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Thermomechanical Properties of Carbon Fibres and Graphite Powder Reinforced Asbestos Free Brake Pad Composite Material

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Abstract

Asbestos is being replaced throughout the world among friction materials because of its carcinogenic nature. This has raised an important issue of heat dissipation in the non-asbestos brake pad materials being developed for automobiles etc. It has been found that two of the components i.e. carbon fibres as reinforcement and graphite powder as friction modifier, in the brake pad material, can play a vital role in this direction. The study reports the influence of these modifications on the thermal properties like coefficient of thermal expansion (CTE) and thermal conductivity along with the mechanical properties of non-asbestos brake pad composite samples developed in the laboratory.

Keywords : *Carbon fibres, Graphite, Brake pad, Steel wool, Thermal conductivity, Coefficient of thermal expansion, Asbestos, Friction materials*

1. Introduction

The most important safety aspect of an automobile is its brake system, which must stop the vehicle quickly and reliably under varying conditions. It is composed of an actuating (hydraulic) system and a frictional system. The frictional system consists of brake lining and it touches rotor material when brake is applied. Frictional systems are generally operated dry in brakes. When brake is applied, brake system transforms the applied pressure to mechanical forces, leading to quick retardation and final stopping of the vehicle [1, 2]. During a stop, kinetic energy of a moving vehicle is converted to heat at the sliding interface of the friction pair. This is then dissipated primarily by conduction through the drum/ disc and by convection and radiation to the atmosphere and adjacent components; secondly by absorption leading to chemical, metallurgical and wear processes at the interface. Typically, normal operating temperature of the rotor is 150~250 °C for passenger cars.

The brake pad materials should not only posses good tribological properties, namely, high friction coefficient and low wear rate but also it is required to exhibit a high thermal conductivity (heat dissipation). The frictional heat causes the melting of contact surfaces and result in the occurrence of the fade phenomenon [3]. From safety point of view heat dissipation is an important factor [4, 5] and primary consideration has to be given while designing a brake pad material.

However, little has been reported on the thermal conductivity of the brake pad materials in the literature [6]. This may be partly due to the complex nature of tribo mechanisms of multi ingredient materials. Peter Filip *et al.* [7] analysed a number of brake lining materials representative of original equipment's in US, Japanese and European automobiles. They have reported the thermal diffusivity values in the range between 0.001 to 0.04 cm ^{2} s^{-1}. It depends on the composition and nature of ingredients in the brake pad material. Inspite of unparalleled combination of essential properties for brakelinings and clutch facings, replacement for asbestos is seriously called for since it is health hazard. This has been extensively reported in literature [7-11]. Carbon fibre [12], kevlar pulp [3, 13], glass fibre [14] and steel wool [7] have been used as the replacement for asbestos as reinforcement.

A systematic approach has therefore been undertaken to develop non-asbestos brake pad composite materials using carbon fibre, kevlar pulp, and steel wool as reinforcement and graphite powder replacing CD-16 as friction modifiers. These samples have been analysed for thermal and mechanical properties.

2. Experimental

2.1. Materials

Phenolic resins of grade HR-6152 with 8~10% Hexamine content in the powder form (mesh size <150) as supplied by Bakelite Hylam was used in the study. The reinforcements consisted of Torayca, grade T300 carbon fibres in the chopped form (25 mm), kevlar pulp procured from Dupont Company and steel wool. Specific grades of friction modifiers and graphite powder were used. Barium sulphate and talc were used as filler materials.

2.2. Processing

Different formulations were made by weighing the individual ingredients separately and mixing them in a mixer until a uniform dispersion was obtained. Composites of size 13 cm × 3 cm × 0.4 cm were prepared by compression moulding the mix in a hydraulic hot press. A pressure of 70 Kg/cm^2 was applied on the mould between 80°C and 165°C and the sample was kept under pressure for two hours to ensure proper curing of the resin.

2.3. Testing

Thermal conductivity was measured using Comparative Thermal Conductivity Instrument Dynatech, model TCFCM-N20. For thermal conductivity measurement cylindrical shape samples of size 50 mm dia and 20 mm height were prepared using special dies.

Flexural strength and flexural modulus of the composite samples were measured on an INSTRON 4411 universal testing machine using three point loading method, ASTM D 790~80. The support span length was fixed at 100 mm and cross head speed was maintained at 5.0 mm/min.

Hardness of the test samples was measured using Scleroscopic hardness tester. 2 cm × 2 cm × 4 cm size sample was calibrated using standard steel material. The results reported are with respect to the standard steel material. A 5 × 3 × 3 mm sample was cut from the main sample and tested for CTE by using TMA-40 module of Mettler TA 4000 Thermal Analysis system. The CTE of the sample was studied up to 400°C at the heating rate of 10°C/min.

3. Results and Discussion

3.1. Composition of the samples

Table 1. Composition (Wt.%) of various brake pad samples

Material	A	B	C	D	E	F
Phenolic resin	16	16	16	16	20	20
Carbon fibre	–	–	5	5	6	6
Kevlar pulp	5	5	–	–	–	–
Steel wool	23	23	23	23	–	–
Friction modifier CD-16	–	7.5	–	7.5	–	10
Graphite powder	7.5	-	7.5	–	10	–
Copper powder	7.5	7.5	7.5	7.5	10	10
Talc	24	24	24	24	32	32
$BaSO_4$	17	17	17	17	22	22

Table 1 below gives composition of various samples. Each composition is designated as A, B, C, D, E and F respectively for comparison. For samples E and F which do not contain steel wool, the total 100% weight was compensated by adding additional quantity of Talc and $BaSO_4$ as fillers.

