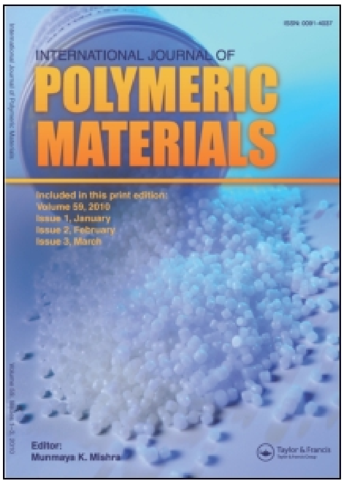

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Glass Fiber Based Friction Materials

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Glass fibers have been considered as a reinforcing agent in friction linings as one component of a potential substitute for asbestos. The mechanical, thermal and frictional properties of six different grades of glass fibers have been evaluated in model phenolic resin based friction materials. The Young's modulus, ultimate tensile strength, flexural strength, flexural modulus, coefficient of thermal expansion and friction coefficients have been determined. It was found that the fiber sizing, length and diameter play a significant role in affecting the mechanical properties. Fiber sizing influences the tensile strength but the fiber length does not. The Young's modulus is relatively independent of fiber sizing, length and diameter. The flexural strength is found to increase with an increase in fiber length and a decrease in fiber diameter. The flexural modulus also increased with an increase in the fiber length. The Coefficients of thermal expansion fall within the normal range observed for glass fiber reinforced phenolic composites. The friction coefficients of these materials fall in the range of 0.21 to 0.33 which appears reasonably good but is not a very high rating for conventional friction linings. These results gives some insights into the use of glass fibers in friction materials.

KEY WORDS: Friction materials, asbestos, glass fibers, phenolic resin, mechanical properties, friction properties.

INTRODUCTION

The recent ban on asbestos by the Environmental Protection Agency (EPA) has forced the friction industry to seek out versatile fibers which can replace asbestos in performance and not pose health hazards. The rule establishes a 3 stage ban on the manufacture, importation and processing of most asbestos containing products, including automotive friction products for which the cut off dates are mid-1993 for original equipment manufacturers (OEM) and mid-1996 for replacement parts. A number of reasons have been cited for the elimination of asbestos in brake linings, including the need for reducing air-borne asbestos in friction material manufacturing plants, the safe disposal of asbestos containing wastes, and the reduction of potential asbestos emissions from brakes in use.[1]

A brake-lining formulation typically consists of several ingredients including: a phenolic binder (polymer), rubber binder, fiber(s), filler(s) and friction particles.

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The phenolic resin is usually based on the condensation product of formaldehyde and phenol or cashew nut shell liquid (CNSL) and performs the function of binding all of the different ingredients together, to produce an integrated composite material. One of the requirements of the binder in a brake-lining formulation is high thermal stability. The characterization and the thermal stability of straight phenolics and CNSL-based phenolics have been studied and reported in the literature.[2,3] The strength and rigidity in brake lining materials is increased by the fiber(s) and the choice of the appropriate fiber, or combination of fibers, is based upon the required properties and economics. The filler(s) is usually a low cost material which may have significant effects on wear and performance of the composite and the friction particle is often a crosslinked phenolic resin or rubber particles added to increase friction.

In an earlier work,[4] the binary interactions in fiber-matrix composites have been studied for a variety of fibers with the goal of characterizing the compatibility of the fiber with the matrix and the extent of reinforcement of the matrix. The composites evaluated in that study[4] were random short-fiber composites. One of the fibers used to reinforce the matrix was chopped glass fibers which were randomly oriented in the plane of the mold resulting in a quasi-isotropic composite, i.e. the properties of the composite are the same in the plane of the molding but different in a direction normal to the surface.

In the present work, we report more detailed studies of glass fiber phenolic materials. Glass fibers are often used in friction formulations because of their physical properties and relatively low cost. In most friction materials, other fibers are used in addition to glass, however, in this work we chose to work with a model, simplified formulation. This was done in order to identify specific resin-fiber effects which might not be obvious in an actual friction material formulation containing many more ingredients. For this model system we have evaluated: mechanical, thermal, and frictional properties so as to broadly characterize glass fiber reinforced friction materials.

