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DEVELOPMENT AND INVESTIGATION OF ALUMINIUM METAL MATRIX COMPOSITE REINFORCED WITH SILICON CARBIDE PARTICULATE FOR AUTOMOBILE BRAKE DISC APPLICATION

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Abstract

Metal Matrix Composite (MMC) has been playing a significant role in engineering applications particularly in light weight materials. Aluminium based metal matrix composite can be an efficient and effective braking material compared to cast iron. In this attempt different weight proportion of Silicon carbide (SiC - 220 µm) particulates (2.5%, 5%, 7.5%, 10%, and 12.5% Wt) were reinforced in aluminium (AA336) matrix using stir casting technique. Thermal and mechanical properties of the fabricated materials were studied by corresponding testing methods. The results revealed that the silicon carbide particulate reinforcement leads to concurrent augmentation of the thermal as well as mechanical properties when compared to base material AA336. Also it increases with increase in proportion of reinforcement. From this study it was reviewed that the chances of using such a (Al/SiC) metal matrix composite in the automotive brake disc system improve the thermal and the mechanical behaviour of the brake disc with a low weight ratio compared to conventional cast iron brake disc.

Keywords: MMC, AMC, AA336, Silicon carbide, Stir casting.

1. Introduction

In a practical application like braking, high stress due to thermal environment may result in rapid crack propagation through the material interfaces. Therefore, a strong interface is highly desirable. Braking application on brake disc involves absorption or transfer of the energy of momentum, usually by means of friction. The energy thus absorbed is dissipated in the form of heat. The brake disc must have good antedate characteristics, their effectiveness should not decrease with prolonged application, and thus it demands that the brakes disc should have good thermal characteristics [1].

During the braking operation, the frictional heat developed results in an occasional uneven temperature distribution on the brake disc inducing severe thermal distortion. As the operational conditions changes, this thermal distortion level to increase or decrease depending upon the frictional heat developed. After the threshold limit, the distortion results in the mechanical failure i.e., usually rupture is observed on the brake disc [2].

The frictional heat developed elevates linearly as the pressure applied increases. During the accelerated conditions, the sudden rise in pressure applied grows the thermal distortions unstably finally resulting in hot spots and leaving thermal cracks on the material. This condition is known as Thermo - Elastic Instability. Thermo - Elastic instability occurs as the speed of rotation increases. The frictional heat developed at this condition deteriorates the braking performance commonly known as “brake fade” [1]. Also an unusual vibration is observed in the vehicle due to this.

Brake disc must have sufficient strength to resist these thermo-elastic instability conditions by having good thermal conductivity, thermal capacity, sufficient mechanical strength and hardness with suitable metallurgical structure [3].

Metal Matrix Composite (MMC) has been playing a significant role in engineering applications particularly in light weight materials. Aluminium based metal matrix composite can be an efficient and effective braking material compared to cast iron[4]. Aluminium alloys have attractive properties such as high specific strength and stiffness, very good formability, good thermal and electrical conductivities, high ductility and weld ability, and excellent atmospheric corrosion resistance which have made them choice materials for many engineering applications [5-8].

But poor wear resistance and high thermal elongation properties of aluminium alloys make them behind the selection of material for brake disc. The reinforcement of Silicon carbide (SiC) particulate will enhance the wear behaviour and reduce the thermal elongation without any substantial modification of the base material properties, in fact it will improves some properties slightly is well[9].

Present attempt involves in developing aluminium based metal matrix composite (AMC) reinforced with SiC particulates with different weight proportion (2.5%, 5%, 7.5%, 10% and 12.5%). Various properties were investigated and the results were discussed.

2. Experimental Procedure

2.1 Materials and processing

Aluminium Alloy AA336 and SiC were chosen as Matrix alloy and reinforcement respectively. AA336 is selected as the matrix alloy which has fewer tendencies to drag than with high silicon alloys containing no other alloying elements. AA336 Alloy has high Resistance to corrosion attack under normal atmospheric condition. Silicon carbide particulates were reinforced with matrix alloy in different weight percentages of 2.5%, 5%, 7.5%, 10%, and 12.5% respectively. The matrix was preheated at 200 °C and the reinforcements were added to the matrix material using double layer feeding mechanism for improving the wet ability of SiC into AA336 as shown in “Figure 1”. The mix was then melted to liquidise temperature of 600°C – 700°C and motor stirrer at 100RPM. The spectro- analysis test report of the matrix alloy is given in Table 1.

