

High Speed Tribological Characteristics Analysis of Aluminium and SiC Composites

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ABSTRACT: Metal matrix composites (MMCs) derive their excellent mechanical properties from the combination of a hard reinforcement phase such as silicon carbide (SiC) and a ductile matrix material such as aluminium or magnesium. Four Al/SiC composites, two of which were fabricated in house & rest two were commercially sourced. Composites were tested on Pin on Disc configuration. Some tribological behaviour was determined under various loads & sliding speeds. Wear rate increased with increasing load, but in a rather complex manner with respect to sliding speed, viz. Low wear rates under Regime I. Catastrophic failures occurred in Regime II. In Regime III excessive melting was pointed out. The size of reinforcement particles influences rate of wear rate in composites.

KEYWORDS: MMC, Al/SiC composites, wear rates.

I. INTRODUCTION

Metal matrix composites (MMC), evolved due to demand of light weight and specific strength materials in aerospace industry. MMC's have good ductility of the metal alloy retained .while modulus & strength of composites is increased in reinforcement phase.

Aluminium-Silicon Carbide is a **composite** material consisting of silicon carbide particles dispersed in a matrix of aluminium alloy. It adjusts the benefits of high thermal conductivity of metal and low CTE (coefficient of thermal expansion) of ceramic.

SiC particles have excellent compatibility with Al matrix and are easy to process, these exhibit excellent wear resistance and this makes it good candidate for any sliding surface.

With these composite features, Al-SiC is an advanced packaging material for high technology thermal management. Al-SiC having wide range of metallic and ceramic substrate and plating materials used in microelectronic packaging for aerospace, automotive, microwave applications. Metal matrix composite allows for a new packaging technology that can replace traditional W-Cu, Mo, Mo-Cu, AlN, AlSi, and Al₂O₃. Aluminium matrix composites find wide applications in the present industrial scenario due to their desirable properties.

Abrasion is the removal of material from a relatively soft surface by the ploughing or cutting action of hard grit particles. Reinforcing aluminium alloys with hard ceramic particles (e.g., SiC, Si₃N₄, B₄C, TiB₂, Al₂O₃, SiO₂, glass, zircon, fly ash, and shell char), and short fibers or whiskers improves the abrasion resistance. Most studies have focused on the tribological performance of Al/SiC) composites, although other hard particles such as zircon [59, 60], flyash [61], TiB₂ [62, 63], and TiC [63] also have been dispersed in Al to improve its wear resistance.

II. LITERATURE REVIEW

The tribological behavior of reinforced AMC's has been investigated by numerous researchers and there are many published works related to this subject. Most of them have demonstrated the enhanced tribological performance of the composites compared to unreinforced alloys. However most of the literature on reinforced AMCs has been focused on homogeneous materials (uniform distribution of reinforces).

Some previous work in the area of FGM aluminium matrix composites include the study of Kang and Rohatgi (1996) who performed a transient thermal analysis of solidification in a centrifugal casting for composite materials containing particle segregation [8]. In this research one-dimensional heat transfer analysis during centrifugal casting of aluminium

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alloy and copper-based MMCs containing Al_2O_3 , SiC, and graphite particles were studied. They proposed a numerical model of particle segregation during centrifugal casting of liquid metal containing suspended particles. In addition, they considered that liquid metal temperature is influenced by the speed of rotation, the variation of reinforcement and the constitution of the base alloy. Additionally, the initial mold temperature and its speed of rotation were found to be significantly affected by the solidification time due to particle segregation (measured as volume fraction). Watanabe and Fukui (2000) carried out an analysis of microstructures and mechanical properties of FGMs fabricated by a centrifugal casting method [7]. The particle distribution gradient of the dispersed compounds (Al/SiC; Al/Al₃Ti; Al/Al₃Ni) was established. The author reported the variation of matrix hardness with the composition gradient. Mechanical properties such as Young's modulus, internal friction, and fatigue crack growth in an *in-situ* Al/Al₃Ni FGM were evaluated. Analysis of thermal residual stress was done on Al/SiC FGM and, wear behaviour of Al/Al₃Ti FGM was determined. This study mainly showed that SiC particles move toward the casting outer parts under the action of centrifugal force (due to the denser particles). The same trend was found in Al₃Ti. Al/Al₃Ni FGM which is an application of the *in-situ* technique using the crystallization phenomena exposed a uniform volume fraction distribution of particles and decrease in particle diameter in the outer region of the casting. Analysis of matrix revealed a direct relation between hardness and volume fraction of particles. Internal friction and Young's modulus increased with increasing volume fraction of particles. Effect of graded composition on the fractography is not clear. However, since the graded composition affects the crack path, this may increase the toughness of material. The analysis on Al/SiC FGM showed that thermal residual stresses are greater for higher composition gradient. Finally, the wear volume of Al/Al₃Ti specimens was much lower than those of pure Al.

