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Original Research Article

Performance assessment of lapinus–aramid based brake pad hybrid phenolic composites in friction braking

T. Singh [a,*], A. Patnaik [b]

[a] Department of Mechanical Engineering, Manav Bharti University, Solan 173229, India
[b] Department of Mechanical Engineering, M.N.I.T. Jaipur, Rajasthan 302001, India

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ABSTRACT

The brake pad hybrid phenolic composites based on lapinus–aramid fibre combination are designed, fabricated and characterized for various physical, chemical, mechanical, thermo-mechanical and tribo-performance. The physical properties such as water absorption, compressibility, void and ash contents increase with increase in lapinus fibre, whereas mechanical (such as hardness, impact energy, tensile and flexural strengths) and thermo-mechanical (loss-tangent, storage and loss modulus) properties increase with increase in aramid fibre. The assessment of braking performance is done using a standard test protocol conforming to ECE R-90 regulation on the Krauss friction testing machine. Comprehensively, it is found that incorporation of higher metallic-silicate lapinus fibre in formulation relative to aramid enhances the overall frictional response. The same successfully arrests highest rise in the disc temperature even though wear losses are maximized. The same show lowest fading and excellent recovery performance. Optimally the formulation having lapinus-to-aramid proportion 25:5 experimentally optimizes the overall braking performance. The SEM micrograph study justifies the overall braking tribology and the associated wear mechanisms.

1. Introduction

Friction material in braking systems have to be designed to qualify stringent quality norms such as: high and stable coefficient of friction, low fade, better recovery and low wear over a wide range of operating conditions [1]. The friction materials normally contain multiple ingredients in varying composition, and they are classified as fibres, fillers, binders and property modifiers [2]. Ample of literature are available widespread citing the role of different fibres [3–5], fillers [6], binders [7,8], property modifiers [9,10], nano filler [11–14] and decision making approaches [15–17] for the development of friction pad material. Therefore, selecting the appropriate ingredients, their combinations and justifiable volumetric loading are the challenging themes in front of material scientists and formulation designers.

In the context of performance, fibres and their various combinations play critical role in absorbing stresses generated in braking interfaces and simultaneously retaining integrity of

* *Corresponding author*. Tel.: +91 9418175001.
E-mail address: tejschauhan@gmail.com (T. Singh).

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the composite at elevated temperatures. The crucial role of various fibrous ingredients and their synergistic combinations, in enhancing physical, mechanical and tribo-performances under severe braking conditions are very well reported in literature [3–5,18–25]. Among them, aramid pulp has attracted much attention because of its peculiar characteristics like better fibrillation with most of the ingredients; ease processing aids by imparting better pre-form green strength [3–5,18–25]. Although addition of aramid fibre to friction formulation is beneficial, but history suggested that, aramid fibre alone is unsuitable for braking application because it loses its strength at elevated temperatures that decreases frictional effectiveness of such composites [2,21–25]. Therefore it is used in combination with other fibres to achieve the synergy effect from dissimilar fibres having the complementary nature [24,25].

Lapinus/volcanic rock fibre inherently comprises of metallic-silicates (viz. mixture of SiO_2 (41 wt.%), Al_2O_3 (20 wt.%), CaO + MgO (25 wt.%), Fe_2O_3 (6 wt.%)) [26]. It is reported to improve the structural integrity as it possesses good dispersion property, reduces sensitivity to cracking and blistering during moulding/post-curing, possess heat resistant up to 1000 °C that results in a stable friction coefficient over a wider temperature range making them suitable for both low and heavy duty friction applications. Lapinus reported to mix synergistic with other fibres and reported to improve the friction-fade resistance, improves recovery, stabilizes friction fluctuations over a broad temperature range, improves wear resistance, reduces squeal noise and reduces wheel dusting under various driving conditions [27–29]. Satapathy and Bijwe [28] studied the influence of aramid and lapinus fibre on the fade and recovery performance of the friction materials. They concluded that incorporation 10 wt.% lapinus with 3 wt.% aramid in the formulations helped in imparting improved fade, recovery and wear characteristics. In another independent study Satapathy et al. [29] showed that 25 wt.% lapinus fibre in combination with 5 wt.% aramid fibre improves the friction performance of the composites.

In light of the above literatures, the present investigation aims to establish an optimum ratio of the concentrations of aramid (organic fibre)–lapinus (inorganic fibre) in order to correlate compositional variables with performance attributes such as friction-fade/recovery, wear and friction stability response.

2. Experimental procedure

2.1. Fabrication details of the composites

Hybrid friction composites comprises of master batch of phenolic resin of Novolac type (JA-10), barites (locally supplied), graphite (Graphite India Ltd.) and complementary combination of aramid fibre (IF-258, Twaron, Teijin-Germany), Lapinus fibre (RB-220, Lapinus intelligent fibres, Holland) amounting to 100% by weight were designed as per Table 1 and fabricated as per processing details illustrated in Table 2. Mechanical isotropy is achieved while mixing via plough shear mixer. The specimens are grounded via mild brushing in order to wipe-off the resinous skin formed over the surface so as to have polished and uniform thickness. Thereafter, the specimens are used for various characterizations.

Table 1 – Details of composites composition and designation.

Composition (wt.%)	Composite designation			
	NL-1	NL-2	NL-3	NL-4
PF resin	15	15	15	15
$BaSO_4$	50	50	50	50
Aramid fibre	2.5	5	7.5	10
Lapinus fibre	27.5	25	22.5	20
Graphite	5	5	5	5

Table 2 – Processing details of the fabrication.

Procedure	Conditions
Sequential mixing	Total duration: 10 min, feeder at 300 rpm, chopper at 3000 rpm; sequence: (a) powdery ingredients and (b) aramid and lapinus fibres
Curing temperature	155 °C, compression pressure of 15 MPa, curing time = 10 min
Post-curing	150 °C, 5 h
Finishing	The brake pad is lightly polished with grinding wheel in order to attain the desired thickness (15 ± 2 mm) and to remove the glazed skin of binder from the brake pad surface

2.2. Characterization of physical, chemical and mechanical properties

The density and void content of the fabricated composites were determined using a standard water displacement method and normalization of the actual density with respect to theoretical. Acetone extraction of the cured powdered mix has been carried out to estimate the amount of uncured resin present in the composite. Water absorption was carried out according to ASTM D570-98. Heat swelling was measured according to SAE J160 JNU 80 standard. The ash content was determined by roasting the powdered sample at very high temperature 800 °C in a muffle furnace following industrial norms. The hardness values of the composites were measured on digital hardness tester following Rockwell-R scale whereas the impact energy of the composites was measured following the ASTM D256 method. Shear strength for the characterization of composite integrity throughout the bulk was measured on universal testing machine from Fuel Instruments and Engineering Pvt. Ltd. India and compressibility have been determined following standards conforming to industrial practice. The tensile and flexural tests are performed on flat composite specimens as per ASTM standards. The thermo-mechanical aspects of the composites were evaluated using DMA instrument Q-800 (TA Instruments, USA) on the sample size of $20 \times 8 \times 1\ mm^3$ in tensile mode, at a frequency of 1 Hz (6.28 rad/s), at a heating rate of 5 K/min and temperature range of 30–350 °C.