THE SELECTION OF BRAKE LININGS IN TURN OF TRIBOLOGICAL AND FADING PROPERTIES

By

L. Tóth and A. A. Khattab

Department of Mechanical Engineering, Technical University Budapest

Received December 20, 1979

Presented by Prof. Dr. F. Lettner

1. Introduction

A friction brake of any design is basically a pair of friction elements. One of them, the metallic drum or disc usually rotates and the other, the brake lining is unmovable. The whole concept of breaking — as generally known — relies on the use of friction to convert kinetic energy to heat, which is ultimately dissipated to the atmosphere. The brakes not only must develop the force required to slow, stop, or hold the vehicle and convert to heat and dissipate the kinetic energy of the vehicle, but they are required to accomplish this by means readily controllable by the operator, to have a long and economical life, and to achieve the highest degree of safety. Thus the brake lining must be compound so as to obtain quietness and smoothness of engagement, to minimize heat and water fade, and to minimize drum wear relative to its own wear.

2. Tribological properties of brake linings

2.1 *Materials used for brake linings*

Friction linings used in vehicle industry may be divided into three main groups: solid woven asbestos; sintered metals; and rigid moulded asbestos.

— Solid woven asbestos friction linings may be produced in two forms; metallic and non-metallic. The metallic woven linings may include zinc and brass wires. The metallic wires reduce the coefficient of friction and result a better antifade properties and wear resistance. Non-metallic woven linings contain synthetic resins as impregnant. This type eliminates drum scoring and has a great resistance to wear.

— Sintered metal linings are produced by hot pressing and partial fusion of mixtures of fine powdered metals. The most common ingredients are copper, iron, tin, lead, graphite and silica. These linings have coefficient of friction of 0.35 dry and 0.06 to 0.1 when immersed in oil. They are normally available in disc form. This type is usually used for heavy-duty vehicles.

— Moulded asbestos linings are produced by heating under pressure a mixture of asbestos fibres, organic resin, fillers and modifiers. The coefficient of friction of this type ranges from 0.4 to 0.1. This type has good antifade and wear properties up to 300 to 450 °C. It is the most commonly used type for vehicles. For this reason it has been chosen to study the tribological properties; fade phenomena and wear resistance connected with this type of brake linings.

2.2 *Wear of brake linings*

Lining or drum wear life usually is referred to a number of brake stops or kilometers. Wear phenomena of brake linings reflect mechanisms and characteristics of both metal-metal and metal-elastomer contacts. Brake linings wear by one or a combination of the following mechanisms: thermal wear, adhesion wear, abrasive wear, macro-shear wear and fatigue wear [1, 2, 3].

— Thermal wear is the material loss caused by frictional heat generated at the interface of lining and metallic drum. It deserves special attention because it encompasses a group of physical and chemical reactions. These reactions include: pyrolysis, or thermal decomposition, oxidation, explosion, melting, and evaporation.

— Abrasive wear is caused by the gouging or ploughing action of the surface asperities or hard particles caught between the two sliding surfaces.

— Adhesion and tearing wear involves the adhesion and tearing of organic or inorganic constituents in the friction material to the metallic drum of disc.

— Macro-shear wear is a relatively sudden failure of a friction material which has been previously weakened by heat, and it is most likely to occur at elevated temperatures and under severe braking conditions.

— Fatigue wear occurs in two forms, namely thermal and mechanical fatigue: Thermal fatigue is caused by repeated heating and cooling, which induce cyclic stresses in the surface and steep thermal gradients. A special case of thermal fatigue is called thermal shock cracking; occurring as a result of a single abusive braking. Mechanical fatigue is caused by repeated mechanical stressing of the lining material.

2.3 *Fading phenomena in brakes*

Probably the most common term applied to brake linings with respect to the response of their coefficient of friction to temperature is "fade". Fade means a drop-off or decrease in friction coefficient with an increase of temperature. This loss of effectiveness due to heat is partly connected with chemical aspects and partly with mechanical changes.

