Carbon Science

Vol. 5, No. 1 March 2004 pp. 6-11

Controlling the Hardness and Tribological Behaviour of Non-asbestos Brake Lining Materials for Automobiles

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(Received November 26, 2003; Accepted February 13, 2004)

Abstract

In spite of unparalleled combination of essential material properties for brake linings and clutch facings, replacement for asbestos is seriously called for since it is a health hazard. Once asbestos is replaced with other material then composition and properties of brake pad changes. In certain cases hardness of the material may be high enough to affect the rotor material. In this study, hardness of the brake pad has been controlled using suitable reinforcement materials like glass, carbon and Kevlar pulp. Brake pad formulations were made using CNSL (cashew net shell liquid) modified phenolic resin as a binder, graphite or cashew dust as a friction modifier and barium sulphate, talc and wollastonite as fillers. Influence of each component on the hardness value has been studied and a proper formulation has been arrived at to obtain hardness values around 35 on Scleroscopic scale. Friction and wear properties of the respective brake pad materials have been measured on a dynamometer and their performance was evaluated.

Keywords : *brake pad, fibres, composite, friction, hardness*

1. Introduction

There have been significant changes in the formulations of friction materials for the brake lining systems of automobiles [1-4]. The shift is in the direction of better heat resistance, higher coefficient of friction, and extended durability. Replacement of asbestos are suggested as carbon, Kevlar, glass fibre, steel wool, wollastonite, graphite fibres and a number of other mineral fibre types [5-9]. In general, the development of friction material with these fibres has quite adequately met the requirements. However, hardness of these many non-asbestos ingredients has been the negative points.

Hardness of the brake pad is one of the important parameters [1, 10]. To withstand adverse braking conditions and to provide a long working life, the friction material should be hard. The harder the material, the less compressible it is. However, if there are substantial amounts of harder minerals, they tend to scratch conventional cast iron brake drums and discs. Most of the suppliers have attacked the abrasion problem by designing harder rotors and discs and by using multiple lubricants in their organic formulations.

Hardness is purely a relative term and is totally different than the wear and abrasion resistance of plastic materials. Polystyrene, for example, has a high Rockwell hardness value but poor abrasion resistance.

In the present study several compositions have been tried to tailor a suitable non-asbestos brake pad material. Efforts have been made to ascertain the influence of individual component and different compositions on the hardness values of these pads. The hardness values were compared with the commercially proven brake disc materials. The samples which were screened through hardness test were then subjected to tribological studies.

2. Experimental

2.1. Materials

Phenolic resin of grade HR-6152 (cream pale yellow with 8~10% Hexamine content in the powder form (mesh size <150, gel time 25~40 secs at 160^{o}C) as supplied by Bakelite Hylam Ltd was used as matrix in the study. The reinforcements consisted of Torayca, grade T-300 (tensile strength, TS 3.5 Gpa, tensile modulus, TM 230 GPa, density 1.78 g/cc, carbon content 93% , electrical resistivity 15 micro ohm m) carbon fibres in the chopped form, glass fibre of 3 mm

Table 1. Composition of various fillers used in our study

S. No.	Filler	Composition
1	Calcite	$CaCO_3$, 98.5%
2	Dolomite	Ca CO_3 60%Mg, CO_3 40%
3	Mica	SiO_2 43-48%, Al_2O_3 33-37%, K_2O 8-12%
4	Talc	MgO 31.7%, SiO_2 63.5%, FeO 0.1-6%
5	Wallostonite	CaO 48%, SiO_2 48.7%

length as supplied by FGP (Fiber Glass Pilkington Ltd), kevlar pulp procured from Dupont Company. Specific grades of friction modifiers and graphite powder (Natural graphite flakes mined from Indian mines, 99.9% pure, Diam. ≈1 mm) were used. Barium sulphate, wollastonite, calcite, mica, talc, magnesium sulphate, etc. were used as filler materials. Composition of various fillers (M/S Wolkem India Limited) is given in Table 1.

2.2. Processing

Different formulations were made by weighing the individual ingredients seperately and mixing them in a mixer until a uniform dispersion was obtained. The various types of fibres appeared to form small clumps but as viewed under the optical microscope the dispersion seemed to be uniform. Composites of size 13 cm × 3 cm × 0.4 cm were prepared by compression molding the mix in a hydraulic hot press. A silicon release agent was first applied inside the mould for the easy removal of the molded specimen. A pressure of 70 Kg/cm^2 was applied on the mould between 80ºC and 165ºC and the sample was kept under pressure for two hours to ensure proper curing of the resin.

