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TRIBOLOGY BEHAVIOR OF A COPPER-BASED COMPOSITE FOR HEAVILY-LOADED WET CLUTCH

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AUTHORS OR INSTITIUTION
Gong Taimin; Yao Pingping.
Central South University, Changsha, Hunan, China

INTRODUCTION

Wet clutches are often used to transmit torque, bring about gear changes and prevent motion in vehicle drivetrains. For heavy-duty equipment applications such as tanks, wet clutches are always under high energy density friction conditions and are required to possess excellent friction and wear characteristics, smooth engagement (anti-shudder), high reliability and a long operating life. As critical components in the clutch system, friction materials strongly affect the force transmission, energy loss and lifetime of clutches, and they ultimately influence the dynamic behaviors of an entire vehicle. Therefore, friction materials should possess an adequate friction coefficient and moderately low wear rate over a broad range of contact pressures and sliding velocities under oil lubrication [1, 2]. Copper-based friction materials manufactured by powder metallurgy have been widely applied to heavily-loaded wet clutches because of their excellent mechanical, thermal and tribological properties. These materials can also withstand higher stresses and temperatures compared with paper-based materials and are fairly cheap to manufacture when compared with carbon-fiber materials in wet clutch applications [3~5].

During wet clutch operation, friction materials will undergo a range of loading and sliding speed conditions, leading to changes in lubricating conditions and tribological factors including the friction coefficient, wear rate and worn surface topography. Many studies have investigated these factors [2, 6, 7]. However, current studies are inadequate for comprehensively understanding the global tribological behaviors of wet clutch friction materials under different operating conditions, especially under high power conditions.

In the current work, copper-based composite manufactured by powder metallurgy has been applied to heavily-loaded wet clutches. Its composition was shown in Table 1. Table 2 shows the physical and mechanical properties of the copper-based friction material, which were relatively low due to the high mass fraction of ductile graphite.

Table 1. Composition of the copper-based friction material (wt. %).

Cu	Graphite	Zn	Sn	SiO_2	Others
54~70	17~22	3~5	3~6	4~7	3~6

Table 2. Physical and mechanical properties of the copper-based friction material.

Density (g/cm^3)	Brinell hardness	Compressive strength (MPa)	Elasticity modulus (GPa)	Transverse rupture strength (MPa)
4.05	16	30.89	3.75	10.98

Friction tests were carried out under oil lubrication using a ring-on-ring braking test system (Figure 1) with a load range of 1.0~3.0 MPa, a braking speed range of 6.7~20.1 m/s and a constant moment of inertia (0.1 Kg•m^2).

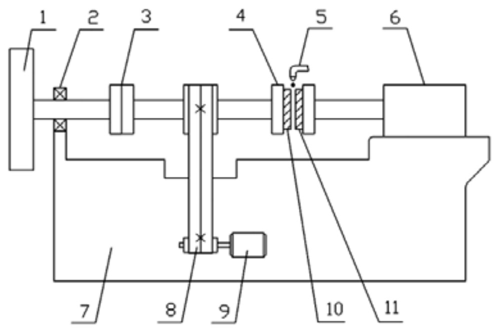

Figure 1. A schematic diagram of the ring-on-ring braking test system：1- Flywheel; 2- Bearing; 3- Clutch; 4- Rotation shaft; 5- Oil outlet pipe; 6- Air cylinder; 7- Concrete base; 8- Feed belt; 9- Motor; 10- Steel counterpart ring; 11- Copper-based friction ring.

The friction coefficient increased nonlinearly with the increase of braking velocity at various loads, and the friction coefficient was obviously higher at 2MPa than 1MPa, as shown in Figure 2. The friction coefficient maintained in the range of 0.062 to 0.100.

