Influence of Graphite on Mechanical Properties of Al6061-hBN-Gr Hybrid MMC’s

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Abstract: ***The demand of Aluminum composite is increasing with each passing day. Due to its special and unique properties than regular Aluminum and its alloys Aluminum composites are extensively used in aerospace, automobile, marine etc. because of the properties like light weight, low density, structural rigidity, high strength and good conductivity. This paper deals with the fabrication and mechanical investigation of Aluminum 6061, Hexa Boron Nitride (hBN), and Graphite (Gr) hybrid metal matrix composites. Al6061 is the matrix metal having properties like good toughness, excellent corrosion resistance, good weldability and brazability. Boron nitride has excellent thermal and chemical stability and also high hardness. Graphite is a self-lubricating reinforcement that enhances the antifriction properties. The fabrication is done by stir casting which involves mixing of the required quantities of reinforcements into stirred molten Al6061. After solidification, the specimens were prepared as per ASTM standards to determine various mechanical properties like tensile, density and hardness. The microstructure of the composite was observed by optical microscope (OM).***

Keywords: Aluminum 6061, Hexa Boron Nitride, Graphite, Stir Casting, Mechanical Properties

1. Introduction

The use of aluminum metal matrix composites has increased in the recent years replacing many conventional metals like steel, iron etc. in the fields of automobile, aerospace, marine, high speed trains etc. because of their superior properties such as low density, high wear resistance, stiffness, reliability, toughness, good combination of strength to weight ratio. Mechanical properties of aluminum can be improved by reinforcing aluminum with proper material and through creating composite material. The most effective improvement of these properties is through creating hybrid composite with two or more reinforcements. By adding boron nitride mechanical properties of matrix changes, causing by adding graphite machinability can be increased.

2. Experiment Details

2.1 Materials

In this work for preparing metal matrix composite, aluminum 6061 (Al6061) was used as base material. Hexa Boron Nitride and Graphite in the powder form are used as the reinforcements. Aluminum alloy was cut into small ingots so that it can be easily placed in the crucible for melting.

2.1.1 Aluminum 6061

One of the most popular matrix material that is used metal matrix composites is Al6061. Because of good corrosion resistance, good electrical and thermal conductivity, low density, good machinability etc Al6061 is quiet attractive. Mechanical properties of this alloy can be enhanced when it is reinforced by other particles. The common reinforcements used with this alloy are aluminum oxide, silicon carbide, silicon dioxide, graphite, boron nitride, boron carbide etc.

2.1.2 Boron Nitride (hBN)

Boron nitride has excellent thermal and chemical stability and also high hardness. The particle size of hexa boron nitride used in this study is 7-11 microns. The grade of hexa boron nitride used is HCV grade. HCV grade is a basic grade of boron nitride and this serves as a starting block for the production of many advanced materials.

2.1.3 Graphite (Gr)

Graphite is a self-lubricating reinforcement that enhances the antifriction properties due to the graphite’s lamellar structure. The addition of graphite to the matrix improves the machinability of the composite. The particle size of graphite used in this study is 260 microns.

2.2 Composite Preparation

Stir casting method was used for the preparation of composite. In this process Al6061 bars were cut into small ingots using a chisel and hammer. These ingots were placed in a clay graphite crucible and the crucible was kept in the electrical resistance furnace. The ingots were melted for 5 to 6 hours at a temperature of 800 ºC. The gaseous impurities present in the molten metal that would cause porosity in the castings are liberated by the addition of degassing tablet (hexachloro ethane) into the molten metal and the slag was removed from the molten metal. The Gr and hBN particles are pre-heated at a temperature of 400 ºC for about one hour to increase the surface reaction. These pre-heated particles were then added into the melt and stirred continuously in order to achieve uniform distribution of particles in the matrix. The size of the graphite and hexa boron nitride particles used is 260 microns and 7-11 microns respectively. Magnesium of 0.5 % weight was added into the melt in order to reduce the non-wetting behavior of the hBN particles that would cause low interfacial bonding with the matrix. After the mixing of the reinforcements with the matrix, the crucible was taken out of the furnace and the molten metal was poured into the metal mould and allowed to solidify. After the solidification, the casted specimen is removed from the mould.

