Testing of LM13/B4C/GR Aluminium Metal Matrix Composite

Vishnu T S
M-Tech Student
Department of Mechanical Engineering
Ilahia college of Engineering & Technology, Mulavoor P.O. Muvattupuzha, India

Faisal M H
Assistant Professor
Department of Mechanical Engineering
Ilahia college of Engineering & Technology, Mulavoor P.O. Muvattupuzha, India

Abstract

Aluminum metal matrix composites provide both light weight, courtesy of the aluminum matrix, and enhanced strength, stiffness and wear resistance through the reinforcement which is added to produce the composite, although this is achieved at the expense of ductility. While commonly used reinforcements include SiC and Al2O3, the more recently used B4C is both the lightest and the hardest of the three, making it a viable choice with respect to the reduced weight criterion. Additionally, the capacity of boron for high neutron capture has created much interest in using B4C reinforced aluminum composites in strategic applications. The enhanced elevated-temperature strength and favorable neutron absorption characteristics of Al-B4C composites are strong points which justify investigating their suitability for use in both current and emerging applications. Aluminum/graphite composites have been used as self-lubricating materials due to the superior lubricating effect of graphite during sliding. The greatest challenge in introducing aluminum graphite composites in industrial components is the negative effect of graphite on mechanical properties of composites.LM13 alloy is selected as matrix material due to its wide acceptability in automobile and industrial use. Stir casting method is employed to fabricate composite with different particulate weight fraction (Gr 2% and B4C 3 %, 5%). Using computerized universal testing machine and rock-well hardness tester mechanical properties such as hardness and tensile strength were tested. The test results indicates that by raising weight % of boron carbide particles in the LM13, tensile strength and hardness of the hybrid composites was increased

Keywords: Boron carbide, Graphite, Hybrid aluminium matrix composite, Tribological, LM13

I. INTRODUCTION

Aluminum alloys are used extensively in aircraft due to their high strength-to-weight ratio. On the other hand, pure aluminum metal is much too soft for such uses, and it does not have the high tensile strength that is needed for airplanes and helicopters. Copper is one of the best alloying elements since the beginning of the aluminum metal matrix composites. In the cast alloys the basic structures consists of dentritic in nature and possesses aluminum solid solution, with a variety of particles at the grain boundaries or inter dendritic spaces, forming brittle components with eutectics in nature. Most alloying elements can improve the modulus of elasticity of aluminum, but the increase is not remarkable for the aluminum-copper alloys. The modulus of elasticity at room temperature is of the order of 70-75 G Pa and practically the same in tension and in compression. It changes regularly with temperature from a value of 76-78 G Pa at 70 K to a value of the order of 60 G Pa at 500 K. The Poisson ratio is of the order of 0.32-0.34. The Poisson ratio increases with increasing temperature. Many of the cast alloys and of the aluminum-copper-nickel alloys are used for high-temperature applications, where creep resistance is important[1].

Commonly used reinforcements in aluminium matrix composites are alumina, silicon carbide, graphite etc. Boron carbide is the third hardest material in the world after diamond and boron nitride. Due to higher hardness and toughness boron carbide is employed as a replacement to Silicon carbide and Alumina. Good toughness, low density, enhanced chemical stability, and hardness, better wear resistance and high strengths are the attractive properties of boron carbide composites [2]. Additionally, the capacity of boron for high neutron capture has created much interest in using B_4C reinforced aluminum composites in strategic applications. The enhanced elevated-temperature strength and favorable neutron absorption characteristics of Al-B_4C composites are strong points which justify investigating their suitability for use in both current and emerging applications. Aluminum/graphite composites have been used as self-lubricating materials due to the superior lubricating effect of graphite during sliding. The greatest challenge in introducing aluminum graphite composites in industrial components is the negative effect of graphite on mechanical properties of composites[3]. Due to the better wettability of the boron carbide particles with the aluminium alloy, homogeneous reinforcement distribution can be achieved. Hardness of the composites gets increased by increasing the wt % of boron carbide particles in the aluminium matrix. This phenomenon is due to the resistance of reinforcement particles to the plastic deformation of matrix material. Up to 8 wt % boron carbide reinforcement, tensile strength increases. Beyond 8%, reduction of tensile strength occurs due to the clustering of reinforcement particles which leads to brittleness. Structural and automotive components of better mechanical properties are developed using this metal matrix composite [4]. Important processing techniques are liquid metallurgy and powder metallurgical techniques .Comparing both techniques liquid techniques are adaptive. There is unidirectional solidification in liquid metallurgy to produce directional metal matrix composites. Famous liquid metallurgy techniques are stir casting, spray casting and pressure infiltration. Comparing to other methods liquid metallurgy techniques were selected due to their inexpensive nature [5].