Gomes et al. (2003) performed a tribological characterization of homogeneous gravity cast aluminium-based matrix composites and aluminium composites with functionally graded properties, obtained by centrifugal casting and reinforced with SiC particles [9]. These composite materials were tested against nodular cast iron in a pin-on-disc tribometer in order to evaluate their friction and wear properties. The worn surfaces as well as the wear debris were characterized by SEM/EDS and by atomic force microscope (AFM). The friction coefficient revealed a slight decrease when FGMs are involved in the contact instead of the homogeneous composite. Relatively low values of the wear coefficient were obtained for functionally graded aluminium matrix composites. Characterization of the worn surface indicated that the effect of reinforcing particles played a decisive role in the friction and wear properties of aluminium matrix composites.

III. MATERIALS USED IN EXPERIMENTATION

Two of four materials were fabricated in house; Al-4.5%Cu-13%vol%SiC composites with two different particle sizes were specially fabricated. Pure Al-150, SiC-50, and Cu-150. Ball mill alloying method was used as it can be rotated at different speeds for different lengths of time.

1. Ball milled @86 rpm for 10hr (PM1).
2. Ball milled @163rpm for 10hr (PM2).

Compacted to disc shaped green compact at 420Mpa to attain 88% green density later sintered at 590 C for 5hr. ageing was made for 17hrs at 175 C.

Commercially sourced composites

1. Al(a356)-20% vol SiC, from Dural Aluminium Composites Corp. (C1)
2. Al (A6061)-15%SiC, from DWA Composites. (PM3)

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Table 1 (Particle sizes, hardness, and green density)

Properties of the four Al-SiC composites used in the present study

Specimen	Particle size (μm)	Hardness after aging (HV)	Green density (kg/m^3)	Sintered density (kg/m^3)
PM 1	27.4	123	2540	2544
PM2	38.7	140	2665	2681
C 1	7.0	78	-	-
PM 3	1.6	158	-	-

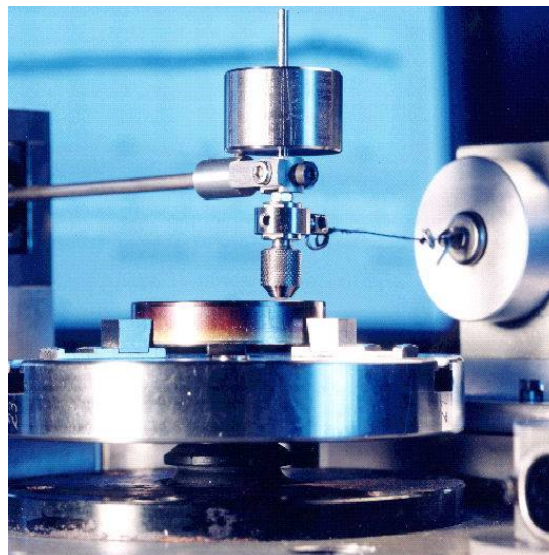


Figure 1. Pin on disc configuration

IV. EXPERIMENT DETAILS AND PROCEDURE

Pin on disc configuration is used to test the specimens; the 30 mm diameter disc was made of AISI01 tool steel of hardened to 63HRC, pins were the composite specimens of 5mm diameter.

A dynamometer measured both normal and tangential forces experienced by the pin. Both disc and pin were polished to same roughness ($R_a < .5\text{mm}$). Loads ranging from 10N-100N and speeds 1m/s – 29m/s were employed. A total sliding distance of 1000m was used in all the tests.