MATERIALS

Chopped glass fibers are available in a wide variety of sizes. For the present study, we used lengths of 1/8" to 0.006" (hammer milled) and diameters of 9 μm

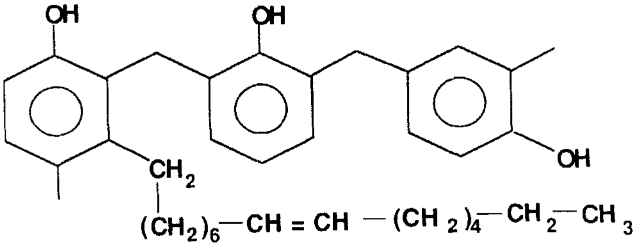

FIGURE 1 The idealized chemical structure of partially crosslinked cashew modified phenolformaldehyde resin.

TABLE I

Grades and dimensions of glass fibers

Label	Fiber grade[a]	Average length inches (mm)	Average diameter μm
1A.1	405 AA (milled)[b]	0.006" (0.15)	13
1A3	405 AA	$\frac{1}{8}$" (3.18)	13
1A6	405 AA	$\frac{1}{4}$" (6.35)	13
2B3	178A-AA	$\frac{1}{8}$" (3.18)	9
2A3	178A-AB	$\frac{1}{8}$" (3.18)	13
3C3	198F X12	$\frac{1}{8}$" (3.18)	16

[a] Owens Corning designation.
[b] Not commercially available.

to 16 μm as supplied by Owens-Corning Fiberglas Corporation, Toledo, OH. These are representative of those currently used in friction materials. Glass fibers are normally given a protective coating or 'sizing' which is typically organic in nature. In addition to protection, sizing aids in bonding between the glass fibers and the matrix. In glass-epoxy systems a reasonable amount of bonding may be achieved due to the polar nature of the epoxy resin. In contrast, since phenolic resins are not very polar, Figure 1, bonding to the fiber may be a concern. Glass fibers which were untreated (no sizing) or greater than $\frac{1}{4}$" in length could not be blended or molded properly with our equipment since a good dispersion could not be achieved. The grades used, their labels, and specifications are listed in Table I. The labels of 1A.1, 2A3, etc. indicate the type of sizing used (by the first number), the diameter of the fiber (by the letter) and the length of the fiber (by the second number). The chemical composition of the sizing used has not been published by the manufacturer.

The formulation used to make the friction linings was based on model formulations used in the industry and also from experiments conducted in our laboratory.[4] The level of glass fibers used was higher than that generally used in a typical formulation to highlight its effect on properties. All of the formulations used in the present study contained 35/20/25/20 by weight% which correspond to 25/34/10/31 by volume% of fiber/resin/filler/friction particles, respectively.

The binder used was NC 126, a cashew modified phenol formaldehyde resin (Cardolite Corporation, Newark, NJ), the chemical structure of which is shown in Figure 1. NC 126 is partially polymerized and chosen because it is used in the industry. With different fibers it has been shown to possess good processibility and favorable composite mechanical properties.[4] The resin was used directly as supplied by the manufacturer which included hexamethylenetetramine (HEXA) as a curing agent. The friction particles NC 104-40, (Cardolite Corporation) were CNSL based, and barytes ($BaSO_4$) was used as the filler.

PROCESSING

The above formulation was made by weighing the different ingredients separately and mixing them in a blender for 3–4 minutes until a uniform dispersion was obtained. The various grades of fibers appeared to form small clumps but as viewed by optical microscopy the dispersion seemed to be uniform. Compression molding was carried out in a hydraulic hot press using a 6″ × 6″ steel mold. A mold release agent was first applied to the hot mold surfaces to enable easy removal of the molded specimen. After ensuring that a dry coat of the release agent had formed on the surface, the batch was charged in the mold. Molding was done at 170°C with 1000 psi pressure for 15 minutes with a few "breathings" to allow for degassing. The 6″ × 6″ × $\frac{3}{16}$″ moldings were then post cured at 170°C for 3 hours at atmospheric pressure. Test samples from these moldings were used for mechanical and thermal tests. For the friction tests, 6″ × 6″ × 0.3″ moldings were made using the same molding conditions as before.

