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Tribological stability of particle reinforced aluminum matrix composites in braking①

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[Abstract] The tribological stability of particle reinforced aluminum matrix composites in braking was studied. Considering the requirements of the intention of present transportation field, high braking pressure and high initial braking rotating speed, as well as different reinforcement volume fractions were selected. The results indicate that under a systematic comparison with traditional braking material of cast iron, SiC particulate reinforced aluminum material composites (PRAMC) can retain stable friction coefficient in various braking pressures and rotating speeds. Even in a concrete course of braking, PRAMC can also maintain friction coefficient with little fluctuation. The existence of a uniform mass transfer layer adhering to the contact surface is an important prerequisite for maintaining a stable friction coefficient.

[Key words] aluminum matrix composites; friction coefficient; stability; mass transfer layers
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1 INTRODUCTION

The transport machine, such as automobile, train and plane intends to become high-speed and lighter one, but the relative heavy braking equipment confines its development. The traditional brake disk, which is manufactured by cast iron, not only has a high density, but also maintains a high temperature on the frictional surface in high initial speed braking. Therefore, in case of high rotating speed and braking press, cast iron can hardly keep a tribological stability. Furthermore, thermal crack occurs on the frictional surface. The development of transport field requires replacing the traditional cast iron with a new material. PRAMC which meets the intention of application field holds a less density compared with cast iron. Additionally, they can maintain a stable friction coefficient in braking and demonstrate themselves to be a kind of prospective braking material. As a matter of fact, they are applied in high-speed trains of Japan and Germany[1~3]. This research identifies that when hard second-phase particles are inputted, the elastic module and stiffness increases obviously. PRAMC has a better tribological behavior by delaying the transition from mild to severe wear[4~9]. This research focuses on the tribological stability of PRAMC in braking. To evaluate application of PRAMC in manufacturing braking disk more efficiently, a systematic comparison between PRAMC and cast iron was carried out.

2 EXPERIMENTAL

Samples were manufactured in ring with the gauge: outer diameter 75.0 mm, inner diameter 52.5 mm, thickness 13.0 mm. PRAMC discs were made by two matrixes (LD_2 and ZL101) and reinforced by different volume factions of SiC which covers 10%, 15% and 20%. Controlled experiments were carried out between PRAMC and traditional disc made by cast iron HT2040.

The experiments were proceeded on MM1000 with the rotating inertia energy of 25 N•cm•s^2. The conditions are as follows:

Braking pressure 0.5, 1.0, 1.5, 2.0, 3.0 MPa;

Braking speed 1 000, 1 500, 2 000, 3 000, 4 000 r/min;

Sampling period 4 μs.

Every sample was tested three times repeatedly on the condition that its temperature is dropped below 40 ℃.

3 RESULTS AND ANALYSES

3.1 Frictional coefficient

When brake pressure is 20 MPa, the relations between friction coefficient of cast iron and PRAMC discs and braking speed are identified in Fig.1 and Fig.2.

When braking pressure is 2.0 MPa, PRAMC can maintain a stable frictional coefficient, whose deviation is less than 0.05 in case of various initial braking speed. When LD_2 acts as the matrix, PRAMC can keep a more stable coefficient with the deviation below 0.025. As far as cast iron is concerned, it can hardly keep a stable frictional coefficient. Its devia-

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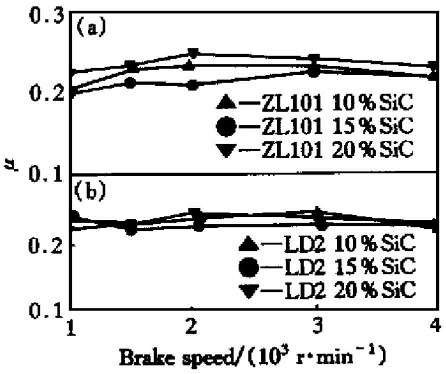

Fig.1 Relations between friction coefficient (μ) and braking speed of PRAMC with different matrixes at pressure of 2.0 MPa
(a) —ZL101 ; (b) —LD_2