Composition A = Al6061-6%hBN-2%Gr
Composition B = Al6061-6%hBN-4%Gr
Composition C = Al6061-6%hBN-6%Gr

2.3 Testing of composites

For the micro structural analysis, optical microscope was used and the specimens were polished by different grades of emery paper, alumina paste, and diamond paste and etched with the Keller's reagent. The density test was conducted by water displacement method to out find the densities of different composition and the base metal. Hardness test was conducted on Vickers Hardness to determine the hardness of the composites and base metal. The tensile test was conducted on a Universal Testing Machine (UTM) to determine the tensile strength and the percentage elongation. The specimens were prepared as per ASTM E8 standard for tensile test.

3. Results and Discussion

3.1 Micro Structural Studies

The micro structural studies were carried out to examine the distribution of reinforcement particles in matrix phase Also the structure reveals grain size separated by thin black grain boundaries. The extent of uniformity in distribution of particles has a significant role in the performance of the composites. Specimens for the microstructure studies were prepared and examined with the help of metallurgical microscope having a magnification of 50X, 100X, 200X, 500X and 1000X. Below Figures shows the microstructure of Aluminum metal matrix with reinforcement particles.

3.2 Optical Microscopy

The etched specimens observed under the microscope revealed the following structure, by using OM (optical microscope). The optical micrographs of the fabricated and polished AMCs are as shown in Figs 3.1, 3.2 and 3.3of three compositions. The porosity and grain boundary are appearing clearly from all the three compositions. The optical micrographs of the fabricated and polished AMCs are as shown figures of three compositions. The effective and constant stirring of the molten can result in uniform distribution of the particles.

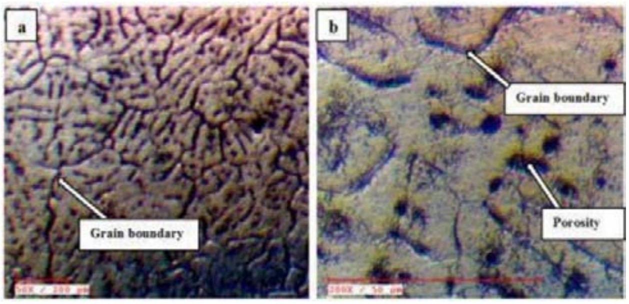

Figure 3.1: Optical micrographs of MMCs composition A (Al6061- 6%hBN-2% Gr)

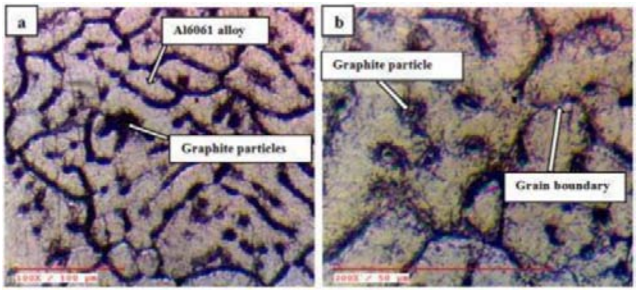

Figure 3.2: Optical micrographs of MMCs composition B (Al6061- 6%hBN-4% Gr)

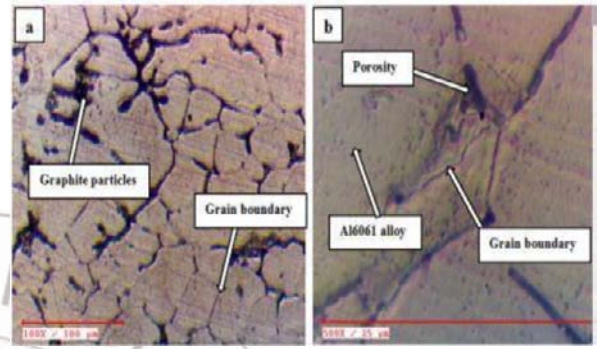

Figure 3.3: Optical micrographs of MMCs composition C (Al6061- 6%hBN-6% Gr)

The metallographic examinations of developed hybrid metal matrix composites make it possible to observe the extent dispersal of the reinforcing particles in the matrix phase grain boundary and porosity in the three compositions of composites. From micrographs we can observe that reinforcements in the composites is fairly uniform in all the compositions studied. Increasing the % of reinforcements the grain boundaries arrangement is increases because the mechanical defects (porosity).