TESTING

The 6″ × 6″ hot pressed composite plates were cut using a band saw into 6″ × 1″ and 4″ × $\frac{1}{2}$″ specimens for tensile and flexural tests, respectively. The specimen edges were finished on a belt sander. These specimens were loaded in uniaxial tension on an Instron testing machine, using a cross head speed of 1.25 mm/min. Flexural strength of these composites were determined by performing 4-point bend tests (ASTM D 790-86) at a loading rate of 1.25 mm/min with specimen length, support span, and load span of 4″, 3″ and 1.5″, respectively. For each grade of fiber, 3–5 replicate runs were made to check for reproducibility.

The thermal expansion tests were done on 1″ long samples using an Orton fused silica dilatometer. For the friction tests, 1″ × 1″ × 0.3″ thick samples were cut from the moldings and the edges were smoothed. The friction tests were conducted in accordance with the SAE J661a procedure (refer to Appendix) on a Chase Machine (Link Engineering, Detroit, MI).

RESULTS AND DISCUSSION

The results of the tensile strength, Young's modulus and other tests are shown in Table II. The Young's modulus of the friction materials were determined from

TABLE II

Mechanical, thermal and friction properties of glass fiber based friction materials

Label	Tensile strength MPa	Young's modulus GPa	Flexural strength MPa	Flexural modulus GPa	α^a	Friction coefficient Normal/Hot
1A.1	4.61	3.14	11.03	2.18	1.28	0.32/0.31
1A3	4.55	3.84	15.35	3.40	1.23	0.32/0.33
1A6	4.40	3.12	19.77	4.32	1.70	0.29/0.27
2B3	7.39	3.85	18.45	3.12	1.40	0.24/0.29
2A3	7.87	3.40	15.59	2.98	1.33	0.28/0.29
3C3	7.60	3.01	14.75	3.32	1.16	0.21/0.23

[a] 10^{-5} in/in °C

the load elongation curves, the cross-sectional area and the gage length of the specimens. It can be seen that the Young's modulus of all the friction materials based on the six different fiber grades are similar. The Young's modulus appears to be relatively independent of the sizing type, length and diameter of the fibers. The ultimate tensile strengths of all the 1A composites (constant sizing and diameter) show similar values which are different from 2A, 2B and 3C composites. Clearly length does not play a critical role in the tensile strength. Comparison of fibers with constant diameter 1A3 and 2A3 show that this is not a critical factor. Consequently, it can therefore be concluded that the sizing has a significant effect on the ultimate tensile strength.

The 4-point bend test results, flexural strength and modulus are also shown in Table II. The effect of the fiber length on flexural strength is plotted in Figure 2 for the 1A glasses as they have the same sizing and diameter. It can be seen that an increase in the fiber length for this variety results in a higher flexural strength. This linear behavior appears to agree with typical curves for composite strength vs. fiber length. Previous studies[5] on short fiber reinforced composites show that the composite strength increases as a function of fiber length. Beyond a certain

