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# Development Of Al/Sic$_{10\%}$ Metal Matrix Composite And Its Comparision With Aluminium Alloy - LM13 On Tribological Parameters

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**Abstract**— Automotive industries are attracting towards the use of aluminium silicon carbide metal matrix composites (Al/SiC$_{10\%}$ MMC) because of its reduction in mass and improved wear resistance properties. In the present study, a stir casting process was developed to fabricate Al/SiC$_{10\%}$ MMC. In this process vortex was formed by using specially designed stirrer for better mixing of silicon carbide (SiC) powder with melted aluminium matrix material. Later on this melted slurry was poured in mould through which 10 amperes current was passed to minimize the settling of SiC powder during cooling of casting .The cast LM13alloy and newly developed Al/SiC$_{10\%}$ MMC were tested for seizer time and its sliding wear tribological parameters using wear tests. The wear test experiments with factorial analysis were carried out at the room temperature under dry operating condition on single pin type 'pin-on-disc friction and wear monitor TR20' test rig. Load and speed were considered as major factors for measurement of sliding wear and coefficient of friction. The comparative study among the aluminium alloy LM13 and Al/SiC$_{10\%}$ MMC was shown that Al/SiC$_{10\%}$ MMC was superior to LM13 aluminium alloy on seizer time and corresponding sliding wear parameters.

**Index Terms**— Stir casting, Electric furnace , Degassing unit, Chemical analysis,Wet analysis, Wear test , Factorial analysis, Mathematical model for seizer time and sliding wear, Al/SiC$_{10\%}$ MMC, Coefficient of friction.

## 1 Introduction

The MMCs are fabricated by powder metallurgy, casting or combination of several methods. The casting process is the most economical process. However, it has some restrictions due to the matrix alloy and density of the reinforced phases (1, 2). Therefore the volume fraction and the size of the reinforcements that can be added are very limited. It is also possible that some defects (e.g. voids because of shrinkage) can form in the cast (3, 4). Powder metallurgy (P/M) has a lot of advantage. A high dislocation density and a small sub grain size in the matrix can be obtained. The strength more than of as-cast composites can be prevented. But (P/M) materials lower toughness.

In some studies hard particulates were added to the casting either by externally addition or by manipulating solidification as in rheocasting [5]. Most of the MMCs fabrication methods have employed stirring to create a vortex. The formation of negative pressure at the vortex sucks externally added particles with air bubbles in the particle-melt slurry resulting in large porosities in cast composites. There are two types of foundry methods for making composites with externally added particles, depending on the temperature at which the particles are introduced in the melt. In liquid metallurgy process the particles are added above the liquids temperature of the molten alloy whereas in compo-casting the particles are introduced into semi-solid slurry at a temperature of the alloy [1, 6, 7]. In both, these processes vortex is used and for this reason the composites have high porosities [8]. Several factors influence the final product, one very important being the metal melt's ability to wet the ceramic particles. The particulate reinforced composites are common due to availability, low cost, independence of mechanical properties from particulate orientation and production via a wide range of manufacturing routes [9]. The strength of discontinuously reinforced MMC is not as high as that of continuously reinforced composites, but the properties and cost of discontinuous MMC make them useful as wear-resistance materials. The literature on the effects of the some eutectic particulates e.g. particles having Si and Cr with ceramic particles and their size on the wear behaviour of stir casting composites is also limited. Al-based MMCs are well known for their high specific strength, hardness and wear resistance. During sliding against metals and abrasives, many studies have reported that MMCs exhibit better wear resistance than the un-reinforced alloys [10, 11].Consequently, MMCs can compete with the traditional materials in many tribological applications such as braking system for automobiles. Weight reduction, improvement in mechanical properties especially wear behaviour, and easy recycling are sought, among other attributes, in order to produce more efficient products leading to a reduction of pollutant emissions. The range of materials that can meet these requirements presently is very narrow, and their final price is greater (e.g. aluminium matrix composites, Al-MMCs) than currently used traditional materials, such as cast iron for brake components [12, 13, 14].

Many efforts have been made in the recent past all over the world by different automobile manufacturers on the possibility of using Al-MMCs in place of cast iron for brake applications in ground transport systems, however available literature resources are still scarce. These efforts are spread in many directions, namely: development of aluminium brake components [10], testing and characterization [15–16], mathematical analysis of brake system [16] particulates composites is necessary. Hence measurements of tribological parameters of composites are much sought after materials for a variety of industrial applications owing to their improved mechanical properties over the conventional alloys and materials.

