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FADE AND TEMPERATURE RISE OF AUTOMOTIVE FRICTION MATERIALS

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ABSTRACT
Natural fibres are used as reinforcement in friction composites to replace asbestos due to the health hazards caused by asbestos fibres which may cause asbestosis, mesothelioma, and lung cancer. Natural fibres such as corn, palm and sugar bars gave relatively high friction coefficient suitable for friction materials. It is necessary to investigate the variation of friction coefficient with temperature. The present work discusses the fade of composites reinforced by corn, palm and sugar bar fibres. Experiments were carried out to determine friction coefficient and temperature rise for the tested composites. The results of the tested composites were compared to that observed from three types of conventional friction brake linings.

The experimental results show that composites containing 25 % palm fibres and 10 % iron powder gave the minimum fade among the conventional brake linings, while friction composites containing sugar bare fibres displayed the highest fade. Besides, addition of aluminium and copper into the matrix of the composites displayed relatively lower fade value due to their high thermal conductivity.

KEYWORDS
Fade, temperature rise, automotive friction materials, friction coefficient.

INTRODUCTION
The brake friction materials in an automotive brake system are considered as one of the key components for overall braking performance of a vehicle. The sensitivity of friction material performance and accordingly brake performance, versus different operating regimes, has always been an important aspect of its functioning, [1]. The formulation of a friction material requires the optimization of multiple performance criteria. These include achieving a stable and adequate coefficient of kinetic friction (μ) and minimizing its sensitivity to the brake operating parameters in order to produce low fade and high recovery characteristics. Among the foregoing requirements, resistance to fade is particularly difficult to achieve. Resin is one of the most important ingredients in friction materials because it binds the ingredients firmly and allows them to contribute effectively to the desired performance. Ideally, there should be no significant deterioration in the function of the binder when the brake is operated under diverse conditions, [2]. However, when excessive frictional heat is generated, changes in the resin can deteriorate performance. Consequently, a friction material's thermal stability, its capacity to retain mechanical properties, and its ability to hold its ingredients together under adverse conditions all depend on the resin.

Different friction materials free of asbestos were proposed to replace the asbestos due to the health hazards caused by its fibres which may cause asbestosis, mesothelioma, and lung cancer. Asbestos free friction composites were proposed to replace asbestos based brake linings. The proposed friction materials are divided into non-toxic fibre reinforced organic, semi-metallic and metallic materials. A typical brake lining formula includes phenolic resin mixed with metal powder, inorganic fillers and fibres. Friction materials made of pure phenolic resin are poor in toughness, [3, 4]. It was observed that, nano powdered rubber can substantially improve properties of friction materials, where the friction coefficient varied steadily with the change of temperature, and the wearing rate of friction materials was relatively low by using nano powdered rubber. Brake linings used in automotive disk brakes are usually made of various components such as phenolic resin, Cu powder, $BaSO_4$, Al_2O_3, [5, 6].

The friction behavior of automotive brake linings is complex and depends on their composition, temperature, rubbing speed, pressure, and most importantly the surface characteristics of the counterface. In the morning, when the brakes are cold, the friction is low. As the pad and rotor interface temperature increases, the brake performance improves. However, under abusive conditions, the temperature may reach as high as 800°C, [7]. At this temperature the organic compounds disintegrate, friction decreases, and wear rate increases exponentially. This event is called fade, [8]. Friction fade took place at high temperatures followed by over recovery upon cooling, [9]. An ideal brake lining is the one which provides uniform and stable friction under all the operating conditions without any fade, [10].

Friction behavior is a critical factor in brake system design and performance. For up-front design and system modeling it is desirable to describe the frictional behavior of a brake lining as a function of the local conditions such as contact pressure, temperature, and sliding speed, [11]. Friction coefficient depends on applied load and metallic content in the tested composites, [12 - 15].

Despite the number of research studies completed on the mechanism of friction in automotive brake lining materials, the phenomenon is still not fully understood, [16]. Complex mechano-chemical processes occurring on the friction interface of a composite friction material make it difficult to understand the correlation between the formulation of brake lining and the frictional performance. In the field of railway braking improving the performances of friction brake systems requires better knowledge of the local tribological behaviour of pad–disc contact under braking conditions, [17].