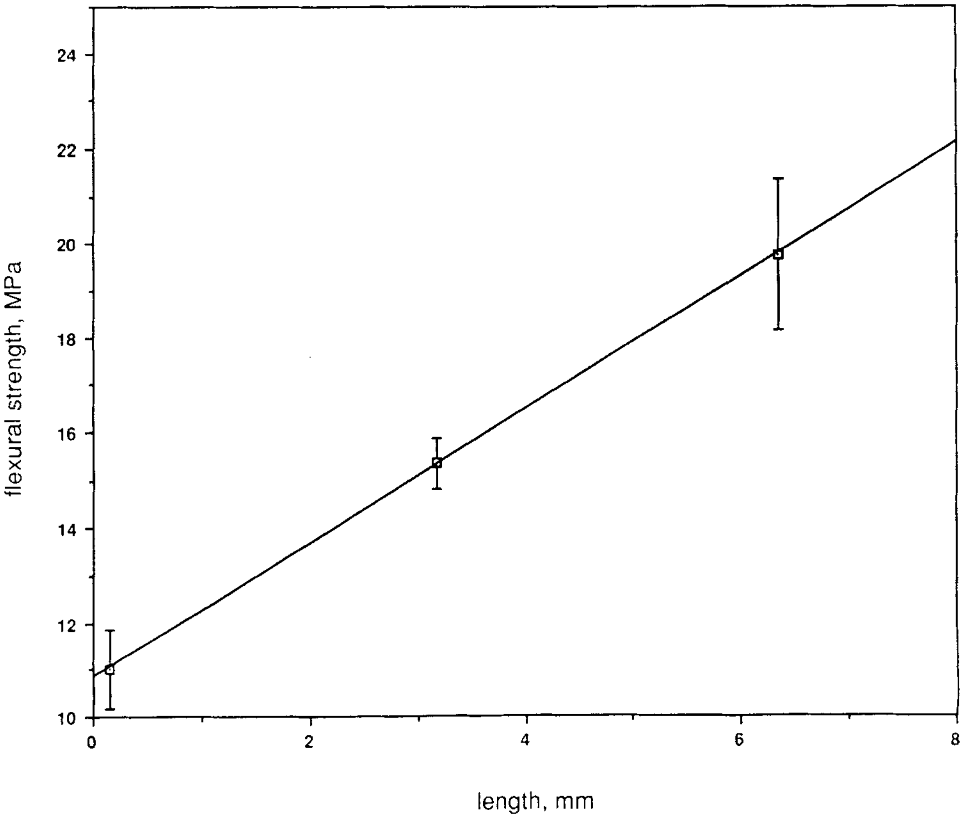

FIGURE 2 Flexural strength of friction materials as a function of the fiber length. The fibers used were 1A grade glass fibers with a diameter of 13 μm. The errors are ±1 standard deviation.

fiber length, however, there is much smaller improvement in strength and the curve attains a plateau. At present we have not attempted to use any models to fit our data since the interfacial shear strengths of the fiber-matrix interface in friction materials have not been determined. Figure 3 shows the effect of fiber diameter on the flexural strength for a given length, $\frac{1}{8}''$. As the fiber diameter decreases, the flexural strength increases. This is in accordance with Griffith's theory which explains the decrease in strength with increasing fiber diameter, due to inherent flaws in the fiber.[6] Thus it can be seen that both the diameter and the length have an influence on the flexural strength.

Combining the above two parameters, from the fiber aspect ratio (length/diameter) point of view, it can be observed that the flexural strength shows an upward trend from 11.03 MPa to 19.77 MPa as the aspect ratio of the fiber (length/diameter) increases from 12 (1A, milled) to 490 (1A, $\frac{1}{4}''$) as shown in Figure 4. The flexural modulus goes up with an increase in the fiber length for the 1A glasses (same sizing and diameter) as shown in Figure 5.