2.3. Testing

Flexural strength and flexural modulus of the composite samples of size 13 cm × 3 cm × 0.4 cm 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 5.3 mm/min. If need required, samples were cut using diamond cutter and the specimen edges were finished by rubbing on sand paper.

Hardness of the test samples was measured using a Scleroscopic hardness tester. A 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.

Tribological studies were carried out using SAE J-661a test method. Samples of size one square inch were tested under load of 19 and 26 Kg/cm^2 respectively at a constant rubbing speed of 1252 rpm and under controlled temperatures. The duration of one braking cycle was 10 seconds and the contact time was 1 second.

3. Results and Discussion

Table 2 shows the composition of the each brake pad sample numbered A_1 to A_5 prepared under similar conditions as discussed in section 2.2. The binder contents were varied from 20% to 40% of phenolic resin and in order to make up for the 100% weight the difference was compensated by changing the filler contents only.

3.1. Flexural properties and hardness of the composite samples

Flexural strength and flexural modulus for the brake pad materials has been reported by several authors [10] in the

Table 2. Composition of brake pad samples by weight percent

Sample No.	Phenolic Resin HR-6152	Glass Fibre (3 mm)	Friction Modifier CD-25	Copper Powder	Barium Sulphate	Wollastonite
A_1	20	6	15	10	25	24
A_2	25	6	15	10	22	22
A_3	30	6	15	10	20	19
A_4	35	6	15	10	17	17
A_5	40	6	–	–	27	27

Table 3. Mechanical properties of composite samples

Sample No.	Phenolic composition (wt%)	Density gm/cm^3	Flexural strength MPa	Flexural modulus GPa	Scleroscopic Hardness
A_1	20	1.8	27.89	6.2	73
A_2	25	1.8	53.49	7.4	65
A_3	30	1.8	49.91	6.4	70
A_4	35	1.8	48.16	6.8	65
A_5	40	1.8	55.32	8.0	77
TVS	–	–	–	–	37
Rane	–	–	–	–	32.6
Allied Nippon	–	–	–	–	33.5
Ferrado	–	–	–	–	32

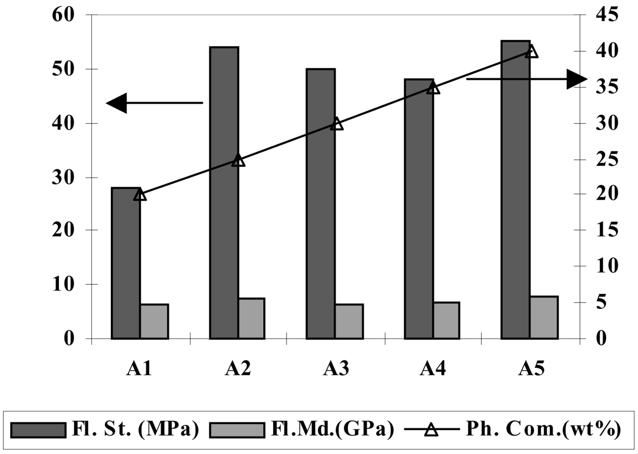

Fig. 1. Change in flexural properties of brake pad composites with respect to phenolic resin contents.

range of 10~40 MPa and 3~8 GPa respectively. Table 3 shows the characteristics of the brake pad samples by changing volume percent of phenolic resin in the composites. For better comparison the strength and modulus values are plotted in Fig. 1. The strength and modulus values reported here are average of three samples for each batch i.e. A_1-A_5 with standard deviation of ±5~10%.

As shown in Fig. 1 there is a sharp improvement especially in the strength values of the composites by increasing the binder content i.e. phenolic resin from 20% to 25%. Further increase in the binder content, however, does not help in improving the mechanical properties further. On the other hand it might have a negative effect in terms of hardness values of the composites as will be discussed later. The Scleroscopic hardness values of samples A_1 to A_5 with the present composition, as seen from Table 3, are quite high as compared to normally acceptable values around 30~40 for commercial samples TVS (brand name of brake pad from M/S Sundram Fastners Limited) and Ferrado respectively.

Since different materials in the composites have different hardness values, it was therefore decided to measure the Scleroscopic hardness of individual component. One has to control the wt./volume percentage of specific component in the mix so that the percentage of component with high hardness should be reduced and that with low hardness values should be increased without sacrificing the other characteristics of the brake pads. Table 4 gives the hardness values of different components, reinforced in phenolic resin by equal volume percent and molded into 12 mm thick pallets.