Reduced-scale or reduced-sample friction testing has the potential to decrease brake system development cost and time. Historically, reduced-scale testing has been used to compare friction materials for quality control ,lining development, and material property assessments. For example, the friction assessment screening test (FAST) was developed to screen the friction stability of disk brake lining materials, [18], while the Chase machine was used to monitor drum brake lining materials [19]. Other reduced-scale devices have been designed to measure friction as a function of temperature, pressure, and temperature by external control of these variables, [20 - 22].

It was found that semi-metallic tested composites gave the minimum fade among the conventional friction materials, while friction composites containing wollastonite, cashew friction particles, aramid fibres showed the highest fade. Fade decreased as the metal content increased for the tested composites containing straw. Besides, addition of aluminium and copper into the matrix of the composites displayed consistent friction coefficient than iron.

Friction composites containing 30 wt. % iron and 10 wt. % straw showed no fade, where friction coefficient showed further increase with increasing sliding time.

EXPERIMENTAL

The test rig used in the present work is a brake dynamometer. The dynamometer has been designed and manufactured to determine the friction coefficient of the tested friction materials. The arrangement of the brake dynamometer is shown in Fig. 1. The dynamometer consists of an electric motor (AC motor of 2.2 KW power and 1500 rpm). Pulley of 50 mm diameter is mounted on motor shaft and drives V – belt drive system. The rotational speed was reduced to 750 rpm. The out put shaft is supported by two bearings. Flywheel of 400 mm diameter and 38 kg weight is mounted to the end of output shaft to achieve inertia of (0.75 kg m^2). Steel disc is assembled to the flywheel of 380 mm outside diameter and 5 mm thickness. Test specimen is held in a specimen holder (chuck) which is mounted in the end of pin supported by load cell to measure the friction force. The contact pressure is applied by weight at the end of the lever. A digital screen is attached to the load cell to detect the friction force. Friction coefficient is determined by the ratio between the friction and the normal forces.

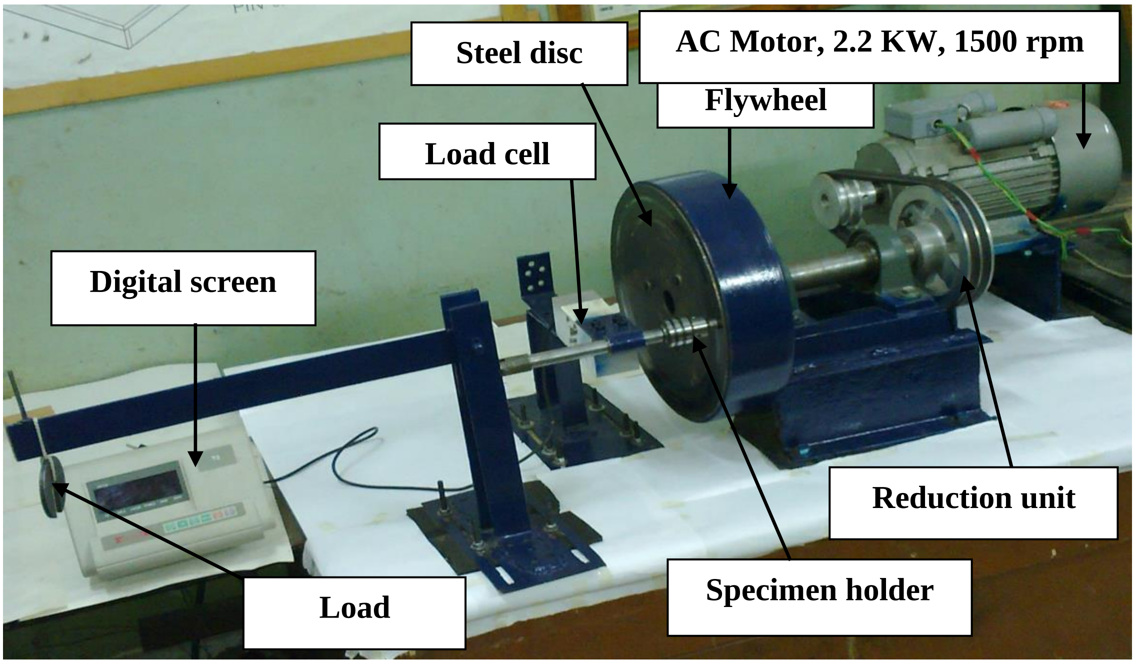

Fig. 1 Arrangement of the brake dynamometer.