Table 1: Spectro Analysis test report of AA336 matrix alloy

Constituents	Composition %
Aluminium	88.12
Silicon	9.35
Ferrous	0.500
Copper	0.910
Manganese	0.321

Vol.2 Issue.4,
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Pgs: 53-60

Magnesium	0.427
Chromium	0.0238
Nickel	0.119
Zinc	0.148
Others	0.0931

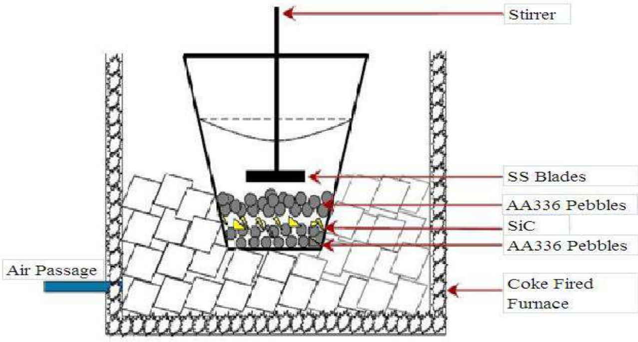


Figure 1: *Schematic diagram of double* layer feeding mechanism

2.2 Mechanical Testing

To investigate the mechanical behaviour of the materials, specimens were prepared for tensile tests. A cylindrical rod specimen of Ø15 is subjected to a tensile load using the Universal Testing Machine (UTM). Test data were used to find the breaking and the ultimate load corresponding to the MMC samples. The axial load applied to the specimen determines the strength of the samples.

The specimens were prepared for measuring hardness tests by polishing them with suitable grades of emery and etching them finally. Rockwell hardness test was carried out with 1/16" steel ball indenter with minor load of 10 kgF and major load of 90 kgF.

2.3 Thermal Conductivity Measurement using Modified Lee's Disc apparatus

Thermal conductivity sample was evaluated using the modified Lee's Disc apparatus method. Specimen of 3.5 mm thickness and 40 mm were machined and grounded well for uniform surface. The experimental setup is shown in "Figure 2". The power supply to heater becomes the input Q for the specimen. The temperature profiles across the specimen were recorded using thermometer T_1, T_2, and T_3 respectively. Heater supply is initially given at 6V for 10 minutes and the temperatures are observed to stabilize. After the temperature gets stabilized, the input was raised to 12V and the readings were recorded. The specimens were insulated using asbestos heat cover to avoid radiation losses. By Fourier's law as follows using which the thermal conductivity k (W/m k) can be found out:

$$Q = kA\left[\frac{T2 - T1}{ds}\right] \tag{1}$$

Where;

1. Q = VI [W]
2. $A = \pi D^2/4$ [m^2]
3. d_s = Thickness of the specimen [m]
4. D = Diameter of the specimen [m]

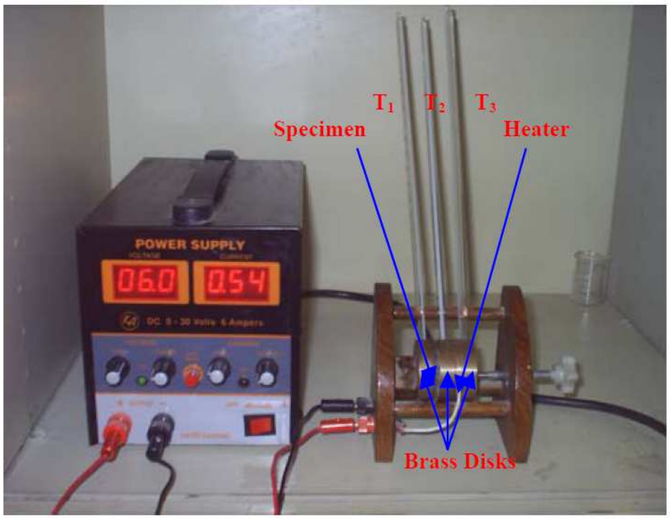


Figure 2: Experimental setup of electrically heated modified Lee's Disc apparatus to find Thermal Conductivity of a metallic bar

