Tribology International 87 (2015) 1–10

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Effect of resins on thermal, mechanical and tribological properties of friction materials

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ARTICLE INFO

Article history:
Received 30 October 2014
Received in revised form
15 January 2015
Accepted 6 February 2015
Available online 16 February 2015

Keywords:
Phenolic resin
Friction materials
Friction
Wear

ABSTRACT

The phenolic resin composites modified with different volume ratios of nitrile rubber and boron were prepared to study the effect of resins on the thermal, mechanical and tribological properties of composites. Experimental results showed that the porosity and flexural strength of fiction material were in inverse proportion. Composites with the ratio of resins being 1:3 showed improved thermal resistance. It also showed high friction coefficient at different loads and speeds, while the wear behavior of it was the worst despite its improved thermal resistance. The worn surface topographies of composites showed that tribological properties were related to the plateaus formed on the contact surfaces.

1. Introduction

Resin-based friction materials are the most commonly used among the friction materials (Metallic Brake Linings, Carbon–Carbon Composites and Organic friction material) in brakes and clutches for normal duty [1]. These materials are generally multiple ingredients to meet the demands of friction materials, such as moderate friction coefficient, good wear resistance, low wear to counterpart, no or minimal vibration and noise, and reliable strength under different operation conditions [2–5]. Though hundreds of raw materials can be used to prepare friction materials, they are mainly classified into four prime classes, namely binders, reinforcements, friction modifiers and fillers [1].

Among many ingredients used in friction materials, binder plays an important role in determining the performance of friction materials. Although it is not a major component by volume or cost, binder is the heart of friction materials. It is used to bind the rest of ingredients in friction materials and maintain the structural integrity of the composites under mechanical and thermal stresses [6]. Phenolic resin is almost invariably used as binder in friction materials for decades due to its low cost, good wetting capability with most of the ingredients and good combination of thermal, mechanical and tribological properties [7]. However, phenolic resin is also often blamed for various brake-induced problems, especially the fade phenomenon at elevated temperature due to its poor thermal resistance. Phenolic resin degrades producing oily degradation products and contributes to the decrease of friction coefficient and excessive wear at elevated temperature [1,3,4]. In addition, phenolic resin showed high hardness and modulus which made friction materials brittle, apart from its sensitivity to humidity and poor shelf life [8,9].

Due to the above mentioned serious drawbacks of phenolic resin, efforts have been made by different researchers to explore new resins for the substitution of phenolic resin, such as polyimide [10], epoxy [11], cyanate ester [12], modified phenolic resin [3,4,7,8,13–15], etc. However, few of these resins are used in commercial friction materials except for modified phenolic resin because of cost factor and other problems related to friction performance [7]. The choice of binders in friction materials is still limited to phenolic resin and modified phenolic resin. Studies on binder system for friction materials are mainly about the development of new resins and comparison of performance of different resins including thermal, mechanical and tribological properties. Among newly developed resins, cashew nut shell liquid modified resin (CR), melamine resin (MR) and nitrile rubber (NBR) modified resin are widely studied for their good toughness, while boron modified resin (BPR) and silicon modified resin have attracted intensive attention because of their good thermal stability. However, few papers are available on hybrid of two or more resins used as binders in friction materials in spite of the fact that single resin is unable to have both good toughness and thermal resistance.

With this perspective in mind, NBR modified resin of good toughness and boron modified resin of good thermal resistance were chosen as binders for the phenolic resin-based friction materials, to

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http://dx.doi.org/10.1016/j.triboint.2015.02.007
0301-679X/

anticipate that they would have positive effects on the performance of friction materials. In this work, friction materials with different relative amounts of resins were prepared. The effects of resins on the thermal, mechanical and tribological properties of friction materials were systematically investigated.

2. Experimental

2.1. Preparation and formulation of sample

The compositions (vol%) and physical properties of friction materials are listed in Table 1. The five types of friction materials were coded as NPR-1, NPR-0.75, NPR-0.5, NPR-0.25 and NPR-0, respectively, according to the volume ratio of the two resins. The boron modified resin (FB88, Bengbu High-Temperature Resistant Resin Factor Co. Ltd., Anhui, China) is a resole phenolic resin and the free phenol content is lower than 6%, while the NBR modified resin (6530A, Jinan Shengquan Hepworth Chemical Co., Ltd., Shandong, China) is a novolak phenolic resin which is cured by HMTA (Hexamethylenetetramine). In this study, the friction materials were prepared by hot press molding. First, the powdered materials were mixed in an electric blender (Philips HR2006) for 2 min, followed by adding aramid pulp mixing for 1 min. The mixture was then molded for 75 min under 180 °C and 30 MPa by a hot press. Several intermittent 'breathings' were also allowed during the hot-pressing processing to expel volatiles. The resulting specimens with the size of 80 mm × 50 mm × 15 mm were finally post-cured in an oven at 120 °C for 1 h, 140 °C for 1 h, 160 °C for 1 h, 180 °C for 2 h, and 200 °C for 1 h to release the residual stress, followed by cutting into preset sizes for tribological and mechanical tests.

