SOLIDIFICATION MICROSTRUCTURE AND TRIBOLOGICAL PROPERTIES OF CENTRIFUGALLY CAST ALUMINUM ALLOY-GRAPHITE COMPOSITES

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Abstract

This paper discusses the processing, solidification microstructure and tribological properties of centrifugally cast aluminum alloy-graphite composites which have potential application as cylinder liners of I.C. engines and other small engines. The influences of process variables, including pouring temperature, die temperature, coating material thickness and mold rotation velocity on microstructure have been analyzed. In addition, the scuffing resistance of these composites have been determined and shown to be superior to other cylinder liner materials.

1. Introduction

The centrifugal casting of molten metal is very attractive for producing near net shaped components having cylindrical symmetry.[1,2] It is particularly attractive for processing cylinders of a particulate composite like aluminum-graphite, since segregation of dispersed graphite particles under the action of centrifugal force allows selective reinforcement. This may be valuable for components such as a cylinder liner of automotive or other I.C. engines.[3-8] The segregation of particles results from density differences between the particles and the base alloy melt. In the case of aluminum-silicon alloys containing graphite particles, centrifugal forces during casting cause the graphite particles (being lighter than Al) to segregate to the inner periphery. The enrichment by solid lubricating graphite particles may provide improved tribological properties to cylinder liners,[9,10] specially in terms of lower friction coefficient and resistance to seizing. In addition, if the graphite particles are nickel coated to aid in synthesis of the composites, the nickel coating, while providing the requisite wettability to the graphite, dissolves in aluminum to form nickel aluminide. The larger size nickel aluminides, with higher density, tend to segregate to the outer periphery under centrifugal force leading to a hard outer shell, which might improve the performance of the centrifugally cast component as a cylinder liner. Some of the nickel aluminide does stay near the inner periphery which is enriched in graphite, and is expected to provide additional wear resistance to the inner surface of the liner in a manner similar to ceramic particles.

However, solidification processing parameters significantly influence the final microstructure and selective reinforcement of the centrifugally cast particulate composite cylinder. Important process variables such as the thickness and uniformity of mold coatings, temperatures of the melt and mold, pouring pattern and rotation speed of the cylindrical mold profoundly influence the final microstructure of the composite.[11,12]

The influences of key processing variables, such as pouring temperature, mold temperature, degassing time, and stirring time, on evolved microstructure are reported in this paper. Further, the results of scuffing tests for some of these composites are presented in this paper and compared with other cylinder liner materials.

2. Experimental Procedure

2.1 Melting

An Al-7% Si alloy was melted in a graphite crucible using an induction furnace. A known amount of nickel-coated graphite (50 Ni/50 Gr) was added to the melts while they were mechanically stirred. Degassing of the molten metal was carried out before and after graphite additions.

2.2 Centrifugal Casting of the Composite

A horizontal centrifugal casting machine was used to produce centrifugal casting. This involved pouring of the liquid metal slurry into a rapidly rotating, horizontally mounted, preheated mold, through a pouring ladle and continuing the rotation until solidification was completed. The mold speed was maintained at 1950 rpm.

2.3 Scuffing Test

A short stroke scuffing test (SST) apparatus was built to model the interaction of piston and/or ring and cylinder liner under simulated engine reciprocating conditions. A specimen was placed on an electrical heater that was driven reciprocally by a variable speed D. C motor. The piston ring was attached by a fixture that connected to a loading beam and thence to a three-dimensional force transducer to measure friction between the ring and/or piston and liner surface. Before the test, a drop of 10W30 engine oil was applied to the sample surface. No additional oil was applied during the scuff tests so that only marginal lubrication was provided. Once the temperature reached its set point, the reciprocating system was activated. The scuffing tests were carried out at either ambient or elevated temperatures. 165 °C (330 °F) was chosen for the high temperature tests based on the experimental observations of engine cylinder bore temperature near the top dead center.

The onset of scuffing was associated with an increase in friction and noise, at which point the test was terminated.

2.4 Preparation of Microstructural Samples

Microstructural analysis was carried out by taking samples at three locations along the length of the cylinder liner. Standard polishing techniques were used to prepare the samples. Quantitative image analysis was conducted on polished microstructures to measure volume fraction of graphite.

