International Journal of Research and Innovation in Engineering Technology ISSN: 2394 – 4854
Volume: 01 Issue: 01 Pages: 13 – 18

IJRIET

THERMAL ANALYSIS OF AUTOMOTIVE CYLINDER HEAD MADE BY ALUMINIUM METAL MATRIX COMPOSITE REINFORCED WITH NANO ALUMINA

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Abstract

Metal Matrix Nano Composites (MMNC's) have been developed to meet the demand for lighter materials with significant improvements in mechanical and physical properties like high strength, excellent wear resistance, good thermal conductivity, low thermal expansion coefficient with particulate reinforcements. Aluminium based nano composites (AA356 – nano Al_2O_3) with three different percentage (1%, 1.5%, 2.5% Wt) of nano – alumina particulate reinforcement (~40 nm) were fabricated using in-situ stir casting technique. Mechanical properties characterization which strongly depends on microstructural properties of reinforcement revealed that the presence of nano – alumina particulates lead to simultaneous increase in hardness, UTS, wear behaviour. The results revealed that UTS, Hardness, Wear behaviour increases with the increase in the percentage of reinforcement of nano – Al_2O_3 whereas the thermal conductivity drops with increasing percentage of reinforcement when compared to the base alloy AA356. An attempt is made in the present study to review the opportunities of using such a MMNC developed in automotive brake drum replacing the current system using cast iron.

***Keywords**:* MMNC, Nano Alumina, In-Situ casting, Mechanical properties, Cylinder head

1. INTRODUCTION

Aluminium composites are used for making various components such as brake drum, cylinder liners, cylinder heads, cylinder blocks etc. Aluminium alloy MMNC is becoming potential engineering materials offering excellent combination of properties. Because of their excellent properties, they are being used in various engineering applications . Particulate reinforcement by employing double layer feeding - stir casting technique proves to be a promising technique in developing MMNC. The properties of MMNC developed are critically governed by selection of type of reinforcement and its compatibility with metallic matrix. Reinforcement of Nano Al_2O_3 ensures uniform distribution and minimal porosity.

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

The process of straightening involves the application of heat, whether in an oven or by flame, and under no circumstances should the temperature be high enough to cause annealing (ie. permanent softening) of the aluminium alloy. The aluminium alloys used in cylinder heads will anneal at 662 F (350° C), but considerable softening begins at around 554-590 F (290-310° C) depending on the alloy and the time that the head is held at that temperature. When using temperature sensitive crayons, excessive temperatures may be experienced due to the delay in the response of the crayon, or to uneven heating of the head. It is recommended that cylinder heads are not heated beyond 482 F (250° C) when straightening. If annealing has occurred in an aluminium cylinder head, the material strength is reduced and it becomes more ductile.

Cylinder heads are made in a variety of aluminium alloys and may be either gravity or low pressure die cast. The heat treatment applied to the casting varies according to the alloy used and results required. It is not possible to generalise on the hardness achieved in manufacture. For example, some aluminium heads are solution heat treated and aged to a hardness of 110-120 Brinell, while others are stabilised only (ie. oven aged) as the removable core is burnt out and these have a hardness of around 80-90 Brinell. The above implies that anyone straightening an aluminium cylinder head should have equipment for measuring hardness

Compared with the cast iron cylinder head, the aluminium composite cylinder head shows less thermal deformation and maximum temperature obtained for aluminium composite is less compared to cast iron cylinder head.

2. EXPERIMENTAL PROCEDURE

2.1 Microstructure and mechanical properties of Materials and processing

Aluminium Alloy AA356 and nano – Al_2O_3 were chosen as Matrix alloy and reinforcement respectively. AA356 is selected as the matrix alloy which has fewer tendencies to drag than with high silicon alloys containing no other alloying elements. AA356 Alloy has high Resistance to corrosion attack under normal atmospheric condition. Nano alumina particulates were reinforced with matrix alloy in different weight percentages of 1%, 1.5% and 2.5% respectively. The matrix was preheated at 200 °C and the reinforcements were added to the matrix material using double layer feeding mechanism. The mix was then melted to liquidus temperature of 600°C – 700°C and motor stirrer at 90RPM. The spectro-analysis test report of the matrix alloy is given in Table 1.