In many cases there is an actual increase in the coefficient of friction. Beyond this, the coefficient of friction begins to drop with increase in temperature. A gradual drop-off in friction is important and desirable, since it acts as a fuse in the brake system. Obviously, one that has a very rapid fade i.e. a rapid dropp-off in coefficient of friction offers no gradual warning. This can create an unexpected condition. Very rapid fade may be catastrophic, espe-

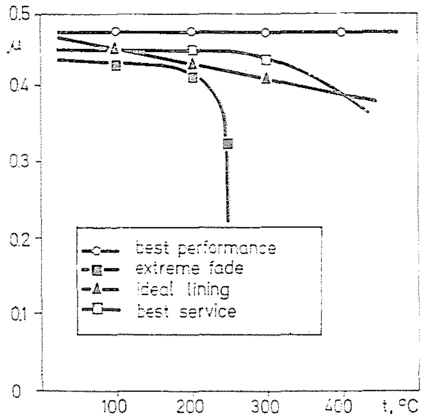

Fig. 1. Friction coefficient of various types of friction materials as a function of temperature after [7]

cially if it occurs at a relatively low temperature, Fig. 1. The ideal friction material with the best performance would not fade at all but would maintain a uniform friction coefficient at all operating temperatures. It can also be mentioned that the ideal friction material should fade gradually. It may be concluded that the best service brake should maintain a constant friction level up to fairly high temperatures and then fade gradually. Newcomb [4] studied theoretically and experimentally the temperature rise due to frictional heating during braking. Kragelsky [5] describes the mechanism for brake fading on the basis of the decomposition of the resin in the friction lining at high temperatures.

Georgievsky [6] investigated the effect of different factors on the friction of the resin-based friction linings. According to his investigations, thermal decomposition of the resin produces liquefied products above 300 °C and gaseous products above 400 °C. The liquefied products create conditions of boundary or semifluid friction and the gaseous products act as an elastic gas cushion which decreases the friction.

Generally speaking, fade may be due to the liquefied products, gas products, low-friction solid products or a combination of the three.

3. Problems of the selection of brake linings

The brake linings' wear mechanism and fade proper es are known to be controlled, among others, by the lining structure and tribological properties. The structure properties include both volume and surface properties. The volume properties are: thermal conductivity, tensile strength, impact strength, hardness etc. The surface properties include roughness, surface energy, chemical activity etc. These properties are determined by the chemical composition, microstructure and the manufacturing processes of the lining.

Thus, the friction lining has to be selected so as to have suitable mechanical, physical, chemical and functional properties i.e. certain surface and volume properties: the chemical composition is one of the most important factors.

Of course, beyond the tribological and the structural properties of the lining; the price and the availability are important questions. Therefore the selection of the brake lining involves a series of mechanical, physical, chemical, functional tests and economical examinations.

There exist several methods for characterizing the lining materials hence helping the suitable selection of friction linings. The *resinography test* was developed for characterizing virgin friction linings in general. Resinography for brake linings is analogous to metallography for metals. It is a procedure for preparing selected surfaces of lining for examination under the microscope and for making photographs when desired for record.

Resinography tests may be used for showing the effectivness of mixing, structural flaws, missing components, as well as the surface structure. In the last time many researchers used the *SEM scanning electronmicroscope* for the investigation of structural changes of brake lining surface. The wear mechanism, the worn out surfaces, and the wear debris are easy to study by the SEM technique.

The thermal properties as well as the chemical reactions that takes place on the surfaces of the brake linings is studied by using thermogravimetric analysis TGA, differential thermal analysis DTA and pyrolysis gas chromatography PGC.

In the *thermogravimetric analysis* TGA, a test sample is weighed continuously while being heated at a uniform rate and weight is plotted as a function of temperature. Changes in the slope of the curve indicate that some new reaction is occurring.

In the *differential thermal analysis* DTA, a test sample is heated at a uniform rate along with a sample of some inert material such as alumina. Thermocouples are in contact with each sample and connected in opposition. When the test sample reaches a temperature at which some reaction occurs, the heat of reaction causes the temperature of the test sample to differ from that of the inert material. The difference ΔT is plotted *vs.* temperature. Peaks and valleys in the curve indicate that reactions are occurring. If they do not correspond to a change in slope at the temperature in the TGA curve, a solid-state reaction or a phase change such as melting is involved.

