Wear 266 (2009) 275–287

Contents lists available at ScienceDirect

Wear

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

On the dry and wet sliding performance of potentially new frictional brake pad materials for automotive industry

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ARTICLE INFO

Article history:
Received 2 May 2007
Received in revised form 10 June 2008
Accepted 9 July 2008
Available online 2 October 2008

Keywords:
Brake pad materials
GCI
Dry and wet continuous braking
Transfer friction films
Friction
Wear

ABSTRACT

In this work, dry and wet continuous sliding performances of newly developed four different non-commercial frictional brake pad materials (NF1, NF2, NF4, and NF5) were evaluated and compared with other two chosen commercial brake pad materials (CMA and CMB) using a small-scale tribo-tester of pad-on-disc type.

Results showed that under dry continuous braking, friction coefficients for all non-commercial brake pad materials including the CMB were insensitive to the type of brake pad materials. In addition, all brake pad materials showed a slight increase in the friction coefficients (5–19%) with increasing pressure or speed. Meanwhile, the wear rates were substantially dependent on the type or ingredient of brake pad materials and the pressure. Conversely, under wet sliding condition, the friction coefficients were decreased by a factor of 2. Moreover, no evidence of HD water film could be evidenced as the measured friction coefficient values were in the order of dry friction. Thus, the wet results suggested that the friction behaviour was influenced by factors other than HD film, and the values of friction coefficient were in the range of dry friction, mixed and boundary lubrication friction. Qualitative assessment of the SEM morphologies of brake pad surfaces showed that tribofilms were easily formed in dry braking and hardly formed in wet braking. Besides, all brake pad rubbing surfaces showed contact plateaus "patches" and disintegrations of various sizes and locations depending on the braking condition. Furthermore, the removal of material was associated with either mechanical crushing action performed by entrapped wear debris or due to disintegration of plateaus which were accelerated by spraying the water.

1. Introduction

The main requirement of a brake pad is to slow down the car speed by transforming the kinetic energy into heat through friction work at the interface between brake pad and rotor disc. Blames always go to brake pads when a brake-related problem arises. This is because brake pads appear more vulnerable to various braking parameters such as pedal pressure, vehicle speed, disc temperature, and environmental conditions, dry or wet. Meanwhile, shape and physical properties of the brake rotor disc can also affect brake-induced problems such as judder (vibration due to rotor warping or uneven disc thickness), fade (loss of brake effectiveness due to frictional heat), and noise [1]. Accordingly, frictional brake pad material should maintain a relatively high, stable and reliable friction coefficient at wide range of braking conditions irrespective of temperature, humidity, age, degree of wear and corrosion, presence of dirt and water spraying from the road, etc. In addition to these, come next safety requirements, long life, and high comfort, i.e. absence of vibration and squeal noise [2–4].

A change in friction coefficient is highly dependent on the ingredients of friction materials and braking conditions. Due to health issues related to asbestos fibres, during the last two decades, major changes in their formulations brake pads and linings have been exercised. In this respect, a significant effort has been made to develop high performance non-asbestos linings [5,6]. The compositions of organic brake pad material are very complex and normally consist of more than 10 ingredients. The type and amount of each ingredient are often determined by trial and error [7] or on the basis of empirical observations [3,8]. Binder resin and metallic fibres are among many ingredients currently available. Binder resin plays a crucial role in determining the friction characteristics and are often blamed for various brake-induced problems [3]. Metallic fibres are used to improve physical strength and friction performance. Studies of the effect of fibres on the friction characteristics have assured that fibres significantly affect the behaviour

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doi:10.1016/j.wear.2008.07.003

Table 1
Chemical composition (vol.%) of gray cast iron

Material	Element (vol.%)									
	C	Si	Mn	S	Cr	Cu	P	Mo	Ti	Fe
Gray cast iron	3.0–3.8	1.8–2.2	0.2–0.4	0.04 max	0.01	0.01	0.07	0.01	0.15–0.25	Bal.

of wear and friction coefficient [9–11]. Rotor discs are most commonly made from gray cast iron [7]. The relative amount and shape of graphite flakes strongly affect the damping and thermal conductivity of gray cast iron and for these reasons, gray cast iron with high graphite content and long graphite has been preferred for brake rotor disc to assist in reducing the brake temperature and decrease the noise propensity during brake applications [1].

Brake pad covers around 10–15% of the corresponding rubbing surface of the rotor disc. During relatively soft braking, the force pressing the pad against the disc is about 5 kN (for a typical pad of 80 mm long and 50 mm wide) resulting in a nominal contact pressure at the pad surface of about 1.2 MPa. In extreme situations, the pressure could reach 10 MPa [2]. Besides, a high surface temperature is generated during braking process and this in turn demands special characteristics from frictional material of brake pads.