It is the objective of this work to evaluate the effect of load and speed on the seizer time & sliding wear [17] on newly developed Al/SiC$_{10\%}$ MMC by using stir casting route.

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## 2 EXPERIMENTAL PROCEDURES

### 2.1 Development Al/SiC10% MMC by stir casting route:

In the first step of stir casting, silicon carbide particles ($SiC_p$) of size 25µms. was preheated up to $900^0$C in a muffle furnace and Aluminium alloy (LM 13) was melted at range 600 to $700^0$C using an electric furnace simultaneously.

Figure 1: Mixing of SiC in Al alloy

The molten slurry of LM 13 was stirred by specially designed Graphite stirrer (Figure1) fitted with the PLC based degassing unit supplied by Foseco India ltd.(Figure2) for 3 to 5 minutes at 400 rpm. in clockwise and anticlockwise direction so that the vortex was formed. Stirring was continued till the second step was not completed. This molten slurry also degassed by using nitrogen gas passed thorough it with the help degassing unit.

Figure 2: Experimental set up for stir casting

Figure 3: Experimental set up for electric current passing through sand cast

In the second step, preheated SiC particles were mixed with the low speed rate in the stirred and degassed molten Al alloy within a time range 12 to 20 minutes at 400 rpm. (figure2)[16]. The melt solidified in the sand cast mould and specially designed mould in which electric current was passed.(Figure3) The current rating was 10 amperes and 60 volts passed for 10 seconds only. It was observed that if current passed more than 10 seconds it will affect the quality of casting. The current passing through the casting agitated the electrons of aluminium and hence SiC particles were not settled at lower portion of casting during cooling. This improves the mixing of SiC with LM13 and gave better quality Al/SiC MMC. The chemical compositions of the matrix alloy and the $SiC_p$ weight percentage of the slip in the fabricated composites were taken in 10:1 ratio. Chemical analysis by wet analysis (Table 1) and microstructure (Figure4) were tested of above sandcast and specially designed casted Al/$SiC_{10\%}$ MMC. The microstructure of specially designed casted Al/$SiC_{10\%}$ MMC was seen better than simple sand casted Al/$SiC_{10\%}$ MMC as there was less amalgamation of SiC as shown in figure 5. This newly developed Al/$SiC_{10\%}$ MMCand cast LM13alloy was used to check the tribological properties using wear test.

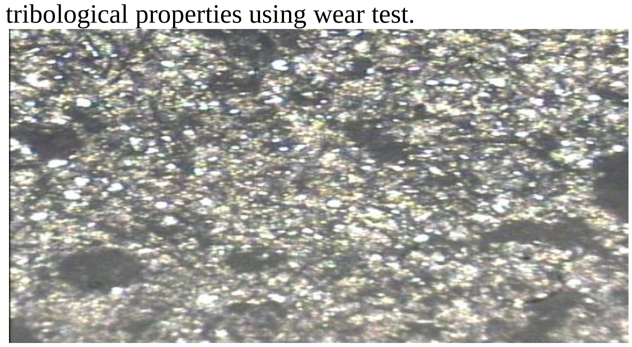

Figure 4: Micrograph of electric current passed sand cast

Figure 5: Micrograph of sand cast

Table1: Chemical analysis of Al/$SiC_{10\%}$ MMC

| Sr.No. | Compositions | Percentage of compositions | Test method |
|---|---|---|---|
| 1 | Cr | 0.013 % | A.A.S |
| 2 | Ni | 0.75 % | A.A.S |
| 3 | Mn | 0.065 % | A.A.S |
| 4 | Si (Total) | 18.96 % | IS 504,P-1:2002 |
| 5 | Pb | 0.050 % | A.A.S |
| 6 | Cu | 0.84 % | A.A.S |
| 7 | Zn | 0.038 % | A.A.S |
| 8 | Sn | 0.0014 % | A.A.S |
| 9 | Fe | 0.57 % | A.A.S |
| 10 | Mg | 1.44 % | A.A.S |
| 11 | Ti | 0.047 % | A.A.S |
| 12 | SiC | 9.94 % | WET ANALYSIS |
| 13 | Al | 67.28 % | Reminder |