3. Results and Discussion

3.1 Microstructural Analysis

Figures 1, 2, and 3 show typical microstructures of three regions of a centrifugally cast composite liner, i.e., the graphite-rich inner region, the boundary between graphite-rich and graphite-free region, and the graphite-free region near the outer surface, respectively. Figure 1 shows the typical uniform distribution of graphite particles in the inner graphite-rich region. It is interesting to note (Fig. 3) that only the longer needles of Ni-Al intermetallics segregated to the outer periphery; this gives rise to the observed increase in hardness in that region. Smaller Ni-Al intermetallic particles were still found in the graphite-rich region near the inner periphery. All the Ni-Al intermetallic particles should have segregated to the outer periphery, as this phase has the highest density. However, it is to be noted that attainment of terminal velocity is a strong function of size of the particles and the presence of other suspended phases. It is influenced by viscosity, volume fraction of different phases and speed of rotation. This may be the reason for the presence of smaller sized intermetallics at the inner periphery. A quantitative analysis of the microstructure shows that measured volume fraction of graphite at the inner periphery was in the range of 20 to 40%. The amount of primary silicon and eutectic Si was observed to be about 20% near the inner periphery.

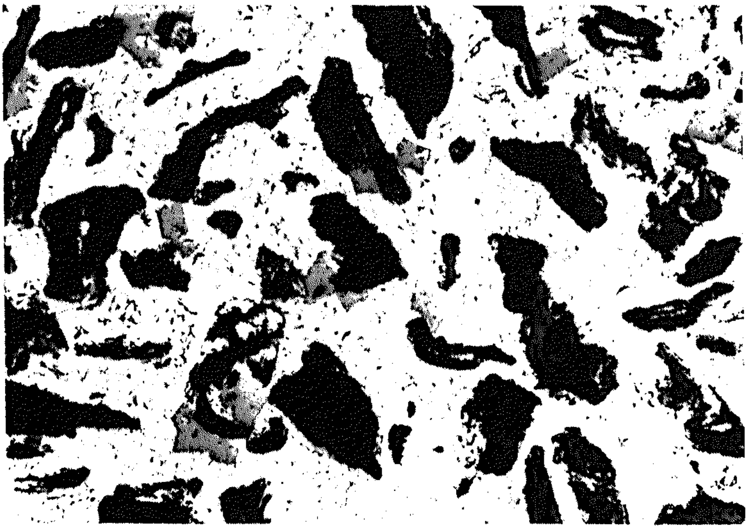

Fig. 1. Distribution of graphite particles near the inner periphery of centrifugally cast Al alloy-graphite composite cylinder liner (x176).

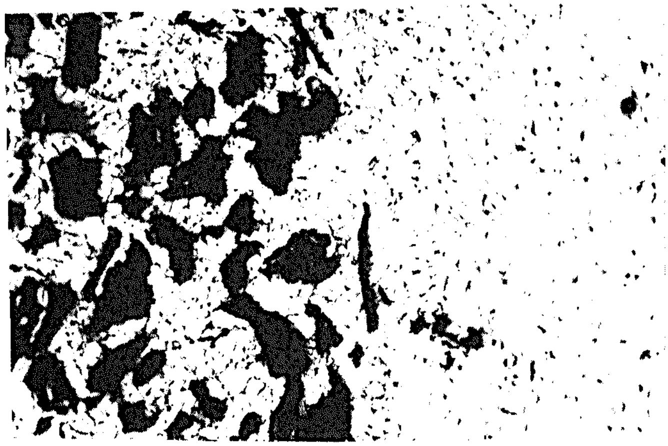

Fig. 2. Graphite distribution in the boundary region separating the graphite-rich and graphic-free regions; centrifugally cast Al alloy-graphite composite cylinder liner (x176).

