PREDICTED TRIBOLOGICAL BEHAVIOUR OF ASBESTOS REINFORCED COMPOSITE FRICTION MATERIAL

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ABSTRACT

It has been herein decided to formulate empirical formulae to correlate tribological behaviour of composite material with operating conditions. Asbestos reinforced resin bonded friction material has been chosen as an examplary composite material to be put under experimental investigation.

To investigate experimentally the tribological behaviour of friction composite material we got to conduct friction and wear tests under either isothermal or transient temperature tests. A constant speed drag dynamometer (SCHENCK) has been used for conducting both the isothermal and the transient temperature tests under constant energy input conditions.

The coefficient of friction has been found to decrease with applied load increase following a power function of the form $f \propto p^a$ with an index (a) ranging from -0.27 to - 0.32.

Arrhenius relation $w \propto e^{-E/RT}$ has been satisfactorily used to express the isothermal wear with activation energy values in the range(25-41 k joule/mole),whereas, under transient temperature test conditions, the material weight loss ($\overline{W}$) has been found to increase with both the contact pressure (p) and sliding distance (L) following a power function of the form $\overline{W}=Kp^cL^d$.

INTRODUCTION

Friction composite materials are generally composed of fibrous matrix, fillers, a binder, and some other constituents such as friction and wear modifiers to satisfy certain service requirements [1]. A binder is necessary to bond together the constituents of the composite friction material [2]. Chemical and physical properties of the binder(eg.

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straight or modified phenol formaldhyde resins) and its changes with temperature have a considerable influence on friction and wear characteristics of the material [3].

Classical laws of friction have been found unapplicable in describing the static friction of organic and semi-metallic friction materials[4], the friction force (F) has been proposed to follow a power relation with applied normal load (P) rather than being directly proportional to the normal load. Hence,

$$F= fP^a$$

where a is a temperature dependent constant, f is the coefficient of friction. Owing to segregation of liquid decomposed resin on the sliding surface, the coefficient of friction of resin bonded materials decreases at temperatures between 100-400°C [5]. By considering the cases of perfectly plastic and elastic behaviour of materials in contact [6], it could be concluded that the coefficient of friction can be dependent on terms defining deformation and shear stresses.

The wear mehanisms of composite friction materials have been found to be of a different nature than those controlling wear of pure metals [7,8]. The wear of semi-metallic friction materials appears to be of a complex nature of the abrasive, oxidative, and surface fatigue types of wear [9]. The wear of organic friction materials has been, thus, explained in light of their physical and chemical changes which may take place to the different constituents at the rubbing surface in service [10]. The wear of absestos reinforced phenolic resins has been described, for example, by a power function of load (P), spead (v), and time (t) [11],

$$W=KP^a v^b t^c$$

where,K,a,b, and c are one set of parameters for a given friction pair. This formula has been found applicable in the case of semi-metallic friction materials in both transient temperature and isothermal tests [7].

It has been herein decided to investigate in some detail the effect of operating parameters under isothermal and transient temperatures on the tribological behaviour of composit materials taking asbestos resin bonded lining material as a test material with the metallic inclusions being varied in quantity and in type.

EXPERIMENTAL SET UP

Test Specimens:

A basic composite friction material composed mainly of asbestos, phenol formaldhyde resin has been used. Aluminium alloy (Al.86%,Cu 13.1%, others 0.9%) chips or brass (Cu 57.15% , Pb 1.69%,others 41.16%) chips have been added to the basic constituents to have a group of test materials with different proportions of metallic chips ranging from 2% up to 8%. friction test specimens have been manufactured by dry mixing, cold pressing, and hot molding of the constituents.

Test Apparatus

A constant speed drag dynamometer [12] has been used to conduct both isothermal and transient temperature tests at a sliding speed of 4m/s. During isothermal tests, the drum surface temperature has been fixed at 110,190,230 and 270 °C under a constant contact pressure of 1.00 MPa.

Transient temperature tests have been run under contact pressres of 0.3,0.6,1.0, and 1.3 MPa at a starting drum temperature of 100 °C.

Another group of tests has been run under a contact pressure of 1.00 MPa for different sliding distances having the values of 1.20,2.16,2.88, and 3.60 km.

