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# Wear and Life Characteristics of Al-B4C Nano Graphite Composite

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## ABSTRACT

Aluminium composites are one of the most widely used composites because of its light weight and weight to strength ratio. They possess important tribological properties and are used in the manufacture of disc pads, brake drums etc. Traditional life tests under normal operating condition would be a time-consuming process due to the longer expected life of the composite and hence accelerated wear testing was carried out to evaluate the life characteristics of the composite. This work focuses on evaluation of tribological performance of stir casted Al-B4C- nano graphite composite under accelerated wear testing methodology using a high temperature pin-on-disc tribometer. The dispersion of the reinforcement in the matrix of the composite and the microstructures were carried out using SEM. Analysis on life characteristics were performed on the time-to-failure data using temperature- non-thermal (T-NT) accelerated life-stress model and time to failure obtained from the accelerated wear testing was extrapolated to normal usage condition. The significant parameters affecting the performance were temperature and pressure.

**Keywords -** Al-$B_4$C-nano graphite composite, life characteristics, stir casting, time to failure, wear.

## 1. INTRODUCTION

The reliability of a product is defined as the probability that it will perform satisfactorily for a specified period of time under stated use conditions. Failure refers to the loss of component or cost lost. The major reason behind the study of failure is to predict the reliability of the component. Failure is the major factor which inhibits the reliability of the component under such conditions. This is caused by the various stresses acting on the component. The various stresses include load, temperature, velocity, etc. In enjoin to introduce a newer material with enhanced properties for an industrial application like brake drum, its performance, reliability, and life characteristics need to be evaluated. Al 6061 was used as the base metal, B4C of size 320 mesh and nano graphine of size 100 nm was used as raw materials. The composite was fabricated by solution casting method. The newly developed aluminium based composite, Al-B4C- nano graphite shows a better performance and characteristics than the existing aluminium based composites. Traditional life data analysis is carried out by analyzing time-to-failure data which is obtained through the tests conducted under normal operating conditions. The valuing of life characteristics under normal operating conditions will be a time consuming process for the highly reliable products [1].

Time-to-failure data of the sliding contact material can be obtained by making this material fail more quickly under accelerated conditions than the normal conditions. It is known as accelerated life testing (ALT) technique which is useful for finding the life characteristics of products/components [2, 3]

ALT was designed, planned and the times-to-failure data were collected under multiple stress condition. In actual field the developed component fails under the combination of multiple stresses [4, 5]. The Al-B4C-CNT composites were subjected to accelerated wear testing under multiple stress conditions. High temperature pin-on disc tribometer was used with various stresses such as temperature and pressure with constant velocities. Reliability analysis of the newly developed aluminium boron carbide- nano graphite composite was carried out through ALTO PRO 6 reliability software.

## 2. EXPERIMENTAL RESULTS OF RELIABILITY ANALYSIS

To understand the influence of the factors affecting the wear performance of Al- $B_4$C- nano graphite composite, Box Bahengen method was chosen. Experiments were planned by varying temperature, load, and sliding velocity. Based on the wear depth, wear criteria has been fixed.

*Table 1 Results of the experiment*

| S.No. | Time to failure (minutes) | Temp (°C) | Load (N) |
|---|---|---|---|
| 1 | 33 | 110 | 5 |
| 2 | 22 | 110 | 10 |
| 3 | 16 | 110 | 15 |
| 4 | 16 | 110 | 20 |
| 5 | 12 | 110 | 25 |
| 6 | 33 | 120 | 5 |
| 7 | 22 | 120 | 10 |
| 8 | 16 | 120 | 15 |
| 9 | 16 | 120 | 20 |
| 10 | 12 | 120 | 25 |
| 11 | 33 | 130 | 5 |
| 12 | 21 | 130 | 10 |
| 13 | 16 | 130 | 15 |
| 14 | 15 | 130 | 20 |
| 15 | 11 | 130 | 25 |
| 16 | 33 | 140 | 5 |
| 17 | 21 | 140 | 10 |
| 18 | 16 | 140 | 15 |
| 19 | 13 | 140 | 20 |
| 20 | 11 | 140 | 25 |
| 21 | 31 | 140 | 5 |
| 22 | 21 | 140 | 10 |
| 23 | 15 | 140 | 15 |
| 24 | 12 | 140 | 20 |
| 25 | 08 | 140 | 25 |