3.3 Scanning Electron Microscopy (SEM)

The scanning electron microscope produces images of the sample by scanning it with a intensive beam of electrons. The electrons interact with the atoms of the sample and produces several signals that can be identified and containing the information about the sample to be examined. Fig 3.3 shows the morphology of prepared MMC for composition (2%graphitre+6% boron nitride) wt% and is clearly seen that the graphite and boron nitride particulates are dispersed uniformly in matrix material. The particles are tightly packed with a homogeneous special distribution in each composite. From the Fig 3.4(a) we can observe the distribution of particles in that the white particle is called the boron nitride and small black particles are graphite. The porosity in a composite can be easily identified by the SEM, these porosity will cause the mechanical defects and finally the material will fail. The microstructures of cast Al-Gr, Boron nitride particulate composites specimen were studied by SEM. The SEM micrographs clearly indicate that the Graphite, Boron nitride particulates are distributed evenly in Al6061 matrix even at weight fraction is as high as 6 % weight and low as 4% weight, 2% weight. The microstructure of the Boron nitride, Graphite and Al6061 composites with dissimilar particle sizes are shown in above micrographs. The particles are tightly packed with a homogeneous spatial distribution in each composite. The distribution of particulate reinforcement is fairly identical. The aluminum matrix is seen as continuous material. Particulates are seen in between the matrix small sizes with grain boundaries and we can observe addition of reinforcements differ in structure increasing the porosity and mechanical defects and it's are relatively large and oval grains. The reinforcement particles are circular and rectangular in shape and dispersed quite homogeneously in all the samples. At some places due to non -uniform distribution we can observe some blunts, especially in higher volume percentage samples, the increased addition of reinforcement particles can also increase the mechanical defects in the composite.

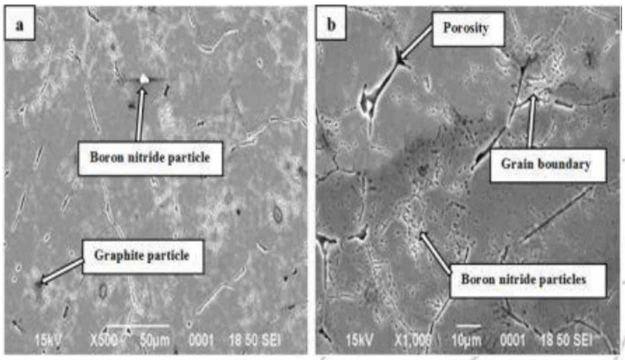

Figure 3.4: SEM micrographs of MMC"s composition A (*Al6061-6%hBN*-2%Gr**)**

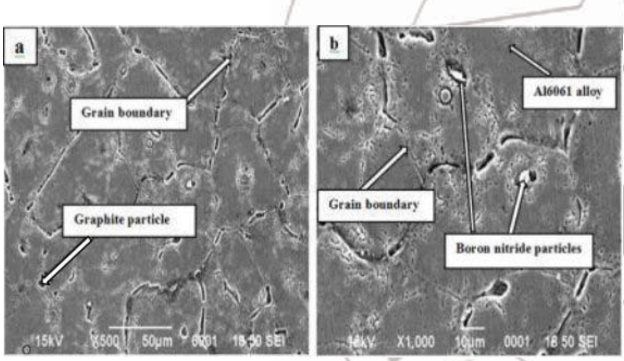

Figure 3.5: SEM micrographs of MMC"s composition B (Al6061-6%hBN4%Gr

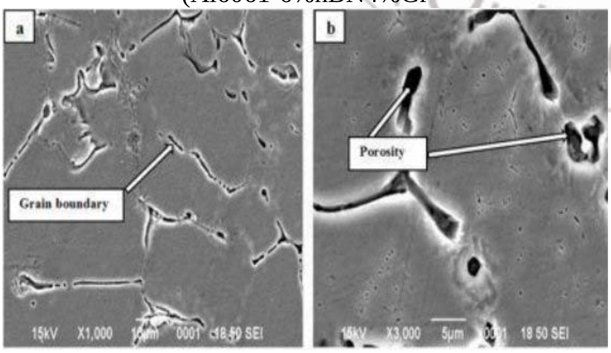

Figure 3.6: SEM micrographs of MMC"s composition C (Al6061-6%hBN-6%Gr)

3.4 Tests for Density

The theoretical density of the composites can be obtained by the rule of mixture approach. Here the weight and density of matrix and the reinforcement is taken individually then by the formula we can obtain the theoretical density. Density tests are conducted by finding the mass of the specimens measured using the water displacement method and are calculated by its mass and volume. The values of density obtained by this procedure are tabulated in the Table 3.1.

