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Thermal Stability Analysis Correlation with Fade Performance of Phenolic Based Composite Friction Materials

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Abstract: Phenolic based Kevlar-lapinus fiber combinations reinforced composite friction materials are designed, fabricated and characterized for their thermal and fade performance. The thermal stability behavior is evaluated via Thermo-Gravimetric Analysis (TGA) in nitrogen atmosphere. The fade performance is evaluated on a Krauss friction testing machine by using a standard test protocol conforming to ECE R-90 regulation. In general, it is found that higher lapinus fibre based friction materials shows the relatively lower percent of weight loss or higher thermal stability and enhanced fade performance relative to higher Kevlar fibre based friction materials.

Keywords: TGA, Friction material, Kevlar fibre, Lapinus fibre, Fade.

I. INTRODUCTION

The friction composite materials utilized for braking applications have to be designed to maintain stable performance attributes in terms of friction, fade, recovery and wear under a wide range of operating conditions [1]. Normally, these heterogeneous composites are consisting more than 10 ingredients, primarily of four classes viz. binder, fibres, fillers and property modifiers which works together under the mechanical and thermal stresses during the braking operation to accomplish various performance related issues [2]. Ample of literature concerning the role of different fibres, fillers, binders, property modifiers and nanofillers in friction composite formulations is available widespread [3-12]. Similarly, the optimization of friction materials by using various optimization techniques are reported to select the optimum friction formulation [13-17]. At lower temperature the friction material possesses enough integrity to hold its constituents due to strong bond energies, cross-linking, as the heat supplemented to the material, heat absorption causes decrease in bond that promotes cleavage of bonds and cross-linking, that consequently initiates and accelerate degradation. The weight loss due to degradation is proportional to rise in temperature/heat supply. Initially degradation of organic matter starts as they have a lower decomposition temperature relative to others ingredients of higher decomposition temperature [18]. Thus, friction composite having more organic matter degrades faster relative to others. Herring [19] proposed that fade is caused by gas evaluation at the braking interface as a consequence of pyrolysis and the thermal degradation of the friction material resulting in a decrease in the applied force at an elevated temperature, which leads to reduction in friction performance. The fade in friction level can be induced by an increase in load, speed, temperature and thermal decomposition of organic compounds [20]. In this paper the thermal stability is studied and correlated with the fade performance of Kevlar/lapinus fibre reinforced phenolic based friction composite materials.

II. EXPERIMENTAL DETAILS

A. Materials and Fabrication

Friction material formulation containing varying proportion of lapinus (RB-220, Lapinus intelligent fibres, Holland), to Kevlar fibres (IF-258; Twaron, Teijin-Germany) were shear mixed with fixed amount of phenol-formaldehyde resin of Novolac type (JA-10), barium sulphate and graphite, amounting to 100% by weight as depicted in Table. 1. The composite fabrication conditions during compression molding are given in [21, 22].

TABLE 1 DETAILS OF FRICTION COMPOSITES COMPOSITION AND DESIGNATION.

Composite designation	Composite (wt.%)				
	PF Resin	$BaSO_4$	Kevlar	Lapinus	Graphite
NL-1	15	50	2.5	27.5	5.00
NL-2	15	50	5.0	25.0	5.00
NL-3	15	50	7.5	22.5	5.00
NL-4	15	50	10	20.0	5.00

B. Thermo-Gravimetric Analysis (TGA)

TGA of the fabricated friction composite was carried on TA-60WS model supplied by Shimadzu scientific instruments at a heating rate of 10°C/min from room temperature to 900°C in the presence of nitrogen atmosphere with the flow rate of 40 ml/min.

C. Oxidation index (OI)

OI was calculated based on the weight of carbonaceous char (CR), which is the solid residue of the friction material remained after TGA and related by the empirical equation given in Equation (1) [23].

$$OI = \frac{17.4 \times 0.4CR}{100} \quad (1)$$

D. Oxidation index (OI)

The fade assessment tests were conducted on a Krauss machine by running ECR R-90 schedule. This machine is fully computer-controlled for feeding the operational inputs and has the data acquisition capability. The detailed description of the test procedure is briefly reported in our earlier publication [24, 25].