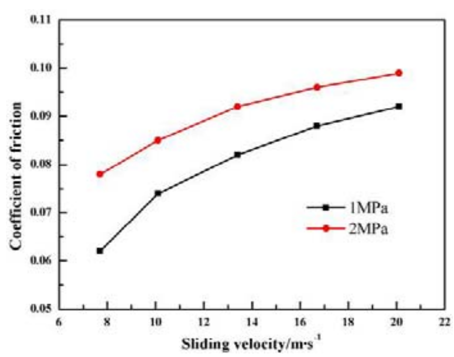

Figure 2. Friction coefficient vs braking speed curves at various loads.

According to previous work in literature and the Chinese mechanical standard, boundaries between wear regimes are identified by the sudden change in wear rates of at least one order of magnitude under different applied loads and speeds [8, 9, 10, 11]. Based on wear rate values of the copper-based friction material, wear was divided into three wear regimes: a) ultra-mild wear < 1×10^{-6} mm^3/J, b) 1×10^{-6} mm^3/J < mild wear < 1×10^{-5} mm^3/J and c) severe wear >1×10^{-5} mm^3/J.

The wear regime map of the copper-based friction material against structural steel under oil lubrication is depicted in Figure 3. This shows that mild wear predominates at high speeds with low loads or low speeds with high loads. Ultra-mild wear regime is observed under relatively lower loads and speeds. Conversely, severe wear exists at higher loads and speeds. The ultra-mild and mild wear zones can be regarded as safe operation zones for copper-based friction materials [10].

Transition boundaries between regimes identified in Figure 3. The relationship between transition loads and transition speeds is almost linear, which can be obtained as follows:

$$P_{T1} = -0.12V_{T1} + 2.77 \quad (1)$$

$$P_{T2} = -0.17V_{T2} + 4.95 \quad (2)$$

where P_{T1} (transition load in MPa) and V_{T1} (transition speed in m/s) correspond to the working condition of transition between ultra-mild and mild wear regimes. P_{T2} and V_{T2} correspond to the working condition of transition between mild and severe wear regimes.

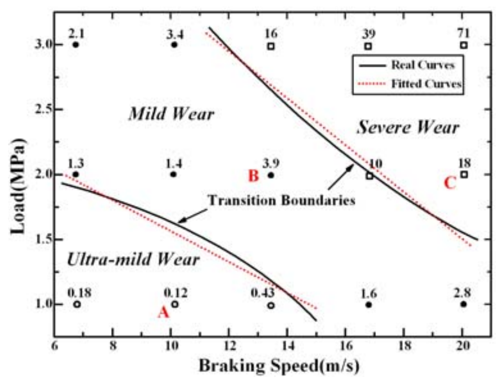

Figure 3. Wear regime map constructed for the copper-based friction material exhibits three wear regimes of ultra-mild, mild and sever wear. The wear rates shown should be multiplied by 10^{-6} to calculate I wear rates in mm^3/J.

Based on our experimental observations and analyses of different wear regimes, a wear mechanism map for the copper-based friction material under oil lubricating was developed and is shown in Figure 4. The dominant wear mechanisms in ultra-mild, mild and severe wear regimes are shown as follows:

- Micro-ploughing and plastic deformation
- Abrasive wear
- Delamination and abrasive wear

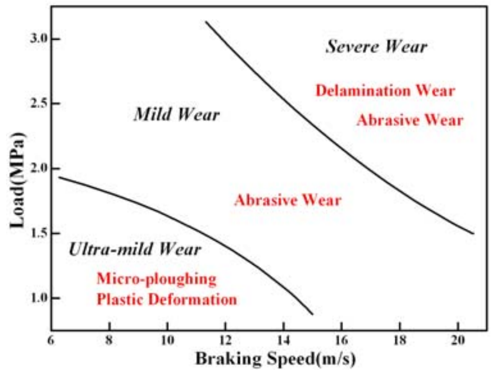

Figure 4. Wear mechanism map for the copper-based friction material.

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KEYWORDS
Gears: Clutches, Materials: Copper, Friction: Friction Mechanisms