Table 3.1: Density with varying percentage of reinforcements

Material	Experimental	Theoretical
Composite A	2.67gm/cm^3	2.34gm/ cm^3
Composite B	2.68gm/cm^3	2.39gm/ cm^3
Composite C	2.73gm/ cm^3	2.45gm/ cm^3

The experimental density is more for all the compositions as compared to the theoretical density values obtained by the rule of mixture. This can be graphically observed from the Fig 3.7, the experimental density increased as the weight percentage of graphite increased, and also the theoretical density values are increased with increase in weight percentage of graphite.

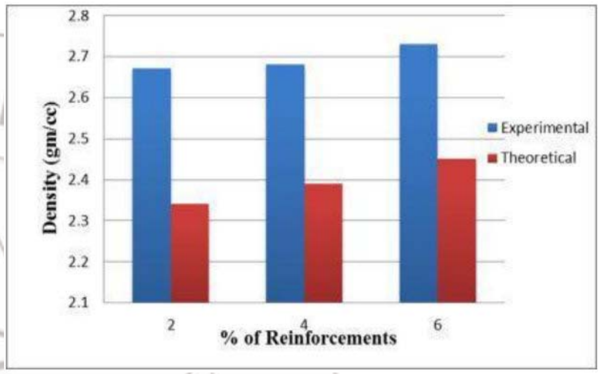

Figure 3.7: Comparison graph of Experimental v/s Theoretical density

Figure 3.8: Density test specimens

3.5 Hardness Test

Hardness test is conducted using the Micro Vickers hardness tester machine in the room temperature. Here considered particularly matrix and reinforcement material with 50gms of load is applied for 10sec, the data on three experiments were conducted for each composition and tabulated in the Table 3.5, it could be seen from the Fig 3.8 that the hardness of the test specimen increased at 4% of graphite and once again there is decrease in the hardness by the addition of graphite reinforcement by 6%.

Table 3.2: Micro Vickers hardness test with varying percentage of reinforcements

Material	*Load Applied (gm)*	*Time (sec)*	*HV*	*HV (average)*
Composite A	50	10	99	99.3±1.24

			98	
			100	
Composite B	50	10	101	100±0.81
			99	
			100	
Composite C	50	10	91	92.33±1.24
			92	
			94	

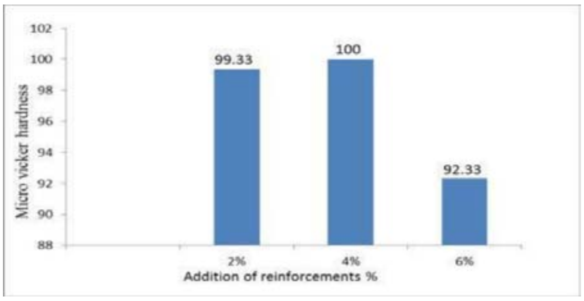

Figure 3.9: Graphical representation of hardness comparison

3.6 Tensile Test

Tension test were conducted on computer-interfaced universal testing machine, with a capacity of 100 KN. Data acquisition software "KALPAK was used for testing, the rate of loading was 1mm/min. The tensile test was conducted at room temperature on the specimens. The experiments are repeated thrice and average readings were computed and presented in Table 3.3

Table 3.3: Percentage of elongation with varying percentage of reinforcements

Composition	UTS (MPa)	Percentage of Elongation (%)
Composition A	133.04±2.05	4.89
Composition B	155.04±11.70	8.64
Composition C	128.88±6.03	6.37

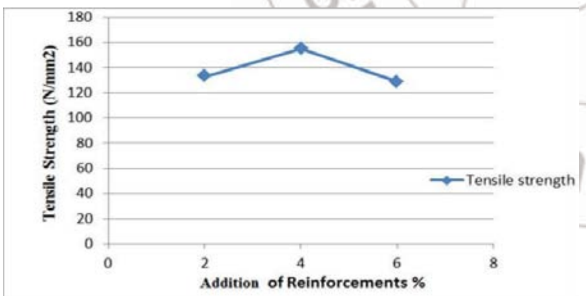

Figure 3.10: Variation of tensile strength with the addition of reinforcements

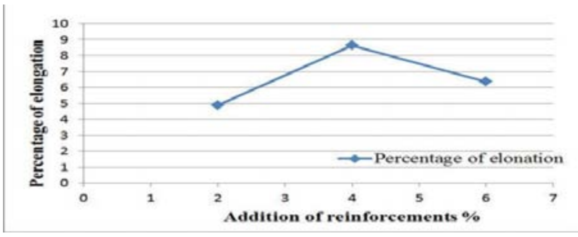

Figure.3.11: Variation of percentage of elongation with the addition of reinforcement

3.7 Wear Test

Wear test is conducted for varying load condition Table 3.4 in which the speed of 400rpm and time 10mins is taken as constant for all the trials and the load is varied at 1kg, 2kg and 4kg respectively.

