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# Dry Sliding Tribological Behaviour of Casted Eutectic Al-Si Alloy with and without Nano Alumina Reinforcement

**S. A. Srinivasan[1*], A. Karthik[2], G. Velukumar[3] and P. Mayilsamy[4]**

[1]Department of MME, National Institute of Technology, Trichy – 620015, Tamil Nadu, India; sasrinivasan@gmail.com
[2]Department of Mechanical Engineering, Saveetha School of Engineering, Saveeetha University, Chennai – 600072, Tamil Nadu, India; karthik.3071988@gmail.com
[3]Department of Mechanical Engineering, MNM Jain Engineering College, Chennai – 600097. Tamil Nadu, India; velukumarmgp@gmail.com
[4]Department of Mechanical Engineering, Shree Venkateswara Hi-Tech Engineering College, Gobichettipalayam – 638455, Tamil Nadu, India; mayilsamy45@gmail.com

## Abstract

An investigation on wear behaviour of Al-Si (eutectic) – ENAC48000 have been carried out which are widely employed in the tribological environment as the silicon imparts high wear resistance. Composites with nano alumina (~40 nm) reinforcement of 1%, 2%, 3% (wt %) were prepared using Squeeze casting technique. The samples were polished and grounded well using emery, alumina and diamond paste to study the micro structural morphology using Optical Microscope (OM) followed by SEM. Pin samples were tested for studying the dry sliding wear behaviour using High Temperature Vacuum Tribometer under the load of 10N, 20 N and 30 N at 3.665 m/s. The hardness survey results show a gradually increasing trend in the hardness value with respect to the reinforcement. Regardless of the increasing in the hardness value proportional to the percentage of reinforcement, the wear resistance shows a detrimental pattern as the load and operating temperature increases simultaneously. Abrasion wear mechanism was observed using SEM results on the induced sub surface wear at higher loads. The COF values and mass loss measurement of the composites shows better wear resistance with respect to the reinforcement percentage as the formation of oxide at high temperatures over the surface tends to resist the wear. The results shows promising to employ the composite is low wear working conditions where the thermal distortions due to wear are lesser comparatively.

**Keywords:** Dry Sliding Wear, ENAC48000, Nano Alumina, Squeeze Casting, Tribology

## 1. Introduction

Aluminium composites finds its major applications in developing light weight automobile components such as brake drum, Pistons, Plungers, etc. Generally Metal Matrix Composites are found to be most employed in various industrial applications[1]. Among which Aluminium alloy MMNC offers excellent combination of properties. Because of their excellent properties, they are being used in various engineering applications[2]. Particulate reinforcement by employing double layer feeding casting technique proves to be a promising technique in developing MMNC[3]. The properties of MMNC developed depend mainly on the selection and compatibility of reinforcement with the matrix alloy. Reinforcement of Nano $Al_2O_3$ ensures uniform distribution and minimal porosity[4,5].

ENAC48000 is mainly used for piston applications and application where temperature and load is high. It has good wear resistance, machinability and corrosion resistance. This eutectic alloy needs cleaning at elevated temperature and corrosion properties can be improved by heat treating the alloy around 520 C followed by

**Author for correspondence*

quenching and ageing. Also the low thermal coefficient of expansion for this alloy is another major property that eases the use of the alloy at high temperature tribological application areas.

Al-Si alloy gives the better strength, high temperature property applications and good wear resistance[6]. Sliding wear rate decreases at the starting for few minutes then it becomes almost constant[7]. Hybrid composite improves the tribological response and mechanical properties[8–12].

The dispersion of about 2-3 % $Al_2O_3$ particles in aluminium alloy matrix gives better adhesive wear resistance to alloy. The dispersion of $Al_2O_3$ in the matrix improves its resistance to abrasion over the contact surface thus reducing the scoring tendency. The presence of $Al_2O_3$ in the matrix gives a tribo-induced thin film at the rubbing interface which prevents the scoring or seizer. The size range of $Al_2O_3$ particles between 40-60 nm yields best results. The coefficient of friction decreases with $Al_2O_3$ percentage more than 2%, reaching the value of $Al_2O_3$ with about 20% and thereafter remaining the same with further increase. For most of the practical applications about 2-3 vol % $Al_2O_3$ in the matrix is enough to give the required mechanical and tribological properties.

## 2. Materials and Methods

ENAC4800 is the alloy under investigation reinforced with nano alumina. The chemical composition of the ENAC48000 was presented in Table 1 which complies with the BS1490 standard.