The *pyrolysis gas chromatography*, PGC, involves the pyrolysis of a sample of a few, 5 to 10 mgs followed by the instrumental separation and the sensing of products of decomposition. The products of decomposition may be used to characterize the organic nature of the organic constituent in the friction linings.

X-ray techniques may be X-ray radiography or X-ray diffraction. The *X-ray radiography* show limits of acceptability for particle size, particle distribution, normal internal structure, missing components, abnormally high or low levels of components normally present, effectiveness of mixing, and structural flaws.

The *X-ray diffraction* is used to study thermal decomposition and other reactions of such crystalline solids as asbestos by identifying the crystal structure.

Function tests may be either continuous operation tests i.e. constant input and constant output tests; or inertia tests i.e. constant input and variable output tests. They are intended to measure the actual properties of interest in brake linings: the coefficient of friction, fade temperature and wear rate.

Spencer et al. [7] developed the resinography test to characterize the virgin friction linings.

Gatrel and Schreiber [8] described various methods for studying chemical changes at brake wear surfaces but provided no specific examples.

Jacko and Ducharme [9] demonstrated that the thermogravimetric analysis TGA of friction lining surfaces was adequate for demonstrating similarities or differences between similar materials.

M. J. Jacko [10] studied extensively the physical and chemical properties of the char layer for a commercial type of brake linings using optical microscopy, X-ray techniques and inertia brake dynamometer.

D. M. Rowson [11] showed that the characteristic chrysotile asbestos fibre was almost absent from the wear debris of brake linings using SEM, TGA, DTA, and X-ray diffraction.

K. Tanaka et al. [12] investigated the effects of various factors on brake friction using the inertia brake dynamometer under arbitrary working conditions.

L. S. Bark, D. Moran and S. J. Percival [13] studied the inorganic and organic changes of two friction materials by the application of various analytical techniques.

In our experimental work for studying different properties of brake linings and for the elaboration of selection methods we used: SEM, X-ray diffraction for surface examination, TGA, DTA and PGC for thermal analysis and continuous and inertia dynamometers for functional properties.

4. Experimental

For studying the tribological and functional properties of brake linings we used a systematic and integrated set of tests. The effect of chemical composition has been studied on the physical, chemical, mechanical and functional properties of moulded asbestos brake linings.

4.1 *Tested material*

Eleven brake samples, described in Table 1, with different chemical compositions were examined. The formulation of each sample consists of asbestos, organic resin as a binder and inorganic friction modifier (barium sulphate).

Table 1

Composition of samples

Sample No.	Asbestos content % by vol.	Resin % by vol.	Modifier %
0— 1	80	20	0
0— 2	65	35	0
0— 3	50	50	0
0— 4	10	90	0
0— 5	75	15	10
0— 6	50	40	10
0— 7	60	25	15
0— 8	65	15	20
0— 9	50	25	25
0—10	40	10	50
0—11	20	10	70

The samples measured $120 \times 120 \times 10$ mm. They were produced under pressure of 2000 N/cm^2 and at a temperature of 150 °C. They have been cured at 180 °C in electric furnace for 10 hours.

4.2 *Test methods*

4.2.1 *Structure examination*

Scanning electron microscopy SEM and X-ray diffraction were found to be good techniques to examine the surface and to study the chemical reactions and topographical changes that take place on the rubbing surfaces.