## 2.2 Wear test:

The wear tests were carried out on single pin type "Pin-on-disc friction and wear monitor TR20", Ducom make, Bangalore test rig (Figure6,7). Tests were carried out at the room temperature under dry operating condition. To avoid rise in temperature at the interface pin and its counter face plate material the sliding time level was set at 1/3rd time for each setting time [17-18] then the aggregate wear value was summed up. The cast LM13 alloy and $Al/SiC_{10\%}$ MMC cylindrical Pin flat ended specimens of size 10 mm diameter and 25mm length (Figure 8) were tested against EN-24 steel disc material. The average surface Roughness value Ra of disc before test was measure as 1.1 µm. Measurement of Ra value was obtained by using "Mitutuyo make:surftext-10", instrument with least count of 0.1 µm.

Figure 6: Pin-On-Disc Machine


Figure 7: control panel of Pin-On-disc machine

Figure 8: used pin specimens after experimentation

Initially experiments were conducted for time 20 minutes with load of 19.2 N, 29.43 N and 39.24 N at 500 rpm. These experiments were helped to compare the sliding wear, frictional force and coefficient of friction of LM13 and $Al/SiC_{10\%}$ MMC using seizer time and its respective sliding wear values Three input parameters and two outputs were considered into factorial analysis. As per factorial analysis total eight experiments were sufficient but one additional replicates was introduced for better responses.. As per factorial analysis 16 experiments were conducted for observing the interaction effect of load and speed. The details of experiments with input and output parameters were given in table 2. Sliding wear, frictional force and coefficient of friction were computed directly from the attached computer software.

Table 2: Wear test observation table

| Sr. No. | Input parameters | | | Output | |
|---|---|---|---|---|---|
| | material | Load (N) | Speed (rpm) | Seizer time (sec) | sliding wear (µm) |
| 1 | LM13 | 19.62 | 200 | 970 | 98.245 |
| 2 | MMC | 19.62 | 200 | 1240 | 121.264 |
| 3 | LM13 | 19.62 | 200 | 950 | 90.165 |
| 4 | LM13 | 39.24 | 500 | 540 | 55.637 |
| 5 | MMC | 19.62 | 500 | 840 | 150.024 |
| 6 | LM13 | 19.62 | 500 | 570 | 119.797 |
| 7 | MMC | 39.24 | 200 | 910 | 58.765 |
| 8 | MMC | 39.24 | 500 | 510 | 72.587 |
| 9 | MMC | 39.24 | 200 | 943 | 62.845 |
| 10 | LM13 | 39.24 | 200 | 940 | 45.975 |
| 11 | LM13 | 39.24 | 500 | 520 | 50.632 |
| 12 | MMC | 39.24 | 500 | 540 | 39.364 |
| 13 | MMC | 19.62 | 200 | 1270 | 139.365 |
| 14 | MMC | 19.62 | 500 | 880 | 162.35 |
| 15 | LM13 | 19.62 | 500 | 600 | 124.325 |
| 16 | LM13 | 39.24 | 200 | 902 | 65.457 |



## 3. Results and Discussion:

### 3.1. Development of $Al/SiC_{10\%}$ MMC:

Stir casting route for development of $Al/SiC_{10\%}$ MMC was more economical solution for maximum utilization of MMC.10A current passed through specially designed sand cast mould was improved the settlement of SiC powder in LM13 matrix. The settlement of SiC powder during cooling of casting is always a mojor issue in the development of Al/SiC MMCand it was resolved by the specially designed mould which was useful for passing the 10 A current .

### 3.2 Seizer time and wear:

From the figure 9, it was observed that LM 13 alloy with 19.62 N load and 500 rpm condition were shown seizer wear developed after 9 min 50 sec with wear of 119.797 microns and for $Al/SiC_{10\%}$ MMC seizer wear was developed after 14 min with wear for 150.02 microns for the same load condition. Similarly for LM13 alloy at load 29.43N the seizer wear was developed after 9 min. with 154.433 microns sliding wear and $Al/SiC_{10\%}$ MMC was given seizer wear after 11min with 98.346 microns. Both the above results were suggested that $Al/SiC_{10\%}$ MMC was better than LM13 alloy. It was also observed that as the load increased, seizer wear time and sliding wear also reduced.

