INFLUENCE OF MULTI DIRECTIONAL FORGING ON HARDNESS AND WEAR BEHAVIOUR OF AL7075-BERYL-GRAPHENE HYBRID MMCS

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Abstract

The current study investigates the microstructure, hardness, and wear behavior of hybrid nano metal matrix composites consisting of Beryl and Graphene Nano Platelets (GNPs) as reinforcing elements and Al7075 as the matrix material. Beryl's weight percentage (wt. %) is 6wt. %, while GNPs' weight percentages range between 1wt. % and 2wt. %. Stir casting, the most practical and widely used liquid metallurgical process, was used to create the hybrid nano composites. The goal of this research was to use a severe plastic deformation technique known as multidirectional forging (MDF) and heat treatment. The effects of various heat treatments on mechanical properties, such as annealing, solid solution, peak ageing, and over ageing before MDF, were investigated in this study. At 200°C, the heat-treated material is processed using the multi-directional forging (MDF) technique. A scanning electron microscope (SEM) is used to study the effect of adding Graphene and Beryl reinforcement material in Al 7075 alloy, and a Vickers hardness test is performed to examine the hardness of developed as-cast and MDF processed composites. The Pin-On Disc test is used to study the wear behavior of the as-cast and MDF processed Composites. The SEM results reveals the uniform distribution of the reinforcement in Al7075 alloy. Increased hardness is noticed post incorporation of Graphene and Beryl reinforcement as compared to Al7075 alloy.

Keywords: Al7075 Alloy, Beryl, Graphene, Severe plastic deformation, Microstructure

Introduction

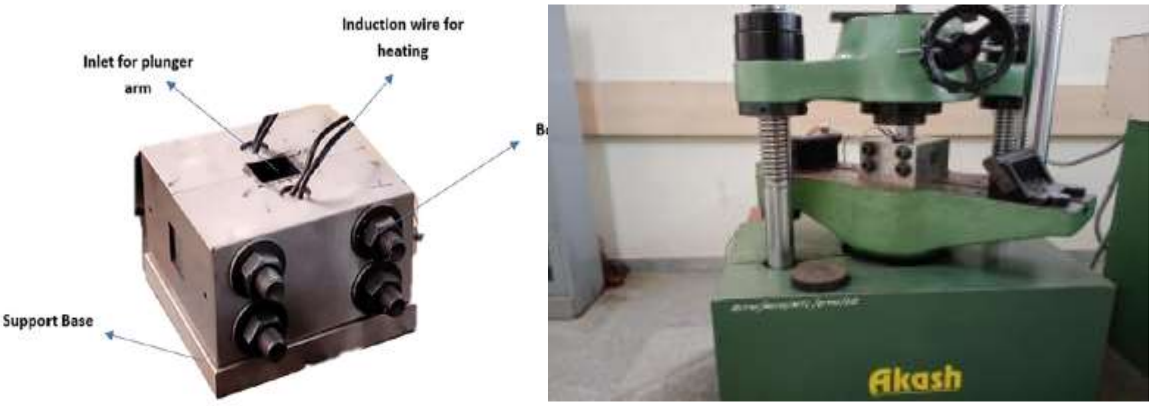
The most adaptable, cost-effective, and visually appealing metallic materials for a variety of applications are aluminium alloys because of the special characteristics combinations they offer. To meet the application demands, the emerging technologies and trends of the current generation necessitate the downsizing of unwieldy structures to light weight structures on the one hand and the integration of various properties on the other [1,5]. The second most used metal in structural applications, behind steel, is aluminium alloys. The several aero plane structural components and other stressed structural applications employ the Al7075 alloy. Metal matrix composites (MMCs) made of aluminium have a number of enhanced customized features that are used in numerous automotive applications. Numerous researchers have been inspired to investigate novel materials and cutting-edge methods of their preparation by the need to enhance the mechanical properties of aluminium alloys. In order to meet the needs of various engineering applications, research primarily focuses on identifying reinforcing materials with superior mechanical properties. The type of reinforcements employed affects the aluminium matrix's performance. Several reinforcements, including SiC, C, B4C, Al_2O_3, Al_3Ni, ZrO_2, W, and TiC, have been utilized by researchers to improve the functionality and characteristics of AMMCs. It has been discovered that beryl and graphene nanoplatelets (GNPs) are the best reinforcing materials for enhancing the characteristics of aluminium MMCs. Al alloy can be strengthened primarily through alloying and age-hardening [5-6]. New complementary and alternative approaches, based on straining and grain refinement, are nonetheless presented. As a result, over the past 20 years, several efforts have been made to develop ultrafine grained (UFG) materials. The Hybrid Metal Matrix is a significant advancement in the development of advanced materials. Aluminium and its alloys are the most commonly used metal matrix materials in the development of MMCs. Al 7075 is a popular aluminium alloy for structural applications due to its appealing comprehensive properties such as low density, high strength, ductility, toughness, and fatigue resistance. It is widely used in aircraft structural parts and other high-stress structural applications. Aluminium reinforced with conventional ceramic materials such as SiC / Al2O3 is gradually being implemented in the automotive industry for the production of pistons, cylinders, engine blocks, brakes, and power transmission system elements. Beryl and Graphene nanoplatelets (GNPs) are better materials with incredible properties, and their addition improves the properties of AMMCs. Many engineering fields, such as automobiles, aerospace, and electronic equipment, are always in need of very light materials with good mechanical properties. Aluminum-based metal matrix composites reinforced with Beryl and GNPs could be a solution for such applications [11-15]. It can meet the requirements of light weight and high strength. The current study focuses on creating hybrid composites with Beryl and GNPs reinforcements for various compositions and evaluating their mechanical properties, as well as investigating the effect of solutionizing (T6) heat treatment on the developed hybrid composites.