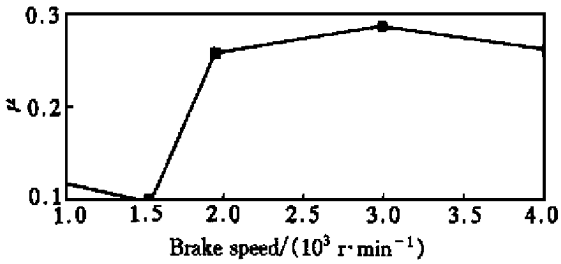

Fig.2 Relation between friction coefficient (μ) and braking speed of cast iron at pressure of 2.0 MPa

tion is about 0.2, which is greatly more than that of PRAMC.

When braking pressure is 3.0 MPa, the relations between friction coefficient of cast iron and PRAMC discs and braking speed are identified in Fig.3 and Fig.4.

When braking pressure is 3.0 MPa, PRAMC can also keep stable friction coefficient, which deviates in range of 0.05. Therefore, it is concluded that PRAMC can keep a stable friction coefficient under various braking speed and pressure, which is a very important tribological property in actual transportation field.

3.2 Stability coefficient

To evaluate the stability of disc, by keeping a relative uniform braking torque, a parameter S is in-

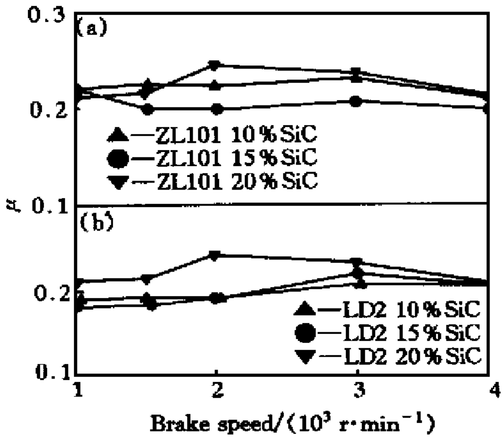

Fig.3 Relations between friction coefficient (μ) and braking speed of PRAMC with different matrixes at pressure of 3.0 MPa
(a) —ZL101 ; (b) —LD_2

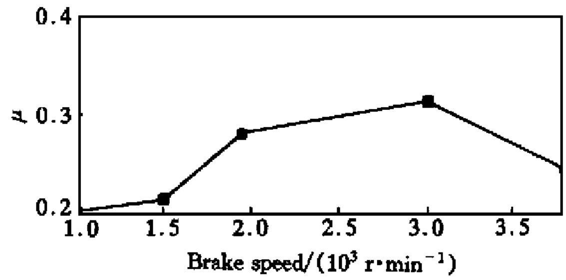

Fig.4 Relation between friction coefficient (μ) and braking speed of cast iron at pressure of 3.0 MPa

troduced. S, named as stability coefficient of friction coefficient, is defined as the ratio of the maximum friction coefficient (μ_{max}) to mean friction coefficient (μ_{cp}) in one braking course.

From Table 1, it is explained that under the pressure of 1.50 MPa, PRAMC braking disk can hold a higher stability coefficient than that of cast iron. PRAMC not only can keep a high stability coefficient (S = 0.988 8) under lower braking speed(1 000 r/min), but also keep a high coefficient(S = 0.940 1) even under higher braking speed. Additionally, it can maintain a coefficient higher than 0.92 within the whole range of braking speed. It is demonstrated that PRAMC can maintain a stable friction coefficient in braking. In contrast to PRAMC, cast iron has a bad

Table 1 Comparison of friction coefficient stability between PRAMC and cast iron (p = 1.5 MPa)