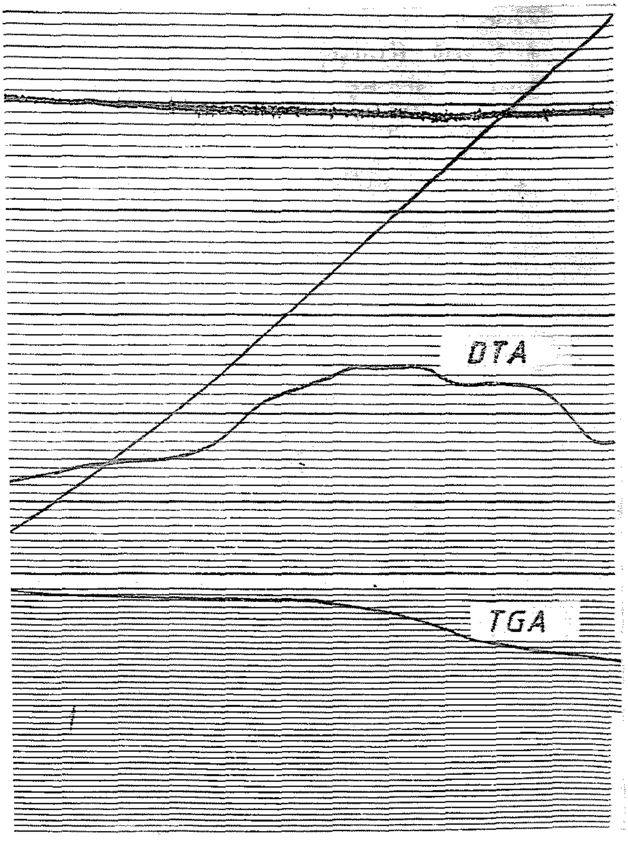

Fig. 2. TGA and DTA curves for virgin sample 0—4

For SEM, samples were evaporated u. g gold to cover the surface with a layer of good electrical conductivity.

The X-ray diffraction suits to detect the variations in the crystalline structure of some components such as baryte, asbestos, iron, olivin etc.

4.2.2 *Thermal analysis*

Thermogravimetric analysis TGA, differential thermal analysis DTA and pyrolysis gas chromatography PGC were used.

For TGA and DTA a sample weighing 500 mg is heated gradually from room temperature to 600 °C at a heating rate of 3 °C/min. The TGA and DTA thermograms are recorded on a photographic chart.

In PGC, a test sample of 5—10 mg undergoes pyrolysis and the products of decomposition are recorded and identified. The product data may be tabulated or recorded.

4.2.3 *Functional properties*

Two test machines were used for the investigation of the functional properties of the prepared samples. One is a continuous testing machine and the other is the scale brake dynamometer.

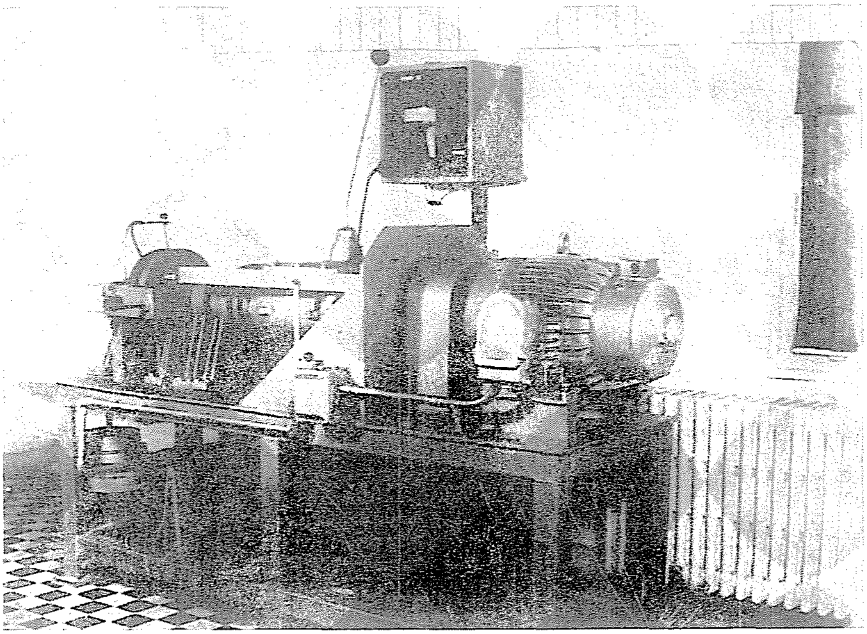

Fig. 3. Continuous testing machine used for testing functional properties

In the continuous testing machine. Fig. 3, the samples are conditioned for 15 minutes at a speed of 8.87 m/sec and a pressure of 80 N/cm^2. The disc surface is then rubbed with an emery cloth and cleaned with aceton to have a clean fresh surface. The sample is then rubbed against the disc surface and $\mu - T$ charts are established. Fade temperature and wear rate are also determined.

