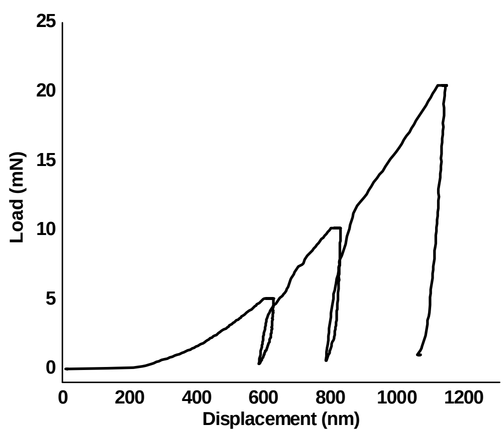
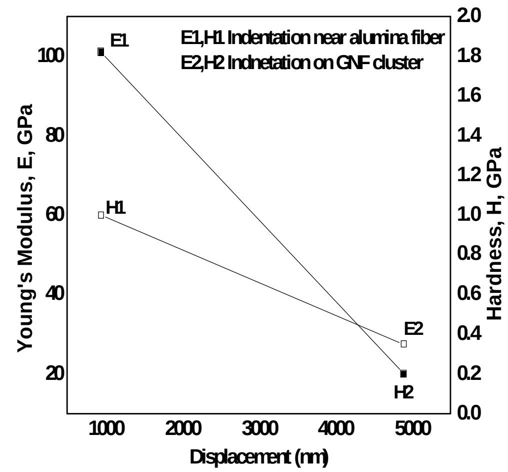
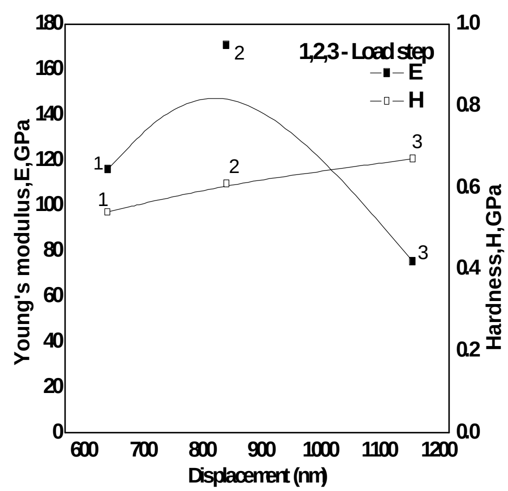


(c)

Fig.7. Load displacement curve of 20mN, Indentation on (a) near alumina fiber and GNF interface (b) GNF cluster (c) number of times to load applied is 3.



(a)



(b)

Fig.8. Hardness (H) and Young's modulus (E) of hybrid MMC measured using nanoindentation (a) the load of 20mN. (b) number times to load step is 3 at 20mN

4. Conclusion

Aluminum based GNF/alumina short fiber hybrid composites were developed by squeeze casting. Based on the microstructure observation, it was revealed that GNF and alumina short fiber well dispersed in the hybrid composites. However, the GNF appeared like clusters due to the mechanical stirring while preforming. Hence, needs for a high frequency ultrasonic agitation while the hybrid preforming. The bonding between the GNF and alumina short fiber is also good. This may due to the percentage of binder in the hybrid preform. From the EDX analysis, it was revealed that hybrid preform is well infiltrated by aluminium alloy. Nanoindentation was used to evaluate the hardness and elastic modulus of hybrid MMCs. Hardness and elastic modulus was increased when the indentation is near the alumina and GNF interfaces. However, the indentation is on other regions shows that hardness and elastic modulus decreases due to the GNF clusters.

Acknowledgment

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