2.4 Coefficient of Thermal Expansion (CTE) using Dilatometry

CTE for the specimens were measured using DIL 402 PC – Dilatometer which was programmed to measure temperature change and even negligible sample strain. The samples were tested as per the ASTM E831. The equipment is calibrated for high degree of reproducibility. The schematic of the dilatometer is shown in "Figure 3".

The horizontal design of the dilatometer with easy to move furnace makes it simple to place samples into the large recess of the tube-type sample carrier, even with less than ideal sample geometries. A thermocouple in direct proximity to the sample yields reproducible temperature measurement. This also allows use for calculation of endothermic and exothermic effects in the sample as well as determination of all the characteristic expansion values.

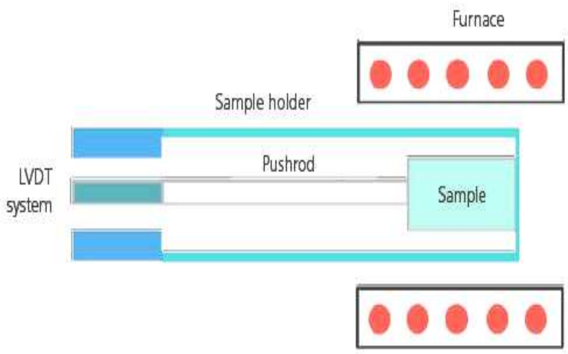


Figure 3: Schematic layout of pushrod dilatometer

The interchangeable furnace was operated at temperature range of RT to 200°C, which would be an ideal operating condition of a heat exchanger of low load equipment. The testing parameters using DIL 402PC is tabulated in Table 2.

Table 2: Experimental Parameters of Dilatometry

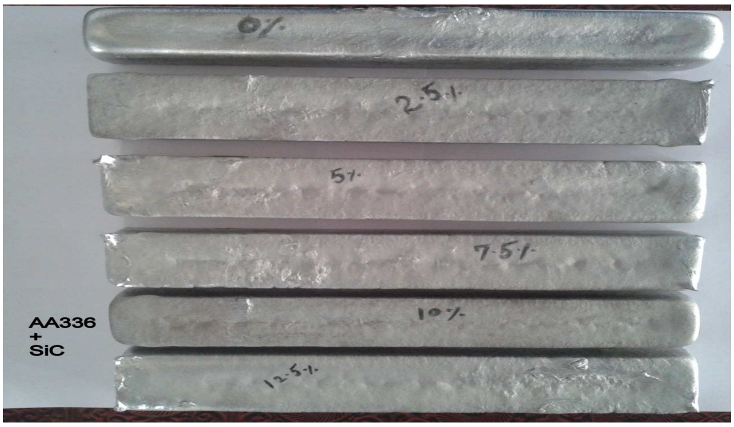
PARAMETERS	SPECIFICATIONS
Δl resolution	8 nm
Sample initial length	25 mm

Sample holder (crucible)	Alumina
Sample nature	Metallic – Solid
Atmosphere	Air
Measuring Range	300 µm
Temperature range	RT to 200 °C
Temperature step	20 °C

3. Results and Discussions

3.1 Preparation of Samples

The samples prepared using the stir casting shows little porosity with increase in the percentage of reinforcements mainly because of the better bonding of the elements. The samples with different reinforcements of SiC were prepared in the form of blanks and rods as shown in the "Figure 4a & 4b"so that it will ease the sample preparation for further testing.



(a)

(b)

Figure 4: Samples with different reinforcements of SiC (blanks (a) and rods (b))

3.2 Mechanical test results

From tensile tests results it was observed that, breaking strength and ultimate tensile strength was at a peak for Al/SiC MMC with 10% silicon carbide reinforcements. Further increase in reinforcements reduces the tensile strength which may be due to the morphological changes. The property of the material changes from ductility to brittle nature on addition of reinforcements in further. The tensile test result plots were shown in "Figure 5".