Wear rate was determined by weight loss methods by means of sensitive chemical balance

V. RESULTS AND DISCUSSION

In house fabrications

5.1 Effect of load:

1. When speed of 1m/s was used both specimens completed complete 1000 m test run without failure, at higher speeds they failed nearly below 100 N in 1m/s. The relation between rate of wear and sliding speed is complicated one. Drastic raise in rate of wear was noted from 3m/s to 5m/s then declining sharply at 15m/s(for lower loads). Failures at high speed were attributed to high flash temperature. In range of 3-5 m/s occurred at high loads; under loads around 60N they were stable in range of 8m/s to 29 m/s. At 3m/s both supported 100 N. Speed tests showed gentle increase in wear rates. Very little change in wear rates was measured between loads ranging from 70N – 100N. All these

characteristics are exhibited due to presence of different wear mechanisms. No Failure was observed between 40N to 60N at all speeds.

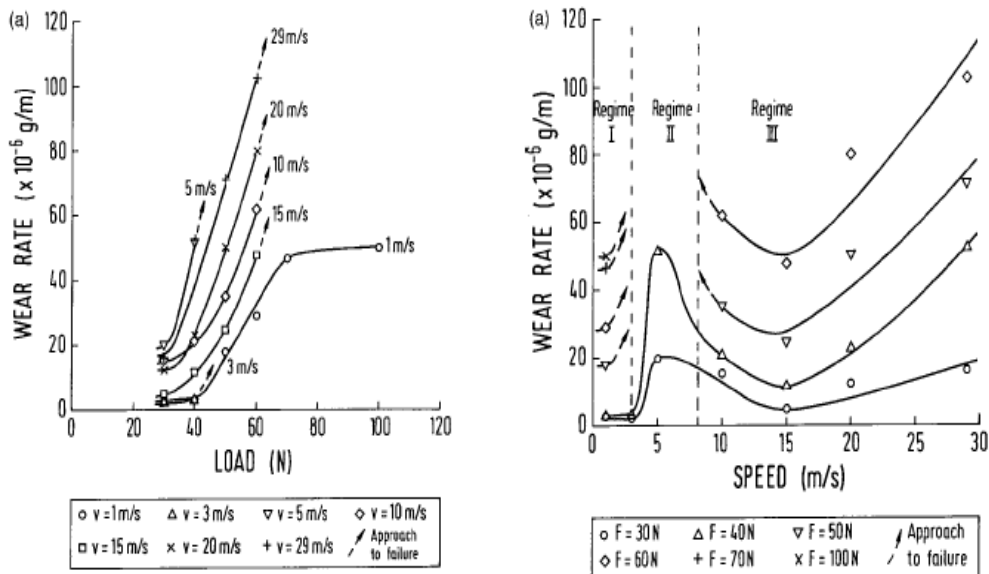


Figure 2. Variation of wear with load & speed for PM1

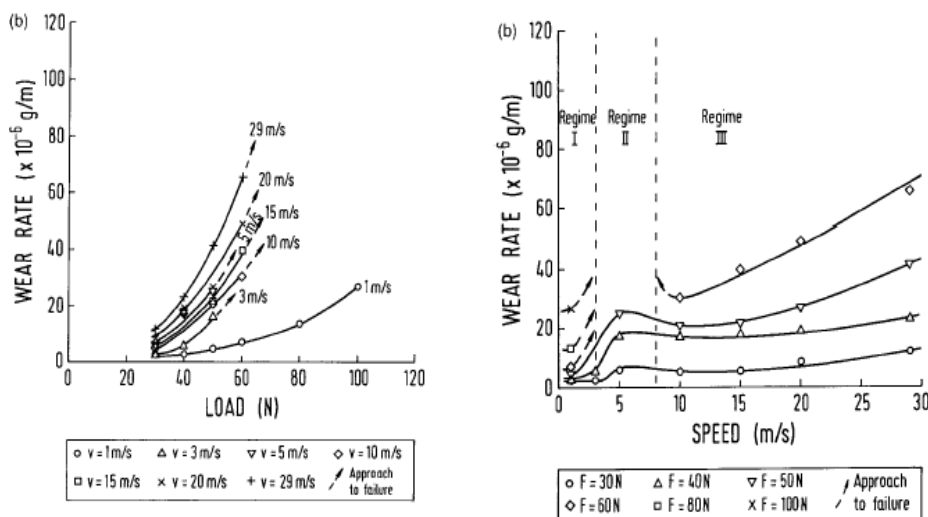


Figure 3. Variation of wear with load & speed for PM2

5.2 Effect of sliding speed:

All speed characteristics are demarcated into three zones

1. Regime I – (1m/s-3m/s)
2. Regime II-(3m/s-8m/s)
3. Regime III-(8m/s-29m/s)

In all wear rate increases with increase in speed well within sliding range.