Table 3.4: Wear test for varying load with varying percentage of reinforcements

Specimen	Trail	Speed (rpm)	Time (min)	Load (kg)	Wear (μm)	Frictional force (N)
Composition A	1	400	10	1	8	3.4
	2	400	10	2	17	6.5
	3	400	10	4	23	6.9
Composition B	1	400	10	1	5	6.1
	2	400	10	2	28	6.2
	3	400	10	4	29	11.9
Composition C	1	400	10	1	14	3.7
	2	400	10	2	21	7.0
	3	400	10	4	29	11.1

As shown in the table 3.4 the wear test is conducted for varying load condition in which the speed of 400rpm and time 10mins is taken as constant for all the trials and the load is varied at 1kg, 2kg and 4kg respectively.

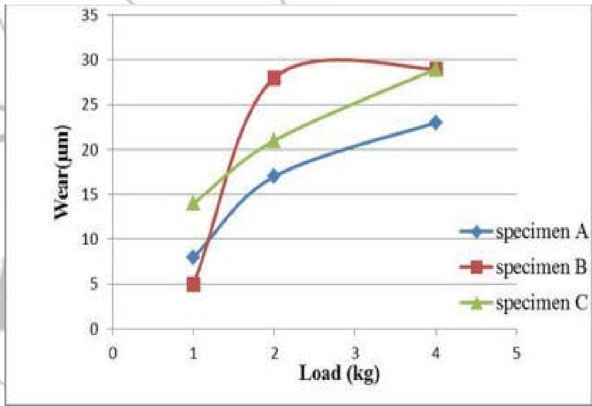

Figure 3.12: Variation of wear v/ s load with the addition of reinforcement

From the Fig 3.12 it can be that the wear of specimen A, specimen B and specimen C increased with the increase in load. All the specimens are finished with a 600 grade emery paper for each trial, and the surface of the specimen and the surface of the 55 disc plate are cleaned with acetone. This will remove all the dust, small blurs and irregularities in the specimen, by this we can obtain effective results.

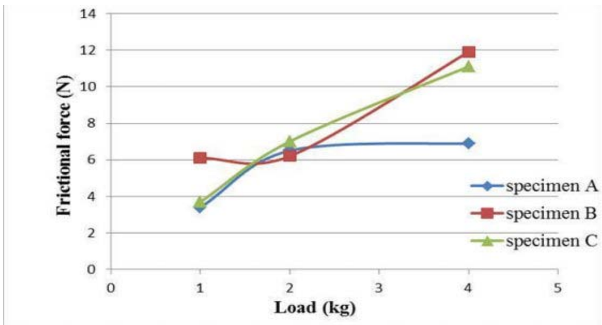

Figure 3.13: Variation of frictional force v/ s load with the addition of reinforcement

From the Fig 3.13, it can be explained that the frictional force of the specimen increased as the load increased.

4. Conclusion

The following conclusions have been made on the experimental results obtained from the study of Al6061 reinforced with Boron nitride and Graphite Hybrid metal matrix composites:

1) Stir casting process is the effective way to obtain the samples with homogeneous microstructure and good mechanical properties.
2) From the composition (6% Boron nitride and 2% Graphite) it is observed that the micrographs have less porosity and grain boundaries because of good bonding in particles and homogeneous distribution of particulates. Composition (6% Boron nitride and 6% Graphite) reinforcement have higher porosity and grain boundaries because of addition of higher percentage of particulates which leads to the higher defects in the composite.
3) By adding the reinforcements the density values are slightly increased with constant range which is due to adding the particulates, the experimental density values are slightly higher than the theoretical density values.
4) The Micro Vickers hardness results obtained shows that the hardness of composition B is higher than composition A and composition C.
5) The computerized wear test results revealed that the wear and frictional force values obtained shows increasing in all the trials of varying load, varying speed and varying time of all compositions A, B and C.
6) Adding boron nitride up to 6% has increased physical, mechanical and wear properties of the composite.
7) From the overall test results the composition B containing 4% graphite shows improved properties as compared to composition A containing 2% of graphite and composition C containing 6% of graphite.

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