As evident from Table 4, the maximum contribution of hardness comes from phenolic resin, percentage of which should be reduced therefore. However, the contribution from reinforcement and friction modifiers is also important. Since the hardness of talc is almost half that of the other filler components like barium sulphate and wollastonite, its percentage should be increased comparatively. However, as shown in Table 3 reducing the phenolic resin percentage, the composite flexural strength is also reduced. So one has to make a compromise between the two i.e. hardness and the flexural strength. A different formulation was therefore prepared to reduce the hardness values of the brake pad materials as shown in Table 5.

Table 4. Scleroscopic hardness of individual component

Sample No	Material	Hardness
1	Phenolic resin HR-6152	76
2	Glass fibre	39
3	Kevlar pulp	56
4	Carbon fibre	57
5	Friction modifier	55
6	Barium sulphate	42
7	Wollastonite	42
8	Talc	23
9	Graphite	22

Table 5. Composition of initial and modified brake pad composite samples

Material	Initial (wt%)	Modified (wt%)
Resin (phenolic HR-6152)	20-40	20
Reinforcement (carbon fibres/ glass fibres/ kevlar pulp)	6	6
Friction Modifier (CD-16/ Graphite)	15	10
Copper powder	10	10
Barium sulphate	17-27	22
Talc	17-27	32

Table 6. Properties of modified brake pad materials

Sample Code	Density gms/cm^3	Flexural Strength (MPa)	Flexural modulus (GPa)	Hardness (Sclereoscopic)
GF	1.8	24.6	4.7	45
GG	1.8	24.2	6.6	31
CF	1.8	24.4	4.4	51
CG	1.8	24.1	5.9	32
KF	1.8	24.8	5.3	48
KG	1.8	25.5	5.8	33
CKG	1.8	21.9	5.1	33

– GF-Glass fibre (6%) and Friction modifier (CD-16),
– GG-Glass fibre and graphite powder,
– CF-Carbon fibre and Friction modifier (CD-16),
– CG-Carbon fibre and graphite powder,
– KF-Kevlar pulp and friction modifier (CD-16),
– KG-Kevlar pulp and graphite powder
– CKG-Carbon fibre(3%), kevlar pulp(3%) and graphite powder.

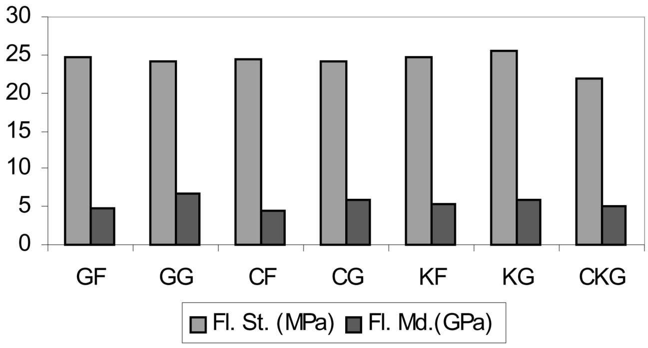

Fig. 2. Change in flexural properties of brake pad composites with friction modifier composition (please refer Table 4).

Effect of modified composition of the composite samples on their mechanical properties and hardness is shown in Table 6. For friction modifier either the standard formulation CD-16 or graphite powder was used while the reinforcement was chosen from glass, Kevlar and carbon fibres.

The results show that the density is almost constant at 1.8 gm/cm^3 for all the samples. Hardness values could be brought down to around 45 with CD-16 as friction modifier, which is still on the higher side than desired. However, use of graphite powder in place of friction modifier helps in further reducing the hardness values to 33.

The study showed that in order to control the hardness of the material to reasonable values a compromise had to be made with the flexural strength which was reduced from 50 MPa to about 25 MPa. Different compositions with different reinforcements do not affect the mechanical properties of the composites as shown in Fig. 2. However, these are still well within the designated value for practical application [10]. Samples KG, GG and CG were short listed for friction studies because of their hardness values, which fall within the desired limits.

