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The Effects of Aging on the Hardness and Wear Behaviour of 2124 Al Alloy/B_4C Composites

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The particulate reinforced aluminum alloy matrix composites are being increasingly used for wear component applications. The influence of matrix aging treatment on wear behavior in a powder metallurgy 2124 Al-B_4C composite was investigated. The aging responses of 2124 Al-B_4C metal matrix composite (MMC) and unreinforced matrix alloy are studied and related to variations in wear resistance properties. The MMC is aged resolution treated. Accelerated aging occurs in both MMC conditions, compared with unreinforced alloy. Wear resistance and hardness were substantially higher in the reinforced alloys. The effects of the percentage of boron carbide addition on the microstructure, hardness and wear tests of the produced material are discussed. The effects of the age hardening process are also considered.

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1. Introduction

Metal matrix composite particulate reinforcements are of great interest to structural engineers, due to their high specific strength and modulus [1, 2]. MMCs display a unique feature in being capable of providing tailor-made materials with unique combinations of mechanical properties [3]. The mechanical behavior of MMC is dependent on matrix alloy and reinforcement. In MMC, the presence of reinforcement significantly affects the nature of matrix microstructure. Interest in the tribological properties of aluminum alloys has increased substantially over recent years because of potential for weight saving in many applications. Superior wear resistance is one of the attractive properties in MMCs. It has been found that particulate-reinforced MMCs show wear resistance on the order of 10 times higher than that of the unreinforced materials, in some load ranges [4]. Since the 1980s there had been extensive investigation of metal matrix composites reinforced with hard ceramic phases, such as Al_2O_3 or SiC, in an effort to understand and improve the tribological properties of aluminum [5–8]. Many studies have been performed in order to understand the effects of various factors such as the particle size [9], the fraction of the reinforcing particles [4], the load [4–9], and the sliding speed [9, 10], on the wear resistance of the particulate-reinforced MMC's. Alu-interfacial bonding between the Al matrix and the B_4C reinforcement seems to be better than that between aluminum and SiC (or Al_2O_3) [11]. Studies on the wear behavior of the B_4C particulate-reinforced MMCs with Al matrices are, however, limited [12]. These MMC's are fabricated by the addition of a reinforcement phase to the matrix by the use of several techniques such as powder metallurgy, liquid metallurgy and squeeze-casting. PM is becoming increasingly important since it reduces cost by minimizing machining operations and material losses by means of producing highly alloyed materials which can't be successfully produced by conventional methods [13]. The purpose of this paper is to understand the dry sliding wear behavior of the 2124 Al-B_4C composites with different weight percentage (5 wt.% and 10 wt.%), worn against SiC paper, and to study the effects of the applied different loads on the sliding wear mechanisms.

2. Experimental method

2.1. Manufacturing of materials

Consolidated 2124 Al alloy composites reinforced with B_4C particulates were produced using powder metallurgy process. Aluminum alloy powders supplied by Alpoco, of average size of 45 μm, were employed as the matrix. Compositions are described in detail in Table I. B_4C powders, supplied by H.C. Stärck, with mean size of < 10 μm, were used as the reinforcements. In this process, 2124 Al alloy matrix composites containing 5, 10 wt.% B_4C were mixed for 45 min. The mixed powders were uniaxially cold compacted at 350 MPa and finally sintered at 600 °C for 3 h in Ar atmosphere. The cylinder specimens had a diameter of 5 mm and height of 6 mm. Prior to wear testing, the materials were tested in as-sintered condition as well after T6 treatment. The wear properties of the different materials were determined in the sintered state and after T6 treatment. The T6 treatment conditions were as follows, solution treatment for 3 h at 600 °C and ageing for 2 h at 220 °C.

TABLE I
Specified alloy composition (wt.%) for 2124 Al alloy; from Alpoco, UK.