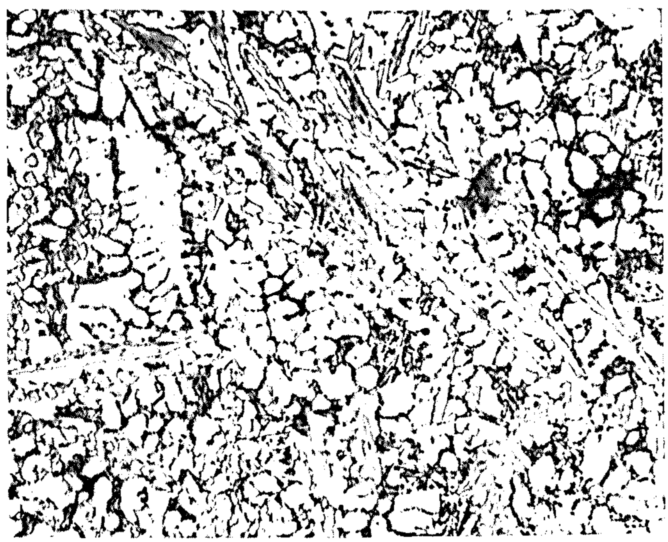

Fig. 3. Distribution of needle-shaped Ni-Al intermetallics and silicon in the graphite-free region of centrifugally cast Al alloy-graphite composite cylinder liner (x176).

It was also observed that the volume fraction of segregated phases is a strong function of mold rotation. Figures 4 and 5 show the theoretical estimates of influence of rotation on the volume fraction of graphite at both the inner periphery and near the graphite-free region. It is evident from the figure that the graphite volume fraction varies linearly with speed. At a mold rotation of 1950 rpm, the predicted graphite volume fraction at the inner periphery is about 40%, which is in the predicted range of the experimentally observed values. Also, near the graphite-free region the graphite volume fraction is about 24% for a mold speed of 1950 rpm.

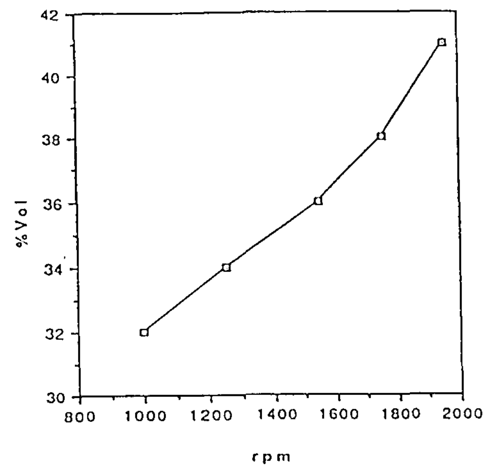

Fig. 4. Influence of rotational speed on vol % of graphite at the inner periphery of the cylinder. Pouring temp. 730°C. Initial graphite, 15 vol %. Average particle dia. 40 μm. Time lapse 8 sec.

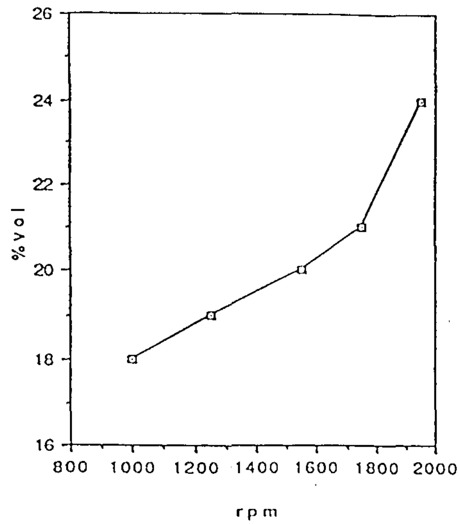

Fig. 5. Influence of rotational speed on vol % of graphite-free region. Initial pouring temp. 730°C. Initial vol %, 15. Average particle dia. 40 μm. Time lapse 8 sec.

3.2 Scuffing Resistance of Base Alloy and Composites

For constant load tests, the results of applied pressure versus scuffing initiation time are presented in Fig. 6. It is apparent from the figure that scuffing initiation time for aluminum alloy containing graphite was about 110 min at a pressure close to 15 MPa. This scuffing time was higher compared to other alloys and composites.

The scuffing test results indicate that the scuffing resistance is increased by adding solid lubricant into Al matrix. Also, it was observed that the scuffing resistance of the Al 356 + 10% graphite MMC is much higher than that of alloys 390, 356 + 2055 SiC and Honda Al-Al_2O_3-C, which are being used or tested for cylinder liner applications. When graphite is present, it provides solid lubrication at the interface between the ring and the liner, since the ring smears the graphite over the entire mating surface, preventing direct metal-on-metal contact. This smearing action of graphite to provide solid lubrication is established by scanning electron microscopic examination of the samples.