Constituents	Composition %
Iron	0.5 max
Silicon	6.5-7.5
Ferrous	0.500
Copper	0.1 max
Manganese	0.3 max
Magnesium	0.2-0.6
Lead	0.1 max
Titanium*	0.2 max
Nickel	0.1 max
Zinc	0.1 max
Aluminium	reminder

Table: 1 Spectro Analysis test report of matrix alloy

2.2 Wear tests

Wear tests were performed using a CSEM pin on disc tribometer. The pin was a 8mm diameter single crystal Al_2O_3 (ruby) ball which was held down stationary on the flat face of the test piece disc under a 10 N load initially. The disc velocity is maintained at 0.1 m/s in unlubricated, open air environment. Before and after each test, the specimen and the discs were cleaned using the acetone and dried up in the open air to avoid any contaminations. Experimental parameters were tabulated in Table II. Also the temperature change in the specimens at the ends of the wear test was measured using the digital temperature indicator with 0.1° C accuracy

Pin Length	30 mm
Pin Diameter	8 mm
Load	10 – 20 N
Track Diameter	60 – 90 mm
Sliding speed	3.665 m/s (1000 RPM)

Table: 2 Experimental Parameters of Wear Test

2.3 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 MMNC 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 10kgF and major load of 90 kgF.

2.4 Searle's bar experiment (Modified) for Thermal Conductivity Measurement

Thermal conductivity of the MMNC is evaluated using the modified Searle's bar method. A 150mm bar of material was heated by using electric heater on one side and the other side cooled down by circulating water, while the intermediate length of the bar is thermally insulated. The flow rate of circulating water was maintained at a constant level of 1.5 litres per minute. A 15 minutes saturation time is maintained before recording the temperatures at various thermocouples in order to avoid the variation of results due. A constant current of 9V supply is given to the heater element and the corresponding ampere ratings were measured. The experiments were assumed to be purely conductive and the losses due to the convection and radiation were assumed to be neglected. The experimental setup is shown in Fig. 1. The heat ΔQ propagating through the bar in a time interval of Δt is given by Fourier's law as follows using which the thermal conductivity k (W/m°C) can be found out:

$$Q = k_{int} A_{int} \left(\frac{\Delta T_{int}}{\Delta x_{int}} \right)$$

Where;

1. $Q = VI$ [W]
2. $A = \pi D^2/4$ [m^2]
3. $T_H = T_3-(T_2-T_3)/2$ [°C]
4. $T_C = T_6 + (T_6 - T_7)/2$ [°C]
5. $\Delta T = T_H - T_C$ [°C]
6. Δx = Length of intermediate section [m]
7. D = Diameter of intermediate section [m]

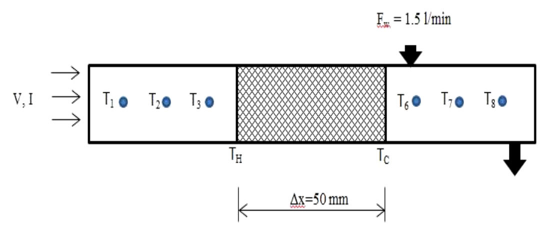

Figure: 1 Experimental layout of Searle's bar experiment (Modified) to find Thermal Conductivity of a metallic bar.

3. RESULTS AND DISCUSSIONS

3.1 MMNC Samples

The MMNC samples prepared shows presence of porosity reduces with increase in the percentage of reinforcement. Samples prepared for hardness shows the presence of porosity clearly through the visual investigation. Fig. 2 shows the surface of the samples. The presence of porosity reduces as the reinforcement increases since the interfacial bonding between the aluminium matrix and the Al_2O_3 particulates is high for higher percentage of reinforcements.