Although the fact that brake must operate under a variety of environmental conditions, most standardized and developed tribo tests for brake materials are surprisingly conducted under dry sliding conditions. Thus, publications concerning the effects of water on frictional behaviour are rare in the tribology literature. Wet and dry braking tests tend to be performed on full-vehicle, on road tests rather than using laboratory-scale tribometers and in this technique both tire performance and braking system contribute to the results. Brake manufacturers and suppliers measure the water absorption characteristics of lining materials. Laboratory-scale tribotesting protocols commonly use constant load (or constant torque) and constant speed. Wet and dry behaviour is not a part of recommended procedures such as the Society of Automotive Engineers procedures J 886 (a Laboratory-scale, coupon test for determining lining friction), J 2430 (a multi-stage dynamometer test for disc brakes), and SAE J 1802 (a test procedure for drum brake linings) [12].

Thus, the present work aimed to investigate the friction and wear behaviour of four non-commercial frictional brake pad materials and compare with other two selected commercial brake pad materials (used for small vehicles) under dry and wet continuous braking conditions. Furthermore, the work also aimed to gain some understanding on the role of water film at the interface from the lubrication theories stand point and on the process of transfer tribofilms. Results in this work are based on the investigation of current formulations of non-commercial frictional brake pad materials and results outside these formulations may be different. In this work, a small-scale tribo testing brake pad disc machine is developed to conduct the tribo tests under different nominal contact pressures (1.11–2.22 MPa) and two different sliding speeds (1.3 and 2.1 m/s). The effect of continuous braking under dry and wet conditions on friction and wear characteristics of all commercial and non-commercial brake pad materials when tested against gray cast iron (GCI) rotor disc was investigated.

2. Experimental work

2.1. Frictional materials

A great deal of effort has been devoted to improve the friction performance of brake rotors including the development of non-ferrous material such as copper alloys, aluminum metal matrix composites (MMCs), and carbon composites as new candidates [1]. However, gray cast iron materials are still commonly used to fabricate frictional brake rotor disc [12] due to its excellent damping capacity, high thermal conductivity, and, in particular, low cost and relatively easy to cast and machine [2]. Thus, rotor disc used in the present investigation was chosen as gray cast iron (GCI) of grade Flo-cast 4E. The chemical compositions of the GCI rotor disc are given in Table 1.

Brake pad materials are usually fabricated from a phenolic resin binder with addition of mineral fibres, fillers, friction modifiers, abrasives, and metallic particles to modify heat flow characteristics [5–7,12,13]. In the present work, four different base matrices of non-commercial materials (NF1, NF2, NF4, and NF5) were designed and manufactured for this work, i.e. non-asbestos semi-metallic materials containing 10 different ingredients. These ingredients comprise fibre reinforcement, binder, friction modifiers, solid lubricant, abrasive, and filler. The relative amounts and type of these ingredients are given in Table 2. The non-commercial friction materials were manufactured by dry-mixing, pre-forming, hot press molding at 2500 psi and 180 °C, post-curing, and heat treatment. All non-commercial friction materials were manufactured at CL Industry Sdn. Bhd. of brake pad manufacturing, Malaysia. Two other commercial brake pad materials (CMA and CMB) were chosen for this work. The chemical compositions of these two commercial brake pad materials are listed in Table 3.

2.2. Preparation of specimens

In the literature, there has been numerous test methods ranging from small coupon rub tests to full-sized vehicle, on the road tests have been developed for evaluating friction brake pad materials. In the present work, specimens of size 9.5 mm × 9.5 mm × 20 mm were machined from non-commercial brake pad plates of size 250 mm × 250 mm × 20 mm by MAZAK CNC Milling machine

Table 2
The ingredients of the non-commercial friction brake pad materials (vol.%)

Raw materials	Sample code			
	NF1	NF2	NF4	NF5
Metal fibre				
Steel fibre	15	20	15	20
Friction modifiers				
Brass	6	6	6	6
Cashew dust	10	10	10	10
Solid lubricant				
Graphite (C)	8	8	8	8
Abrasive				
Zircon ($ZrSiO_4$)	3	3	3	3
Binder (matrix)				
Phenolic resin	20	15	20	15
Rubber (SBR)	–	–	10	10
Organic fibre				
Aramid pulp	10	10	–	–
Fillers, reinforcements				
$CaCO_3$	8	8	8	8
$BaSO_4$	20	20	20	20