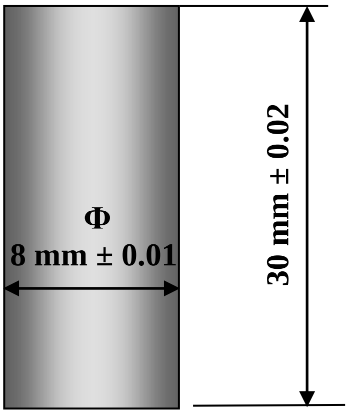

Fig. 2 Dimension of the test specimen.

The test specimen materials were asbestos free composites. Test specimens were prepared in the form of a cylindrical pin of 8 mm diameter and 30 mm length as shown in Fig. 2. Each specimen contained 20 % wt. silica, 10 % wt. graphite, and 10 % wt. barium sulfate as well as different contents of organic fibres (corn, palm and sugar bar), metallic powder (Al, Cu and Fe) and phenol formaldehyde resins. The contents of fibres used were 10, 15, 20 and 25 % wt. The metallic powder contents were 10, 20 and 30 % wt. Test specimens were prepared by the conventional powder metallurgy (P/M) process, which involved the steps of mixing, pressing and sintering. The fade test was carried out using brake dynamometer at constant speed of 12.6 m/s at contact pressure of 1.4 m/s and running time of 200 Sec. Maximum temperature rise was measured at the end of sliding duration. To measure the temperature rise during friction at the sliding interface, a thermocouple (Digital Thermometer Type-K DM6801A$^+$) was put closely to the contact surface between specimen and disc.

RESULTS AND DISCUSSION

The friction decrease during brake application is called fade, and resistance to fade at high temperatures is a critical requirement for commercial friction materials. The friction coefficient depends on the temperature rise since adhesion and deformation resistance of the materials change as a function of temperature. In this study, composites were tested by continuous test at contact pressure of 1.4 MPa and running time of 200 sec. Maximum temperature rise was measured at the end of the sliding time. Figure 3 showed the change with time of friction coefficient displayed by the commercial brake lining A. The friction coefficient decreased from 0.36 to 0.19 as the temperature increased up to 433º C. The relatively high reduction in friction coefficient (fade) may be attributed to the high ratio of silica in brake lining A which increased the temperature during the test. At high temperature, the asbestos will be burned and a layer of carbon induced on the contact surface causing reduction in friction coefficient.

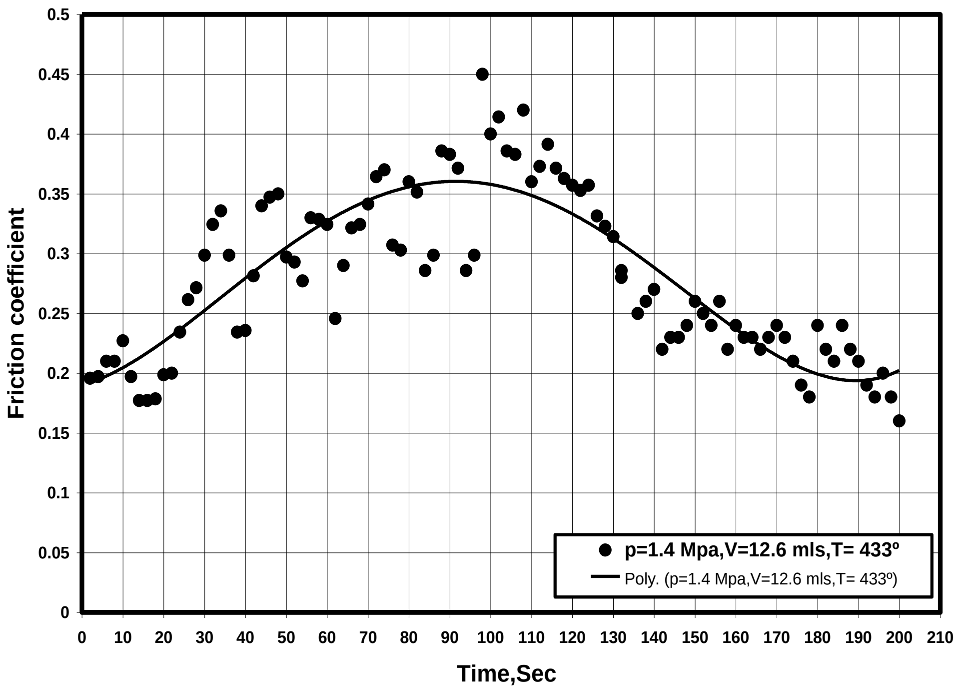

Fig. 3 Friction coefficient versus time for brake lining A.