In case of hardness test results it was observed that, the Al/SiC MMC samples with higher percentage of reinforcement shows higher hardness. The hardness values of the test samples were shown in "Figure 6".

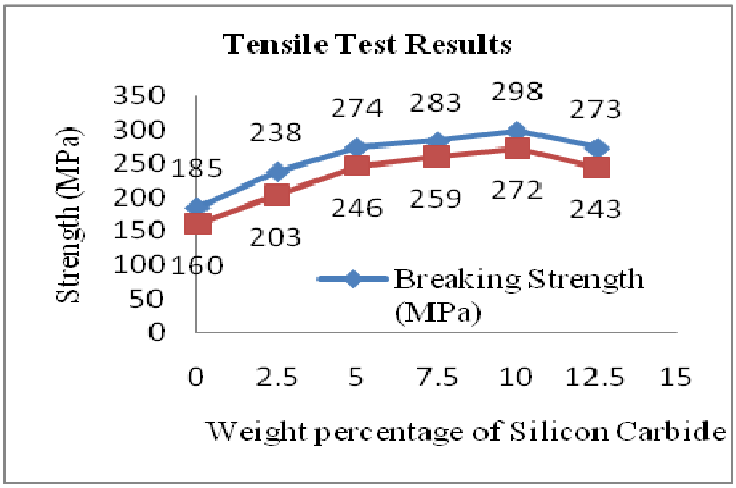


Figure 5: Tensile test plots results of pure AA336 and Al/SiC MMC

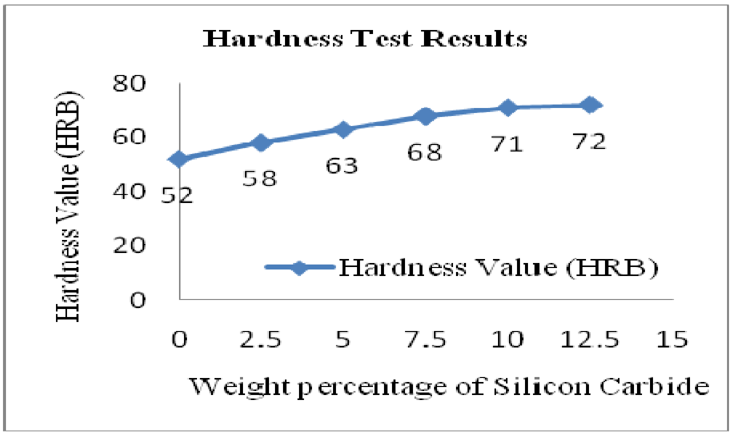


Figure 6: Hardness test plots results of pure AA336 and Al/SiC MMC

3.2 Thermal conductivity results

It was observed that the thermal conductivity of the Al/SiC MMC samples increases with increasing the percentages of particulate SiC up to 10%.this may be due to presence of porosity and silicon molecule. The conductivity beyond 10% of SiC decrease with increasing the percentages of particulate. This may be due to the addition of the ceramics nature in the morphology of the component. The thermal conductivity results were shown in "Figure 7".