5.3 Frictional characteristics:

Measured by co-efficient of friction (μ), In regime I (1m/s-3m/s) initially μ was 0.2 steadily increased to 0.6, later no change was observed. The increase was due to induced roughness due to constant sliding, over distance. Regime II (3m/s -8m/s) encompasses a sharp increase in wear rate and ultimately to failure, μ initially was recorded 0.2 but due to high friction it reached high as 1. High friction was responsible for premature failures of specimens. Under regime III (8m/s-29m/s) a peculiar behaviour was noted μ , initiated with 0.2 raising to 0.4-0.5 again falling back to 0.3. This is due to melt lubrication, as at high speeds bulk temperature reaches near to melting point of Al alloy matrix.

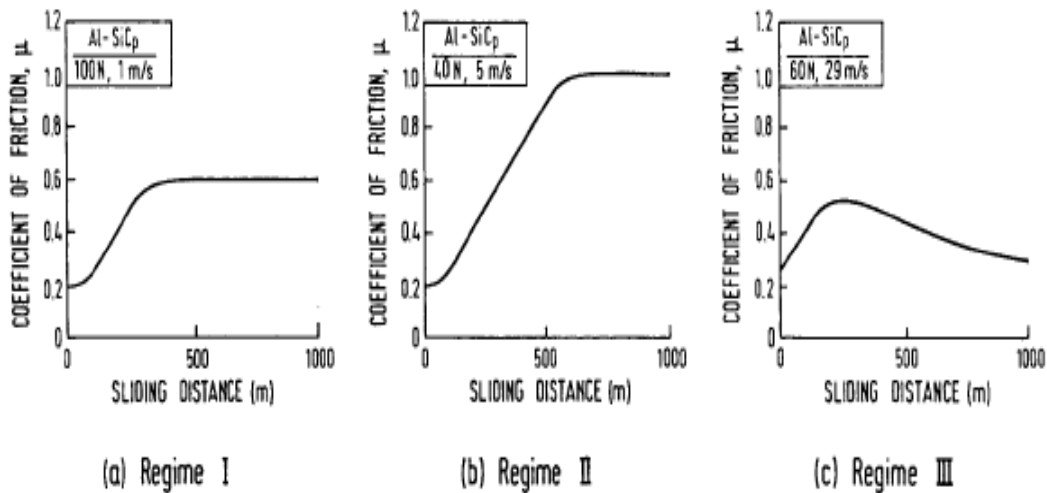


Figure 4. Representative plots to illustrate the variation of μ with sliding distance for PM1 and PM2 in the three sliding regimes

5.4 Commercially sourced composites:

1. Al(A356)-20 vol% SiC (C1)
2. Al(A6061)-13 %vol SiC (PM3)

1. Effect of load:

C1 behaved very similar as a kin to PM1 & PM2, At 1m/s both C1 & PM3 supported 30N to 100 on test run of 1000m. But only 10N was supported by PM3. PM3 did not support any load greater than 20 N for speed greater than 1m/s.

2. Effect of Speed :

In regime I C1 supported upto 100N But PM3 only supported 10 N. Under Regime II C1 satisfactorily sustained up to 50N, but PM3 not more than 10N. Regime III has a record of C1 supporting load of 60N, but PM3 less than 10N. PM3's poor frictional properties attributed by small grain size of SiC particles. But it shows excellent slow speed characteristics even better than rest of 3.