III. RESULTS AND DISCUSSION

Figure 1 represents the thermogram of the friction composite material. From the start of the test at 30°C indicates certain peculiar characteristics like gradual decomposition due to evaporation of volatile matter upto certain determined temperature, thereafter rate of this decomposition accelerates upto certain temperature thereafter the rate little bit becomes gradual again. The thermal behavior of the investigated friction composites could easily be understood by dividing each thermograph of the respective composite in three major temperature stages. During the first stage, from room temperature to 350°C, weight loss was very low, about 2% may be attributed to the loss of water and gas contained in the polymeric friction composite materials. In the second stage from 350-600°C, the weight loss mainly due to the degradation of the phenolic resin by oxidation into volatile elements and was 5-7%.

During the third stage at higher temperatures from 600-900°C, the weight loss was 12-16%. Table 2 highlights the relative comparison among the investigated composites to assess material stability across three temperature stages under study. The ash contents of the friction composites increases with increase in lapinus contents and lies in the range 73.76-79.94%. Higher the value of oxidation index (OI), higher will be the thermal stability [26]. From the Table 2 it was observed that the oxidation index values increases with increase in lapinus fibre content with corresponding decrease in Kevlar fibre content and it lies in the range 5.13-5.56. This data indicates that the increased lapinus fibre reinforced friction composites are more thermally stable than that of lower content of lapinus. It is observed from Fig. 2 that the magnitude of fade coefficient of friction remains in the range of 0.139-0.335 and observed to lower for the friction material having lapinus fiber <25 wt.% and Kevlar fiber >5 wt.% i.e. NL-3/NL-4. At higher temperature, the presence of too much organic ingredients results in the formation of thick lubricating friction film that drastically diminishes the frictional response hence lowers the frictional coefficient whereas higher lapinus fibers continued to control the formation-deformation-destruction-reformation of friction film hence maintain higher frictional fade response. The thermal stability of NL-1/NL-2 remained much higher in TGA investigation indicating that the resistance of these friction composites to thermal degradation may be superior, an aspect which may, qualitatively, have a bearing onto the higher fade resistance compared to NL-3/NL-4.

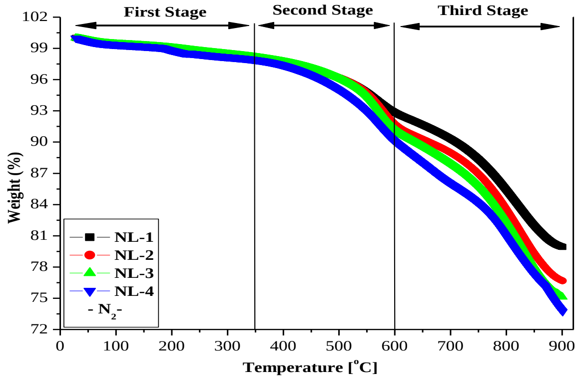

Fig. 1. TGA thermograms of friction composites materials

TABLE 2 TGA and oxidation index of friction composites.

Composites designation	Weight loss (%) with respect to temperature (°C) 30-350	350-600	600-900	Ash content	Oxidation index (OI)
NL-1	1.91	5.24	12.91	79.94	5.56
NL-2	1.91	6.36	15.04	76.69	5.34
NL-3	1.86	6.89	16.11	75.13	5.23
NL-4	2.08	7.86	16.30	73.76	5.13

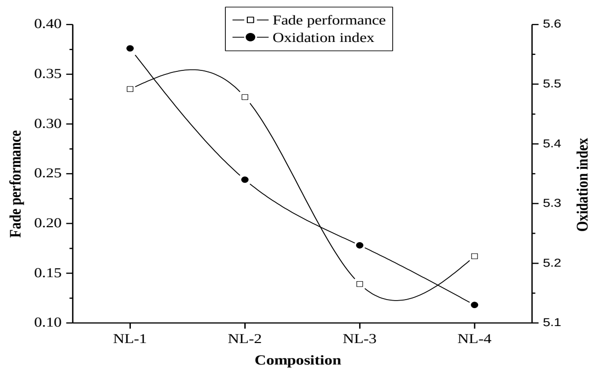

Fig. 2. Variation in fade performance with oxidation index

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IV. CONCLUSION

Phenolic based Kevlar-lapinus fibre combinations reinforced composite friction materials are fabricated and characterized for thermal and fade-performance. Results show that the decomposition of the friction composites was due to decomposition of organic constituents. The incremented lapinus fibre content imparts higher thermal stability in the friction composites as detected by the TGA and enhanced fade performance relative to higher Kevlar fibre based friction materials.

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