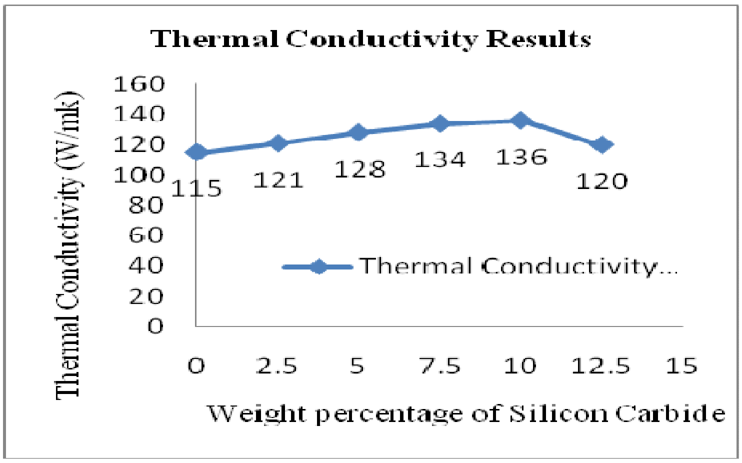


Figure 7: Thermal conductivity results of pure AA336 and Al/SiC MMC

3.3 Coefficient of Thermal Expansion

The CTE was measured for the samples with weight percentages of 2.5%, 5%, 7.5%, 10% and 12.5%,. The tests were conducted as per the parameters listed in Table 2. The experiment was conducted to find the linear CTE only. The volumetric expansions were not considered. The change in length is taken into account for the present study and it is shown in “Figure 8”. The results revealed that as the percentage of reinforcement increases in the matrix the linear CTE reduces.

The results also revealed that the Al/SiC MMC with 10% reinforcement exhibits better results. The Al/SiC MMC with further reinforcement does not show any significant improvement in resistance to expansion. Moreover it is evident from “Figure 8” that the Al/SiC MMC with 12.5% SiC have more interference patterns associated with Al/SiC MMC with 10 % SiC.

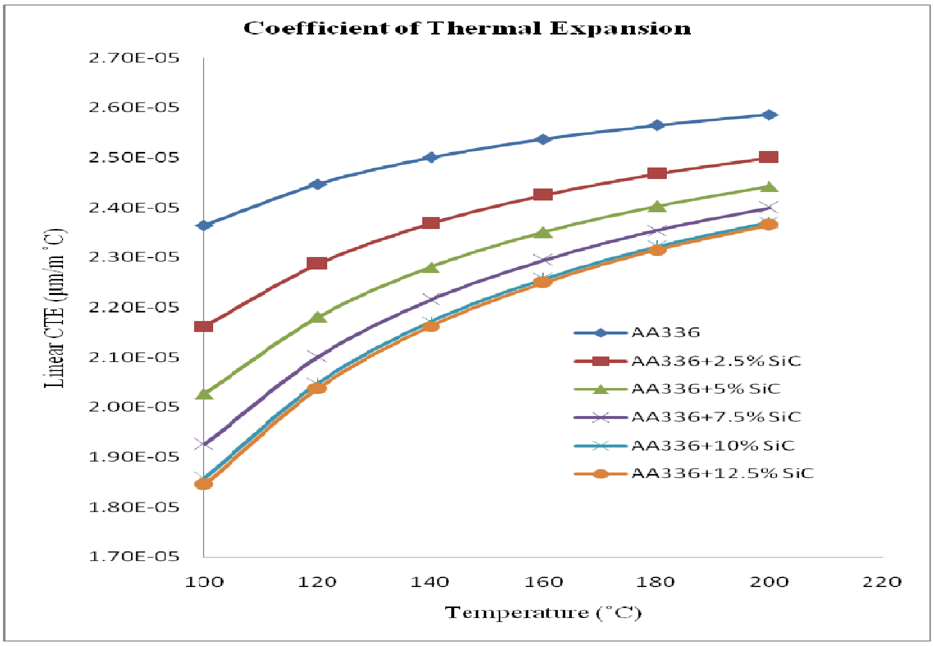


Figure 8: Thermal expansion results of pure AA336 and Al/SiC MMC

4. Conclusion

The Aluminium alloy (AA336) hard particle MMC can be synthesized successfully using the double layer feeding - stir casting solidification process. The Al/SiC MMC thus prepared exhibits good hardness, tensile strength and good thermal properties compared to the conventional materials. Beyond the critical load the Al/SiC MMC may exhibit the same characteristics as that of base alloy.

Additionally the temperature rise in the Al/SiC MMC brake disc is considerable less (74° C) compared to that of the cast iron brake drum (147° C) [4] during the hard braking condition. Also the thermal test results revealed that Al/SiC MMC can be employed promisingly in the field of development of automobile engineering as a replacement to the existing materials.

Al/SiC MMC with 10% SiC reinforcement provides good characteristics over mechanical as well as thermal properties. And it will be an efficient and effective braking material compared to cast iron. The results revealed the potential to replace the existing components by using the Al/SiC MMC so far discussed.

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