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Research paper

Comparison of mechanical and wearing properties between LM13 matrix and Stir cast LM13/B_4C/Gr hybrid composites of various composition

M.H. Faisal [1*], S. Prabagaran [2], T.S. Vishnu [3]

[1]*Research Scholar, Department of Mechanical Engineering, Karpagam University, Karpagam Academy of Higher Education, India.*
[2]*Professor, Department of Mechanical Engineering, Karpagam University, Karpagam Academy of Higher Education, India.*
[3]*M-Tech Student, Department of Mechanical Engineering, ICET, Muvattupuzha.*

Abstract

Aluminium/graphite composites are the need of modern times for addressing the fuel saving issues. The graphite in such composites act as solid lubricant and it reduce external fuel requirements. But such composites are having degraded mechanical properties due to the graphite content in composite. In order to solve the negative effect of graphite on mechanical properties of LM13/Gr self-lubricating composite this study was conducted to find out the mechanical properties of LM13/B4C/Gr Metal Matrix Composites. Boron carbide was selected as reinforcement because of its better reinforcement properties compared to alumina and silicon carbide. The properties of the hybrid composites were compared with the LM13/Gr self-lubricating composite to study the enhancement in mechanical properties that has been caused by the boron carbide particles. Using computerized universal testing machine and rock-well hardness tester mechanical properties such as hardness and tensile strength were tested. Pin on disk testing machine was used to analyse the wear behavior. 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 compared to self-lubricating composite accompanied by better tribological properties.

Keywords: *Boron carbide, graphite, hybrid aluminium matrix composite, LM13*.

1. Introduction

Aluminum metal matrix composites are light weight in nature possessing better wear resistance, stiffness and high strength, when reinforcements are added to produce metal matrix composite. Alumina, silicon carbide, fly-ash etc are repeatedly used as reinforcements. Boron carbide, the recent reinforcement is both the hardest and the lightest of the four, which makes it a feasible choice. Boron has high neutron capture capability which makes usage of boron carbide reinforced AMC's in strategic applications. Advantages like superior wear resistance, light weight nature, better strength etc make metal matrix composites more preferable in various industrial and automobile applications.
In Comparison with fibre reinforced composites, particle reinforced composites has lot of advantages. Due to their enhanced wear resistance and light weight they can be easily fabricated with less cost and can be used for the automobile parts which are in transmission like connecting rods, cylinder liners, brake drum, pistons and cylinder block by Raviteja T [1]. Microstructural parameters like size, shape, fraction of volume and particles distribution have impact on the mechanical properties of AMCs. Composite with 3 to 12 wt% were produced by stir casting process using LM13 alloy as matrix and silicon dioxide as dispersed phase. Mechanical properties are enhanced and uniform distribution of the particles was obtained. Up to 9% micro hardness and strength increases. Beyond 9% decreases in the properties were observed. LM13-Silica composite have superior mechanical properties by Mallikarjuna GB [2]. Ceramic particles like alumina, silicon carbide are commonly reinforced with aluminum matrix to suit the demands of applications necessary properties like toughness, hardness and low wear rate.
Comparing to Al-SiC composites, boron carbide reinforced aluminium matrix composites have better properties like less density, greater hardness and enhanced tensile strength. CaC2 also has better mechanical properties with low density. Here CaC2 and B_4C are reinforced with 6063 Al alloy. Resulting composites have better properties such as toughness, shear strength and tensile strength. Higher percentage of CaC2 causes an increase in toughness. Reduction of weight without any damage in the mechanical properties is achieved by the addition of CaC2 particles in composites by Madheswaran K [3]. Friction coefficient is high and wear is negative at lower load for LM13/10 % SiC composite. Destruction of transfer layer causing formation of wear debris occurs at higher load. AA6061-B_4C and AA6061-B_4C-Gr composites were fabricated by employing the stir-casting method. A SEM analysis revealed that boron-carbide and graphite particles are distributed uniformly in the aluminium matrix.
The AA6061-B_4C composite had a higher hardness compared to AA6061. The wear resistance of the AA6061-B_4C-Gr hybrid composite and Al-B_4C composite increase steadily with the sliding load and velocity by Prabagaran S [4]. Friction coefficient is high and wear is negative for composite material at 1250 C temperature of pin material. Because of the stable adherent transfer layer formation, the wear is negative at high temperature. Friction coefficient and frictional force is low at average