3.3. Tribological properties

3.3.1. Friction behavior

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 [10, 11]. Figs. 3 and 4 show the variation of coefficient of friction (μ) with two different load cycles i.e. 19 and 26 kg/cm^2 for samples KG and GG respectively. Each point in the curve denotes the mean value of friction coefficient during one braking cycle. As shown in the figures, the friction coefficient remains quite steady (μ=0.24-0.26) for the sample KG under both the load cycles. On the other hand in case of sample GG, the friction coefficient increases steadily at lower load. The sample with glass fibre shows not only higher coefficient of friction comparatively but also shows adverse fade characteristics at higher loads of 26 kg/cm^2. It may therefore be concluded

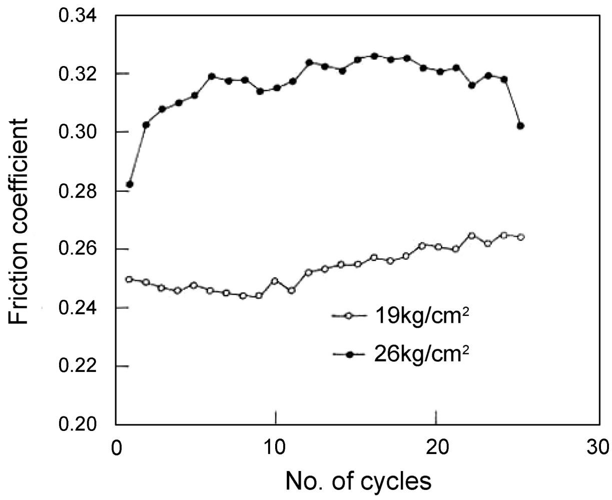

Fig. 3. Variation of friction coefficient (μ) of brake pad sample KG with number of pressure cycles.

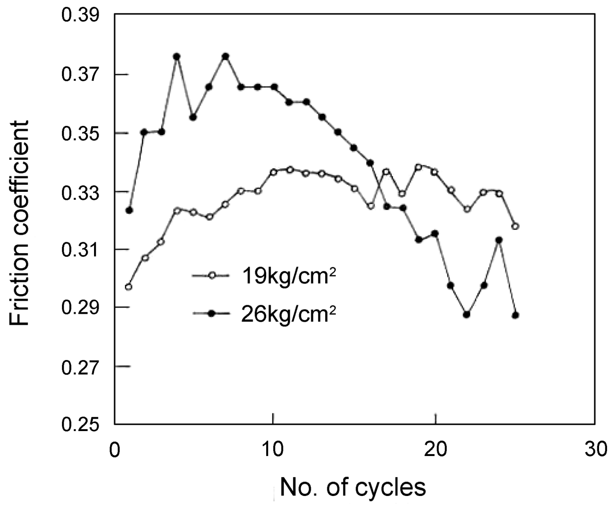

Fig. 4. Variation of friction coefficient (μ) of brake pad sample GG with number of pressure cycles.

that Kevlar pulp based material shows better friction properties than the glass fibre reinforced ones. Fig. 5 shows the the variation of coefficient of friction (μ) with two different load cycles i.e. 19 and 26 kg/cm^2 for sample for commercial sample Rane. The value of (μ=0.37-0.38 for 19 kg/cm^2 and 0.39-0.42 for 26 kg/cm^2) remains almost uniform for the total duration of the experiment of 25 cycles. The value is somewhat higher for lower load of 19 kg/cm^2 compared to the value for higher load of 26 kg/cm^2.

Figs. 6 and 7 show the variation of pad temperature with the number of braking cycles under two different loads for samples KG and GG respectively. As shown in the figures the pad temperatures varies from 80 to 100^{o}C at 19 kg/cm^2 and shows a maximum value of 180^{o}C at 26 kg/cm^2 in both the cases. The curve for sample KG tends to become steady

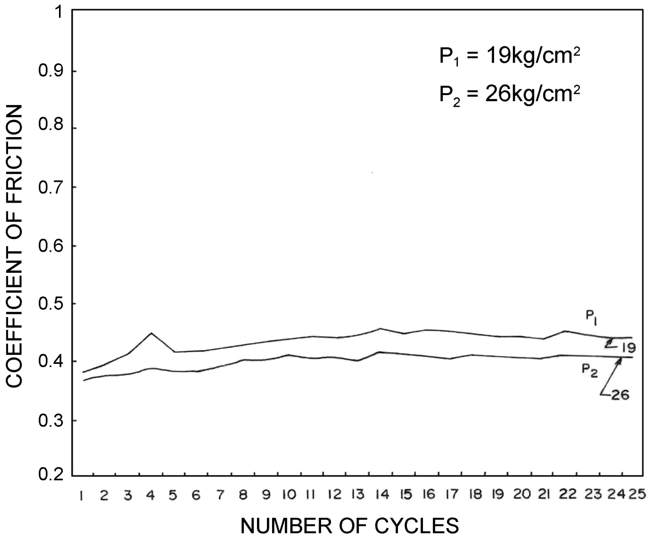

Fig. 5. Variation of friction coefficient (μ) of brake pad sample Rane with number of pressure cycles.