### 3.3. Frictional forces and coefficient of friction:

The common phenomenon for frictional forces is that if higher load applied then more frictional forces are developed and more wear is observed. The above phenomenon was observed in figure 10. For $Al/SiC_{10\%}$ MMC if load applied were 19.62 N and 39.24 N, then frictional forces were 15 N and 18N while for LM13 al-

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loy it was 18N and 20 N respectively. These results were indicated larger frictional forces for LM 13 alloy than Al/$SiC_{10\%}$ MMC material. The same output was observed from coefficient of friction (figure 11). From the figure11, it was concluded that coefficient of friction for Al/$SiC_{10\%}$ MMC was very close to 0.15 to 0.2 while for LM 13 it was 0.12 to 0.25

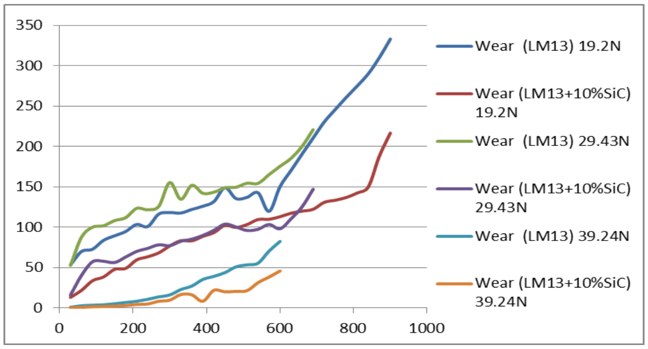


Figure 9: Seizer time and sliding wear

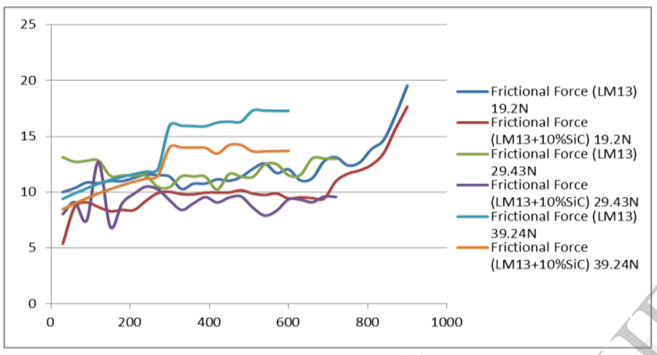


Figure 10: Frictional forces

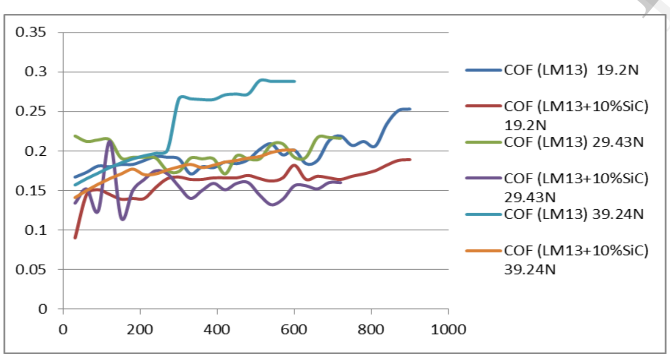


Figure 11: Coefficient of friction

### 3.4 Factorial analysis:

#### *3.4.1 Mathematical model for Seizer Time:*

Mathematical model for seizer time was computed by using MINITAB release 15 software.
From the analysis, seizer time model was developed as follows:
Seizer time (sec) =

$$1540.42 + X_1^{-302.083} + X_2^{-8.98318} + X_3^{-1.24583}$$

Where,

$X_1$= material value (1: LM13 and r -1: Al/$SiC_{10\%}$ MMC)
$X_2$ = load
$X_3$ = Speed

The residual plot for the computed values was shown in figure 12. This residual plot was given the best fit of computed data with R-square 98.34%. This plot also showed the linearity in residual fits within limit of ± 20sec.