For the scale brake dynamometer a tapped program for scaled drum brake of saloon-car is used. The $\mu - T$ charts, fade temperature and dynamometer comulative wear may be determined.

5. Results and discussion

5.1 *Structure examination*

The surfaces of virgin and tested samples were examined using SEM (Figs 4, 5). According to the photographs the leading mechanisms of wear are abrasion, adhesion, and thermal wear.

Fig. 4. SEM photograph for virgin sample (100×)

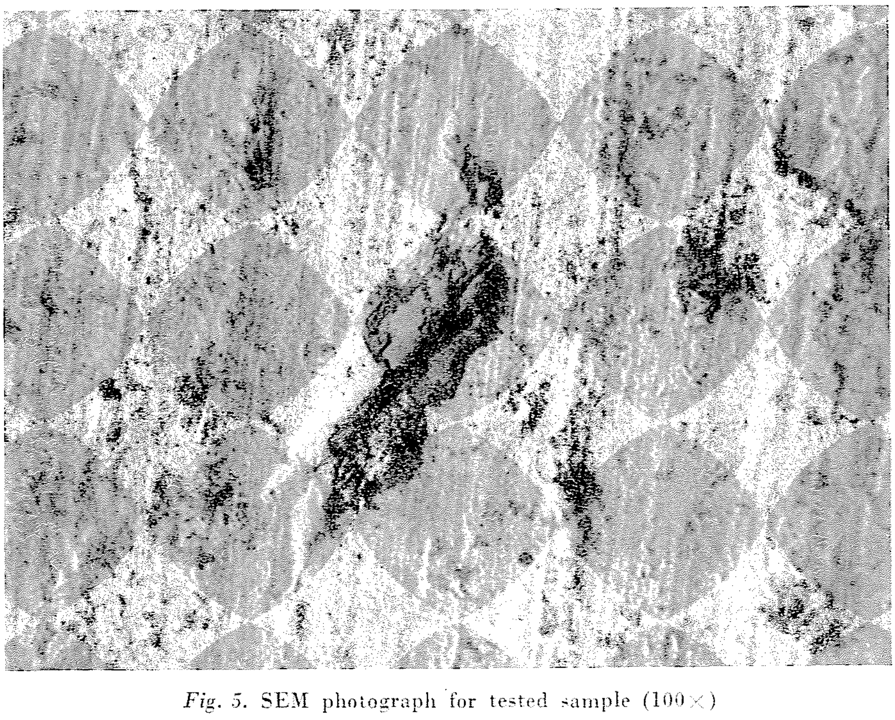

Fig. 5. SEM photograph for tested sample (100×)

Ploughing and shearing of irregularities on the surface may be observed (Fig. 5). The adhesion of the asbestos to the metal surface of the disc is also observed in the same figure.

During severe braking conditions, pyrolysis thermal decomposition, oxidation, melting, evaporation, sublimation and explosive reactions may occur.