	Chemical Composition (wt. %)					
Material	Cu	Fe	Si	Mg	Mn	Al
Composite matrix	3.9	0.1	0.06	1.5	0.5	Balance

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2.2. Density, hardness and wear tests

Density (ρ) measurements of sintered composites were performed in accordance with Archimedes principle. Rockwell B hardness values were measured under a load of 60 kg-f for each sample and the average hardness values and standard deviation were calculated. A pin-on-disc type of apparatus was employed to evaluate the wear characteristics of MMC's. Wear tests were carried out at RT without lubrication. In wear tests, the normal loads on the pin were 10, 20 and 30 N at a constant sliding speed of 1 m s^{-1}, and a constant sliding distance of 60 m for each composite sample. Each test was performed with a fresh SiC paper of 400 grits, which corresponds to $\sim$ 37 μm.

3. Results and discussion

The results of theoretical and measured densities and of the hardness test for all materials are shown in Fig. 1 and Table II, respectively. The hardness and density of the ageing materials are much higher than those of the non-ageing materials, and clearly increase with the increasing percentage of B_4C weight.

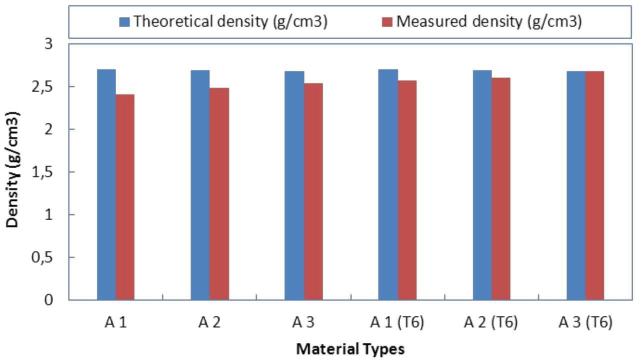

Fig. 1. Theoretical and measured density of 2124 Al alloy and its composites.

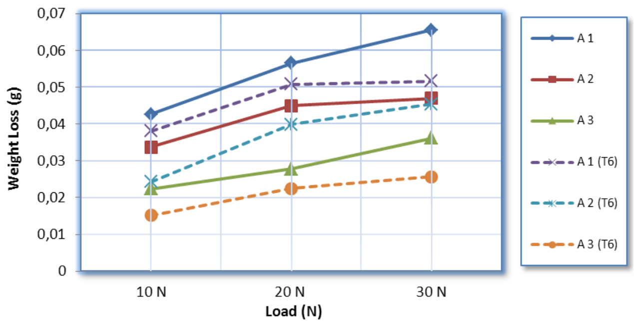

Fig. 2. The variation of weight loss values as a function of applied load and heat treatment for composite materials and unreinforced alloy.

The hardness of the composite materials had changed with heat treatment, indicating that precipitation hardening of the matrix materials had taken place [14]. Full