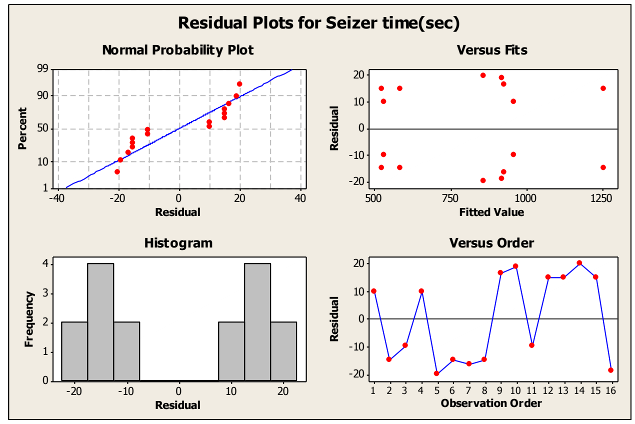


Figure 12: Residual plot for seizer time

Main effect plot of seizer time means (sec) (Figure 13) was represented that seizer time for Al/$SiC_{10\%}$ MMC (900 sec.) was better than LM13 alloy (750sec.). While the interactions plot (Figure 14) was suggested that Al/$SiC_{10\%}$ MMC (1200sec.) was better at speed and load conditions. The interaction plot also indicated that at higher load there was a possibility of interaction. It means that at higher load both materials were equally stronger but interaction plot of speed and load rejected the conclusion and suggested that Al/$SiC_{10\%}$ MMC (750-1200 sec.) was superior to LM13 alloy (500-800 sec.) as there was no interaction in this two materials.



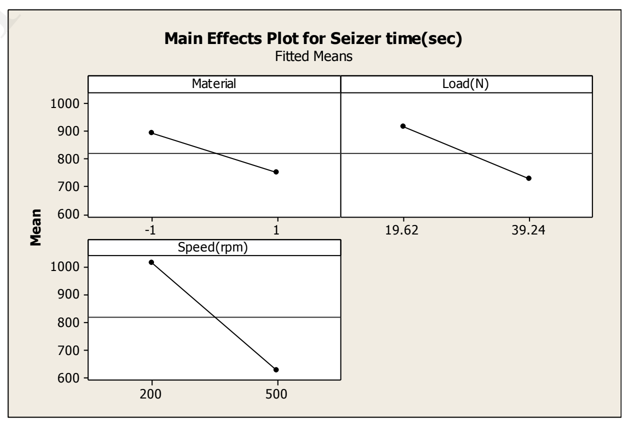


Figure13: Main effect plot for seizer time

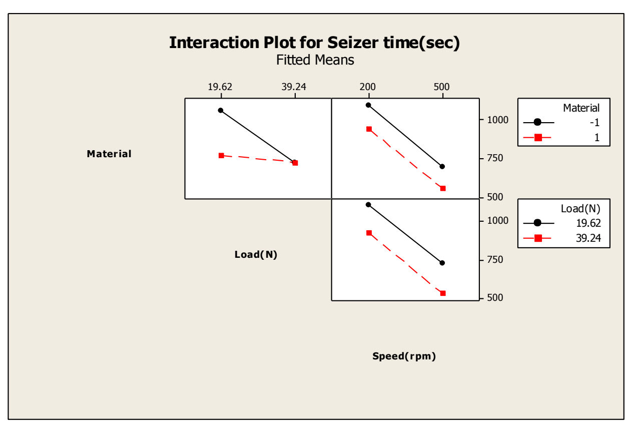


Figure14: Interaction plot for seizer time

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### *3.4.2 Mathematical model for Sliding Wear:*

Mathematical model for sliding wear were computed by using MINITAB release15 software.
From the analysis, sliding wear model was developed as follows = Slding wear (µms)=

$$127.97 + X_1^{-34.138} + X_2^{-1.713} + X_3^{0.191}$$

Where,

$X_1$= material value (1: LM13 and -1: Al/SiC$_{10\%}$ MMC)
$X_2$ = load
$X_3$ = Speed

The residual plot for the computed values was shown in figure 15. This residual plot was given the best fit of computed data with R-square 82.74%. This plot also showed the linearity in residual fits within limit of ± 20microns.