The thermal expansion results are also shown in Table II and the coefficient of

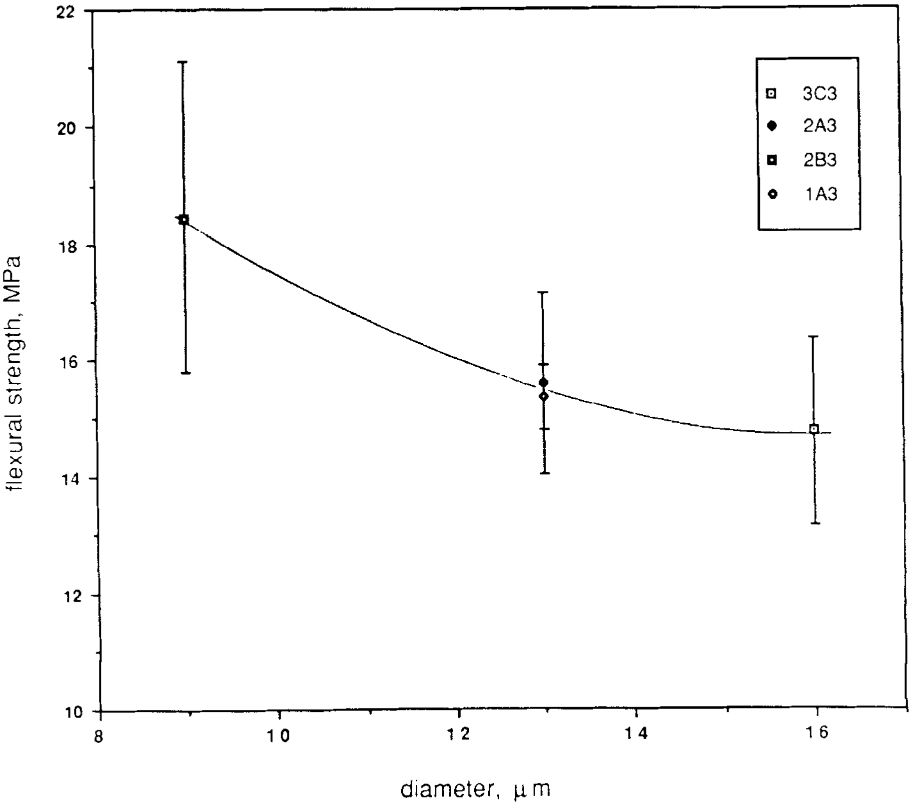

FIGURE 3 Flexural strength behavior as a function of varying fiber diameter. The fiber length in all three cases is the same ($\frac{1}{8}''$). The errors are ±1 standard deviation.

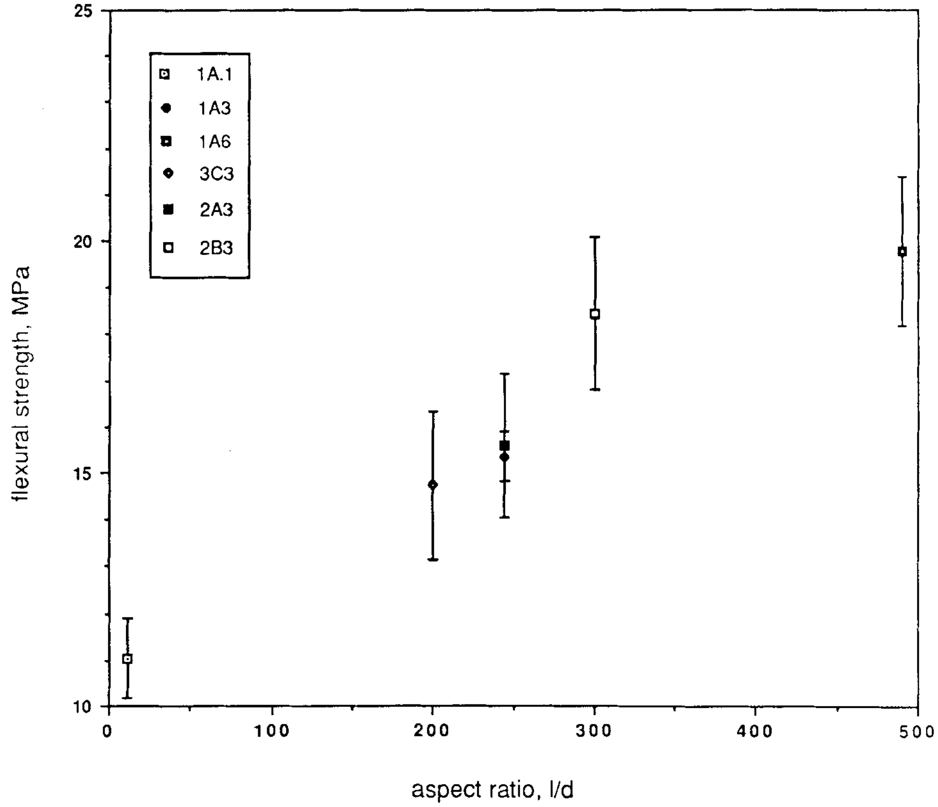

FIGURE 4 Effect of the aspect ratio of the fiber on the flexural strength of friction materials. The errors are ±1 standard deviation.

linear expansion is denoted as α(in/in °C). The values fall within the range normally observed for glass fiber reinforced phenolic composites.[7]

The friction coefficients were measured using the method of SAE J866 (refer to Appendix). The 'Normal' coefficient of friction is defined as the average of 4 points on the second fade curve, located at 200, 250, 300 and 400°F. The 'Hot' friction coefficient is defined as the average of 10 points located at 400 and 300°F on the first recovery; 450, 500, 550, 600 and 650°F on the second fade and 500°F, 400°F and 300°F on the second recovery. The friction results are presented in Table II with the normal friction rating given first. It can be seen that the friction coefficients fall within the range of 0.21 to 0.33 which is not a very high rating but is a satisfactory requirement for a friction lining.[8]