RESULTS AND DISCUSSION

Average friction coefficent values obtained during transient temperature tests under different contact pressures for materials with Aluminium alloy and Brass chips[13,14] are presented in Figure 1 . A decreasing trend of the coefficient of friction with contact pressure increase following a linear relationship (on the log-log scale) has been observed. Hence, a power function can be assumed to correlate the friction (F) with contact load (P) for test materials as follows:

$$F \propto P^{\beta}$$

$$\left(\frac{F}{P}\right) \quad P^{\beta-1}$$

$$f \propto P^{\beta-1}$$

where from diffinition, f will represent the coefficient of friction. Hence,

$$f = AP^{a}$$

where, A is the proportionality constant and a is the index. The colculated values of the load index (a) have been found to be in the range of (-0.308 to -0.274) for materials with Aluminium alloy chips and (-0.324 to -0.30) for materials with brass chips. These values come in some conformity with previous work as the static friction of some "organic" and "semi-metallic" resin bonded materials has been found to be proportional to normal applied load by a power function with a temperature dependent load index [4]. Also, the kinetic friction of filled phenolic resins has proven to vary by

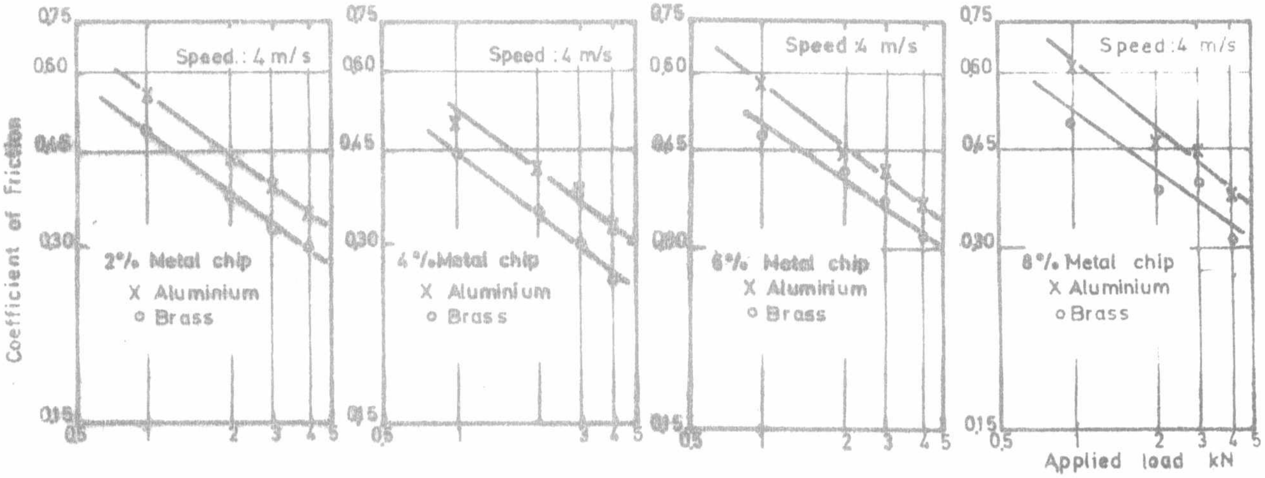

Fig.1. Coefficient of friction versus applied load

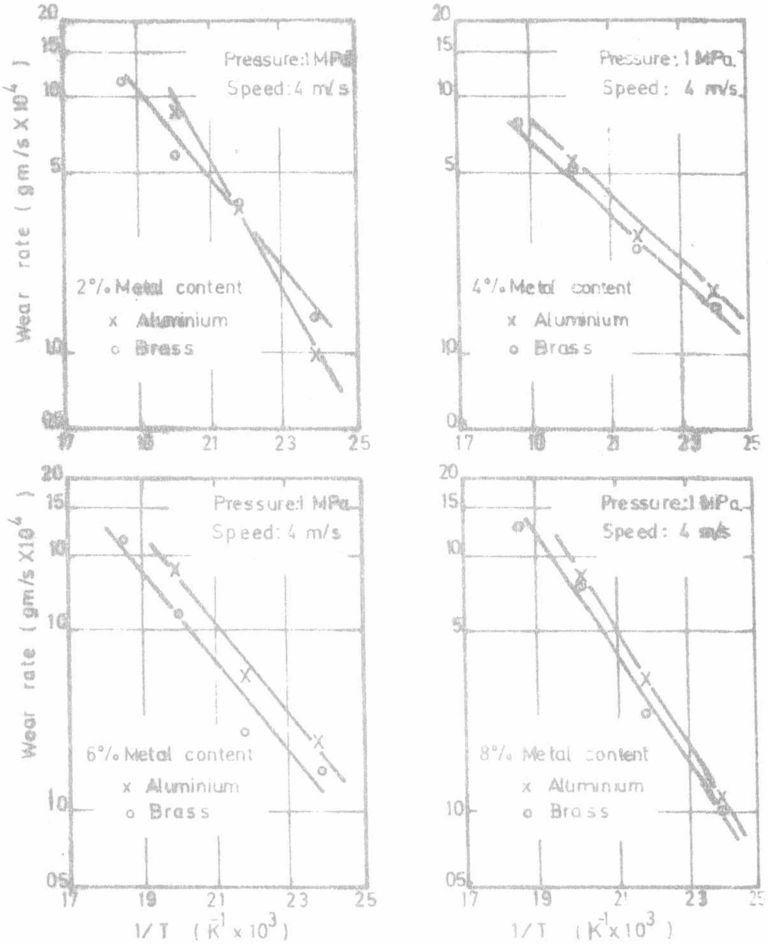

Fig.2. Isothermal wear rate (Arrhinius plot)

power law with normal load and sliding speed at constant temperature [15, 16]. In the present work, the calculated values of load index for materials with Aluminium alloy or brass constituents, are found to be in the range of-0.3. The variation of the value of the coefficient of friction with applied loads can be partially attributed to the viscoelastic properties of the resin binder.

Isothermal wear values of materials with Aluminium alloy chips and brass chips are plotted against the reciprocal of isothermal temperature levels on a semi-log scale (Arrhenius plot) as shown in Fig. 2 . A linear function has been found to reasonobly describe this behaviour. The wear rate of test materials (W) can, thus, be expressed as a temperature (T) dependent function by the following formula [17] .