3.2. Mechanical properties

Mechanical properties along with bulk density for samples A-F are given in Table 2. Flexural strength and modulus for samples A-D ranges from 40~44 MPa and 811 GPa respectively, which is almost twice that for samples E and F. If we look at the composition of the samples in Table 1 it becomes clear that the improvement in the mechanical properties in samples A-D is because of steel wool as reinforcement. Addition of carbon/Kevlar fibres as reinforcement, however, has little influence comparatively so far as the strength of the composite samples is concerned. Density of composites A-D is also higher compared to A-E because of high density of steel .

Hardness of the various samples was measured on Scleroscopic scale and the average values are shown in column 3 of Table 2. Since hardness is also a crucial factor in tailoring the brake pad, an optimum value between 30~35 on scleroscopic scale has been identified and also measured for commercially available automobile brake pad samples e.g. TVS and Ferrado. It is quite evident from the results that graphite powder as friction modifier is better option than the commercially available CD-16. The values of hardness with CD-16 ranges between 40~50, whereas the one with graphite powder are in the required range of 30~35.

3.3. Thermal properties

Thermal properties like thermal conductivity, thermal diffusivity, specific heat capacity, CTE of brake pad samples were determined and are presented in Table 3. As seen from the table the values of thermal conductivity for samples A and C which has graphite powder as friction modifier is maximum and is nearly 1.5 W/mK. Comparatively samples B and D which contains CD-16 as friction modifier the value lies between 1.2~1.3 W/mK. This is because of higher

Table 2. Mechanical properties of brake pad materials

Sample ID	Bulk density g/cm^3	Hardness (Scelero-scopic)	Flexural strength (MPa)	Flexural modulus (GPa)
A	2.4	32.5	43.1	11.3
B	2.4	53.4	44.7	8.2
C	2.4	39.3	41.2	10.1
D	2.4	54.2	40.2	8.5
E	1.8	32.3	24.1	5.9
F	1.8	51.5	24.4	4.4

Table 3. Thermal conductivity and CTE of brake pad samples at 100°C

ID	Thermal conductivity W/mK	Specific heat J/g·K	Thermal diffusivity cm^2 s^{-1}	CTE × 10^{-6}/K parallel to plane	CTE × 10^{-6}/K perpendicular to plane
A	1.48	–	–	8.42	7.4
B	1.31	1.23	0.0059	12.51	25.77
C	1.54	0.81	0.0102	10.68	21.03
D	1.18	0.95	0.0069	15.02	26.88
E	1.10	–	–	–3.3	–5.63
F	0.85	1.33	0.0032	–2.41	+5.6

thermal conductivity of graphite powder compared to that of friction modifier CD-16. There seem to be some influence of carbon fibres on the overall thermal conductivity of the composite, sample C showing a value of 1.54 W/mK as compared to 1.48 W/mK for sample A. The small change might be because of small fraction of carbon fibres i.e. 5% in the sample C. Higher percentage of carbon fibre reinforcement might help in further improvement in the thermal conductivity, but it is not advisable as it has been found by us to increase the hardness of the composite. However, contribution to thermal conductivity from steel wool is quite significant and obvious if one compares the values for samples A-D with 23% steel as compared to that for samples E and F which does not contain steel wool.

Thermal diffusivity values of the brake pad materials have been reported in the literature [7]. In order to compare the values of thermal conductivities of the samples developed by us with the one already reported in the literature thermal diffusivity of the samples was alculated from the thermal conductivity formula

$$\alpha = k/\rho\ Cp$$

Where,

α – Thermal diffusivity
k – thermal conductivity
ρ – Specific gravity of material
Cp – specific heat

Using the values of specific heat for samples B, C, D and F, obtained by DSC-20 module of thermal analysis syetem, thermal diffusivity values were calculated and are shown in Table 3. These values fall in the range of 0.003 to 0.010 cm^2 s^{-1} which are in the same range as reported in literature [7].

Coefficient of thermal expansion (CTE) of the composite samples was measured in both parallel and perpendicular to the moulding directions. The results shown as parallel to the plane of the sample in the Table 3, is actually perpendicular to moulding direction and vice-versa. Looking at the results it is quite clear that the samples prepared with steel wool (A-D) always show positive CTE while. Except for sample A, samples B-D show that the value of in plane CTE of the sample is almost half that across it. Interestingly, for samples E and F the value of CTE is much lower in both the directions and also shows negative values in some cases.

4. Conclusions

The study shows that graphite powder when used as friction modifier helps in improving the thermal conductivity of the composite brake pad material. It also helps in controlling the hardness of the brake pad to desired level. Reinforcement of carbon fibres at the present level does not influence the properties as much as the steel wool. Higher fractions of carbon fibres in the composites could not be incorporated in order to keep the other characteristics of the brake pad material in the desired range.

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