II. Scope and Objective

A. *Scope*

Aluminum/graphite composites have been used as self-lubricating materials due to the superior lubricating effect of graphite during sliding. The greatest challenge in introducing aluminum graphite composites in industrial components is the negative effect of graphite on mechanical properties of composites. There are many approaches to reducing the damaging effect of graphite particles on the deterioration of mechanical properties. For example, using hybrid aluminum metal matrix composites containing ceramic particles and graphite particles shows better tribological behavior compared to aluminum alloys or Al/Gr composites. In these hybrid composites, graphite acts as a solid lubricant and ceramic particles have load bearing ability, which leads to decrease in wear rate.

B. *Objectives*

Fabrication of a hybrid aluminium metal matrix composite to improve the characteristics of self-lubricating composites.
Evaluation of wear characteristics and other mechanical properties of hybrid aluminium metal matrix composite.
MATERIALS AND METHODOLOGY

1) LM13

LM 13 aluminium alloy was selected as the base matrix in this study. It is often used for piston, pulleys, sheaves and bearings and other areas where higher thermal stresses are occuring. Capability to withstand high temperature and loads, good wear resistance and better machinability makes LM13 favourable for such applications.

Table – 1
Mechanical properties of LM13

PROPERTIES	*VALUES*
Density (kg/m3)	*2700*
Tensile strength (Mpa)	*170-200*
Melting point(°C)	*695*
Poison's ratio	*0.36*
Young's modulus (Gpa)	*86*

2) Boron carbide

After diamond and cubic boron nitride, Boron carbide is the third hardest material. Elevated temperature stability, better hardness and elastic modulus, low density, outstanding thermoelectric properties and greater chemical inertness of boron carbide than alumina and silicon carbide results it a favourable reinforcement for metal matrix composites. Compared to aluminum matrix and silicon carbide, interfacial bonding between the aluminum matrix and the boron carbide reinforcement is more effective.

Table – 2
Mechanical properties of Boron carbide

PROPERTIES	*VALUES*
Density (kg/m3)	*2550*
Tensile strength (Mpa)	*500*
Melting point(°C)	*3500*
Poison's ratio	*0.17*
Young's modulus (Gpa)	*460*

3) Graphite

Generally graphite is opaque and have greyish-black colour. Both metal and non-metal properties makes it unique. Greater electrical and thermal conductivity, flexibility, high refractory nature and chemically inertness are dominant properties of graphite. Low adsorption of neutrons and X-rays make graphite a helpful material in nuclear sectors. Its engineering applications also extends to vanes, journal bearings, piston rings and thrust bearings. In the fuel pumps and shafts of many aircraft jet engines carbon based seals are used

Table – 3
Mechanical properties of Graphite

PROPERTIES	*VALUES*
Density (kg/m3)	*1950*
Tensile strength (Mpa)	*76*
Melting point(°C)	*3800*
Poison's ratio	*0.21*
Young's modulus (Gpa)	*12*

4) Stir casting

Stir casting apparatus is shown below. For the fabrication of metal matrix composites it have a graphite crucible which is in cylindrical shape. This crucible is designed in such a way that it is capable of withstanding higher temperature. As the melting point of graphite is round 3800 degree celsius it will not react with aluminum at working temperature. Graphite crucible is positioned on high ceramic alumina muffle. Initially heater temperature is set to 500°C and then it is steadily increased up to 900°C. LM13 is used as matrix material. From the aluminium alloy ingots needed quantity is chopped in rectangular pieces. Properly cleaned Aluminum alloy is weighed and then placed in the graphite crucible for melting. Graphite and boron carbide Powder are used as reinforcements. Melting point of LM13 alloy is 695 degree celsius and due to high muffle temperature it is quickly melted. Elevated temperature also results in lowered oxidation level and intensified wettability of the reinforcement particles in the matrix metal [5].

Fig. 1: Stir casting equipment.

Fig. 2: Casting process

This is the layout of the stir casting apparatus. It consist of cylindrical shaped graphite crucible is used for fabrication of AMCs, as it withstands high temperature which is much more than required temperature [680°C].Along that graphite will not react with aluminum at these temperature. This crucible is placed in muffle which is made up of high ceramic alumina. Stir casting process starts with placing empty crucible in the muffle. At first heater temperature is set to 500°C and then it is gradually increased up to 900°C.High temperature of the muffle helps to melt aluminum alloy quickly, reduces oxidation level, enhance the wettability of the reinforcement particles in the matrix metal. Aluminum alloy LM13 is used as matrix material. Required quantity of aluminum alloy is cut from the raw material which is in the form of rectangular pieces. Aluminum alloy is cleaned to remove dust particles, weighed and then poured in the crucible for melting. Powder of boron carbide (B_4C) and graphite are used as reinforcement[6].