The change of friction coefficient versus time for commercial brake linings B and C is shown in Figs. 4 and 5 respectively. The friction coefficient decreased from 0.37 to 0.28 at maximum temperature rise of 395º C. Brake lining B displayed friction coefficient reduction (fade) less than that observed for brake lining A. Brake lining B contained high ratio of graphite, so that the friction coefficient was more stable than that of brake lining A.

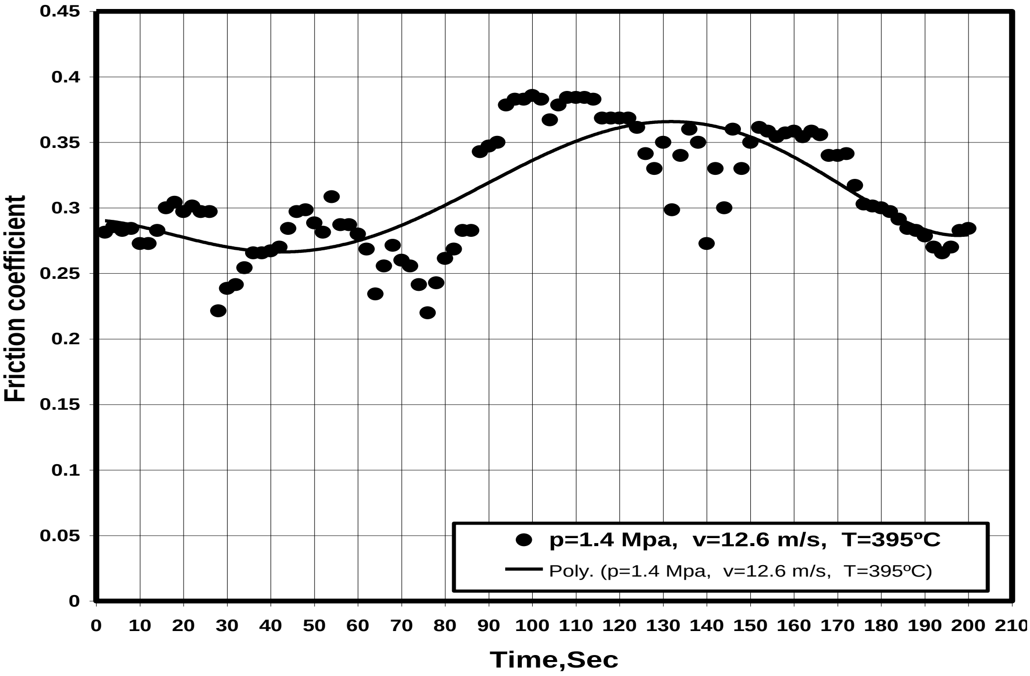

Fig. 4 Friction coefficient versus time for brake lining B.