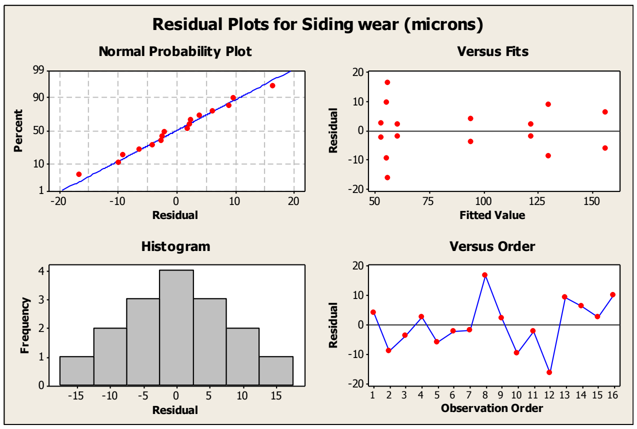


Figure 15: Residual plot for sliding wear

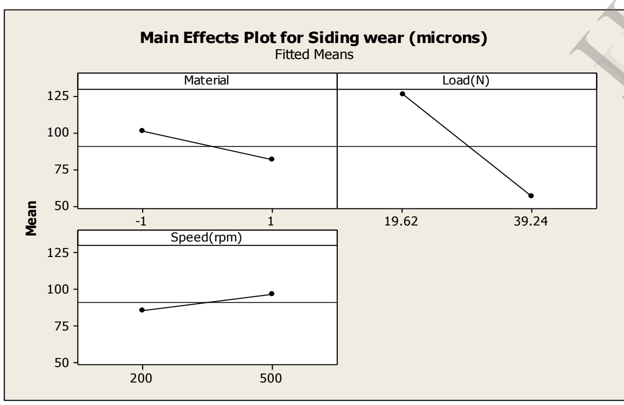


Figure16: Main effect plot for sliding wear

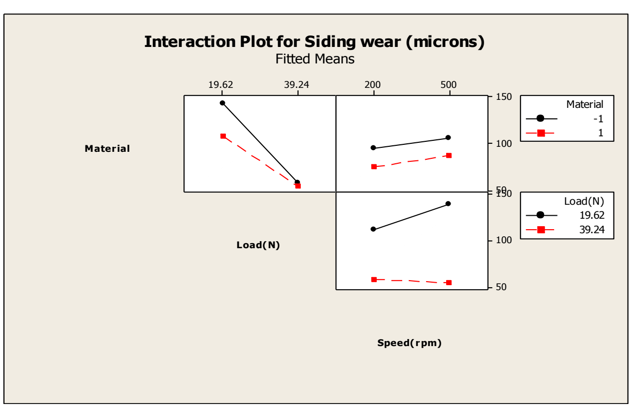


Figure17: Interaction plot for sliding wear

Similarly main effect plot of fitted means (Figure 16) for sliding wear was showed that sliding wear for Al/SiC$_{10\%}$ MMC was 100µms and for LM13 alloy was 80 µms. This means that Al/SiC$_{10\%}$ MMC was seizer out at higher wear than LM13 alloy at higher seizer time. This plot also suggested that as load increased sliding wear wear was redced and as speed increased (figure16) sliding wear was increased. The interaction plot (Figure 17) showed that both materials were interacted at higher load 39.24 N . But when load and speed combinely observed then it had shown the Al/SiC$_{10\%}$ MMC was seizer out at sliding wear 100-150 µms and LM13 alloy was seizer out at 60-80 µms. at speed range 200-500rpm hence plot was suggested very low chance to interact sliding wear values of LM13 and Al/SiC$_{10\%}$ MMC (figure17) for higher speed and load parameters.

## 4. Conclusion:

1) Development of Al/SiC$_{10\%}$ MMC by using stir casting route was more economic than the any other manufacturing process for mass production and 10A current passing for 10 sec. during cooling of casting was improved the quality of Al/SiC$_{10\%}$ MMC.
2) Seizer wear time of Al/SiC$_{10\%}$ MMC was superior to LM13 alloy by 21% with the same load condition.
3) Frictional forces of Al/SiC$_{10\%}$ MMC were lesser than LM13 alloy by 14% for same load condition.
4) Coefficient of friction for Al/SiC$_{10\%}$ MMC was lies in 0.15 to 0.2 while for LM13 was 0.12-0.25.
5) If the combined effect of load and speed was taken then also Al/SiC$_{10\%}$ MMC was superior than LM13 by 22% .

Hence it is concluded that Al/SiC$_{10\%}$ MMC is better material for use in brake drum & piston ring type automotive utilities where wear playes impotant role on the basis of Seizer time and sliding wear tribiological parameters.



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