The present paper deals with the study of hardness and wear behavior of Al7075-Beryl-Graphene hybrid nano-composites processed by multidirectional forging process.

Experimental Procedure

In this study, Al7075 alloy with Beryl 6wt. % and varying wt. % of GNPs (1 wt.% and 2 wt.%) has been used. The samples were prepared using liquid metallurgy process is shown in Figure 1. Liquid metallurgy vortexing was used to create Al7075/Beryl composites and Al7075/Beryl/Graphene hybrid composites (Stir casting technique). Stir casting is a well-known technique in liquid metallurgy in which a vortex is created using a mechanical stirrer. A predetermined quantity of Al7075 alloy ingots was first kept in a crucible before being placed in an electric furnace to melt. While aluminium alloy melts at 660°C to 700°C, it is superheated to 800°C in the melting furnace to produce the molten matrix slurry and vortex. The tablet hexa-chloro-ethane (C_2Cl_6) was then used as a degassing agent. The use of hexa-chloro ethane degassing tablets is critical in the dissolution of Hydrogen (H2) gas in an aluminium matrix. Porosity is caused by the presence of H2 gas during casting. Stirring facilitates the uniform dispersion of reinforcement into a matrix. For 10 minutes, the molten Al7075 alloy was agitated with a mechanical stirrer at a speed of 300 rpm. By preheating the oven to 500°C, the moisture content of the beryl and graphene reinforcement was removed and the wettability was increased [16-20]. The preheated and calculated weight percentage of reinforcement was included, along with a 5-minute stirring time in the vortex. Metallic solid cast iron moulds were preheated prior to pouring the melt mixture to avoid surface cracking caused by rapid cooling and inadequate filling of the moulds. Finally, Al7075 was dispensed into a preheated solid cast iron mould along with varying weight percentages of Beryl and Graphene particles for solidification. The samples of Al7075/Beryl/Graphene composites produced are shown in Table 1.

Following the stir casting process, the sample was subjected to Multidirectional forging (MDF). MDF is a severe plastic deformation (SPD) technique used to refine grain size down to the nanostructure range. The basic idea behind this technique is to perform multiple repeats of open-die forging operations while rotating the load axis by 90° at each pass. Grain refinement has a significant impact on several material properties, including strength, fatigue, and super-plasticity. Heat treatments are applied to samples in order to investigate the effects of various heat treatments prior to MDF on the evolution of microstructure and mechanical properties. The die design are shown in the figure 2. The samples were cut 30mm x 30mm x 25mm. MDF was processed in three passes at a temperature of 200 degrees Celsius. In one pass, the material accumulates a total strain of 0.18. The material accumulates 0.54 strain in three passes. In MDF processing, these three passes complete one full cycle. H11 tool steel heat treated to 50 HRc was used to make the MDF die. The MDF die is made in a split design with a bottom plate support. Figure 2 depicts the MDF die setup used in this study. MDF was processed using a 40 Ton universal testing machine (UTM). Following the completion of one pass, the sample is rotated 90 degrees over the horizontal axis and pressed to the same strain as in previous passes. Microstructure study and hardness tests were performed. MDF processed Al 7075 reinforced with 6 wt% Beryl and varying wt% Graphene, as-cast Al 6Al7075 alloy, as-cast Al 7075 reinforced with Beryl and Graphene Scanning electron microscopy was used to investigate the microstructures (SEM)



a) Die used for MDF process b) UTM for MDF process

Figure 2: MDF process set up used in the present work

[20-25]. The Vickers hardness test method, also known as a micro-hardness test method according to ASTM E-384, was used to conduct hardness tests on the developed composites as shown in Figure 3. Pin on-disc setup TR20-LE (Ducom Instruments-Bengaluru) was used to analyze wear behavior of Al7075-Beryl-Graphene as per ASTM G99 standard as shown in Figure 4.