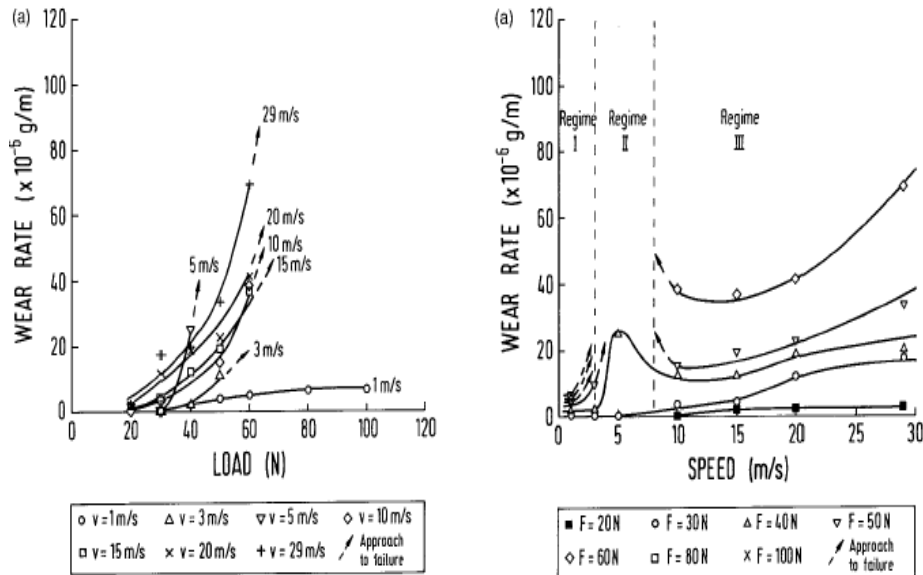


Figure 5. Variation of wear with load & speed for C1

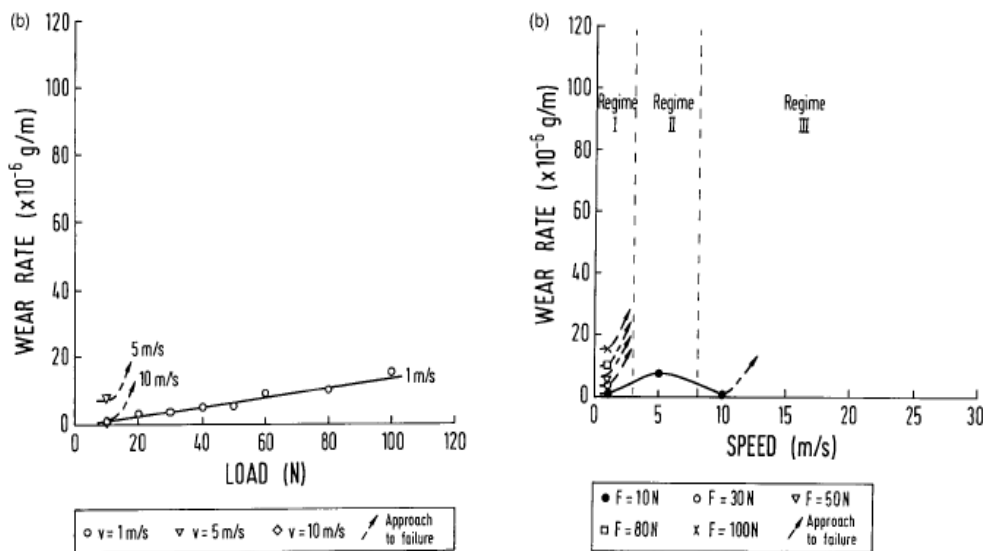


Figure 6. Variation of wear with load & speed for PM3

5.5 Frictional characteristics:

C1 behaves similar to PM1 & PM2 at all conditions μ initially was 0.2 and showed same variations under all regimes of speed. But PM3 has only in slow regime. And no generalization is made.

VI. CONCLUSIONS:

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1. Generally wear rates increase with load and speed, in range of speed. Not for PM3.
2. Wear rate varies in a complex manner; it either increases or falls with sliding speeds.
3. Three demarcated regimes, low wear rate in regime I. Catastrophic failure at critical load under regime II. Severe melting and adhesion in regime III.
4. Sizes of SiC particles appear to be an important factor, as small size leads to inferior high speed resistance.
5. μ varies with sliding distance but no unique value can be assigned at each sliding conditions. Three general characteristics were deduced in three regimes.

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