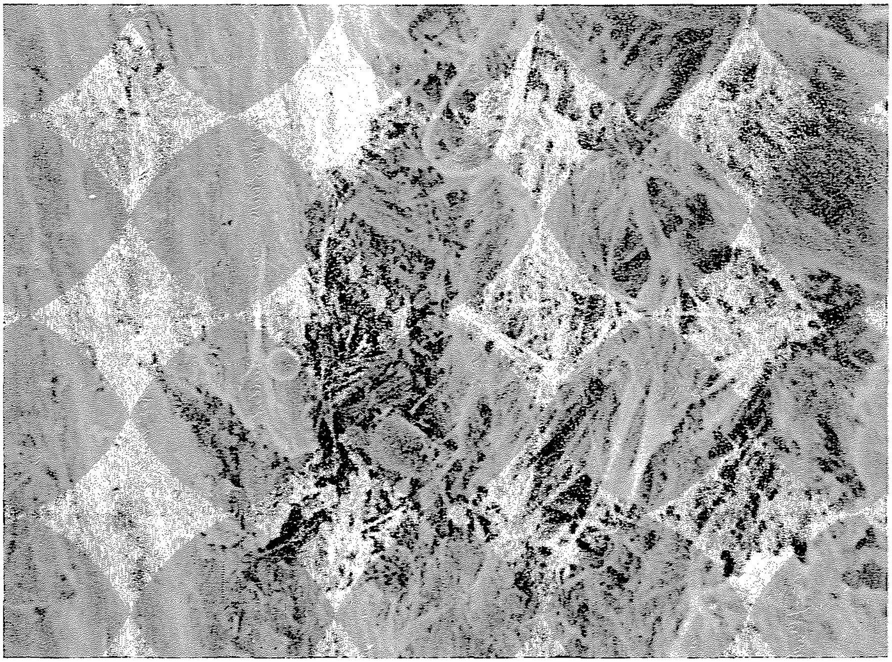

Fig. 6. SEM photograph for tested sample (3000×).

Due to the conversion of the solid organic constituents into gases under the surface at high temperatures, explosion and rupture of the surface may occur. This explosive wear is shown in Fig. 6.

From the diffractograms of both virgin and tested samples (Fig. 7), the asbestos was observed to change from chrysotile type to olivin one. Also iron particles were identified, indicating that the iron particles are transferred from the disc and embedded in the lining surface.

5.2 *Thermal properties*

The chemical reactions taking place on the surface of brake linings have been studied by thermogravimetric analysis, TGA, and differential thermal analysis DTA.