The base metal (Al), alloying elements with reinforcement was subjected to squeeze casting process, where in the aluminium is placed in a preheated furnace to 700°C for complete melting of Al and all the components are added into the molten Al one by one. The vortex created by the impeller disperses the reinforcement particles and maintain uniform distribution in to the melt homogeneously. Subsequent solidification prepares the composite for investigation. The Casting parameters can be seen in Table 2.

Casted samples were prepared for micro-structural examining after grounded flat with emery, alumina and diamond polishing followed by etching. The wear performance of the ENAC48000 Aluminium alloy and MMCs was investigated by conducting dry sliding wear test using High temperature vacuum Tribometer (TR-20 HTVT, DUCOM). The samples were made as a stationary pin, subjected to mate with the rotating disc under predefined load conditions to study the wear characteristics. The samples were cleaned and weighed before and after the wear test. EN32 disc was used as a counter body. The wear test were conducted under dry sliding conditions at room temperature and high temperature with varying loads for a constant sliding time of 1000s. The experimental parameters are show in the Table 3.

## 3. Results and Discussion

The optical micrograph of composite ENAC48000 and the reinforcement with their different percentage are shown in Figure 1(a) and Figure 1(b). The mistrostructures shows the formation of dendrites and spine liked structures which are due to the distribution of the reinforcement. From Table 4 it is clear that with the increase in the percentage of reinforcement, grain size of the particles go on decreasing because of the formation of nucleation site for grain formation and reinforcement acts as obstacles in grain growth hence resulting in grain size reduction.

**Table 1.** Chemical composition of ENAC48000

| Constituents | Composition (wt%) |
|---|---|
| Silicon | 9.919 |
| Magnesium | 1.358 |
| Copper | 1.149 |
| Nickel | 1.164 |
| Iron | 0.515 |
| Manganese | 0.07 |
| Zinc | 0.446 |
| Others | 0.3 |
| Aluminium | Remaining |

**Table 2.** Casting parameters

| Melting Temperature | 700 °C |
|---|---|
| Super heating | 30–40 °C |
| Die temperature | 250 °C |
| Stir speed | 600 rpm |

**Table 3.** Dry sliding wear test parameters

| Temperature | RT, 250 C |
|---|---|
| Track diameter | 50 mm |
| RPM | 780 |
| Test time | 1000 s |
| Load | 10 N, 20 N, 30 N |
| Sliding Distance | 2000 m |

Fine particles of reinforcement of same weight are having higher surface area hence it creates more obstacles in grain growth during solidification process. Hence in this way we can conclude that finer the size of the particle higher will be the obstacles hence finer will be the grain size of cast product. The white region on the micrograph is the Al rich region and the black portion of the micrograph shows the Si rich region.

As the cooling rate increases grain size becomes finer and finer. Dendritic formation may be due to the slow cooling (air) rate during the stir casting process which on the other hand can be attributed to the shearing of initial dendritic arms. Initially local solidification of the melt occurs induced by the particles as there is a temperature difference between particle and the melt giving rise to dendrites. Further, the length of the dendrites and tip diameter also reduces due to the presence of particles.

Figure 2(a) and Figure 2(b) shows the effect of time of sliding on the coefficient of friction for ENAC48000 with 1% nano alumina reinforcement. It is observed that by increasing the load on the disc (keeping all other parameters constant) COF increases. If we compare the result of same loading condition but at different temperature range the COF increases but the effect of increasing load causes more increase in COF.

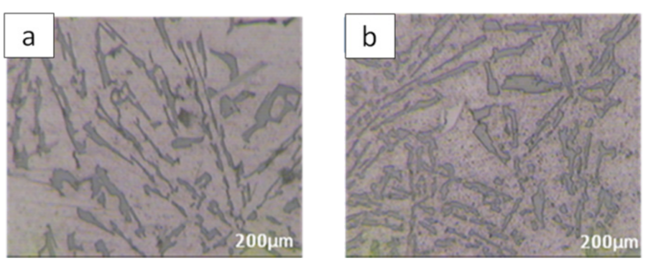


**Figure 1.** Optical micrograph of ENAC48000 (a) Without reinforcement and (b) ENAC48000 with 2% $Al_2O_3$.

**Table 4.** Grain size and porosity

| Property | ENAC48000 | ENAC48000 with 1% $Al_2O_3$ | ENAC48000 with 2% $Al_2O_3$ | ENAC48000 with 3% $Al_2O_3$ |
|---|---|---|---|---|
| Grain size (µm) | 10.7051 | 9.2123 | 7.9214 | 7.1031 |
| Porosity % | 13.9939 | 8.5292 | 6.2733 | 8.435 |