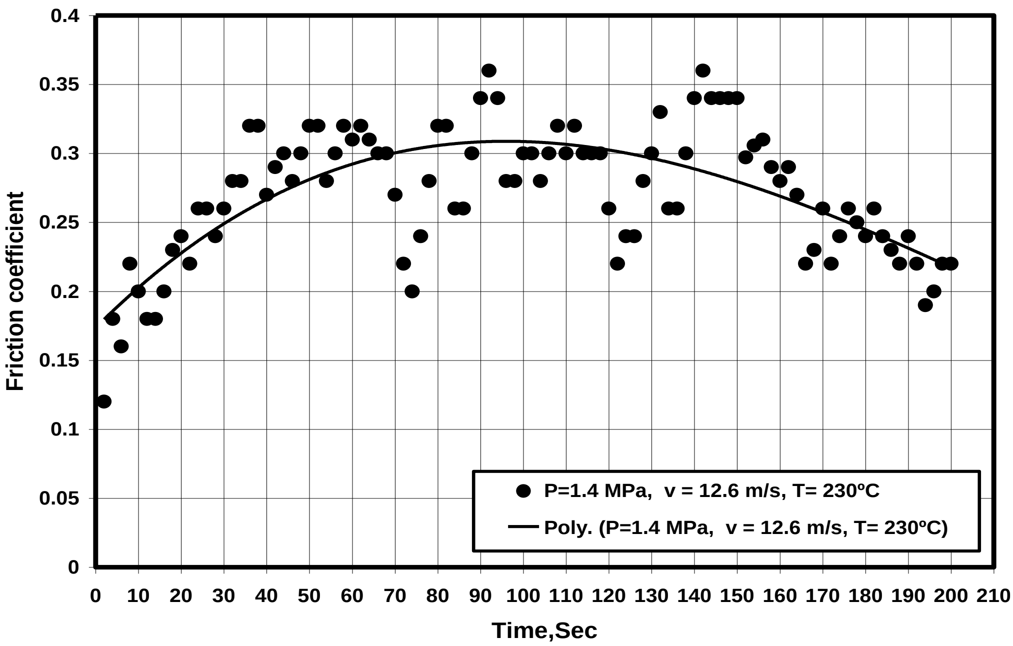

Fig. 5 Friction coefficient versus time for brake lining C.

Friction coefficient displayed by the tested composites containing 25 % corn fibre and 10 % aluminum powder is shown in Fig. 6. Friction coefficient increased from 0.6 to 0.7 and then decreased to 0.52 at a temperature rise of 232º C. These composites displayed value of fade lower than that of observed for commercial brake linings due to the presence of aluminum powder of high thermal conductivity.

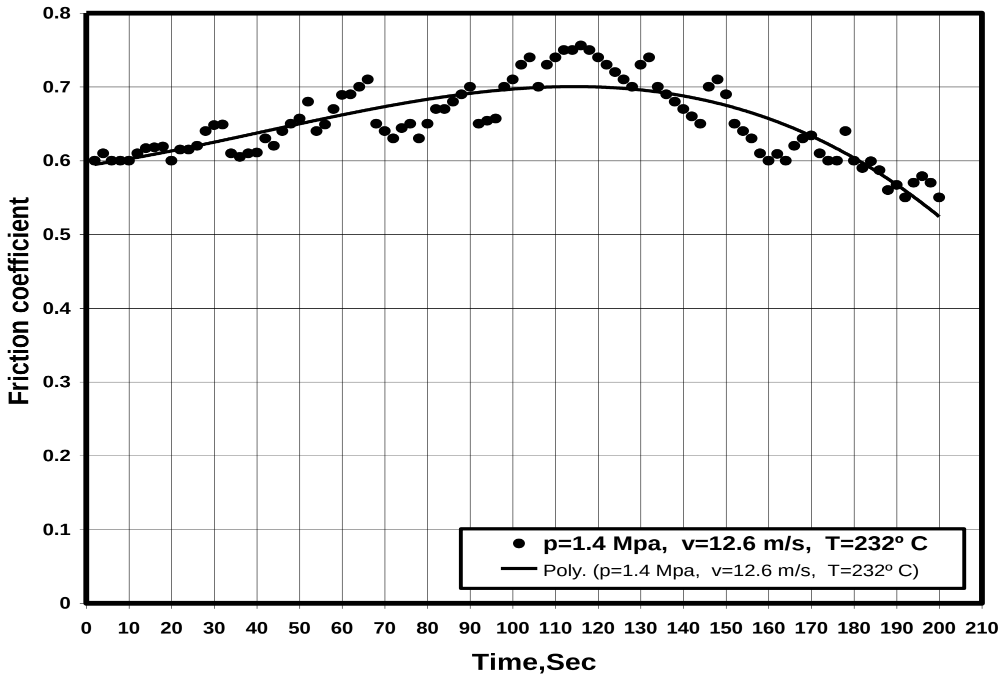

Fig. 6 Friction coefficient versus time for composites containing 25 % corn fibres and 10 % Al aluminum powder.