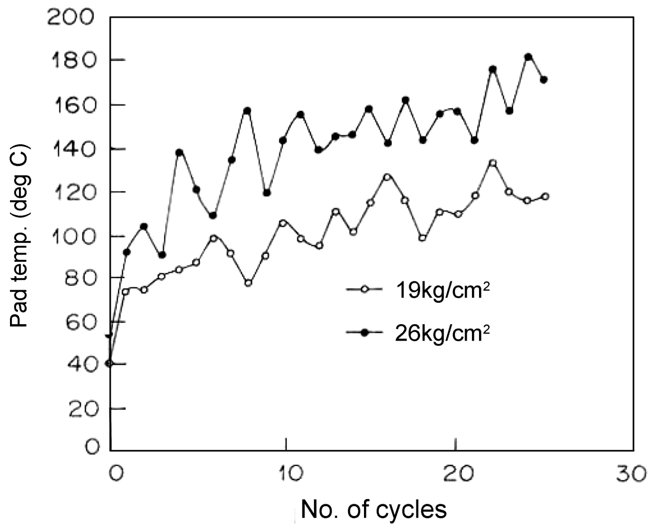

Fig. 6. Change in temperature (°C) at brake pad sample KG with number of pressure cycles.

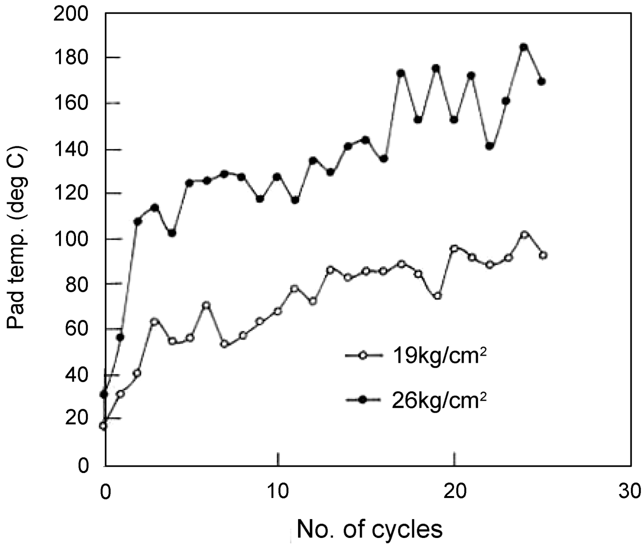

Fig. 7. Change in temperature (°C) at brake pad sample GG with number of pressure cycles.

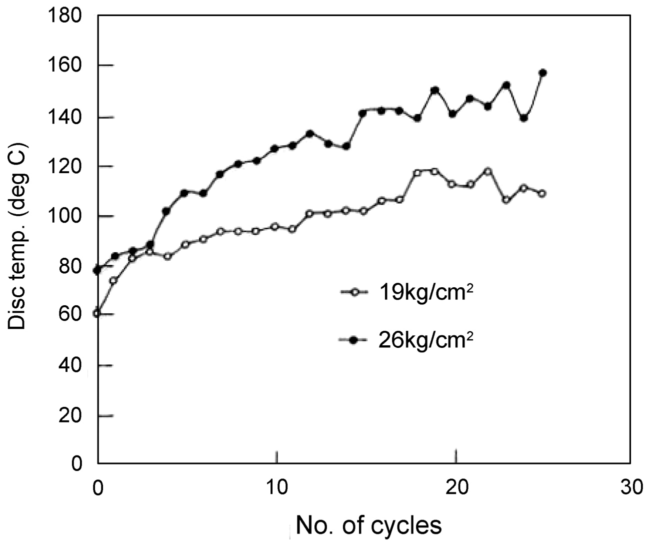

Fig. 8. Change in disc temperature (°C) with number of pressure cycles using brake pad sample KG.

after 10 cycles as compared to GG sample. Figs. 8 and 9 show the variation of disc temperature against number of cycles for the two systems i.e. KG and GG respectively. Both the samples show a rise in the disc temperature of about 80°C at 26 kg/cm^2 load and about 40°C at 19 kg/cm^2. While the curve for sample KG tends to flatten up with number of cycles, the sample GG shows a continuously increasing trend.

