FABRICATION AND WEAR BEHAVIOUR OF AN ALUMINIUM MATRIX COMPOSITE REINFORCED WITH A HIGH CONTENT OF SILICON CARBIDE PARTICLES

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SUMMARY: Aluminium matrix composites reinforced with silicon carbide particles (SiCp) are of great interest for several automotive applications due to their notably high wear resistance. On the other hand, the electronic industry is very interested in new materials for electronic packaging to meet the needs arising from issues such as increasing packaging density, more severe environments, weight restrictions, etc. Among the most important needs can be mentioned low CTE, high thermal and electrical conductivities or low density for weight-critical systems.

The life time of these components could be further improved by increasing the final volume fraction content (V_f) of the hard ceramic particles. In this way, high content Al/SiCp composites have been already manufactured by means of powder metallurgy techniques but their final price is too high for their application at a commercial scale. As a result of this study, a modified casting sequence of a conventional Al-Si/SiCp (15% volume fraction) composite has been developed to increase the final volume fraction of the SiCp to the range of 50-60%v.

KEYWORDS: Casting, wear properties, silicon carbide particles, automotive applications, electronic packaging.

INTRODUCTION

It has been found that Silicon carbide particle reinforced aluminium composites, with its interesting properties [1] such as higher yield strength and elastic modulus, lower thermal expansion coefficient and good wear resistance, together with its lower cost and easier formability, have a brilliant future and catch more and more attentions. A lot of methods have been applied to fabricate this kind of composite, each one having its own profit and showing its special material properties [2, 3].

European commercial industries require the incorporation of new materials with improved performance not reached by the materials currently employed, in their everyday more and more demanding productive processes and working conditions of components.

In this sense, the electronic industry is very interested in new materials for electronic packaging to meet the needs arising from the issues such as increasing packaging density, increasing requirements reliability, more severe environments, weight restrictions, etc. Among the most important needs, it can be mentioned low and tailorable CTE, high thermal and electrical conductivities or low density for weight-critical systems.

Materials used in electronic packaging are undergoing a revolution because of a number of key factors: increasing packaging density; increasing reliability requirements; increasing use of large solid-state, phase-array antennas; more severe environments; stringent weight restrictions for airborne and other systems as well as cost constraints.

To meet the needs arising from these issues, packaging materials must have, as above explained, several attributes: low, tailorable coefficient of thermal expansion; high thermal conductivity; low cost and low density, for weight-critical systems. This is mainly because packaging materials support and protect integrated circuits and other electronic components, playing a key role in heat dissipation.

The development of MMC electronic packaging materials is in a relatively early stage, and new composites undoubtedly will emerge. At this time, the materials that have received the most attention are aluminium and copper reinforced with high-thermal-conductivity carbon fibers[4, 5-15] and silicon carbide particle-reinforced aluminium [5-11, 14, 15].

MMC are primarily of interest because of their ability to combine desirable coefficients of thermal expansion (CTE) with higher thermal conductivities, lower weights, and potentially lower costs than competitive materials.

The (SiC)p/Al material, actually a class of materials, has a variety of advantages. First, with existing constituents, which are relatively inexpensive, it is possible to make materials with thermal conductivities in the range of aluminium alloys and with suitable CTEs. Use of high-purity SiC particles, potentially could result in thermal conductivities much higher than aluminium.

On the other hand, and from the point of view of other industries such as the automotive one, commercial industries need the development of lighter components with improved characteristics for the next future, in order to develop more efficient products with reduced pollutant emissions, at low cost. In this way, the objective is to obtain low cost components with improved properties in the needed areas. For this reason, components made of SiCp reinforced aluminium offer the possibility of improving some of the mechanical properties required by the automotive industry, such as the improvement of the wear resistance of components.

Reinforced alloys show higher wear resistance than their base alloy. This is due to solid lubricants used for reinforcement. Hard particles can act as load bearing elements and impede plastic flow and fracture of the matrix during wear.

Silicon carbide particles reinforced aluminium composites offer a good chance of improving the wear properties of the materials and, depending on the volume fraction of particles, the higher the percentage of particles present, the better the wear properties achieved are.

The problem here is basically how to obtain high percentages of particles at low cost. At the moment, powder metallurgy seems to be the easiest way to obtain high percentages. However, the high price involved in this technique is a handicap. To solve this problem, this study has developed a modified casting technique in order to obtain and aluminium with a high content of silicon carbide particles, being this around 55%, but with a considerably lower price.

EXPERIMENTAL PROCEDURE

A commercial composite, consisting of a typical Al-Si alloy and a 20 % content of SiC particles from Duralcan, was used for the experiment.