Figure: 2 Visual Investigation of Porosity corresponds to (a) MMNC with 1% Al_2O_3, (b) MMNC with 1.5% Al_2O_3, (c) MMNC with 2.5% Al_2O_3.

3.2 Wear Characteristics

Pin-on-disc dry sliding wear test results with pins of pure Aluminium reinforced with up to 1%, 1.5%, and 2.5% weight of (40nm) nano-sized alumina showed that wear rate decreases with increasing percentage of reinforcement. The volumetric wear rates of Aluminium and its composites are plotted against the time to the wear in micrometer. It is immediately apparent that there is consistent improvement in wear resistance with increasing amounts of reinforcement. This corresponds directly to the rise in hardness and strength of the composites with reinforcement level, and agrees with Archard's equation that the wear of a material is inversely proportional to its hardness. The 2.5% Al_2O_3 -reinforced MMNC, being the best performer shows an improvement in the wear resistance of 1.2 times at the lowest speed of 1 m/s, and more importantly, up to 1.6 times under the higher-speed, and thus, more severe sliding conditions. The wear rates are plotted against the time and are shown in Fig. 4.

There is a gradual reduction in the wear rates of all the specimens over a fairly wide range of sliding velocities, from 1 to 7 m/s. In this series of tests under a 20 N load, the optimum speed for these materials appears to be around 7 m/s, beyond which, the wear rates begin to rise.

The results of this study have shown that nano-sized alumina particulates 1%, 1.5% and 2.5% volume are able to bring appreciable improvement to the wear resistance of pure aluminium matrix alloy, especially under higher sliding speeds. The small volume fraction of reinforcement used presently is significant because the earlier studies have found there exists an optimum level of reinforcement for a given particulate size and sliding condition, beyond which, despite an increase in hardness, results in wear rates comparable to or even higher than the unreinforced material.

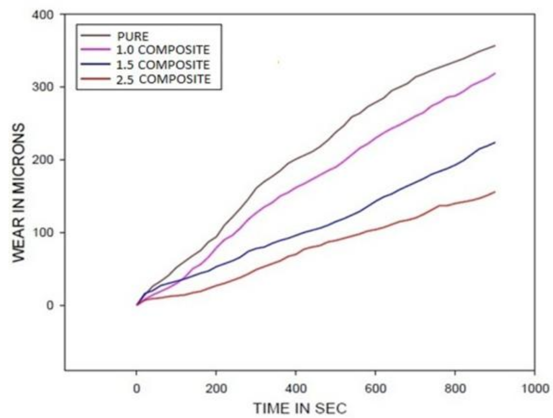

Figure: 3 Volumetric Wear rates of pure matrix alloy and MMNC

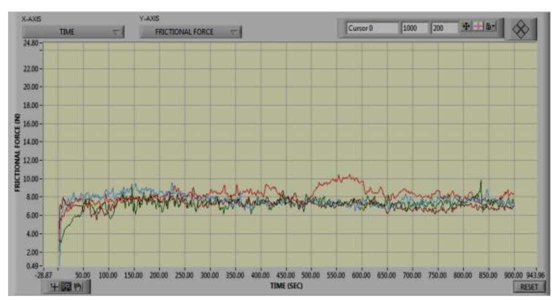

Figure: 4 Frictional force resistance offered by AA356 and MMNC

The resistance to the frictional force was also being studied. The results shown in Fig. 4 revealed that composites offer less frictional loss as they are able to withstand high temperatures induced due to the friction and the better wear property was also studied. The temperatures at the end of the wear test were measured by placing the thermocouple probe in the small drilled hole near the end of the sample. It was observed to be 83°C in case of matrix alloy and 76°C for MMNC with 2.5% Al_2O_3 reinforcement.