temperature. Stir casting is the low cost method for creating LM13/10 % SiC composite by Londhe VD [5]. 50-80 nm boron carbide particles whose reinforcement fraction ranging from 3-12% was used for preparing metal matrix composite with aluminum 12% Si alloy matrix. Upgraded mechanical and tribological behavior was detected. In chilled composites boron carbide distribution is more uniform. Differentiating with unreinforced alloy the mechanical properties of chilled composites such as wear resistance, hardness and ultimate tensile strength and were observed to be better. Up to 9%, strength, hardness and wear resistance of the chilled composites increases by Hemanth J [6].

2. Materials and methodology

LM13

LM13 aluminium alloy is commonly used for pulleys, sheaves, pistons, bearings and other sliding contacts. It has better wear resistance, excellent machinability and is capable to withstand high loads and temperature.

Boron carbide

Boron carbide has good properties such as low density, elastic modulus, high temperature stability, good hardness and elastic modulus, better thermo-electric properties. Being the third hardest material and its chemically inert nature compared to alumina and silicon carbide makes it a convenient reinforcement for metal matrix composites. Excellent interfacial bonding with matrix material makes boron carbide more favourable to researchers.

Graphite

Graphite, natural form of crystalline carbon is mainly seen in igneous and metamorphic rocks. It is an important solid lubricant which is opaque and black in appearance. It has flexibility, refractive nature, better chemical inertness and good electrical/thermal conductivity. It exhibits both non metal and metal properties. It is also used in industrial applications such as thrust bearings, vanes, piston rings and journal bearings.

Stir casting

The stir casting apparatus is mainly used for the fabrication of particulate metal matrix composites. Uniform distribution of reinforcement particles can be achieved by this method which ensures a homogeneous composite. The equipment has a graphite crucible designed to withstand high temperature. Due to higher melting temperature (3800 ^{o} C) it will not react with molten metal. A ceramic muffle is used to ensure proper seating position of graphite crucible. At first, equipment temperature is fixed to 500°C and then it is slowly increased to 900°C. Required quantity of alloy ingots is cut down into rectangular pieces and deposited in the graphite crucible for melting. LM13 alloy is melted at 695 degree Celsius. Then the preheated boron carbide and graphite particles are added to the molten matrix and the uniform stirring is performed for 5 minutes to achieve the uniform reinforcement particle distribution in the composite. After that the molten metal is poured into the prepared sand moulds and kept for enough time to solidify. Composite specimens are taken out from the moulds after solidification. By changing weight % same steps are repeated for all composites by Rama Rao S [7]. Four samples (LM13/Gr 2%, LM13/B4C 3%/Gr 2%, LM13/B4C 5%/Gr 2%, LM13/B4C 7%/Gr 2%) are prepared.

Fig. 1: Stir casting equipment

Fig. 2: Casting process

Molten composite mixtures were poured in to the prepared cast specimen moulds. After solidification of the molten mixtures casted specimens were taken out. Proper machining were performed on lathe machine so that test specimens of required dimensions as per ASTM A370:2015, ASTM E18:2014 and ASTM G99-04 were prepared with high accuracy. Compositions of four samples prepared are given below

Sample 1: LM13/ Gr 2%
Total 500 g: 490 g of LM13 & 10 g of Gr
Sample 2: LM13/ Gr 2% / B4C 3%
Total 500 g: 474 g of LM13, 16 g of B4C & 10 g of Gr
Sample 3: LM13/ Gr 2% / B4C 5%
Total 500 g: 464 g of LM13, 26 g of B4C & 10 g of Gr
Sample 4: LM13/ Gr 2% / B4C 7%
Total 500 g : 454 g of LM13, 36 g of B4C & 10 g of Gr

Fig. 3: Casted specimens

Fig. 4: Test specimens

Tensile test

Tension test is mainly used for getting information of the material. Tensile strength, yield strength or yield point, percent elongation and the reduction in area and elastic modulus are the main parameters that explain the stress-strain curve obtained during the tension test. Computerized Universal Testing Machine (UTM) is used for conducting tensile test. ASTM E8:2016 standard is used for preparing composite test specimens. Between the jaws of the computerized UTM, machined specimens are properly fixed and input specimens data are fed into the UTM software. Gradual load is applied on the specimen's 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 by Raviteja T [8]. The testing machine and specimens after tensile test are shown in figure 5 and 6.