A modified casting technique was used to manufacture high silicon content MMCs from the Duralcan composite, commercially available. In this way, this composite is poured within a metallic mould at a temperature of 740ºC, following the casting guidelines recommended by Duralcan. At the end, the composite shows a high silicon particles content (55%v. average) within an aluminium alloy poor in Si.

It must be said that this material with a high content of SiC particles, was very difficult to machine. Due to this, in order to carry out some of the further explained tests, such as wear behaviour, difficulties were found in machining samples, because of the high hardness and abrasive properties of this material.

This process constitutes an interesting alternative to powder metallurgy for composite manufacturing with high content of SiC particles. The process parameters can be tailored for obtaining the high reinforcement content required in certain areas of the component, getting this way the percentage of particles needed, up to a 65%.

RESULTS AND DISCUSSION

Metallographic studies by optical microscopy revealed that the composite manufactured showed a fairly homogeneous particle distribution of SiCp, as it can be seen in Figure 1.

Several measurements of the percentage of SiCp present in the composite manufactured were performed. With that purpose, an OMNIMET MHT image analyser was employed. Eleven different samples were used for this purpose, obtaining with those a mean value of 55%v SiCp.

Once these two tasks were carried out and in order to observe the wear properties of this material and compare them with other composites and conventional alloys, wear tests were carried out with the following five different materials:

- Grey Cast Iron.
- Duralcan: Al 2024 + 15% Al_2O_3 p .
- Aluminium-Saffil: AS12UNG + 15% Al_2O_3 Saffil.
- Piston Alloy (AS 18UNG).
- Studied Material.

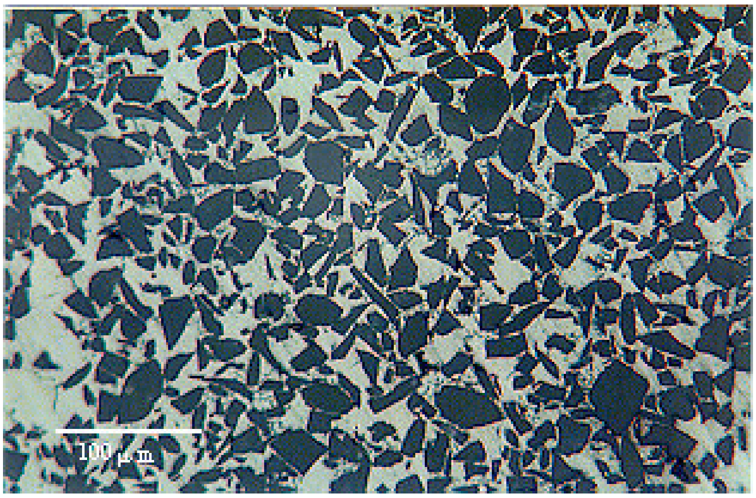

Fig. 1 : Optical micrograph of a SiCp (Vf : 55%)/Al composite

The wear tests were carried out according to the ASTM G 99-90 Standard in a BICERI testing machine at a temperature between 18ºC and 20ºC and a relative humidity of 40-70%. The tests were ball over sliding plate type, in reciprocating movement.

In all the cases, the surfaces were worn against bearing steel balls (F131), 6 mm of diameter. The pressure between the surfaces is done by means of fixed loads on the ball, while the movement is applied on the studied surface. The employed samples are based on square plates of a thickness of 7 ± 0.05 mm, polished with a 3μm diamond spray. The balls and the samples are cleaned and degreased with acetone before each test, keeping them in a drier before and after the tests. This is the summary of the applied conditions: Room temperature, 25N, 5 Hz., wear track of 25 mm, reciprocated movement, three tracks for each measurement.

The tracks made for each measurement on the studied material were observed with the help of a UBM optical surface measurement system profilometer, with microfocus sensor and a resolution of 100 points/mm × 10 point/mm.

The data were obtained at three different sliding distances: 24m, 180m, and 360m. The obtained results can be seen in Table 2. They are also plotted in the attached graph (Figure 2).

As observed in the graph and the table, the lowest wear values were obtained with the studied material, not only in relative values but even in absolute values. This effect is much more evident when we compare the values obtained in the case of the studied material with the values obtained for the other type of commercial materials.

There is not possible comparison with the hipereutectic high hardness Al-Si alloys, where, with the same conditions, the wear is excessive, even at the mildest conditions.

In the automotive field, and until now, the substitution of ferreous alloys by aluminium alloys was based mainly upon the achievement of a lower weight. However, with the studied material, apart from decreasing the weight of the components, the properties are also improved in an absolute way. Due to this, the introduction of this material to the automotive industry is guaranteed.