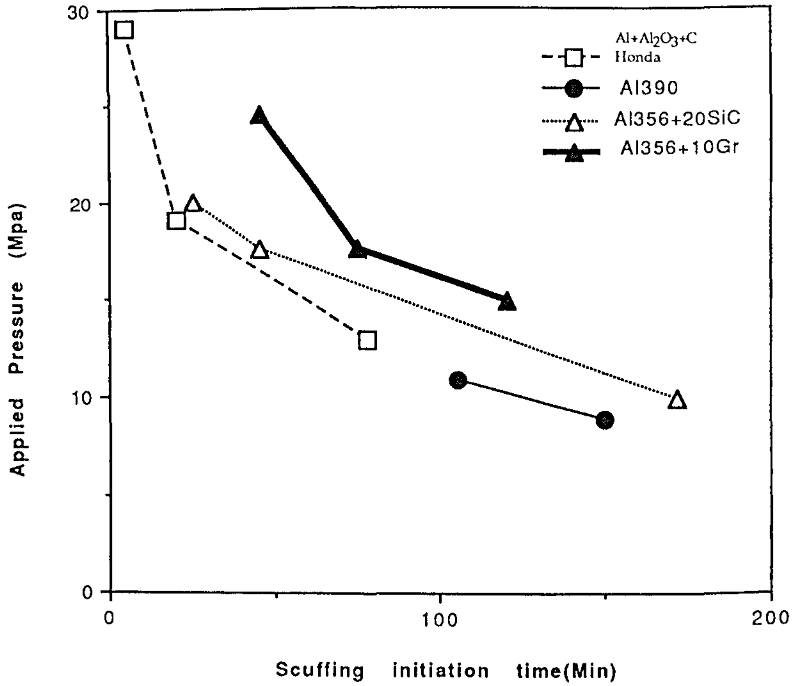

Fig. 6. Applied pressure as a function of scuffing initiation time.

4. Conclusions

1. Distribution of graphite in centrifugal casting is markedly influenced by pouring temperature and pouring pattern.

2. Microstructural analysis near the graphite-free and graphite-rich region indicates that by rotating the mold at 1950 rpm, the volume fraction of graphite in the graphite-rich region is in the range of 20% to 40%. This is in the range of the estimated values of volume fraction by heat transfer analysis.

3. The scuffing tests demonstrate that the presence of graphite in aluminum alloy matrix and composites improves the scuffing resistance of the matrix material. The scuffing resistance of the aluminum alloys containing graphite is superior to most currently used cylinder liner materials including A390 and Honda Al-Al_2O_3-C, as well as A356-20% SiC which is being tested for cylinder liner applications.

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AGE HARDENING RESPONSE OF SiC WHISKER REINFORCED DILUTE Al-Cu-Mg-Li COMPOSITES

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Abstract

The influence of SiC whisker content on the precipitation hardening response of Al-1Cu-0.95Mg-0.9Li reinforced with 5 and 10 volume percent SiC whiskers has been monitored during natural and artificial aging utilizing hardness, electrical conductivity and transmission electron microscopy. Initial aging is characterized by an increase in hardness without a change in electrical conductivity. Upon continued exposure for longer aging times this hardness increase is accompanied by an increase in conductivity. Transmission electron microscopy has shown that primary strengthening is associated with δ' and to a lesser degree heterogeneous precipitation of δ and S'; increased SiC_w content tending to promote δ and S' formation.

Introduction

Replacement of conventional aerospace aluminum alloys with advanced materials for increased structural efficiency continues to be of world-wide import. This interest has resulted in the development of a wide range of alternative materials, e.g., Al-Li alloys, Gr-polymer composites and SiC reinforced metal matrix composites. It has also been shown that synergistic benefits may be achieved through suitable combinations of these materials, e.g., the incorporation of discontinuous SiC particulate and whisker reinforcements in a Al-Li matrix[1-3]. These latter studies additionally suggest that lower levels of SiC reinforcement may be utilized to achieve increased specific stiffness and strength, thereby potentially enhancing the tensile ductilities and fracture toughness' of the metal matrix composites. Since Al-Li composites would normally be expected to be utilized in a heat treated condition property optimization will require an in-depth understanding of these composites aging response. The study reported herein was designed to provide this information and was a companion investigation to that reported previously[3].

Experimental Procedures

The chemical composition of the SiC whisker reinforced Al-Cu-Mg-Li composites examined is shown in Table I. These composites, supplied by Advanced Composite Materials