Figure 1: Stir Casting set up

Table 1:- List of Specimens prepared with reinforcement wt. % of different composition.

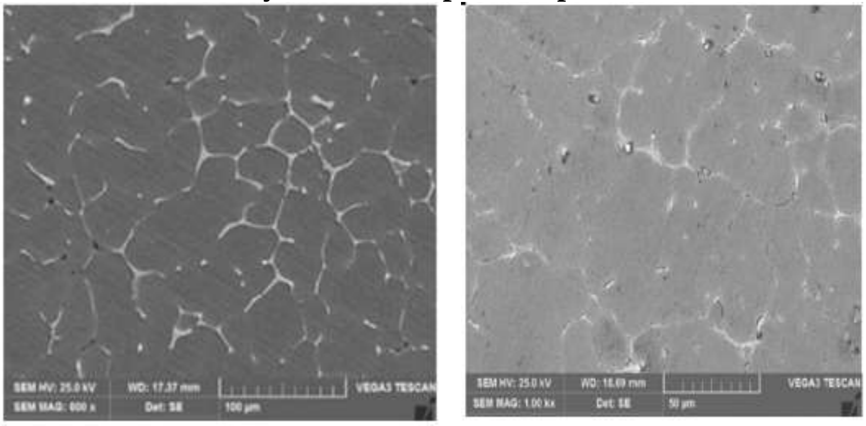
Specimen	**Aluminum 7075**	**Beryl**	**Graphene**
S1	100 wt. %	0 wt. %`	0 wt. %
S2	93 wt. %	6 wt. %	1 wt. %
S3	92 wt. %	6 wt. %	2 wt. %

Figure 3: Vickers Hardness Tester

Figure 4: Pin-On Disc set up for wear test

Results and Discussion

Microstructure Analysis of developed composites

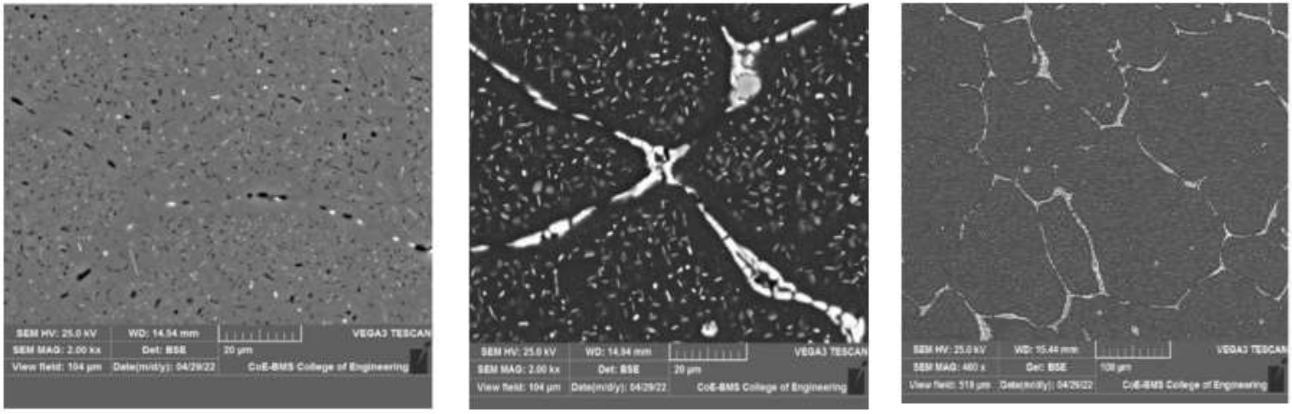


a) Al7075 as cast

b) Al7075 /6wt. %Be / 1Wt. % GNPs as cast

Al7075 /6wt. % Be / 2Wt. % GNP as cast

Figure 5: SEM micrographs of as cast samples



a) Al7075 as cast

b) Al7075 /6wt. %Be / 1Wt. % GNPs as cast

Al7075 /6wt. % Be / 2Wt. % GNP as cast

Figure 6: SEM micrographs of MDF samples

The microstructural characteristics of GNPs as received prior to fabrication and after fabrication of Al7075-Beryl-GNPs composites are thoroughly investigated. Figure 5 and 6 depicts scanning electron microscopy (SEM) images of as cast and MDF processed samples.