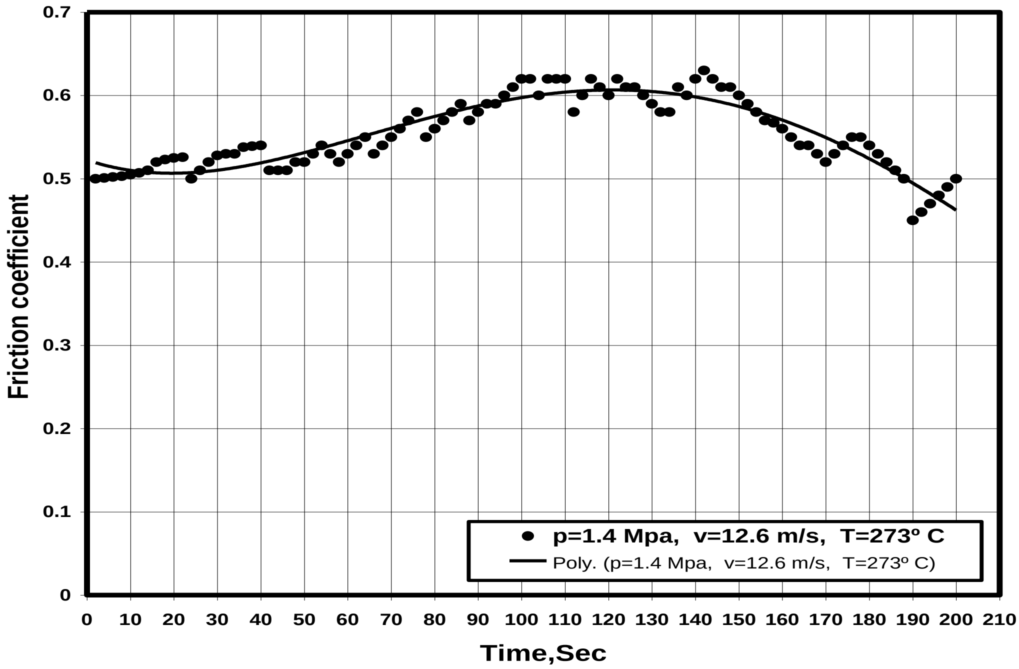

Fig. 7 Friction coefficient versus time for composites containing 20 % corn fibres and 30 % Cu copper powder.

Friction coefficient displayed by composites containing 20 % corn fibres and 30 % copper powder is shown in Fig. 7. The friction coefficient decreased from 0.6 to 0.46 accompanied by a temperature rise of 273º C. These composites showed friction coefficient reduction (fade) less than that displayed by commercial brake lining A. The low reduction in friction may be due to the relatively high thermal conductivity of copper as well as the formation of copper oxides at the friction interface, which was responsible of the improved fade resistance at elevated temperatures. Friction coefficient displayed by composites containing 15 % corn fibres and 30 % iron powder is shown in Fig. 6. Friction coefficient decreased from 0.63 to 0.47 at a temperature rise of 276º C. The high fade may be attributed to the high temperature which burns the bonding material and fibres, so that a layer of carbon covered the contact area causing reduction in friction.