Compositions of two samples are given below

Sample 1: LM13 95% , Graphite 2% and Boron carbide 3%

Sample 2: LM13 93% , Graphite 2% and Boron carbide 5%

Table – 4
composition of LM13, B4C & Gr

S.I NO.	*LM13*	*B4C*	*Gr*	*TOTAL*
Sample 1	*474 g*	*16 g*	*10 g*	*500 g*
Sample 2	*464 g*	*26 g*	*10 g*	*500 g*

Fig. 3: Casted specimens.

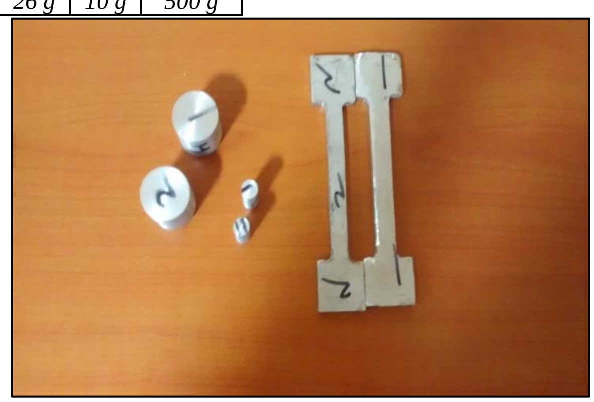

Fig. 4: Test specimens

5) Tensile test

Tensile Strength is the maximum stress that the material can support. Because the tensile strength is easy to determine and is a quite reproducible property, it is useful for the purposes of specifications and for quality control of a product. For brittle materials, the tensile strength is a valid criterion for design. Yield strength is the stress level at which plastic deformation starts. The beginning of first plastic deformation is called yielding. It is an important parameter in design. Computerized Universal Testing Machine (UTM) is used for conducting tensile test. ASTM E8:2016 standard is used for preparing composite test specimens. Gradual load is applied on the specimens two ends by pulling. After the neck formation specimen gets broken. Test specimen is then removed from the UTM. Software provides the test results in the graphical form [7]. The testing machine is shown in figure 5.

Fig. 5: Universal testing machine

6) Hardness test

The Rockwell hardness test method consists of indenting the test material with a diamond cone or hardened steel ball indenter. The indenter is forced into the test material under a preliminary minor load F0 usually 10 kgf. When equilibrium has been reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter, is set to a datum position. While the preliminary minor load is still applied an additional major load is applied with resulting increase in penetration. When equilibrium has again been reach, the additional major load is removed but the preliminary minor load is still maintained. Removal of the additional major load allows a partial recovery, so reducing the depth of penetration. The permanent increase in depth of penetration, resulting from the application and removal of the additional major load is used to calculate the Rockwell hardness number For conducting hardness test specimens of 22 mm diameter and 27 mm length is used and ASTM E18:2014 standards were followed. The average of three readings is calculated and selected as the specimen hardness value. [7] The Rockwell hardness testing machine is shown in figure 6.

Fig. 6: Rockwell hardness testing machine

III. RESULTS AND DISCUSSIONS

Mechanical testing plays an important role in evaluating fundamental properties of engineering materials as well as in developing new materials and in controlling the quality of materials for use in design and construction. If a material is to be used as part of an engineering structure that will be subjected to a load, it is important to know that the material is strong enough and rigid enough to withstand the loads that it will experience in service. As a result engineers have developed a number of experimental techniques for mechanical testing of engineering materials subjected to tension, compression, bending or torsion loading.