$$W \propto e^{-E/RT}$$

Where, E is the activation energy (joule / mole), T absolute temperature(°K), and R gas constant (8.314 joules/ mole-K). The calculated activation energy has been found to be in the range of (25.66-40.49 k joule / mole) for materials with Aluminium alloy chips and (30.238-31.194 k joule / mole) for materials with brass chips. Previous experimental findings [8,17] have shown activation energy levels in the range of (16-58 kjoule/mole) for three different resin bonded composite friction materials. In another group of tests[18], the activation energy could be as low as (4-10 k joule/mole). Also,it has been found that the activation energy of some phenolic resins is in the range of (4-115 k joule/mole) for initial stage of thermal decomposition [19]. It is claimed that the thermal decomposition of the binder may be the prevailling wear mechanism at temperatures higher than 230 °C [7]. In the present work,the wear of test materials begins to increase exponentially at temperatures as low as 150 °C. This may be attributed to the lack of post curing process of considered materials. The calculated values of activation energy for materials with different inclusions are found to be of the same order. This indicates that the decomposition of the binder used is the controlling wear mechanism at high temperature levels [7].

During transient temperature tests, the wear of test materials are plotted against contact pressure and sliding distance on a log-log scale as shown in Figs 3 and 4 respectively. The observed linear relationships indicates that the wear rate can be expressed by the following power function

$$\overline{W} = Kp^{b}L^{c}$$

where, W is the wear rate (mg/km), p contact pressure (MPa), L sliding distance (km), and K,b,and c are a set of constants The values of wear constants K,b,and c are in the ranges of (32.8-115),(1.428-2.172), and (1.113-1.858) respectively. It has been previously proposed [11,20] That the wear rate of