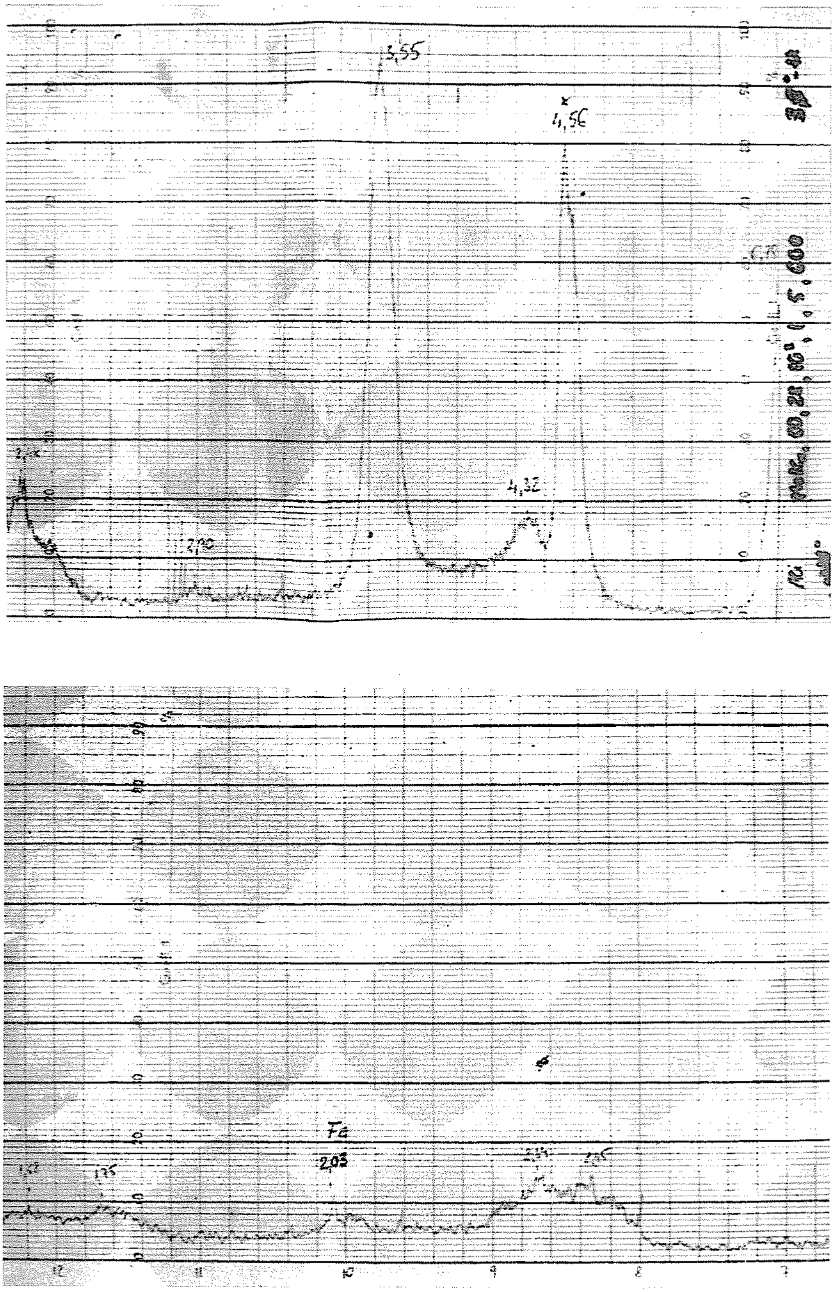

Fig. 7. Diffractograms for virgin and tested samples

The degradation of the phenolic resin, used as a binder in the formulation, results in energy and weight changes. Fig. 2 shows the TGA and DTA curves for virgin sample 0–5 — as characteristic — when uniformly heated from room temperature to 600 °C. A 12% weight loss is observed, due to the degradation of the organic constituent. The asbestos and barium sulphate did not show any weight loss when heated under the same conditions.

The TGA curve of functionally tested sample 0—5 showed only 7% of weight loss. According to our opinion, this difference of losses is due to the resistance of resin to degradation. This organic retention was previously observed [14].

The changes of the organic constituent have been studied in functional tests using the PGC. The pyrolysis products of the virgin and tested samples have been compiled in Table 2.

Table 2

Pyrolysis products of virgin and tested sample

Sample		Fragment peak area							
		Non-Phenolic				Phenolic %			
No.	weight mg	Total	%	phe	2M—	4M—	2—6DM	2—4DM	2—4,6TM
0—11	5.1	870	27	56	8.2	5.8	1.0	2.0	—
*0—11	6.0	400	100	—	—	—	—	—	—

0—11 virgin sample.
*0—11 tested sample.

The simple organic compounds which remain after testing are seen in Table 2 to have some stable structure. The absence of phenolic compounds indicate the absence of oxygen.

5.3 *Functional properties*

Results of scale brake dynamometer and continuous testing machine lead to the following conclusions:

The friction at each temperature is seen in Fig. 8 to depend on the asbestos content. In case of sample 0—4 where the asbestos content is very low (10%) no variation in the coefficient of friction may be observed. This means that the asbestos plays an important role in the friction mechanism. The coefficient of friction decreases with the increase of asbestos content up to a certain value. It increases over a range of contents of 40 to 60%, Fig. 9.

The wear increases with the asbestos content (Fig. 10). For the samples having 3 components (asbestos, resin, and modifier), with high modifier

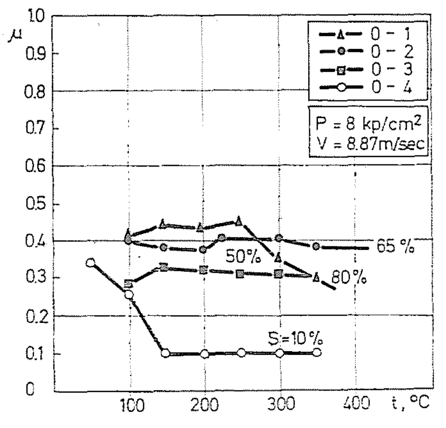

Fig. 8. Relationship between coefficient of friction μ and bulk disc temperature

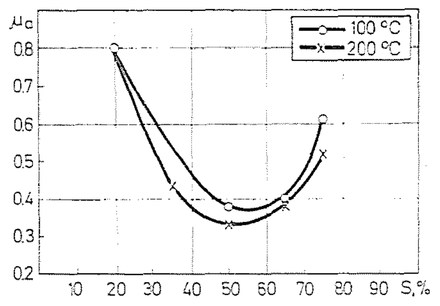

Fig. 9. Relationship between average coefficient of friction μ_a and asbestos content ratio S

