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Effect of phenolic content on tribological behavior of carbonized copper-phenolic based friction material

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Abstract

The purpose of the present study is to investigate the effect of phenolic content on mechanical and tribological properties of a series of semi-carbonized copper/phenolic resin-based semi-metallic friction materials with resin contents ranging from 30 to 70 vol% (5–25 wt%). Experimental results indicate that all materials reduced in thickness and weight after semi-carbonization treatment. The amounts of the reductions increased with phenolic content. The sample comprising 50 vol% resin (R5) exhibited the maximum compressive strength, hardness and increase in density after semi-carbonization. Among all materials, R5 demonstrated the greatest potential with high and stable coefficient of friction (COF) value (0.3–0.4) and reasonably low wear. The materials containing 60 vol% (R6) and 70 vol% (R7) phenolic resin showed relatively low COF values. The sample containing 40 vol% resin (R4) faded quickly, while the sample containing 30 vol% phenolic resin (R3) failed prematurely during testing. Semi-carbonization treatment itself did not cause significant oxidation, but friction-induced heating caused extensive oxidation to surfaces of the materials. More counter-face material was transferred to the surfaces of samples with higher phenolic contents (R4, R5, R6 and R7) during sliding, while more extensive abrasion-type wear occurred to samples with intermediate phenolic contents (R4, R5 and R6).

Keywords: Phenolic content; Semi-metallic friction material; Frictional properties; Carbonization; Scanning electronic microscopy

1. Introduction

Semi-metallic friction material has been exploited for parts, such as clutch and brake pad used in automotive transmission in both dry [1] and wet [2] circumstances. The formulation of semi-metallic friction material takes advantage of using binder resins reinforced with metal, fillers, lubricants and abrasive particles [3]. Generally speaking, when designing friction material to obtain desirable friction/wear properties, a binder resin should have good durability, stability, processing feacibility and heat-resistance [4]. Synthetic resins, such as phenolic resin, are the most-commonly-used binder material [5]. However, thermal decomposition or liquescence of phenolic resin due to frictional heating can cause this type of material to fade away [4,6].

There exists an abundant wealth of information regarding how to use a variety of fillers and resins with different ratios to obtain desired friction and wear characteristics. Bartram [7] pointed out that the composition containing a thermosetting binder (phenolic resin and rubber) of 15–40 vol% and inorganic/organic fibers of 33–70 vol% is a robust friction material appropriate for the abrasive qualifications of clutch facing. In their study of a friction material for brake linings and clutches comprising a binder resin, mica powder and a variety of fibers, Moraw and Paul [8] indicated that the binder content of 5–25 wt% produced the best friction performance. Iwata and Asano [9] asserted that a friction material comprising 40–95 vol% binder resin and a variety of powders with different functions showed improved fade and wear resistance. In terms of wet friction material, Tanaka et al. [10] proposed a material comprising 5–20 wt% binder resin, 10–50 wt% carbon or aromatic polyamide fiber, 5–30 wt% solid lubricant and 5–20 wt% ceramic powder depicting such advantages

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Table 1
Sample codes and compositions

Sample code	Compositions (wt%/vol%)	
	Phenolic resin	Cu powder
R3	5.6/30.0	94.4/70.0
R4	8.4/40.0	91.6/60.0
R5	12.0/50.0	88.0/50.0
R6	17.1/60.0	82.9/40.0
R7	24.3/70.0	75.7/30.0

as high and stable friction force along with excellent wear resistance. Previous studies clearly indicate that tribological behavior of semi-metallic friction material is sensitive to both phenolic contents and reinforcing materials.

Alongside of using phenolic resin as matrix, in the recent past, emphasis was placed on the use of pitch to initiate a carbonization or semi-carbonization process. Although, high temperature friction behavior might be improved to some extent by adding certain kinds of powders or fibers into the material [11–14], a carbonization/semi-carbonization treatment could be a more effective approach in enhancing the high temperature tribological performance of phenolic resin-based friction materials. For example, Ohya and Sayama [15] reported improved anti-fade properties by semi-carbonizing a polycyclic aromatic pitch/cyanate ester resin-based friction material to a temperature of 270–800 °C. By semi-carbonizing a steel fiber-reinforced mesophase pitch/sulfur/aromatic nitro compound-matrix friction material to a temperature of 400–650 °C, Kojima et al. [16] also obtained an improved high temperature friction behavior.

