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Composite friction materials based on organic fibres: Sensitivity of friction and wear to operating variables

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Abstract

The frictional response of a multi-component friction material is highly complex under a set of dynamically variable loads and speeds. The present paper discusses the sensitivity of friction and wear behaviour of selected composites based on variation in inclusion of organic fibres, viz., aramid, PAN, carbon and cellulose, to braking pressure and sliding speed. The studies on the sensitivity of μ and wear to the operating variables have been carried out on a subscale *brake-test-rig*, following 4 loads × 3 speeds experimental design. Inclusion of cellulose fibre tended to increase the friction coefficient while aramid fibre improved the wear resistance. The fibres of carbon and PAN made the friction composites least sensitive to dynamic variations in braking pressure and sliding speed. Regression analysis of μ values following an orthogonal L_9 (3×3) experimental design method revealed that the first order influences of braking pressure and sliding speed were significant while the contribution of their mutual interaction was negligible. Comprehensively, the influence of operating parameters was more dominating as compared to the influence of individual organic fibre variation.

Keywords: A. Polymer–matrix composites (PMCs); B. Wear; C. Stress-transfer; A. Aramid fibre; A. Carbon fibre

1. Introduction

Friction composites mainly consist of four classes of ingredients, viz., binder, fibres, fillers and friction modifiers. Fibres play a critical role in absorbing stresses generated at the braking interfaces while simultaneously retaining the integrity of the composite at elevated temperatures. The incorporation of organic fibres has been of particular interest, ever since the carcinogenic nature of the conventionally used asbestos fibres was realized. Organic fibre inclusion in friction materials plays multiple roles. It improves toughness and strength of the product apart from increasing the organic contents without increasing the level of resin. Several organic fibres such as aramid (AF), carbon (CF), poly-acrylo-nitrile (PAN), cellulose (SF) etc. have been tried in combination with mineral and ceramic fibres in attempts to replace the asbestos [1–4]. Each of these fibres is reported to impart some different features into the friction materials as per literature collected in Table 1 [5–14]. The friction and wear of the friction material are controlled by the mechanisms of abrasion, adhesion, fatigue and mechanical damage up to a temperature of 200 °C and beyond this thermal crazing, thermal fatigue and pyrolysis predominates [15–17]. Such transitions in wear mechanisms from abrasive to adhesive or from adhesive to fatigue depend on braking pressure (P), sliding speed (V) and the frequency of braking (N). The shear stresses generated at the interface as a result of sliding of the multi-ingredient composite against a metallic disc or drum decide the domination of mechanisms and the sensitivity of friction and wear to the operating parameters like braking pressure, sliding speed, number of braking applications etc. [18]. Compared to the many reports on fade and recovery behaviour of friction composites [19–22] very less

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Table 1
Literature data on the influence of fibre inclusion on tribo-properties of friction materials

Fibres/combinations/nature of composites	Functional roles displayed	Mechanism/reference
Aramid (AF) and carbon (CF); binary composites	Thermally induced lubrication due to shear thinning rheology	Film transfer [5]
Combination of AF and basalt fibre	High μ at elevated temperatures	Material transfer [6]
AF	Stable and high μ along with improved noise, judder and wear performance	[7]
AF; binary composites	Fibre orientation effects; improved wear performance in the direction normal to sliding	[8]
EMCOR 66, UHMWPE fibres	Ready processability, smooth μ curve and high temperature stability	[9]
Cellulose fibres	Processing aid and cost reduction, improves the resiliency	[1]
Carboflex, CF	Improved braking efficiency at high temperature, pressure and sliding speeds, high fade resistance and less braking effectiveness time	[10]
Acrylic fibre, PAN	Higher binding effect and mechanical strength at elevated temperatures	Endothermic cyano-oligomerisation reaction [11]
Acrylic, AF, CF, and other fibres in non-asbestos semimetallic formulations	Under high pressure speed conditions μ increased but wear decreased with organic fibres, CF as processing aid to improve wear performance	CF imparts lubricating effect to the friction film [4]
CF, GF and AF in commercial friction materials	Stabilized μ, depended on critical temperature, which was a function of pressure and speed	[12]
PAN-pitch and C/C composites	μ behaviour was dependent on debris morphology	Wear debris compaction and friction film formation [13,14]

is reported on load–speed (*P*–*V*) sensitivity of such materials [23,24]. This is an important performance criterion for selection of friction materials and it is expected to be as low as possible to attain reliable and expected braking performance. Especially nature of fibre combination e.g., of volcanic rock fibres and organic fibres, was reported exhibiting a decisive role in influencing the pressure–speed sensitivity of friction materials [25]. Gopal et al. [23] have extensively studied the load–speed sensitivity of friction composites based on various fibres like, aramid, glass, steel wool and carbon. These composites showed little variation in wear rate with braking speed when tested against a cast iron drum of an initial temperature of 100 °C or less on Chase type friction tester. They reported that the influence of speed on tribo-performance is via abrupt changes in interfacial temperatures. Beyond a threshold speed value wear has also been reported to be stabilized [26]. However, these observations were based on reduced scale composites and not on realistic friction materials and hence cannot be generalized.

In our earlier work, the temperature sensitivity characteristics were highlighted while studying the influence of nature of organic fibres on fade and recovery performance of realistic friction composites [20,22]. Multiple criteria decision model (MCDM) was also employed to the performance attributes in order to find out the contribution of each individual organic fibre to the overall performance of friction composites [21]. However, tribo-sensitivity of these materials towards load and speed could not be highlighted. Hence, this paper investigates the influence of selected organic fibres on the sensitivity of friction and wear to pressure and sliding speed. Tribo-performance of the friction composites is evaluated keeping the actual vehicle-braking pattern in view, where the driver controls the dynamics of the vehicle through applied pressure on the pads and speed of the vehicle.

2. Experimental

2.1. Fabrication and characterisation of the composites

The friction compositions were designed based on a fixed master batch consisting of NBR modified phenolic resin, graphite flakes, cashew dust, brass swarfs, calcined

Table 2
Details of the formulated composites based on the variation in the type of organic fibres

Class of ingredients	Specifications	Designation and composition by weight %				
		N[a]	A	P	C	S
Master batch	–	72	72	72	72	72
Space filler	$BaSO_4$	**28**	**25**	**25**	**25**	**25**
Organic fibres	Aramid (Kevlar-49, Dupont)	**0**	**3**	**0**	**0**	**0**
	PAN (Sterling CFF V 110)	**0**	**0**	**3**	**0**	**0**
	Carbon (Indcarf-12K)	**0**	**0**	**0**	**3**	**0**
	Cellulose (paper pulp)	**0**	**0**	**0**	**0**	**3**

[a] N: with no organic fibre, A: with aramid fibre, P: with PAN fibre, C: with carbon fibre and S: with cellulose fibre.