2.2. Characterization

The flexural strength and flexural modulus of the samples were evaluated on an Electron Omnipotence Experiment Machine SANS-CMT5105 (Shenzhen Sans Testing Machine Co. Ltd., China) at room temperature, according to Chinese Standard GB/T1449-2005. The hardness of the friction materials was measured using the HS-D TH-210 hardness tester (Beijing Time Technology Co. Ltd., China) on a shore D scale. Porosity was obtained using a mercury porosimeter (AutoPore 9500). Differential scanning calorimetry (DSC) was performed on a NETZSCH DSC-200F3 thermal analyzer in nitrogen, and the thermogravimetric analysis (TGA) was measured in air with STA449F3 instrument (Netzsch, Germany) from 26 °C to 800 °C with a heating rate of 10 °C/min. The worn surfaces of some typical samples were characterized on a JEM-5600LV scanning electron microscope (SEM) equipped with an energy dispersive X-ray spectrometer (EDS) to understand the wear mechanism. The chemical states of some typical elements on worn surfaces of friction materials were confirmed by XPS (PHI-5702 electron spectrometer, PerkinElmer).

Table 1
Compositions and physical properties of friction materials.

Raw materials	NPR-1	NPR-0.75	NPR-0.5	NPR-0.25	NPR-0
Aramid pulp	14.6	14.6	14.6	14.6	14.6
$K_2Ti_6O_{13}$	23.6	23.6	23.6	23.6	23.6
Nitrile rubber	2.2	2.2	2.2	2.2	2.2
Vermiculite	23.6	23.6	23.6	23.6	23.6
Potash feldspar	3.4	3.4	3.4	3.4	3.4
Flake graphite	5.6	5.6	5.6	5.6	5.6
$BaSO_4$	3.4	3.4	3.4	3.4	3.4
NPR	23.6	17.7	11.8	5.9	0
BPR	0	5.9	11.8	17.7	23.6
Shore hardness (H_D)	83.1	83.7	81.4	81	82.3
Porosity (%)	18.93	21.05	21.86	22.41	19.46
Flexural strength (MPa)	71.69	70.59	67.41	60.88	66.52
Flexural modulus (GPa)	16.39	15.1	15.06	14.63	15.41
Impact strength (KJ/m^2)	3.14	2.82	2.83	2.61	2.77

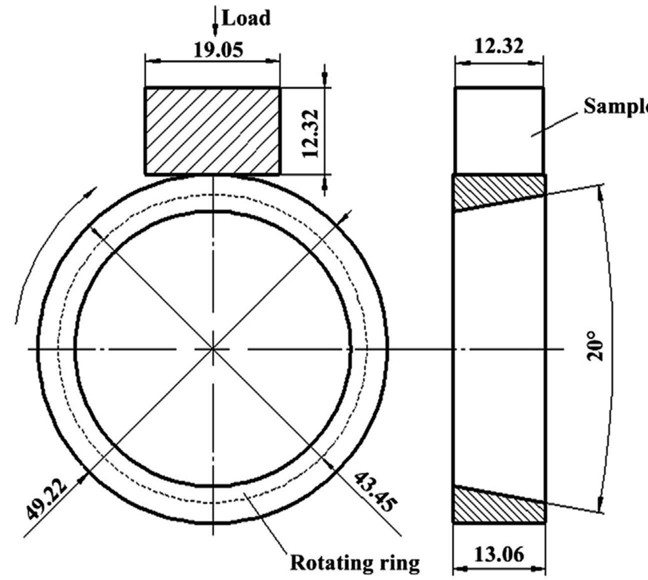

Fig. 1. Contact schematic diagram of friction couple.

2.3. Test procedure for tribo-evaluation

The friction behaviors of friction materials were evaluated on a MRH-3 type ring-on-block test rig (Jinan Yihua Testing Machine Factory, China). The contact schematic diagram of the friction couple is shown in Fig. 1. The dimensions of the counterpart (GCr15) and the test specimens are Φ 49.22 mm × 13.06 mm and 19.05 mm × 12.32 mm × 12.32 mm, respectively. The friction and wear tests were conducted with normal loads ranging from 200 to 350 N and sliding speeds varying from 1 to 2.5 m/s during a period of 120 min under dry sliding condition. The sample temperature was monitored at 5 mm below the contact surface of samples. Prior to each test, sample blocks and bearing steel were polished with abrasive papers to reach a surface roughness (Ra) of about 0.30 μm, and then cleaned with n-hexane. The friction coefficient was automatically recorded by a computer connected to the friction and wear tester. The specific wear rate W (mm^3/N m) was calculated from the volume loss using the following equation [16–18]:

$$W = \frac{\Delta V}{PL}$$

where ΔV is the wear volume loss (mm^3), P is the load (N), and L is the sliding distance (m). The wear volume loss ΔV of the specimen was calculated from the following equation:

$$\Delta V = B\left[\frac{\pi R^2}{180}\arcsin\frac{b}{2R} - \frac{b\sqrt{R^2-(b/2)^2}}{2}\right]$$

where R is the radius of the steel ring (mm), b is the width of the wear trace (mm), and B is the width of the sample (mm). Three repeated friction and wear tests were carried out for each specimen and the average of three repeat tests was reported.