Fig. 5: Universal testing machine.

Fig. 6: Tensile test specimens

Hardness test

For conducting hardness test specimens of 22 mm diameter and 27 mm length is used and ASTM E18:2014 standards were followed. By using the Rockwell hardness tester, hardness test is performed on all the test specimens. Emery sheets are used for are polishing test specimens. Initially a minor load of 10 kg-f is applied on the surface of test specimen and the indenter is permitted to touch the specimen surface for producing indentation. After that a major load of 100 kg-f is applied on the same point of the specimen for 30 seconds resulting improvement in penetration. After equilibrium has reached, additional major load is removed maintaining the preliminary minor load. Then the specimen is removed from the machine after releasing the load. For calculating the Rockwell hardness number, the permanent penetration depth increase caused by the application and removal of the additional major load is used. At three different places on the specimen surface hardness is tested and the HRB value of the indentation is noted. The average of three readings is calculated and selected as the specimen hardness value by Kiran Deore [9]. The Rockwell hardness testing machine and test specimens are shown in figure 7 and 8.

Fig. 7: Rockwell hardness testing machine

Fig. 8: Hardness test specimens

Pin on disc test

Pin-on-Disk wear testing is mainly conducted to identify wear, frictional force and the coefficient of friction. According to ASTM G99-04 standards, it consists of a rotating disc in contact with a fixed pin. Rotating disc is placed perpendicularly with respect to pin. Test specimen is of 30 mm length and 10 mm diameter. Pin is held with a jaw on a hardened steel disk. The rotation of disc causes wear of pin on a fixed path. Unidirectional speed, applied normal load and environmental parameters such as type of gas, pressure and temperature etc can be regulated by the user. Transducers are used for measuring normal and friction forces by identifying the deflection of fixture by Nair SS [10]. Different specimen geometries can be be used to replicate the system operation.

Table 1: Specifications [8]

PARAMETER	UNITS
Pin size	3, 6, 10 & 12 mm diameter
Disc Size	165 x 8 mm
Disc Rotation Speed	0 – 2950 RPM
Wear Track dia. Mean	50 – 100 mm
Load	1 – 200 N
Sliding Speed Range	0 to 10 m/s
Frictional Force	0 – 200 N
Wear Measurement	0 – 2000 micrometer
Temperature	ambient to 300 deg C
Power	230V, 50 Hz S phase

Fig. 9: Pin on disk testing machine

Fig. 10: Pin on disk test specimens

3. Results and discussion

The test results are explained in the following sections.

