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WEAR BEHAVIOR OF SiC-PARTICLE REINFORCED ALUMINUM MATRIX COMPOSITES IN VARIOUS ENVIRONMENTS

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Wear behavior of SiC-particle reinforced aluminum matrix composites (MMC) were investigated by pin-on-disk tests in vacuum with various pressures, argon, and air with various levels of humidity. The wear rate of 2024Al and MMC increased in the following order: in a vacuum at 5.0×10^{-4} Pa, at 1.0Pa, in argon at 0% RH, in argon at 60% RH, in argon at 90% RH, in air at 0% RH, in air at 60% RH and in air at 90% RH. In other words, the influence of environment on wear becomes stronger in the following order: moisture, oxygen, and a combination of moisture and oxygen. In various environments, the difference of the wear rate of 2024Al and MMC was compared. In argon and air at 0% RH, the wear rates of MMC were higher than that of 2024Al. In contrast, in argon and air at 60, 90% RH, the wear rates of MMC were lower than that of 2024Al.

Keywords : Metal matrix composites, SiC-particle, Aluminum, Wear, Vacuum , Humidity

1. INTRODUCTION

Ceramics whisker-, fiber-, and particle-reinforced aluminum matrix composites (MMC) have been used as tribomaterial. MMC generally posses superior wear resistance compared with unreinforced aluminum alloys. Numerous studies of the dry sliding wear behavior of MMC have been reported and comprehensively reviewed [1]. Since the strength of aluminum alloys is generally affected by oxygen and moisture, it is necessary to determine the effects of environment on the wear resistance of MMC. We have reported that SiC-whisker reinforced MMC was markedly affected by humidity in the air [2]. However, very little research on the effect of environmental factors on MMCs has been conducted.

In this study, in order to determine the effects of oxygen and moisture on the wear of MMCs, the wear behavior of SiC-particle reinforced MMC was investigated by pin-on-disk tests in various environments such as vacuum, argon, and air with various levels of humidity.

2. EXPERIMENTAL METHODS

2.1 Test materials

Test materials were unreinforced matrix material and its composites containing a 10% volume fraction (V_f) of particles fabricated by a powder metallurgy technique. The matrix material was a 2024 aluminum alloy. The reinforcement was SiC particles of 5 μm in diameter. The mechanical properties of the test materials are listed in Table 1. The counterface material was 0.45% carbon steel, the Vickers hardness of which was 320.

Table 1 Composition and mechanical properties of MMC

		2024Al (Matrix)	MMC
Particle diameter	, μm		5
Particle volume fraction V_f	, %		10
Density	, g/cm^3	2.80	2.83
Tensile strength	, MPa	533	534
elongation	, %	19.4	9.6
Brinell hardness	HB	106.3	109.9
Vickers hardness	HV	151	205

2.2 Experimental apparatus and procedures

The pin-on-disk test device was installed in a vacuum chamber. The MMC pin was rubbed against a carbon steel disk with a load of 40 N at a sliding velocity of 0.1 m/s. The MMC pin had a flat surface with a diameter of 4 mm. The steel disk was 30 mm in diameter and 5 mm in thickness. The diameter of the wear track was 23 mm. The test surfaces of both the disk and the pin were polished using grade #1200 emery paper.

The friction force was measured by the bending strain of a cantilever attached to the pin holder. The virtual displacement of the pin holder was continuously measured with an eddy current method to detect the progression of the wear process. The mass loss was measured after ultrasonic cleaning of the specimen in acetone, using a precision balance having a sensitivity of 0.01 mg. The measured mass loss was converted into a volume loss by dividing by the corresponding density.

Tests were performed in various environments such as vacuum, argon, and air with various levels of humidity. The vacuum was obtained by using both a rotary pump and a turbo-molecular pump, and was measured by an ionization vacuum gauge. The argon and air, which were adjusted at 0 to 90% RH in an external vessel, were inserted into the test chamber at several liters per minute. RH was controlled using equipment with a psychrometer.

3. RESULTS AND DISCUSSION

In our wear tests, the virtual displacement of the pin of 2024Al and MMC increased linearly with sliding distance, such that steady state mild wear occurred from the beginning of the test. The wear rate was calculated by volume loss divided by the sliding distance. Fig.1 shows the friction coefficient, the wear rates of pin specimens (2024Al and MMC), and disk 0.45% carbon steel specimens in various environments.

3.1 Wear in a vacuum

In the vacuum, the friction coefficient of 2024Al and MMC showed a minimal value at 1 Pa. The friction coefficient of MMC was higher than that of 2024Al, regardless of pressure. At 5.0×10^{-4}Pa, the wear rate of 2024Al and MMC decreased to about 1/50 of that in the atmosphere. The counterface against 2024Al and MMC did not show a mass loss.