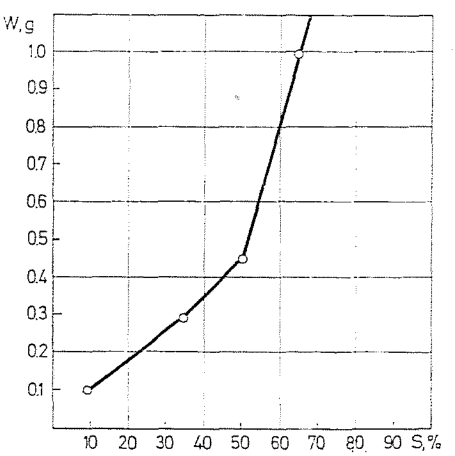

Fig. 10. Relationship between cumulative wear w and asbestos content ratio S

contents the wear decreases rapidly as the asbestos content increases but assumes a more gradual slope above 50% asbestos content (Fig. 11).

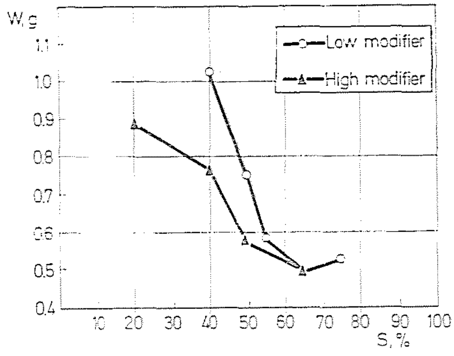

Fig. 11. Relationship between dynamometer cumulative wear W and asbestos content ratio S

For resin-asbestos samples with more than 50% asbestos no fade has been observed. For low asbestos content, very low fade temperatures have been observed. For the 3 component samples the increase of modifier decreases the fade temperature.

Summary

This paper has been dealt with the tribological properties and the problems of selecting moulded asbestos brake linings. On the ground of literature survey, the paper analyses the wear and fading phenomena and the methods of investigating these properties. After this the effect of the chemical composition was examined and measurements showed the asbestos to play an important role in wear fade phenomena. The effect of the modifier is also examined.

References

1. Moore, D. F.: Principles and Applications of Tribology. Pergamon Press, London, 1975.
2. Spurgeon, W. M.—Spencer, A. R.: Reliability and Durability of Automotive Friction Materials. Bendix Tech. J. 2. 57 (1969).
3. Burwell, Jr. J. T.: Survey of Possible Wear Mechanisms. Wear, 1. 119 (1957—1958).
4. Newcomb, T. P.: Aut. Engr., 50, 288 and 326 (1960).
5. Kragelsky, I. V.: Friction and Wear. Butterworths, London, 1965.
6. Georgievskij, G. A.: Friction and Wear in Machinery, 16, 104 (1962).
7. Spencer, A. R.—Spurgeon, W. M.—Wing, J. L.: Four Tests For Consistency of Brake Linings. SAE paper No. 660412.
8. Gatrell, R. L.—Schreiber, T. P.: Chemical Changes at Brake Wear Surfaces. SAE paper No. 670511.
9. Jacko, M. J.—Ducharme, R. T.: Simulation and Characterization of Used Brake Friction Materials and Rotors. SAE paper No 730191.
10. Jacko, M. J.: Physical and Chemical Changes of Organic Disc Pads in Service. Wear, 46, 163 (1978).

11. ROWSON, D. M.: The Chrysotile Content of the Wear Debris of Brake Linings. Wear, 47, 315 (1978).
12. TANAKA, K.—VEDA, S.—NAGUCHI, N.: Fundamental Studies on the Brake Friction of Resin-Based Friction Materials. Wear, 23, 349 (1973).
13. BARK, L. S.—MORAN, D.—PERCIVAL, S. J.: Inorganic and Organic Changes During Friction Material Performance. Wear, 53, 107 (1979).
14. BARK, L. S.—MORAN, D.—PERCIVAL, S. J.: Polymer Changes During Friction Material Performance. Wear, 41, 309 (1977).

Dr. Lajos TÓTH
Ali Ahmed KHATTAB } H-1521 Budapest