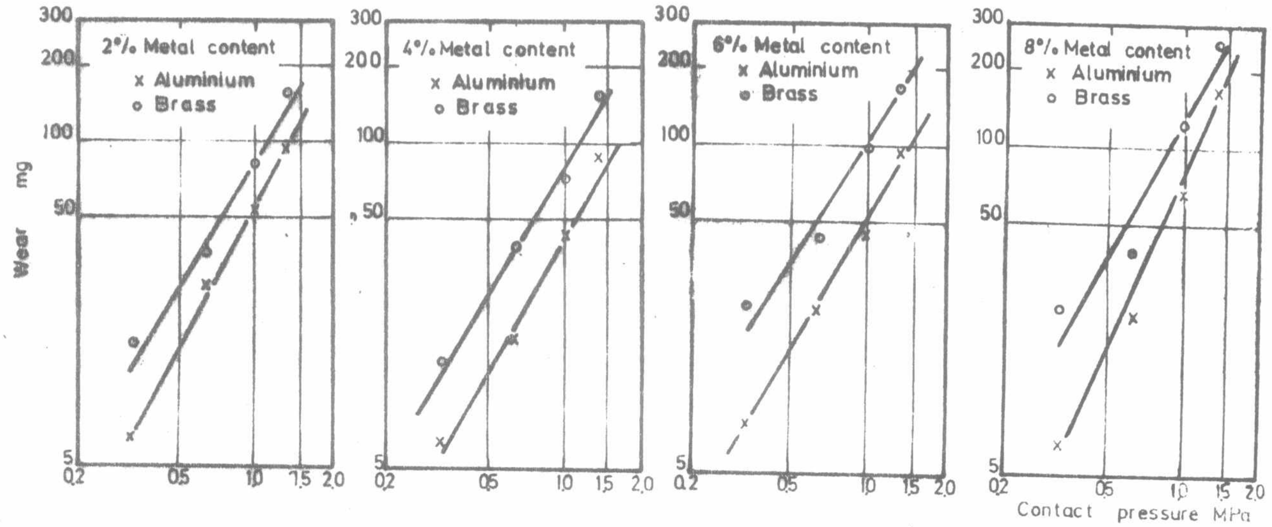

Fig.3. Material weight loss versus contact pressure
(speed= 4 m/s, sliding distance = 1.2 km)

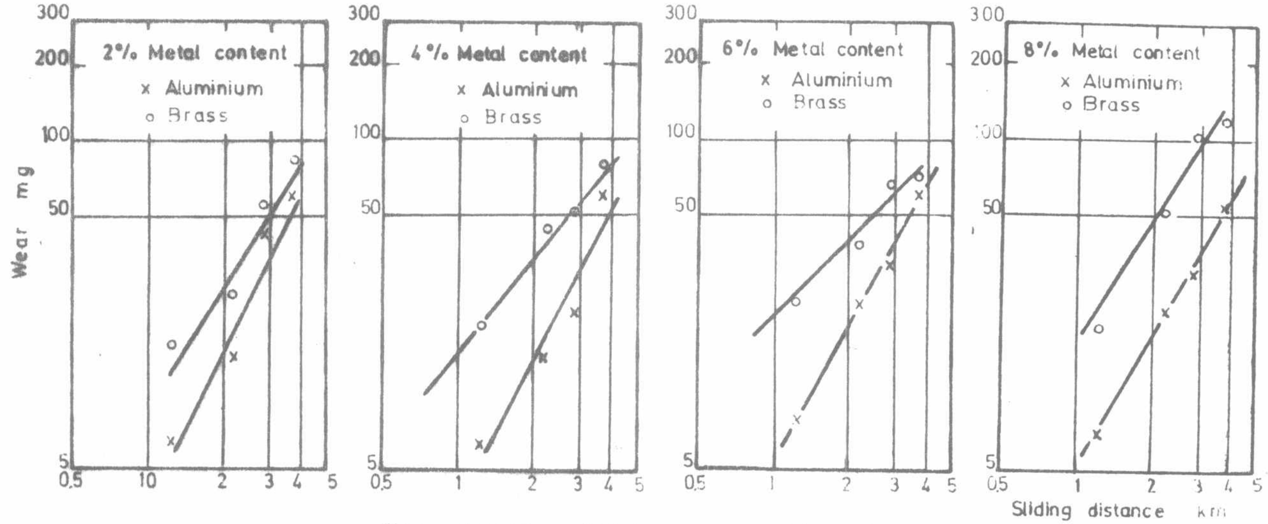

Fig.4. Material weight loss versus sliding distance
(pressure = 1.0 MPa, speed= 4 m/s)