The preliminary wear test trials confirmed that there was a change in the wear mechanism with the increased in normal load, large amount of wear fragments dislodged from the worn out surface could be observed beyond the wear depth of 0.1 mm. Similar observations were also reported for copper-based sliding materials. The wear criterion hence was chosen as 0.1 mm and the same was maintained for all accelerated wear testing conditions. Temperature and load were chosen as the process parameters for the accelerated life testing. Accelerated temperature chosen for the experiments was 110-140°C by the step of 10°C. The load chosen for the experiment was 5, 10, 15, 20 and 25N. Speed is kept constant at 2m/s. The assumption made is that the pin is in continuous contact with the disc, particle reinforcements are uniformly distributed and volumetric wear at specific condition is constant and working at an ambient temperature. The softening temperature of AA6061 is 180˚C and the working condition of the brake pad is between the temperature of 100 ˚C and 150˚C and pressure between 5N and 30N. Speed is an insignificant parameter [8]. So these parameters were opted for the experiment.

## 3. CHARACTERIZATION OF THE COMPOSITE

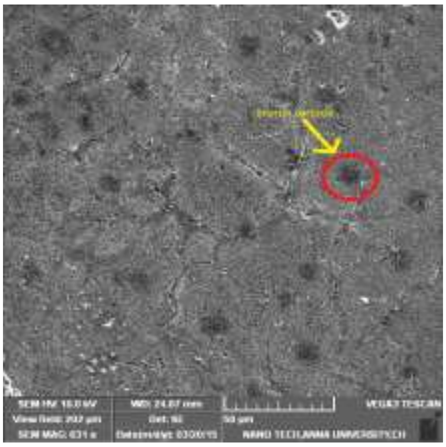

*Fig. 1 SEM image showing dispersion of boron carbide in aluminium*

The microstructure of composite is shown in Fig. 1. The dispersion of boron carbide in the aluminium matrix is clearly observed in the Fig. 1and is highlighted with a red coloured rounded mark. The presence of carbon particle is not seen in the low magnification range of the SEM image as shown in the Fig. 1.

The EDS of composite is shown in Fig. 2 confirms the presence of aluminium, boron and graphite peaks.

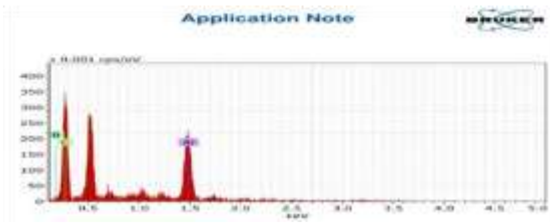

Fig. 2 EDS showing the composition

### 3.1 Wear morphology

Fig. 3 and 4 shows the SEM image of the composite at low load (5N) low temperature (110˚C) and high load (25N) and high temperature (140˚C). Wear resistance of composite decrease with increasing in testing temperature due to oxide formation paralysis the wear performance. Increase in load increases the coefficient of friction which decreases the frictional wear resistance of the composite. Wear track observed in Fig. 4 is reduced to a large extent compared with the Fig. 3. This clearly shows that the wear rate of the composite is increased when the load is increased.

### *3.1.1 Effect of temperature*

From table 1, it is observed that the time to failure of the fabricated composite decreases with increase in temperature.