The microstructure is revealed by SEM micrographs to be a homogeneous dispersion of fine Beryl particles, GNPs, and intermetallic compounds dispersed along the grain boundary in the matrix of Al 7075, with good bonding between Beryl, GNPs, and Al 7075 alloy. The uniform scattering and strong bonding of GNPs-Beryl within Al 7075 improves its properties. SEM micrographs of Al7075 and its hybrid composites are shown in Figure 5 [30-34].

From the Figure 6, it's clear that after the MDF process the porosity is reduced. Along with porosity, regional clusters of nano particles are observed. There is good interfacial bonding between the matrix material and the carbon nano tubes. The type of reinforcing particles, density, distribution, and size will all have an impact on the properties of the composite material produced.

Hardness

Vickers hardness number of the alloy in different processing states of the material. Al 7075 alloy in cast state possess hardness of 102.2 VHN. After adding 6 wt. % Beryl and 1 wt. % GNP reinforcement to the Al 7075, the hardness increased to 38% VHN as shown in Figure 7. It is noticed that hardness is increased by 15% adding 6 wt. % Beryl and 2 wt% of GNP The hardness of the material is increased by 20% and this process is before MDF. After MDF Al 7075 in cast state process hardness of 85 VHN. After adding 6 wt. % Beryl and 1 wt% of GNP to Al 7075 hardness number of 105 VHN. It is noticed that hardness is increased by 20%. After adding 6 wt% Beryl and 2 wt% GNP to Al7075 hardness number of 130 VHN. It is noticed that hardness is increased by 14%.

It is inferred from the test results that, the increasing of weight percentage addition of Beryl and GNPs enhances the hardness of Al7075 and its composites. The hybrid composites attain peak hardness on the addition of 6wt. % of Beryl particles and 2% of GNPs (sample. The hybrid composites having 6wt.% of Beryl particles and 2% of Graphene developed using casting showed enhancement of 49.23% as compared to Al7075 matrix material for the as cast process. The hybrid composites attain peak hardness on the addition of 6wt. % of Beryl particles and 2% of GNPs (sample C)[35]. The hybrid composites having 6wt. % of Beryl particles and 2% of Graphene developed using MDF process showed enhancement of 70.97% as compared to Al7075 matrix material for the as cast process. This happens due to increases in the surface area of the matrix and the reduced grain size of the GNPs and also Beryl particles are harder than Al7075. This results shows that the MDF process increases Hardness of Al7075 matrix material. The MDF process in which severe plastic deformation leads to formation of precipitates and refinement of grain structure. The presence of hard and high strength Beryl and GNPs enhances the hardness and offer restricted deformation during indentation. Table 2 depicts the micro hardness results of as-cast and MDF processed of developed composites

Table 2: Vickers hardness test results

As-Cast-VHN	MDF-VHN	Percentage Increase in Hardness
85.1	102.2	20.09%
103.6	124.9	17.05%
127	145.5	14.56%

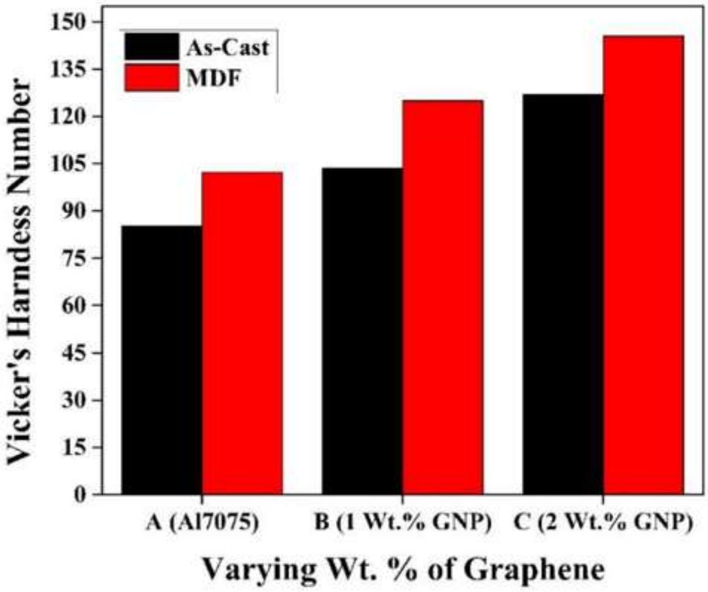


Figure 7: VHN of the developed composites

Wear Behavior of Al7075-Beryl-GNPs Hybrid Composites

One of the most important parameters in material wear loss is the application of load. The wear behaviour of the developed as-cast composites and MDF processed is studied at various loads, namely 10N, 20N, and 30N, while the other two factors, namely sliding speed and sliding distance, are kept constant, namely 1.5 m/sec and 1000m, respectively.