Despite all the positive results due to carbonization or semi-carbonization treatment, it is known that, as a binder material, pitch has some inherent disadvantages compared to thermosetting resin such as phenolic resin. Typical examples for such disadvantages of pitch include heating-induced bloating [17] and low carbon yield [18]. According to a study of Thomas [18], the char yield of pitch carbonized at atmospheric pressure was only 25–30%, compared to a char yield of 60–65% for phenolic resin.

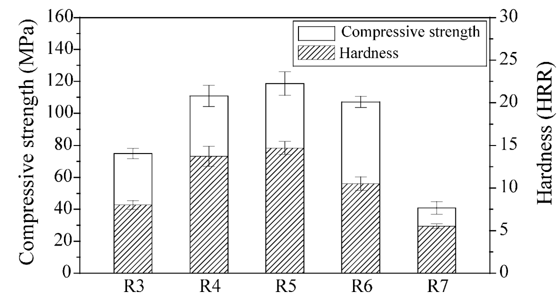

Fig. 2. Compressive strength and hardness of semi-carbonized materials.

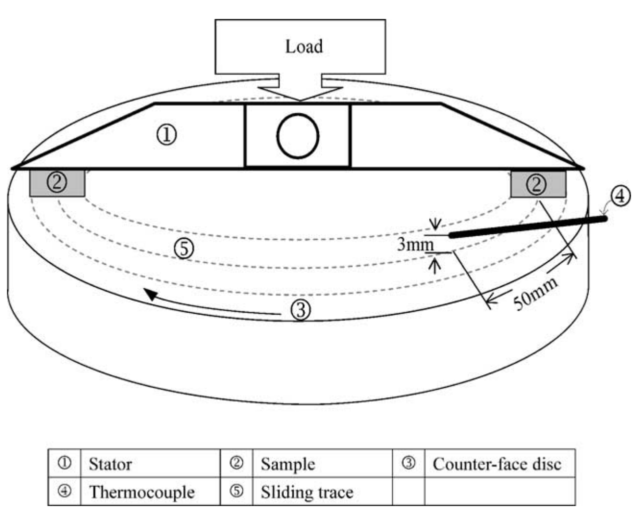

Fig. 1. Schematic drawing of test rig used for the study.

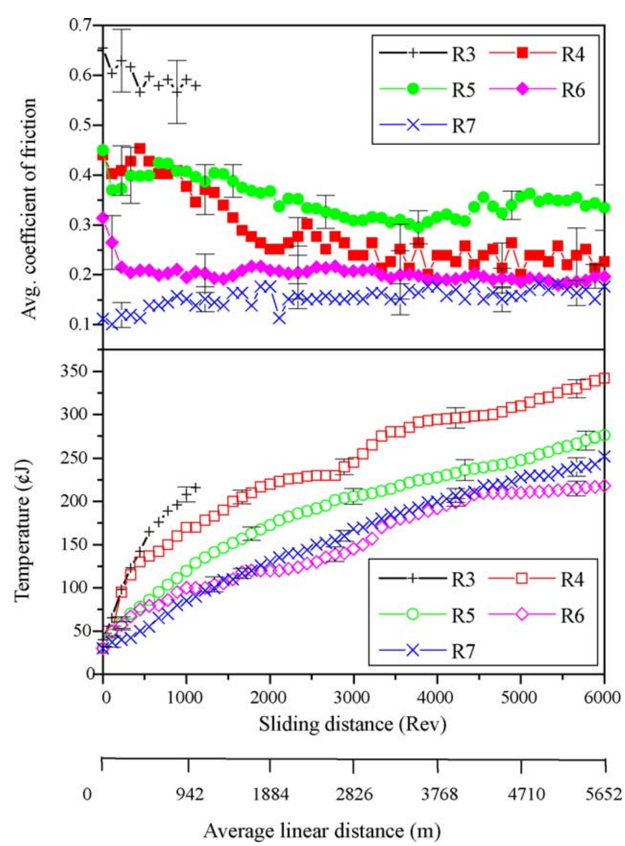

Fig. 3. Variations in average COF and temperature of semi-carbonized materials during sliding.

Table 2
Changes in thickness, weight and density of samples after semi-carbonization

Code	Thickness (%)	Weight (%)	Density (%)
R3	−0.59	−2.08	2.88
R4	−2.19	−2.99	5.64
R5	−2.99	−3.51	8.76
R6	−3.33	−4.33	6.24
R7	−3.82	−8.79	3.51