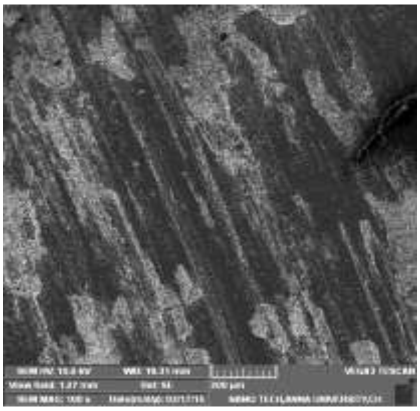

*Fig. 3 SEM image of 85% Al, 10%$B_4C$ and 5% nano graphite at load 25N*

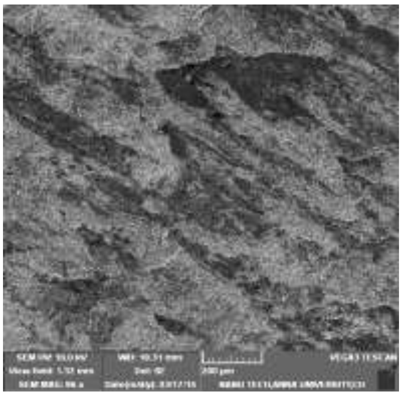

*Fig. 4 SEM image of 85% Al, 10%$B_4C$ and 5% nano graphite at load 5N*

### *3.1.2 Effect of load*

From Table 1, it is prominently seen that the time to failure of the fabricated composite decreases with increase in load from 5N to 25N. The increased pressure weakens the carbon film formed during sliding process.

## 3.2 Life characteristics

### *3.2.1 Probability density function*

Analysis of ALT data by selecting an underlying life distribution can describes the component behaviour at different stress states. Stress-life relationship model quantifies the life characteristic of component across the stress levels. The tests are not censored by allowing run until they attain wear criterion. Lognormal distribution is widely accepted to describe many tribological phenomena. Hence it is used as the underlying life distribution for sliding wear testing of components. The probability density function (pdf) of the lognormal distribution is given by Eqn. 1,

$$f(T) = \frac{1}{\sigma_{T'}\cdot\sqrt{2\pi}} e^{\frac{-1}{2}\left[\frac{T'-\bar{T'}}{\sigma_{T'}}\right]} \qquad (1)$$

Where T′ is the ln(T), T is the time-to-failure, and $\bar{T}'$ is the mean of the natural logarithms of the times-to-failure, $\sigma_{T'}$ is the standard deviation of the natural logarithm of the time to- failure or shape parameter of distribution or shape parameter.

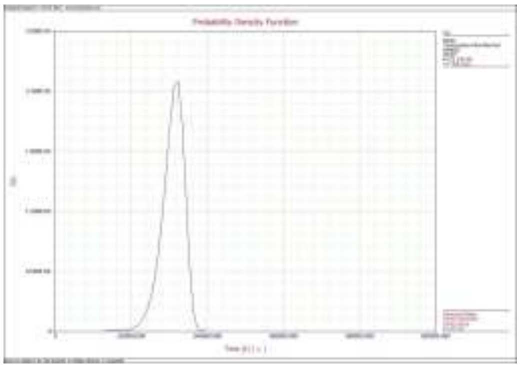

*Fig. 5 Probability density function*

In order to calculate the distribution parameters for all tested data, time-to-failure data of the each stress level assumed to be lognormal distribution. Probability density function of tested data is shown in Fig.5

### *3.2.2 Life stress relationship*

The Arrhenius life-stress relationship is one of the most common life-stress used in the case of stimulus or acceleration stress is thermal (i.e., temperature) (Ref. 6). Hybrid of Arrhenius and the IPL models resulted temperature-nonthermal (T-NT) model. This model is given by Eqn. 2,

$$L(P,V) = \frac{C}{P^n e^{-\frac{B}{V}}} \qquad (2)$$

Where, L represents a quantifiable life measure; P represents pressure (KPa); V represents temperature (˚C); B, C, and n are model parameters.