On the other hand, it was found very appropriate to measure the value of the CTE of the studied material. With that purpose an Adamel L'Hormagy, DT-1000 dilatometer was employed. The specimens employed for that had the following dimensions: ϕ = 2 mm, and L = 12.5 ± 0.5 mm.

	Sliding Distance (m)	Wear Volume (mm^3)
Grey Cast Iron	24	1.79
	180	2.08
	360	4.29
Duralcan	24	5.16
Al-Saffil	24	0.38
	180	4.42
	360	8.28
Studied Material	24	0.31
	180	0.82
	360	1.63
Piston alloy (AS18UNG)	24	unmeasurable because of excessive wear.

Table 1. Data of Wear volume Vs Sliding distance of five different materials

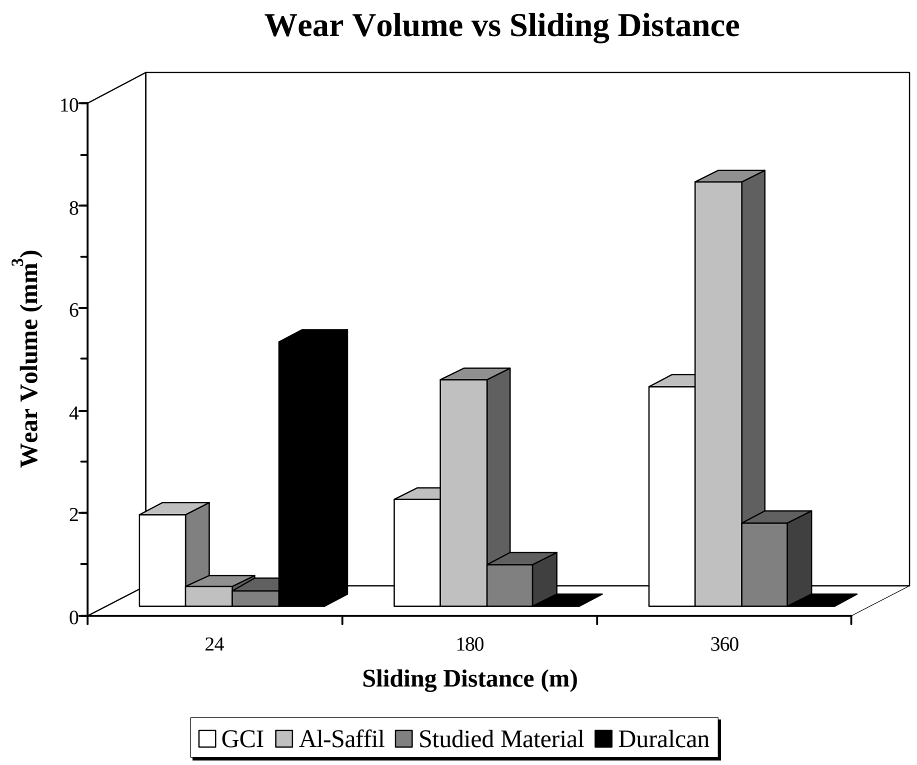

Figure 2. Wear volume Vs Sliding distance of four different materials

It should be noted that SiCp aluminium materials are isotropic and that the analytical and measured values are in reasonably good agreement.

In this study, the CTE of the material was studied from 20 to 350ºC. The value obtained was $\alpha = 18\times10^{-6}$ C^{-1}. It must be cleared that this is a longitudinal CTE value, while an in-plane CTE of 10-12 $\times 10^{-6}$ C^{-1} is currently reported in the bibliography. Considering that the CTE of a conventional aluminium alloy often used on the electronic packaging field is around 23-24 $\times 10^{-6}$ C^{-1}, the difference is outstanding in terms of reducing thermal stresses of electronic components.

Taking into account that an important requirement for materials used in packaging applications is the achievement of a low CTE, this lower value makes this studied material as a good option for such components.

CONCLUSIONS

1. The material obtained by this fabrication method, gives the high content SiCp in an aluminium alloy, that can be, up to now, only obtained by other techniques, such as powder metallurgy, but with a lower cost.

2. The particle distribution observed within the material is good and so is the metallurgical quality of the material.

3. The wear properties obtained for this material, compared with those obtained for other conventional materials often employed for the same applications, have been demonstrated to be higher. Therefore, this material has been found as a suitable material to be used on the automotive industry.

4. Due to the properties achieved with the high SiCp content (55%v) present on the prepared MMC (mainly the low CTE), this material seems to be an adequate material to be also introduced in the electronic industry.

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