3.1. Tensile test

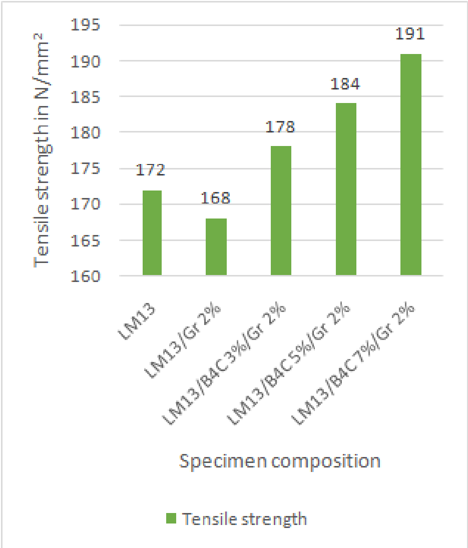

Fig. 11: Tensile strength of tensile test specimens

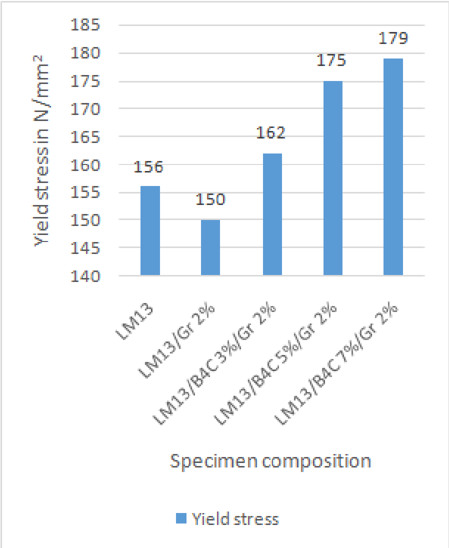

Fig. 12: Yield stress of tensile test specimens

The tensile test results of the LM13, LM13/ Gr 2 % and LM13/ B_4C/ Gr 2 % composites are shown in fig 11 and 12. Both tensile strength and yield stress of LM13/Gr 2% decreases by 2.38 and 4% compared to LM13 alloy. 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 these phenomena. So the boron carbide particles tend to withstand the tensile load acting upon the matrix by Gowri Shankar MC [11]. By adding 3% of B_4C particles, 3.37% increase in tensile strength was observed. 5% and 7% of B_4C reinforcement causes 6.52% and 10% increase in tensile strength than the unreinforced alloy. Similarly in the case of yield stress, 3% of B_4C particles results in 4% increase in yield stress. 5% and 7% of B_4C reinforcement results in increase in yield stress by 11% and 13% respectively.

3.2. Hardness test

Table 2: Hardness Test Results

Sl. No	**Sample Id**	**Observed values, HRB**			**Average, HRB**
		1	2	3	
1	LM13/Gr2%	70	71	70	**70**
2	LM13/Gr2%/B4C 3%	85	87	84	**85**
3	LM13/Gr2%/B4C 5%	90	91	93	**91**
4	LM13/Gr2%/B4C 7%	95	98	94	**96**

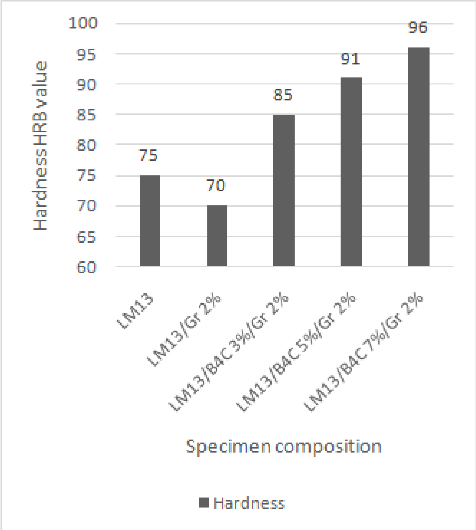

Fig. 13: HRB value of hardness test specimens

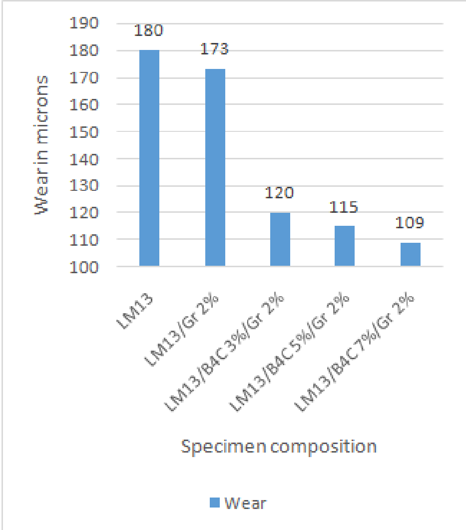

Fig. 14: Wear of pin on disc test specimens

The hardness test results of the LM13, LM13/ Gr 2 % and LM13/ B_4C/ Gr 2 % composites are shown in fig 13. Hardness LM13/Gr 2% self lubricating composites decreases by 7.14%. 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. Dislocations 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 by Kalaiselvan SK [12]. By adding 3% of B_4C particles, 12% increase in hardness was observed. 5% and 7% of B_4C reinforcement causes 18% and 22% increase in hardness of hybrid composite than the parent metal alloy.

