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ORIGINAL ARTICLE

Assessment of braking performance of lapinus–wollastonite fibre reinforced friction composite materials

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Abstract Brake friction materials comprising of varying proportions of lapinus and wollastonite fibres are designed, fabricated and characterized for their chemical, physical, mechanical and tribological properties. Tribological performance evaluation in terms of performance coefficient of friction, friction–fade, friction–recovery, disc temperature rise (DTR) and wear is carried out on a Krauss machine following regulations laid down by Economic Commission of Europe (ECE R-90). The increase in wollastonite fibre led to an increase in density and hardness whereas void content, heat swelling, water absorption and compressibility increased with the increased in lapinus fibre. The performance coefficient of friction, friction–fade behaviour and friction–stability have been observed to be highly dependent on the fibre combination ratio i.e. coefficient of friction, fade and friction–stability follow a consistent decrease with a decrease in the lapinus fibre content, whereas the frictional fluctuations in terms of $\mu_{max} - \mu_{min}$ have been observed to increase with a decrease in lapinus fibre content. However, with an increase in wollastonite fibre content in formulation mix, a higher wear resistance and recovery response is registered. The worn surface morphology has revealed topographical variations and their underlying role in controlling the friction and wear performance of such brake friction composites.

1. Introduction

Brake friction materials have a crucial role to play in fulfilling the performance requirements such as: high and stable coefficient of friction, low wear along with a low fade and high recovery at wide ranges of operating conditions such as: speed of vehicle, braking temperature, braking force and braking duration for efficient braking of an automotive system.

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Usually, a typical friction material formulation contains many ingredients (sometimes more than 10). The ingredients used can be mainly classified into four prime classes as fibres, space filler, friction modifiers (abrasives, lubricant) and binder (Bijwe, 1997). The role of each class viz. fibres (Satapathy and Bijwe, 2005; Kumar and Bijwe, 2013; Ikpambese et al., 2016), space filler (Handa and Kato, 1996), friction modifier (Cho et al., 2006; Lee et al., 2009) and binder (Bijwe et al., 2005; Shin et al., 2010) in the friction material has been extensively studied for improving the tribological performance and new ingredients are still being developed to attain higher tribo-performance (Dadkar et al., 2009; Singh et al., 2011, 2013a; Yawas et al., 2016; Tiwari et al., 2014; Idris et al., 2015).

Among the many ingredients currently available for friction materials, the fibrous reinforcement: such as organic fibre (Satapathy and Bijwe, 2004), inorganic fibre (Satapathy and Bijwe, 2005; Dadkar et al., 2010), ceramic fibre (Han et al., 2008), metallic fibre (Kumar and Bijwe, 2013) and their combinations (Patnaik et al., 2010; Singh and Patnaik, 2015a) have been found to play a crucial role as they reinforce the composites during fabrication and also help in the formation of topographical features which enhance the tribo-performance. The role of Kevlar fibre has been well reported to aid wear minimization and friction stabilization (Gopal et al., 1996; Kim et al., 2001; Kumar et al., 2011). Lapinus fibres inherently comprising metallic-silicates, when combined synergistically with other fibres that improved the tribo-performance and suppress the unwanted phenomenon like noise, vibration, judder over wide range of driving conditions (Satapathy and Bijwe, 2005; Dadkar et al., 2010; Singh et al., 2015b). Wollastonite fibres having high thermal resilience and inherent hardness have been found to stabilize the coefficient of friction (μ) and maximize recovery performance (Santoso and Anderson, 1985; Kogel et al., 2006).

In the present situation, the development of friction material formulations with stable coefficient of friction, higher recovery performance, higher fade resistance and fibre inclusion is of vital significance. Therefore, the role of lapinus and wollastonite fibres has been reported to improve the recovery, fade, improving wear resistance and stabilizing friction fluctuations over a wide range of braking conditions. Hence, their combination may potentially enhance the tribo-performance for a friction formulation. However, there has been no systematic effort to assess the fade and recovery behaviour as a part of evaluating comprehensive performance of friction formulations containing lapinus and wollastonite fibres in combination. This paper deals with utilization of lapinus and wollastonite fibres in varying proportions to study possible synergistic effect of their combination on the tribological performance parameters such as friction performance, friction fade, recovery and wear characteristics.

2. Experimental procedure

2.1. Materials and fabrication details

Friction material formulation containing by varying the proportion of lapinus (RB-220, Lapinus intelligent fibres, Holland), to Wollastonite fibres (Wolkem India Ltd.) are sheared mixed with fixed amount of phenol–formaldehyde resin of Novolac type (JA-10), barium sulphate, graphite (Graphite India Ltd.) and Kevlar fibre (IF-258, Twaron, Teijin-Germany), that amounting to 100% by weight as depicted in Table 1. The ingredients are mixed sequentially in a plough type shear mixer, where mixing of powdery ingredients is followed by fibrous ingredients to ensure the proper distribution of ingredients before moulding. The mixture is preformed to the shape of brake pads and then heat cured in a compression-moulding machine under a pressure of 15 MPa for 10 min at temperature of 155 °C, with four intermittent breathings to expel volatiles evolved during curing. The specimens are post-cured in an oven at 165 °C for 4 h to relieve residual stresses developed during moulding cycles.

2.2. Physical, chemical and mechanical characterization

The composites are characterized for their physical, chemical and mechanical properties respectively. The density is measured following the standard water displacement method and void content is calculated theoretically by normalization of the actual density with respect to the ideal density. However, the heat swelling is measured according to SAE J160 JNU 80 standard whereas, water absorption is carried out according to ASTM D570-98. Acetone extraction of the cured powdered sample is carried out to estimate the amount of uncured resin present in the friction composite. The mechanical properties such as hardness (a measure of resistance to indentation under loads), cross-breaking/shear strength (a measure of composite adhesion to the back plate) and compressibility characteristics are determined as per standards conforming to industrial practice.

2.3. Tribological performance evaluation methodology

The fade and recovery assessment tests are conducted on a Krauss machine in conformance to regulations laid by Economic commission of Europe (ECE R-90), details of which are mentioned elsewhere (Singh et al., 2013b). The Krauss machine is fully computer-controlled having data acquisition capabilities. Concisely, a pair of friction composites is pressed against the brake disc for undergoing bedding (to ensure conformal contact), cold, fade and recovery cycles.

3. Results and discussion

3.1. Physical, chemical and mechanical properties of the friction composites

The results of physical, chemical and mechanical properties of the friction composites are compiled in Table 2. It can be seen

Table 1 Details of composite composition and designation.

Composition (wt.%)	Composite designation			
	LW-0	LW-1	LW-2	LW-3
Phenol formaldehyde	10	10	10	10
$BaSO_4$	50	50	50	50
Graphite	5	5	5	5
Kevlar fibre	5	5	5	5
Lapinus fibre	30	20	10	0
Wollastonite Fibre	0	10	20	30