CONCLUSION

A variety of short glass fibers used as potential substitutes for asbestos in friction materials has been studied. The mechanical properties of these composites,

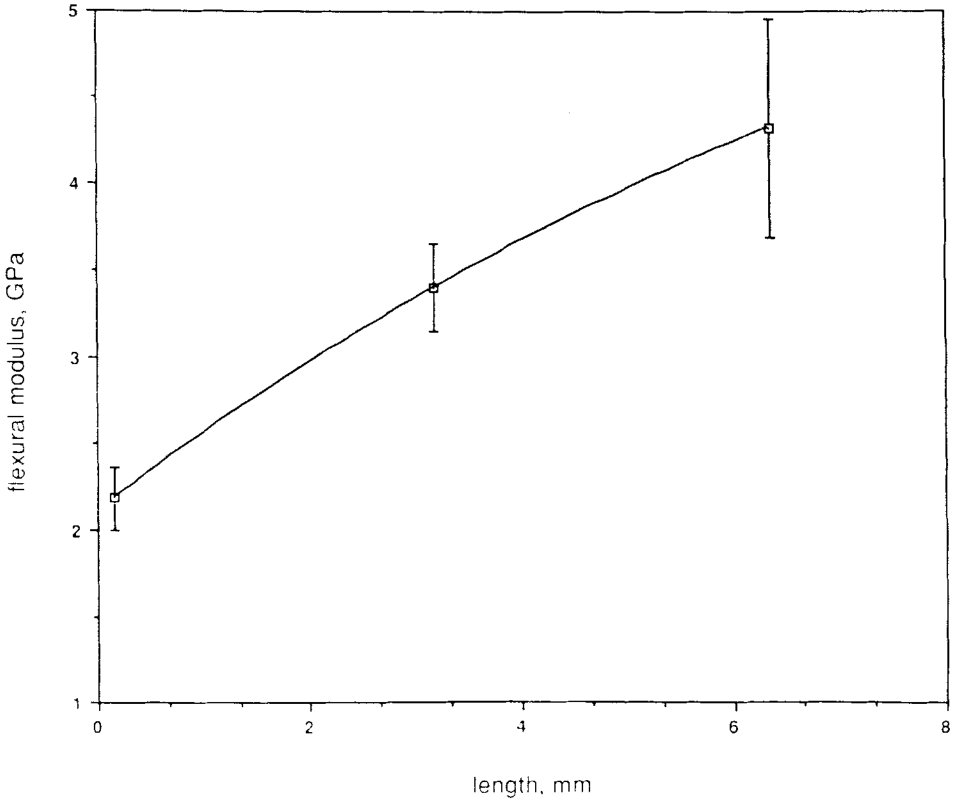

FIGURE 5 Flexural modulus of friction materials as a function of the fiber length. The fibers used were 1A grade glass fibers with a diameter of 13 μm. The errors are ±1 standard deviation.

particularly flexural strength is affected by fiber length and the diameter while flexural modulus increases with an increase in fiber length. Tensile strength is affected by the 'sizing' of the fibers but the fiber length has no influence on it. While no direct correlation can be drawn between the mechanical and frictional properties of these friction materials, one can conclude that the 2A and 2B grades have good mechanical properties like flexural strength and tensile strength while the 1A grades appear to have better frictional properties combined with reasonable mechanical properties.

APPENDIX

The basic function of a friction material is to produce a high coefficient of friction and at the same time it should also have excellent resistance to wear. Wear is an important consideration for a friction material and is related to the amount of work done by the brakes. A lining's resistance to wear is generally related to its friction levels. Normal wear occurs when the high lining temperature chars the

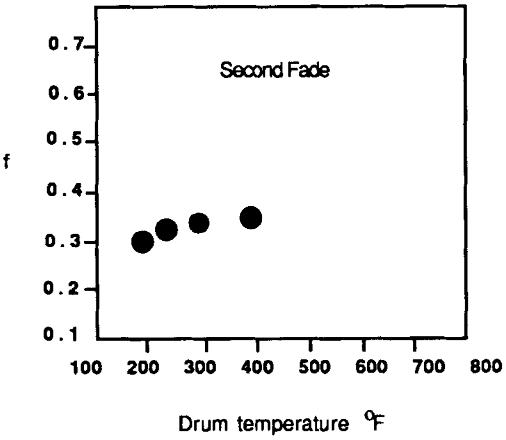

FIGURE A1 Normal coefficient of friction (*f*) shown as a function of drum temperature.

friction surface and forms a minute film. This then wears away exposing a new friction surface. Hence a good quality lining is a fairly good insulator and therefore protects the deeper layers from the high temperatures generated therein.