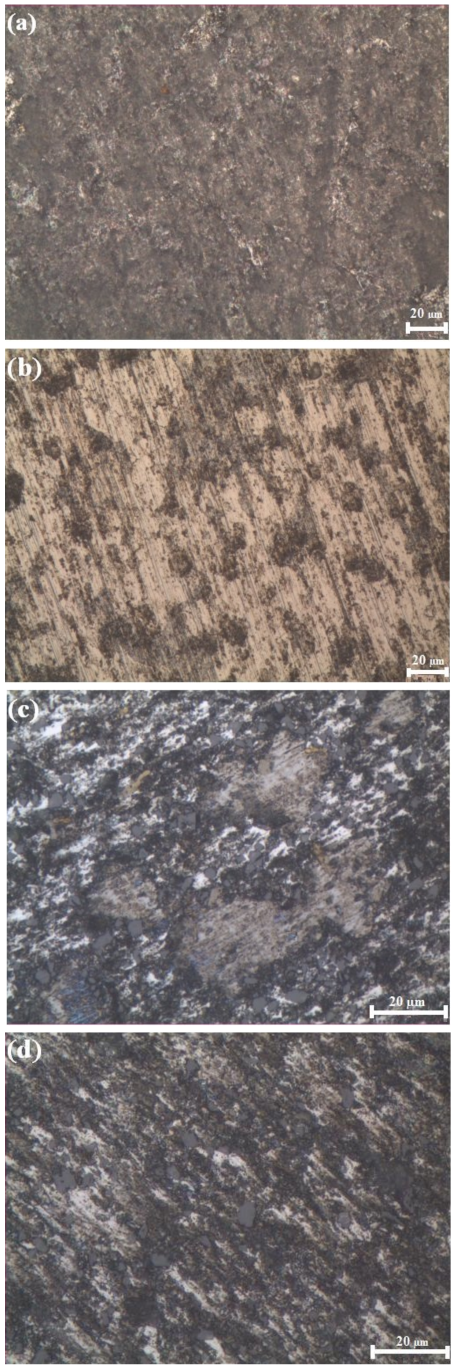

Fig. 3. Microstructure of 2124 Al alloy and its composites. (a) 2124 Al alloy. (b) 2124 Al alloy (T6). (c) 2124-10 wt.% B_4C. (d) 2124-10 wt.% B_4C (T6).

heat treatment of this type of aluminum alloy is achieved in the three stages. First, the material is heated to the solution treatment temperature at which the copper atoms form a solid solution within the aluminum matrix. Second, the material is rapidly quenched, preventing the diffusion of the copper atoms and thus producing a supersaturated solid solution. Third, the hardening is achieved by re-heating the material to a lower temperature, which is referred to as the ageing temperature. This ageing treatment results in the precipitation of extremely fine, partially incoherent θ'-$CuAl_2$ precipitates within the aluminum matrix, increasing the hardness of material [14].

Hardness of 2124 Al alloy and its composites. TABLE II

Material Type	A_1	A_2	A_3	$A_{1(T6)}$	$A_{2(T6)}$	$A_{3(T6)}$
HB $_{(60\ \text{kg-f})}$	59.04 $\pm$0.7	68.23 $\pm$1.5	75.4 $\pm$2.3	68 $\pm$1.3	74 $\pm$0.88	85.65 $\pm$0.41

The average volumetric wear rate of 2124 Al-B_4C reinforced composites is illustrated graphically in Fig. 2 as a function of the applied load and reinforcement amount in the as-sintered condition and after T6 heat treatment. It is found that the wear rate of the composites increased with all applied loads for tested materials. It is evident from the Figure that the composite had lower wear rates than that of the 2124 Al alloy matrix at all loads. In addition, the weight loss of non-aged composite was generally lower than that of non-aged unreinforced alloy for 10, 20 and 30 N. The similar observations are valid for the composites after the T6 heat treatment. In the composites, there was a stable behaviour under 10 N and 20 N loads. At loads of over 20 N , slight increases in wear rate of the composite were observed. In addition, ageing of 10 wt.% B_4C particle reinforced 2124 Al alloy gave lower wears than those of 10 wt.% B_4C unreinforced non-ageing composites.

The microstructure of the specimens was obtained using Nikon MA200 optical microscope with Clemex vision Image Analyser. Figure 3 shows the microstructure of the 2124 Al alloy and its composites. The homogeneity will promote the attainment of good results from the point of view of mechanical properties. These results are improved in heat-treated materials due to the interaction between the matrix and reinforcement. It is greater in this case because of the interdiffusion at the boundary of the intermetallic, which leads to their perfect integration in the matrix [15]. In addition, a tendency for the materials with the greater microstructural homogeneity after the T6 treatment is observed.

4. Conclusions

The effect of aging and presence of B_4C particles on wear and mechanical properties of 2124 Al alloy was investigated. The hardness of 2124 Al alloy has improved with introduction of B_4C particles. The volumetric wear rates of the 2124 Al alloy and its composites were increased with increasing the load. The maximum hardness and minimum specific wear rate were measured in the specimen A3 (T6). At loads of 10, 20 and 30 N, composite materials offered superior wear resistance compared to 2124 Al alloy matrix. The wear properties evaluated, with the base material and with composite material in the sintered state, are better than those of equivalent conventional materials. The wear behaviour of these composite materials is further improved after T6 aging heat treatment.

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