Braking speed /(r· min^{-1})	LD_2 reinforced by 10 % SiC			ZL101 reinforced by 10 % SiC			Cast iron		
	μ_{cp}	μ_{max}	S	μ_{cp}	μ_{max}	S	μ_{cp}	μ_{max}	S
1 000	0.267 5	0.270 6	0.988 8	0.241 8	0.245 2	0.986 1	0.275 6	0.339 9	0.810 8
1 500	0.258 6	0.266 1	0.972 0	0.251 5	0.256 7	0.979 8	0.278 0	0.321 0	0.866 0
2 000	0.257 5	0.279 6	0.921 3	0.241 6	0.243 0	0.994 0	0.270 2	0.299 1	0.903 5
3 000	0.252 8	0.264 9	0.954 4	0.235 5	0.248 9	0.966 0	0.237 0	0.303 7	0.771 3
4 000	0.238 6	0.253 8	0.940 1	0.241 7	0.246 9	0.978 7	0.205 9	0.269 0	0.765 6

Table 2 Comparison of friction coefficient stability between PRAMC and cast iron (p = 3.0 MPa)

Braking speed /(r·min^{-1})	LD_2 reinforced by 10% SiC			ZL101 reinforced by 10% SiC			Cast iron		
	μ_{cp}	μ_{max}	S	μ_{cp}	μ_{max}	S	μ_{cp}	μ_{max}	S
1 000	0.221 6	0.238 5	0.929 0	0.221 5	0.230 7	0.960 0	0.277 8	0.301 6	0.920 8
1 500	0.203 8	0.208 3	0.978 4	0.225 1	0.233 1	0.965 6	0.283 4	0.296 9	0.954 3
2 000	0.205 7	0.213 3	0.964 2	0.221 6	0.230 5	0.961 2	0.281 3	0.333 9	0.842 6
3 000	0.190 6	0.225 1	0.947 1	0.239 7	0.249 1	0.962 4	0.313 0	0.380 8	0.822 0
4 000	0.210 8	0.242 4	0.869 5	0.213 4	0.243 2	0.877 6	0.231 1	0.327 0	0.706 8

friction stability.

Under lower braking speed, cast iron can hold a relative higher friction coefficient stability. With increasing the braking speed, friction coefficient stability drops from S_{max}(0.903 5) to S_{min}(0.765 6).

As the results shown in Table 2, when braking pressure is increased to 3.0 MPa, PRAMC can maintain a relative higher friction coefficient stability. Even under the condition of high pressure and braking speed, it can still maintain a high stability above 0.85. Under the same condition, cast iron holds a lower friction coefficient stability. Especially under high braking pressure and speed, the friction coefficient stability is about 0.7.

3.3 Morphology of surface of braking disk pair

3.3.1 Morphology of surface of braking disk

Morphology of friction surface of PRAMC and cast iron in braking is shown in Fig.5.

During the course of braking, there is little clear micro-cutting trace on the surface of PRAMC. Hereby, it can hold a uniform flat contact with surface during braking. Comparatively, there is much micro-cutting and crack (as shown in Fig.5) on the frictional surface.

The morphology of cross section of PRAMC and friction surface of cast iron is shown in Fig.6. As far as PRAMC is concerned, there is a uniform transfer layer on the friction surface. According to cast iron, it can be observed apparently the existence of transfer layer.

3.3.2 Morphology of surface of braking liner

The morphology of surface of braking liner contacting with PRAMC and cast iron is shown in Fig.7. When liner contacts PRAMC disk, the surface has a high flat level. While according to cast iron, it can be clearly observed some steel fibers are pulled out in braking. Furthermore, surface of the liner is not as flat as contacting PRAMC, which will affect the friction condition undoubtedly.

In contrast to cast iron, tribological stability of PRAMC in braking is represented by a relative stable friction coefficient under the condition of various braking pressure and speed, it still hold a curve of friction coefficient with little fluctuation. According to a specific course of braking, the friction coefficient fluctuates little with the change of braking time. As far as braking liner is concerned, when contacting