3.3.2. Wear tests

Wear of friction material is one of the important characteristics of the brake pad. Good brake pad is closely associated with the quality of the material, as well as with the safety and economy of operation. It is directly related to the amount of work done by the brakes. There are different ways in which wear can be expressed and for the present studies it has been expressed in terms of the loss in the sample thickness after 50 cycles, with rotor rpm of 1252 and load on the sample at 26 kg/cm^2. It was found that the wear of sample KG was 0.582 mm whereas it was 0.639 mm for sample GG under the above conditions whereas wear of commercial sample Rane (M/S Rane Brakes Limited, India) is only 0.20 mm.

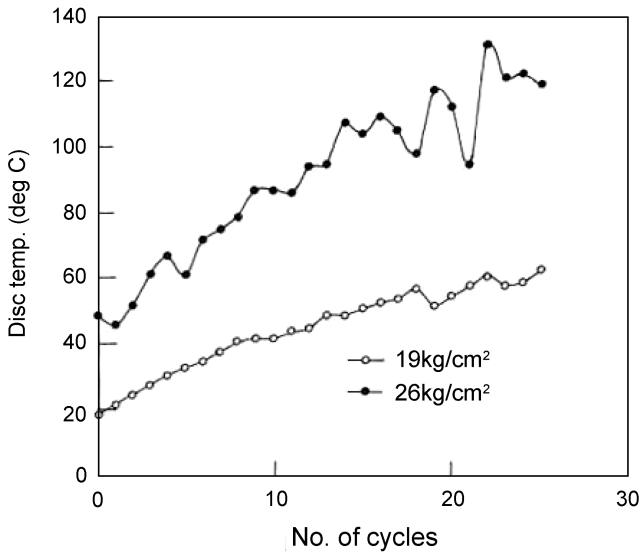

Fig. 9. Change in disc temperature (°C) with number of pressure cycles using brake pad sample GG.

4. Conclusion

Carbon fibres as reinforcement and graphite powder as friction modifier are two potential carbon materials which are useful in the formation of asbestos free brake pad materials. For tribo-performance, hardness of materials plays a crucial role and can be controlled by suitable modifications in the composition of the composite material. In case of friction based brake pads, hardness could be reduced by using graphite powder as friction modifier without affecting flexural properties. Samples made with Kevlar pulp showed superior tribological properties.

Acknowledgements

The authors wish to thank Prof. Vikram Kumar, Director NPL, for his kind permission to publish the results and to Dr. A.K. Gupta, Head of the Division, for fruitful discussions during the course of the study. Authors are thankful to Dr. (Mrs) J. Bijwe, ITMMEC, Indian Institution of Technology New-Delhi, for the tribological properties. Ones of us (P. Thiyagarajan) would like to thank CSIR for awarding Sr. Research Fellowship. Authors are thankful to DST for funding the study.

References

[1] Danner, G. E.; Jefferies, J. K. *Society of Automotive Engineers* **1986**, Paper No. 860768.
[2] Jacko, M. G.; Tsang, P. H. S.; Rhee, S. K. *Wear* **1984**, *100*, 503.
[3] Bijwe, J. *Polymer Composites* **1997**, *18*, 378.
[4] Subramanium, N; Brijnaresh, R. S.; Frank, D. B.; Blum; Dharani, L. R.; Yung-Rwei Chen. *SAMPE Quarterly* **1990**, *21*, 17.
[5] Sinha, S. K.; Biswas, S. K. *Journal of Material Science* **1992**, *27*, 3085.
[6] Halvery, L. *Soc. of Automotive Engineers* **1980**, Paper No. 800667.
[7] Subramanium, N.; Brijnaresh, R. S.; Frank, D. B.; Dharani, L. R.; Yung-Rwei, C. *Intern. J. Polymeric Mater.* **1991**, *15*, 93.
[8] Hettinger, Jr. W. P.; John, W. N.; Krock, R. R.; Boyer, D. C. *Soc. of Automotive Engineers* **1986**, Paper No. 860767.
[9] Washabaugh, F. J. *Soc. of Automotive Engineers* **1986**, Paper No. 860630.
[10] Mohan, N. J. *Soc. of Automotive Engineers* **1980**, Paper No. 800782.
[11] Feng, D.; Frank, D. B.; Dharani, L. R. *Polymer and Polymer Composites* **1996**, *4*, 155.