At 5.0×10^{-4}Pa, the worn surface underwent plastic deformation, but was smooth for 2024Al and MMC, and transfer films of matrix Al alloy were formed on the counterface. It was noted that the matrix Al alloys rubbed on each other at the contact surface of the pin and disk specimens. Therefore, the adhesion and transfer of Al alloys was easily repeated on the contact surface, but wear debris did not fall out of the wear track, resulting in a remarkable decrease in the wear rate.

3.2 Wear in argon

In argon with various levels of humidity, the friction coefficient of 2024Al was almost constant, regardless of humidity. On the other hand, the friction coefficient of MMCs was higher at 90%RH than at both 0 and 60%RH. The wear rates of 2024Al and MMC, as well as that of the corresponding counterfaces, increased with increasing humidity.

At 0% RH, the worn surface of the MMC was smooth and similar to that in the vacuum. Since argon is inactive, the wear rates of MMC decreased, due to the slight influence of oxygen. In contrast, at 90% RH, the worn surface of MMC was found to be very rough, with characteristic brittle fracture due to the moisture.

3.3 Wear in air

In air with various levels of humidity, the friction coefficient of 2024Al was lowest at 60% RH. The friction coefficient of MMC was scarcely affected by relative humidity. The wear rate of 2024Al increased with increasing humidity. The wear rate of MMC became constant up to 60% RH and increased at 90% RH. The wear rate of counterfaces against 2024Al and MMC showed the minimum value at 60% RH. In air, which contains oxygen and moisture, the wear rate of the MMC was lower than that of the matrix material 2024Al.

3.4 Comparison of wear of 2024Al and MMC in test environments

The wear rates of 2024Al and MMC increased in the following order: in the vacuum at 5.0×10^{-4}Pa, at 1.0 Pa, in argon at 0% RH, in argon at 60% RH, in argon at 90% RH, in air at 0% RH, in air at 60% RH, and in air at 90% RH. In other words, the influence of environment on wear becomes stronger in the following order: moisture, oxygen, and a combination of moisture and oxygen.

In various environments, the difference between the wear rates of 2024Al and MMC were compared. The wear rates of MMC were higher than those of 2024Al in argon and air at 0% RH, but the opposite result was obtained in argon and air at 60, 90% RH.

4. CONCLUSIONS

Sliding wear tests were carried out in a vacuum with various pressures, argon, and air with various levels of humidity. The following conclusions were made based on the observations.

(1) The wear rate of 2024Al and MMC increased in the following order: in a vacuum at 5.0×10^{-4}Pa, at 1.0Pa, in argon at 0% RH, in argon at 60% RH, in argon at 90% RH, in air at 0% RH, in air at 60% RH and in air at 90% RH. In other words, the influence of environment on wear becomes stronger in the following order: moisture, oxygen, and a combination of moisture and oxygen.

(2) In argon and air at 0% RH, the wear rates of MMC were higher than that of 2024Al. In contrast, in argon and air at 60, 90% RH, the wear rates of MMC were lower than that of 2024Al.

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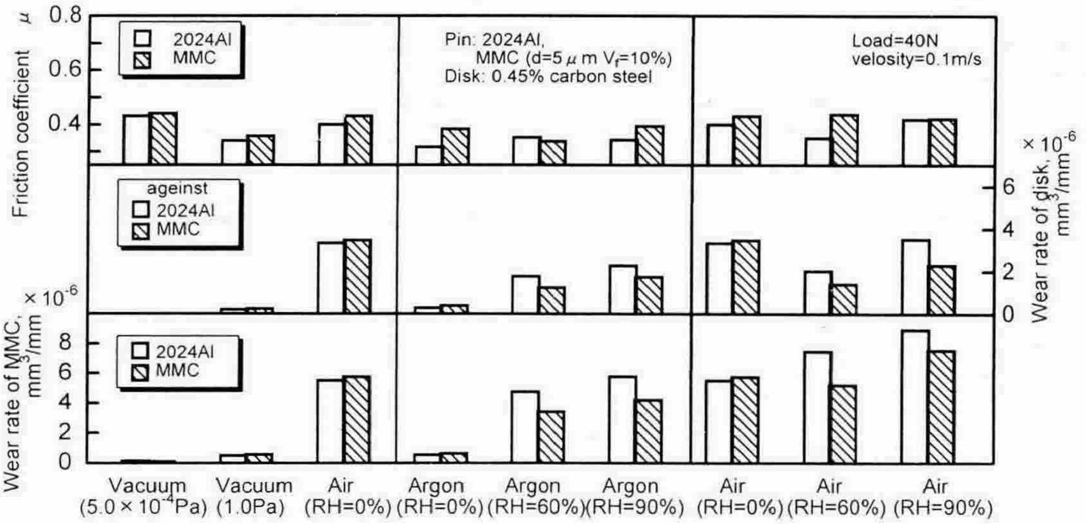

Fig.1 Wear rate of MMC, wear rate of carbon steel and friction coefficient in various environments