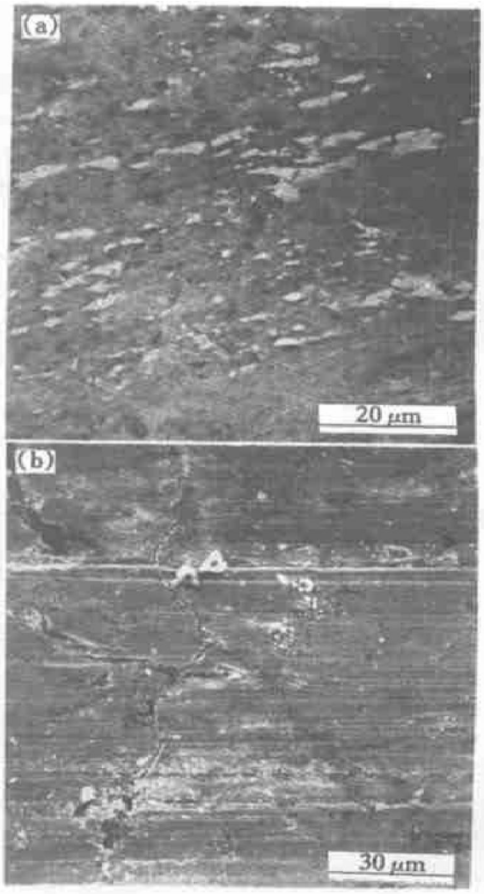

Fig.5 Morphology of frictional surface of PRAMC and cast iron in braking
(a) —PRAMC; (b) —Cast iron

with cast iron, the liner morphology changes greatly because of the high temperature in friction surface. Because the inferior heat transfer property of cast iron is less which causes the temperature on the friction surface increasing greatly[9]. Some organic items in braking liner will be softened for the high temperature and result in the pulling out of steel fiber for the high temperature on the surface. Furthermore, the pulling out fiber will act as micro-cutting abrasion particle in braking and leave apparent abrasive trace on the surface of braking disk. When contacting with PRAMC, the pulling out of steel fiber is prevented for the relative lower temperature on the surface for superior heat transfer property of aluminum alloy matrix.

Additionally, the existence of a uniform layer of mass transfer layer adhering to the interface of fric-

Fig.6 Cross section images of PRAMC and friction surface of cast iron in braking
(a) —PRAMC; (b) —Cast iron

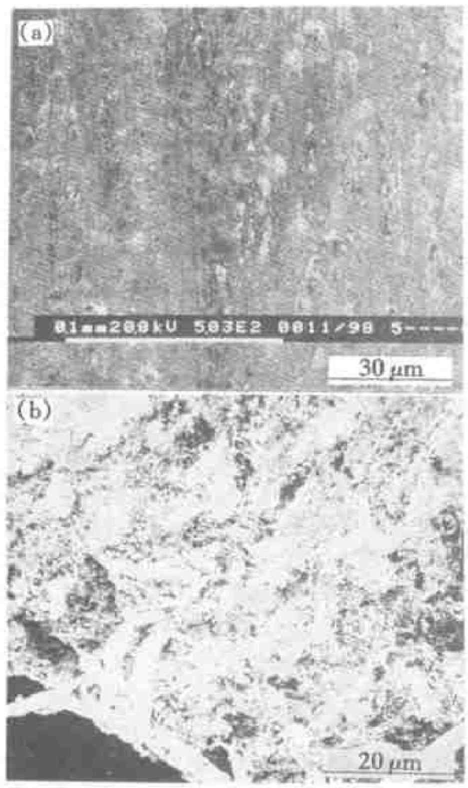

Fig.7 Friction surface images of braking liner contacting with PRAMC and cast iron
(a) —PRAMC; (b) —Cast iron

tion couple will improve the contacting condition of the couple and prevent the pulling out of steel fiber and two-body abrasion efficiently.

4 CONCLUSIONS

1) Compared to cast iron, PRAMC disk can hold a friction coefficient with appropriate amount and high stability under various braking pressures and speeds.

2) In a specific course of braking, PRAMC can maintain a friction coefficient with little fluctuation and hold friction coefficient more stable than cast iron does. It is obvious that this friction stability will meet the safety and reliability requirement of modern transportation field.

3) The braking material has less change in geometric morphology of surface when contacting with PRAMC than cast iron. Therefore, the pulling out of steel fiber on surface of braking material and micro-cutting of steel fiber on surface of braking disk are efficiently prevented.

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