C. Tensile Test:

1) Sample 1:
OUTPUT DATA

- Yield stress : 162 N/mm2
- Tensile strength : 178 N/mm2
- Elongation : 2.20%

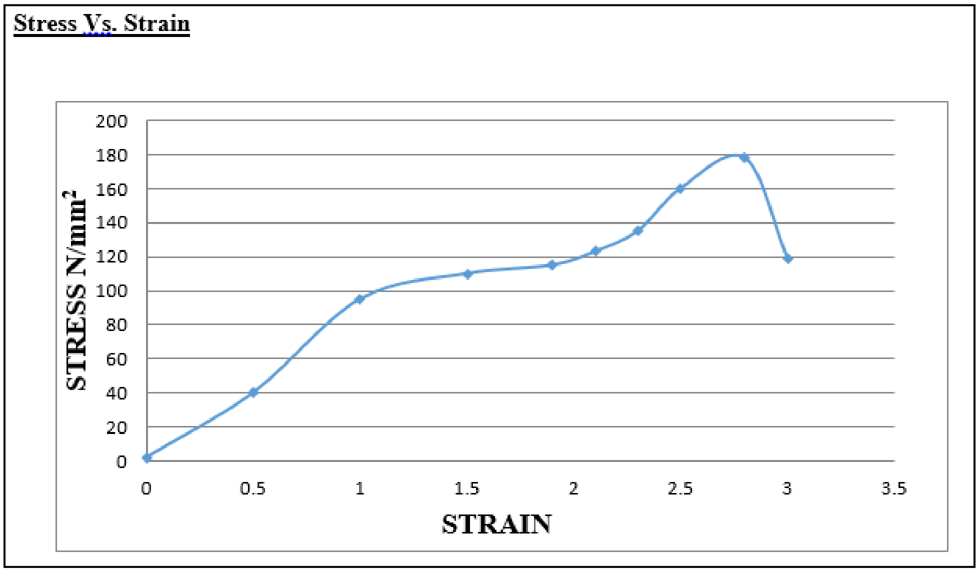

Fig. 7: Stress strain graph of sample 1

2) Sample 2:
OUTPUT DATA

Yield stress : 175 N/mm2
Tensile strength : 184 N/mm2
Elongation : 1.90%

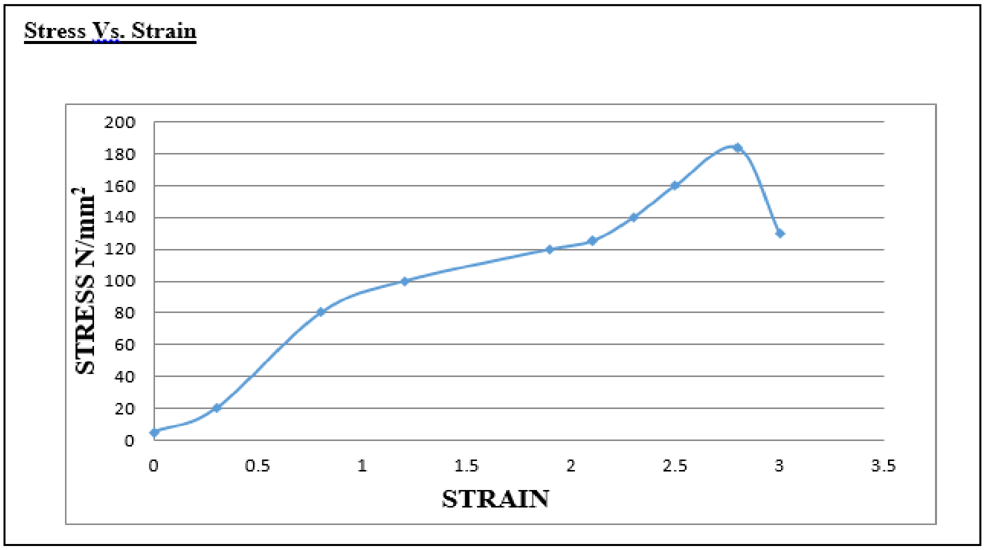

Fig. 8: Stress strain graph of sample 2

Table – 5
The hardness test results

Sl. No	Sample Id	Observed values, HRB			Average, HRB
		1	2	3	
1	Sample 1	85	87	84	85
2	Sample 2	90	91	93	91

The tensile test results of LM13/ B_4C/ Gr 2 % composites are shown in fig 7 and 8. It is noticed that by increasing the percentage of boron carbide particles in the composite both tensile strength and yield stress are increased. Better interfacial bonding between the matrix and the reinforcement is the reason behind this phenomena. So the boron carbide particles tends to withstand the tensile load acting upon the matrix [8]. The hardness test results of the LM13/ B_4C3%/ Gr 2 %composites and LM13/ B_4C5%/ Gr 2 % composites are shown in fig 9. It is observed that by increasing the wt % of boron carbide particles in the composites, hardness value is increased. Decrease in grain size and increase in reinforcement surface area are the perceived results by adding the B_4C particles to the composites. Also material plastic deformation was resisted by the presence hard boron carbide particles. Dislocation of atoms are reduced by increasing the wt % of boron carbide particles. Grain boundary strength also increases to maximum level. Due to such effects hardness of the composite gets increased[9].

IV. CONCLUSION

Due to enhanced properties obtained by adding various reinforcements, aluminium matrix composites are far better than aluminium alloys. Using stir casting procedure, LM13/B4C/Gr aluminium matrix composites with varying wt % of 3 and 5 are fabricated. Uniform reinforcement distribution of particulates on aluminum matrix can be achieved with the stir casting technique. Due to the greater wettability of the boron carbide particles with the matrix alloy homogenous dispersion was observed. With the increase the amount of boron carbide, the density of the composite decreased whereas the hardness is increased. The tensile strength of the composite was increased with increase in the weight percentage of the boron carbide and Gr in the composite.

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