Fade is the inability of the friction material to maintain its normal, low temperature effectiveness at elevated temperatures. A lot of heat is generated as a result of 'braking' and there is a reduction in the coefficient of friction. Gradual and predictable fade actually prevents the lining from destroying itself. Once the lining cools, it should repeatedly "recover" its original friction value—this is termed "recovery". Baseline, first fade, first recovery runs depend on how well the material has been cured. Hence the most important facets of the SAE J661a test are second fade, wear test and second recovery.

The friction and wear characteristics of friction materials is measured by the

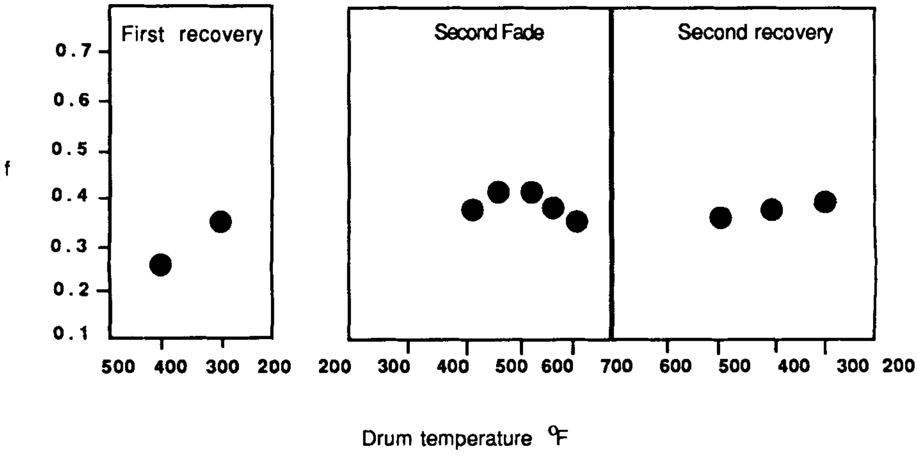

FIGURE A2 Hot coefficient of friction (*f*) shown as a function of drum temperature.

brake lining quality test procedure as per SAE J661a in conjunction with SAE J866. The specimen used in this test is about 1 in. square and a pressure of 1034 KPa (150 psi) is applied to it at a speed of 417 rpm under controlled temperature. The coefficient of friction is then measured as a function of drum temperature and the data plotted on standard charts. In all, seven runs are carried out including baseline, first fade, first recovery, wear, second fade, second recovery and baseline. The 'Normal' coefficient of friction is defined as the average of 4 points on the second fade curve, located at 200, 250, 300 and 400°F, Figure A1. The 'Hot' friction coefficient is defined as the average of 10 points located at 400 and 300°F on the first recovery; 450, 500, 550, 600 and 650°F on the second fade and 500°F, 400°F and 300°F on the second recovery, Figure A2.

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References

1. M. G. Jacko, P. H. S. Tsang and S. K. Rhee, *Wear,* **100,** 503 (1984).
2. D. O'Connor and F. D. Blum, *J. Appl. Polym. Sci.*, **3,** 1933 (1987).
3. B. R. Sinha, F. D. Blum and D. O'Connor, *J. Appl. Polym. Sci.*, **38,** 163 (1989).
4. S. Narayan, B. R. Sinha, F. D. Blum, Y. R. Chen and L. R. Dharani, *SAMPE Quarterly* **21(2),** 17 (1990).
5. P. K. Mallick, *Fiber-Reinforced Composites,* (Marcell Dekker, Inc., NY 1988) Chap. 3, p. 83.
6. K. H. G. Ashbee, *Fundamental Principles of Fiber Reinforced Composites,* (Technomic Publishing Company, Inc., PA 1989), Chap. 1, pp. 8–9.
7. *Modern Plastics Encyclopedia,* **50,** No. 10A (1973).
8. M. N. Joshi, *SAE transactions,* 800782 (1980).