Wear tests on Al7075 matrix alloy and Al7075-Beryl-GNPs hybrid composites revealed that wear loss increases as applied load increases. The wear loss of as-cast and MDF processed Al7075 alloy is highest in all loading conditions, as shown in the figure. Wear loss of hybrid composites composed of Al7075-Beryl-GNPs decreased as the weight percentage of GNPs in Al7075 increased. The Al7075-6 wt.% Beryl - 2 wt.% GNPs have the greatest reduction in wear and increase in wear resistance. This is due to the Al7075's high hardness and homogeneous dispersion of GNPs and Beryl particulates. GNPs and Beryl particulates act as a barrier and have a significant impact on wear resistance enhancement.

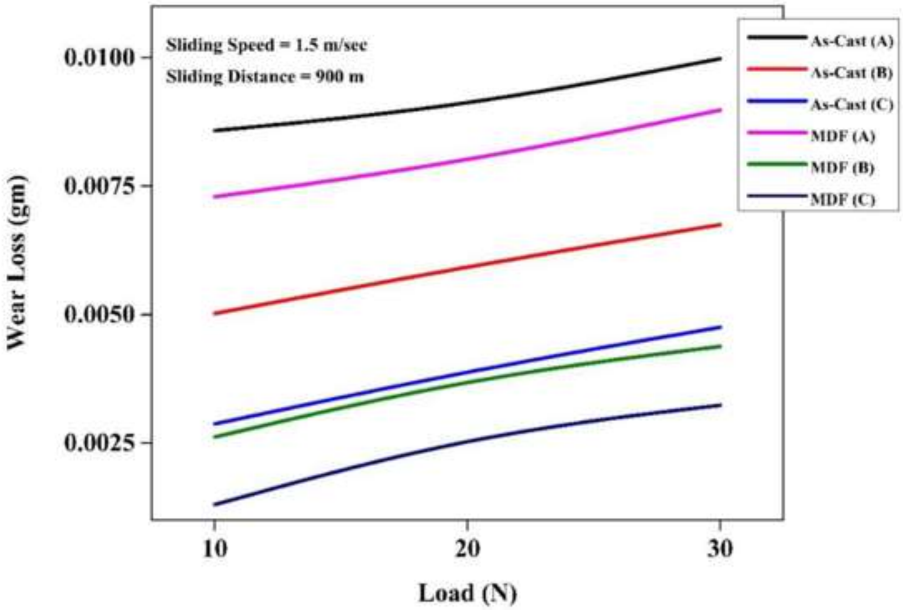


Figure 8: Wear loss of as-cast and MDF processed Al7075 and its hybrid composites at different loads

Conclusion

1. Al7075 alloy – varying wt. % of Beryl (2 wt. %, 4 wt. %, 6 wt. %, & 8 wt. %) composites were successfully fabricated via melt stirring method and multi-directional forging process.
2. The reinforcements Beryl and GNPs particulates were introduced into Al7075 alloy using melt stirring which caused in uniform dispersion of Beryl and GNPs with very less or clustering/agglomeration which is observed in SEM micrographs.
3. The increase in weight percentage of Beryl and GNPs increases the hardness of Al7075 and its hybrid composites. The hybrid composites attain peak hardness on the addition of 6wt. % of Beryl particles and 2% of GNPs. The hybrid composites having 6wt. % of Beryl particles and 2% of Graphene developed using casting showed enhancement of **49.23%** as compared to Al7075 matrix material for the as cast process. The hybrid composites attain peak hardness on the addition of 6wt. % of Beryl particles and 2% of GNPs (sample C). The hybrid composites having 6wt. % of Beryl particles and 2% of Graphene developed using MDF process showed enhancement of **70.97%** as compared to Al7075 matrix material for the as cast process.
4. The effect of the applied load on Al7075-Beryl-GNPs composites was studied. The wear loss of the Al7075-Beryl-GNPs hybrid composites increases with increase in the loads. And also wear loss of the Al7075-Beryl –GNPs hybrid composites decreases with increase in weight percentage of reinforcements GNPs in the Al7075 alloy.

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