3.3. Pin on disc test

For conducting pin on disc test following input conditions were used.
Input
1. Load : 20 N. 2. RPM: 300 3. Sliding Velocity: 1.5 m/s
4. Time Duration : 10 mins

Table 3: Pin on Disc Test Results

SI.No	Material	RPM	Load(N)	Time Duration	Sliding velocity(m/s)	Wear in(microns)	COF	Frictional Force N (Average)
1	LM13	300	20	10 Min (600 sec)	1.5	180	0.5012	10.5
2	LM13 +Gr 2%	300	20	10 Min (600 sec)	1.5	173	0.4568	9.5
3	LM13+Gr 2% +B4C 3%	300	20	10 Min (600 sec)	1.5	120	0.4348	9.0
4	LM13+Gr 2% +B4C 5%	300	20	10 Min (600 sec)	1.5	115	0.3908	8.0
5	LM13+Gr 2% +B4C 7%	300	20	10 Min (600 sec)	1.5	109	0.3862	7.5

Track Radius D = 0.05 M (50 mm)

The pin on disc test results of the LM13, LM13/ Gr 2 % and LM13/ B_4C/ Gr 2 % composites are shown in fig 14,15 and 16. Wear, COF and frictional force of LM13/Gr 2% decreases by 4, 10, 11% with respect to LM13 alloy. From figures, it is observed that by increasing the B_4C percentage in the composite, wear, COF and frictional force are decreased. Better tribological properties were observed. By adding 3% of B_4C particles 50% decrease in wear was observed. 5% and 7% of B_4C reinforcement causes 57% and 65% decrease in wear than the LM13/Gr 2% composite. In the case of COF, 3% of B_4C particles results in 15% decrease. 5% and 7% of B_4C reinforcement results in decrease in COF than LM13/Gr composite by 28% and 30% respectively. Compared to LM13/Gr 2% composite, frictional force reduces by 17, 31 and 40 percentages for 3, 5 and 7% B_4C reinforcement in the case of LM13/B_4C/Gr hybrid aluminium composites.

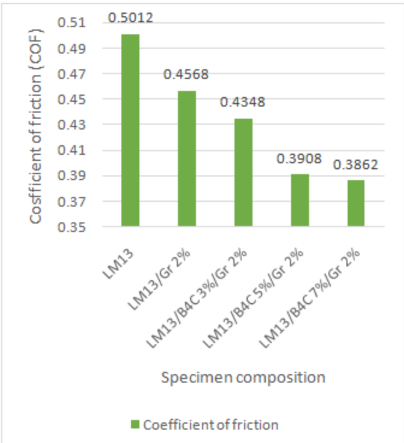

Fig. 15: COF value of pin on disc test specimens

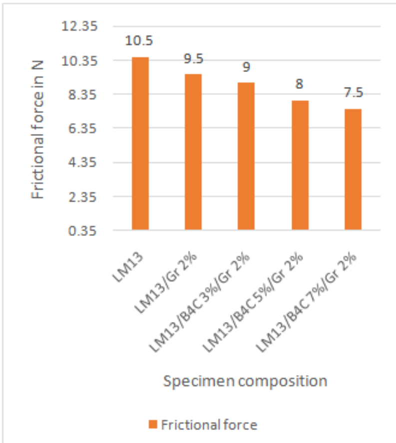

Fig. 16: Frictional force of pin on disc test specimens

4. Conclusion

Mechanical properties such as tensile strength, yield stress, hardness, wear, COF and frictional force of LM13, LM13/Gr self lubricating composite and LM13/B_4C/Gr hybrid aluminium composite (3,5,7% of B_4C particles respectively) were studied using tensile, hardness and pin on disc tests. Due to the resistance offered by the B_4C particles to the plastic deformation, hardness of the composites got increased by increasing the B_4C wt % in the aluminium matrix. The tensile strength of the composites also increases by increasing the percent of boron carbide particles. Properties such as wear, coefficient of friction and frictional force decreases with increase in B_4C percent. This shows that mechanical properties of LM13/Gr self-lubricating composite can be improved by adding boron carbide in to it. Structural and automotive components with superior mechanical properties can be developed using the results acquired from this study

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