### *3.2.3 T-NT lognormal model*

For the T-NT Lognormal model, the reliability for a given time T for the T-NT Lognormal is determined by Eqn. 3.

$$R(T,P,V) = \int_{T'}^{\infty} \frac{1}{\sigma_{T'}\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{t-\ln(C)+n\ln(P)-\frac{B}{V}}{\sigma_{T'}}\right)^2} dt \qquad (3)$$

The T-NT Lognormal mean life function can be written by in the Eqn. 4,

$$\bar{T} = e^{\ln(C)-n\ln(P)+\frac{B}{V}+\frac{1}{2}\sigma^2 T'} \qquad (4)$$

The estimation of parameters such as B, C, and n are obtained using maximum likelihood estimation (MLE) through ALTA PRO 6 tool as follows $\sigma_{T'}$=4.7817E-02; B = 177.4474, C = 15219.6871, and n = 0.4898. B is a measure of the effect that the temperature on the life. Larger value of B indicates that the life is highly affected by temperature. 'n' is model parameter which indicates the effect of load or pressure on the life of the tested composite.

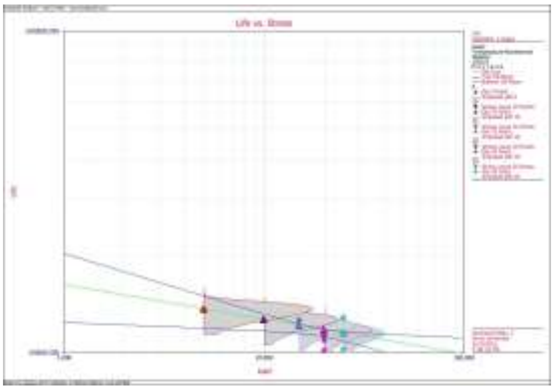

*Fig. 6 life v/s stress relation with varying load*

Depending on the application (and where the stress is exclusively thermal), the parameter B can be replaced as shown in Eqn. 5. ,

$$B = \frac{E_A}{K} \qquad (5)$$

By using the above parameters, a probability plot based on median rank method was obtained at the usage level of 99.5%, as shown in Fig. 6 and 7 with varying the load and temperature respectively. In this plot, the points are extrapolated from the accelerated load conditions. The linearity of the data supports the use of the lognormal distribution Eq. 1.

The mean life of the tool under normal usage condition is estimated from the equation 2, as 32050km.

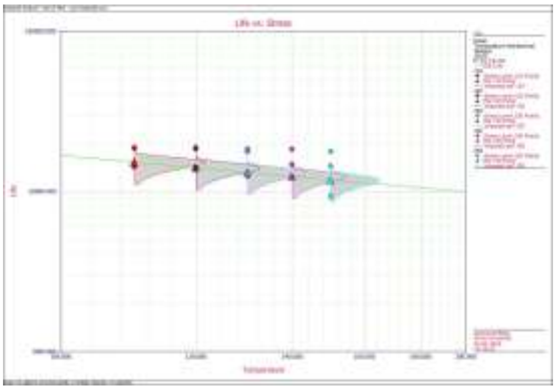

Fig. 7 Life v/s stress relation with varying temperature

## 4. CONCLUSIONS

Temperature and load were found to be significantly affecting the wear properties of the developed composites. The oxide film formation was helpful in the mild wear regime but worse in wear performance with increasing in temperature. T-NT Lognormal life-stress model of the Al-B4C- nano graphite predicted the life time of 50054.770 km for the reliability at 90%.

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**Nomenclature**

T = Time to failure
T˚ = ln T
$\bar{T}$ = Mean of the natural logarithm of the time to failure
$\sigma_{T'}$ = Standard division of the natural logarithm of the time to failure
L = Mean life
V = Temperature, ˚C
P = Pressure, KPa
EA = Activation energy, eV
B, C& n = Modal parameters.