3.3 Mechanical test results

It was observed that the MMNC samples with higher percentage of reinforcement shows higher hardness. The hardness values of the test samples were shown in Fig. 5. In case of tensile tests, the results revealed that breaking strength and ultimate tensile strength was at a peak for MMNC with 2.5% nano alumina reinforcements. 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 Fig. 6.

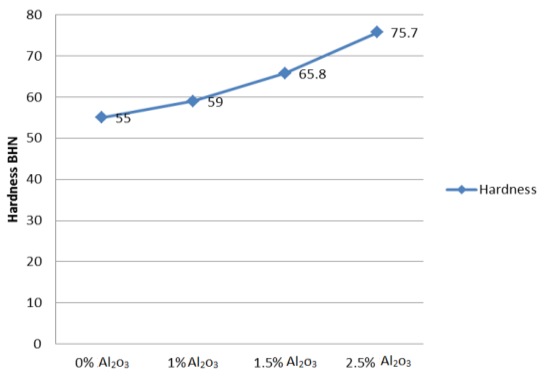

Figure: 5 Hardness survey results of pure AA356 and MMNC

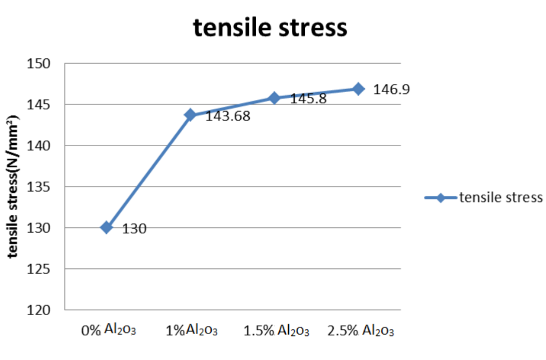

Figure: 6 Tensile test plots results of pure AA356 and MMNC

3.4 Thermal conductivity of MMNC Samples

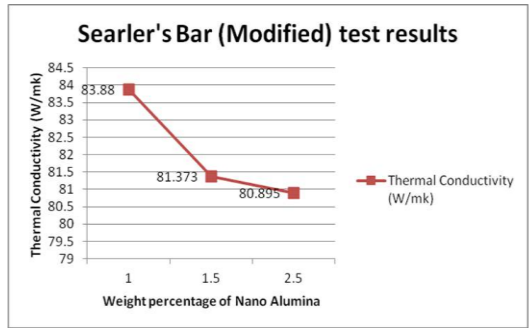

Figure: 7 Thermal conductivity Vs percentage of reinforcement of nano alumina with the matrix alloy

It was observed that the thermal conductivity of the MMNC samples decreases on increasing the percentages of particulate Al_2O_3 reinforcement. The conductivity decrease may be due to the addition of the ceramics nature in the morphology of the component. The thermal conductivity results were shown in Fig. 7.

4. CONCLUSION

The Aluminium alloy (AA356) hard particle MMNC can be synthesized successfully using the double layer feeding - stir casting solidification process. The MMNC thus prepared exhibits good wear resistance compared to the ethnic materials. Beyond the critical load the MMNC may exhibit the same characteristics as that of base alloy. Further, frictional heating and coefficient of friction are noted to be considerable less in composite as compared to that in the alloy.

Additionally the temperature rise in the MMNC cylinder head is considerable less compared to that of the cast iron cylinder head during the high condition. Also the various mechanical test results revealed that MMNC can be employed promisingly in the field of development of automobile engineering as a replacement to the existing materials. The results revealed the potential to replace the existing components by using the MMNC so far discussed.

Acknowledgement

We would like to acknowledge the support of Prof.R.Surendran, GCE, salem for his valuable guidance in carrying out this work. We extend the thankfulness to the Professors & Staffs of Dept. Mechanical Engg, GCE, Salem for their valuable suggestions at various stages of the project.

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