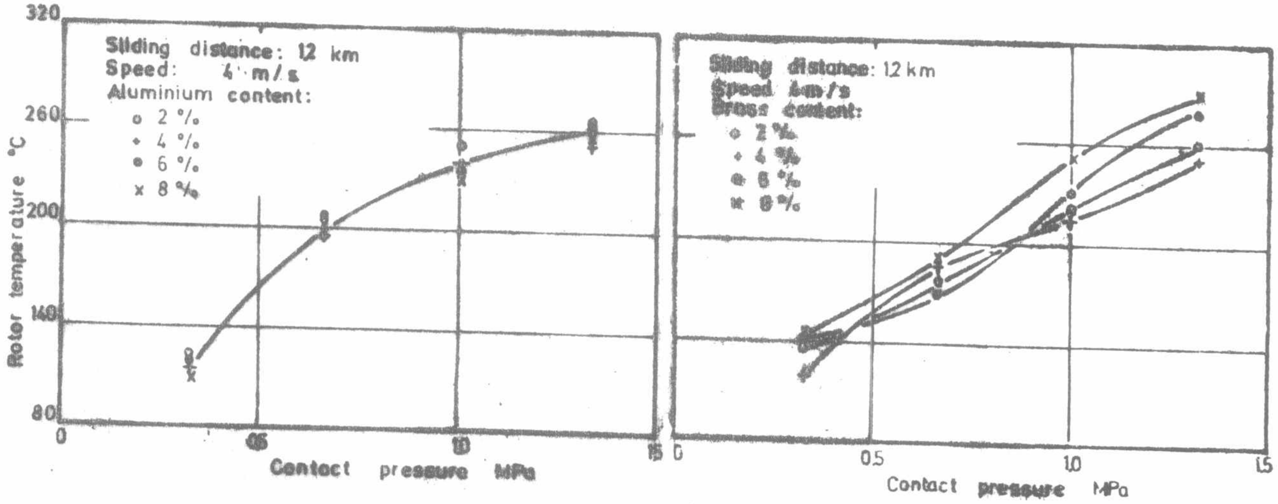

Fig. 5. Average maximum rotor temperature
versus contact pressure

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"organic" and "semi-metallic" composite materials can be expressed by the formala

$$W = KP^aV^bt^c$$

where, K,a,b, and c are a set ofmaterial constants. This equation has been tested for different friction materials under different test conditions of load (P), speed (V), time (t), and rotor material [17,18,21,22]. The values of power indices of load, speed, and time have been found in the ranges (0.28 -1.3),(0.28-1.45), and (0.56-1.00) respectively. However, the value of K may vary markedly depending on test conditions. The previous and present experimental power relationships may favour that the wear of composite friction materials can not be explained by adhesion and delamination theories[23]. However, the proposed wear formula can be considered as a medified form of the previous postulated formula with equal indices of sliding speed and time. Also, the load factor is herein represented in the more convenient form using contact pressure instead of applied load which expresses operating conditions in practical use.

The average maximum drum surface temperature attained at the end of a 1.20 km sliding distance is illustrated in Fig. 5. for materials with Aluminium alloy and brass chips. It has been observed that the surface temperature increases with the contact pressure increase. This agrees with the theoritical findings of Newcomb [24]. It is obvious that the increase of contact pressure increases the dissipated frictional heat and consequently a corresponding temperature rise is attained. The decreasing rate of temperature rise can be attributed to the increasing rate of heat dissipation which is proportional to the difference between rotor and ambient temperatures[24,25]

It has been noticed that the increase of metallic chip proportion in test materials has no significant effect on the average rotor temperature. It is previously proposed [24] that the produced frictional heat is dissipated partly through the brake shoe and the rotor with a proportion depending on geometry and properties of the brake assembly. For commercially used brake linings it was concluded that the heat dissipated through the lining is in the range of 2-5% of the produced frictional heat. Therefore, a slight effect of lining properties on rotor surface temperature is expected. Furthermore, the increase of metallic chip content may increase the thermal conductivity of lining. But, on the other hand, it may decrase its thermal capacity due to low levels of specific heat and density of metal chips which may incraase the rotor surface temperature.

CONCLUSIONS

From the present work the following conclusinns can be drawn:

a-The coefficient of friction follows a power function of the form

$$f \propto P^{a}$$

where a takes an average value (in the test scope and material used) in the range of -0.3

b-The isothermal wear of test materials can be reasonably expressed by the experimental function

$$W \propto e^{-E/RT}$$

where, the activation energy E has values(in the test scope and material used) in the range of 25.66-40.49 k joule/mole.

c-The transient temperature wear rate can be predicted using the emperical formula

$$\overline{W} \propto p^{c} L^{d}$$

where c, and d are set of present material constants having average values of 1.8 and 1.45 respectively.

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NOMENCLATURE

f	Coefficient of friction
F	Friction force
L	Sliding distance
p	Contact pressure
P	Applied normal load
$\underline{W}$	Wear rate per unit time
$\overline{W}$	Wear rate per unit sliding distance