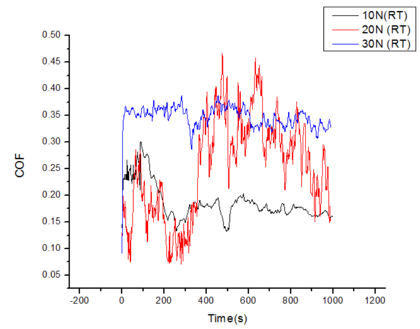


**Figure 2(a).** Coefficient of friction against sliding time in room temperature and unlubricated condition.

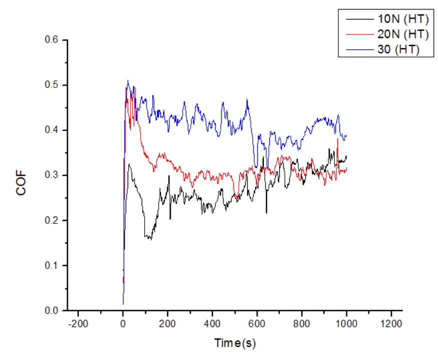


**Figure 2(b).** Coefficient of friction against sliding time in room temperature and unlubricated condition.

The experimental data reveals that the wear rate is observed to be very high at 30 N, 250°C compared to room temperature which was shown in Figure 3. The delamination of the surface at higher load and detachment of oxide layer resulting in micro cracks may be the reason behind the behaviour.

The sliding wear mechanism involved is studied by the surface morphologies of worn out pins and debris collected. SEM results of worn surfaces of composite prepared using 1% nano-alumina reinforcement at 30 N, 250°C temperature is shown in Figure 4. SEM results shows deep scratches and shallow grooves runs parallel to the sliding direction on the worn surfaces of the composites followed by fracture of the oxide layers. The ploughing marks are deeper. Onset of transition of mild to severe wear is observed at high temperature by formation and delamination of oxide layers on the wear surface at 250°C as shown.

Wavy longitudinal grooves run parallel to the sliding direction on the worn surfaces of the composites due to the ploughing action. At 250°C the worn surface shows the oxide cover over a thick area along with fresh surface. The depth of micro ploughing is more in high temperature and new large cavity oxide area is created in this temperature.

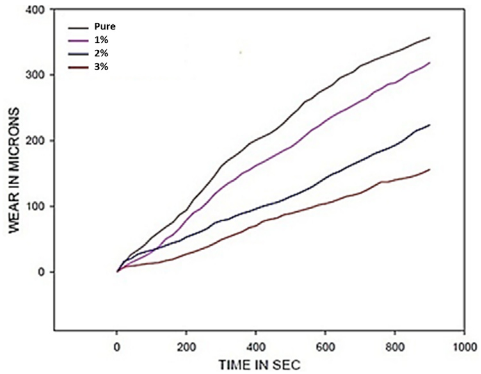


**Figure 3.** Wear rate of pure ENAC48000 and their reinforcements at 30 N, 250 °C.

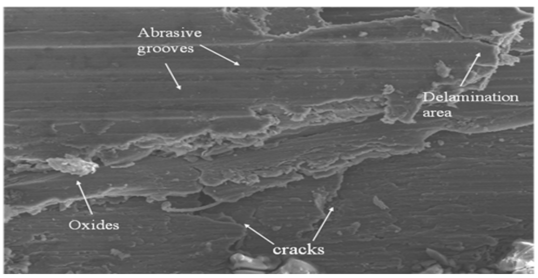


**Figure 4.** SEM Micrograph of MMC with 1% nano alumina reinforcement at 30 N, 250 °C.

## 4. Conclusion

The results have shown that nano-sized alumina particulates 1%, 2% and 3% volume are able to bring notable improvement in wear resistance property of pure alloy, especially under higher loads. The small volume fraction of reinforcement used presently is significant against the earlier studies which employed 15-20 % of reinforcement as previous studies have found there exists an optimum level of reinforcement for a given particulate size and sliding condition, beyond which, despite an increase in wear rates comparable to or even higher than the unreinforced material.

Through this present investigation it is seen that wear via delamination was lesser due to the small amount of reinforcement. Abrasion and adhesion observed to be the dominant wear mechanisms the alloy undergoes and it agrees with an earlier report of adhesion and micro ploughing in silicon carbide-reinforced aluminium alloy composite while large particulates were found to introduce delamination and third-body abrasive wear with an attendant increase in wear rates.

Argument to the above discussion, the present wear tests have employed a relatively low normal load (only 30 N) compared to the earlier reports for loads below 15 N. The formation of a transfer oxide layer on the surface protected the surface from abrasive wear. Even though delamination was observed at some places, no correlation was found between wear rates and volume fraction.

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