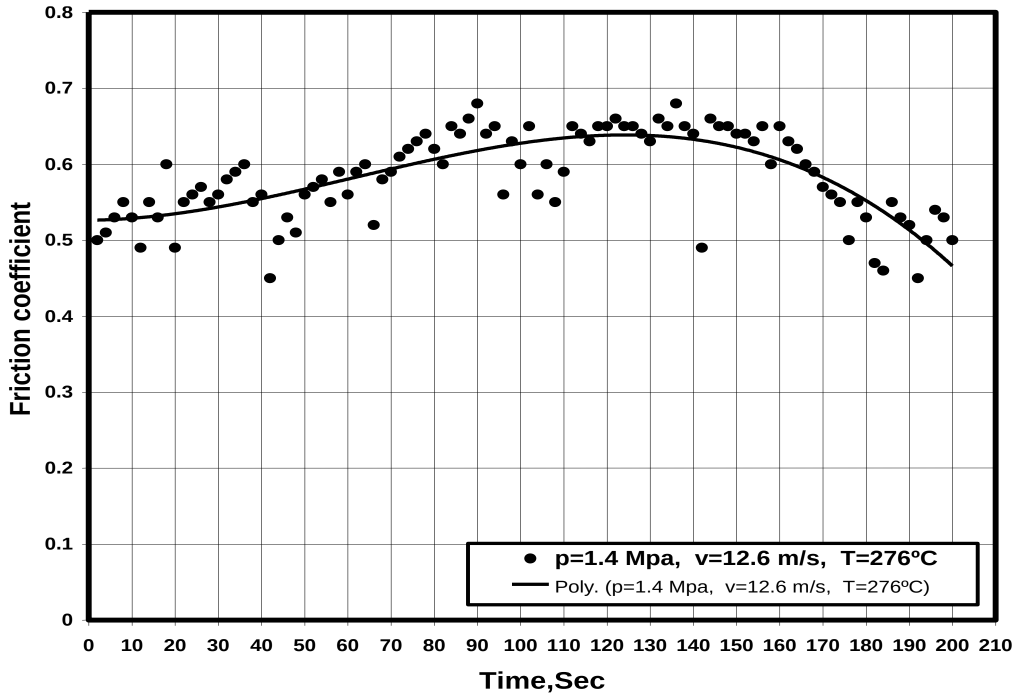

Fig. 8 Friction coefficient versus time for composites containing 15 % corn fibres and 30 % Fe iron powder.

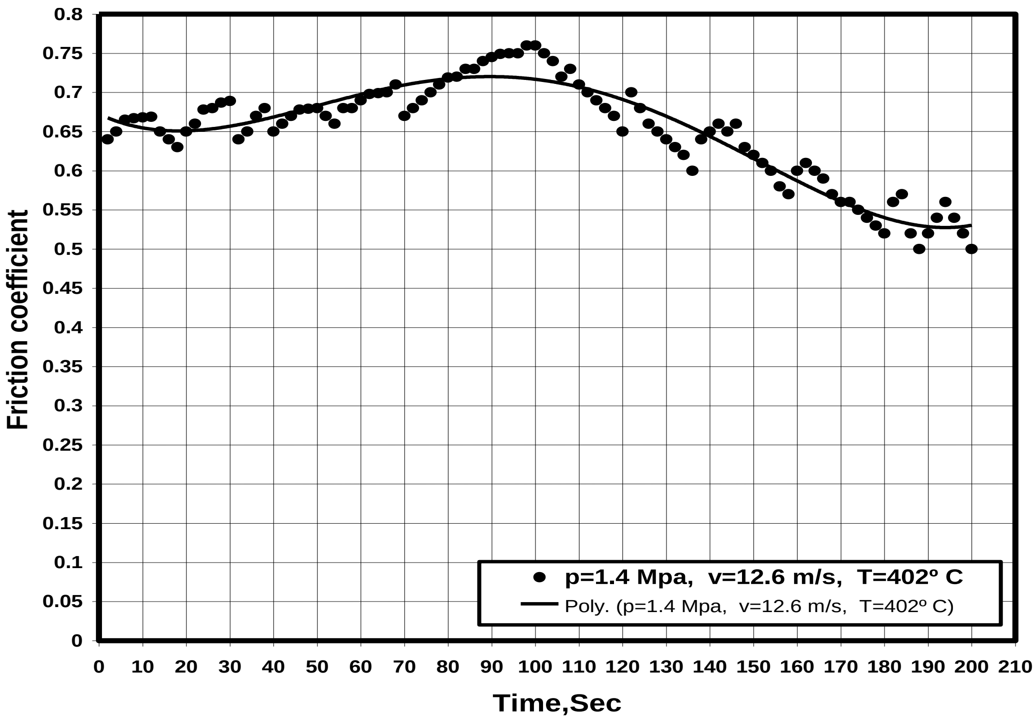

Fig. 9 Friction coefficient versus time for composites containing 25 % palm fibres and 10 % Al aluminum powder.

Friction coefficient of composites containing 25 % palm fibres and 10 % aluminum powder decreased from 0.72 to 0.53 at a temperature rise of 402º C, Fig. 9. The relatively high fade may be due to the high temperature which burns the bonding material and fibres producing a carbon film on the contact area, causing reduction in friction. Friction coefficient of composites containing 15 % palm fibres and 10 % copper powder is shown in Fig. 10. The friction coefficient decreased from 0.69 to 0.54 at a temperature rise of 294º C. These composites showed friction coefficient reduction (fade) less than that displayed by commercial brake lining A.

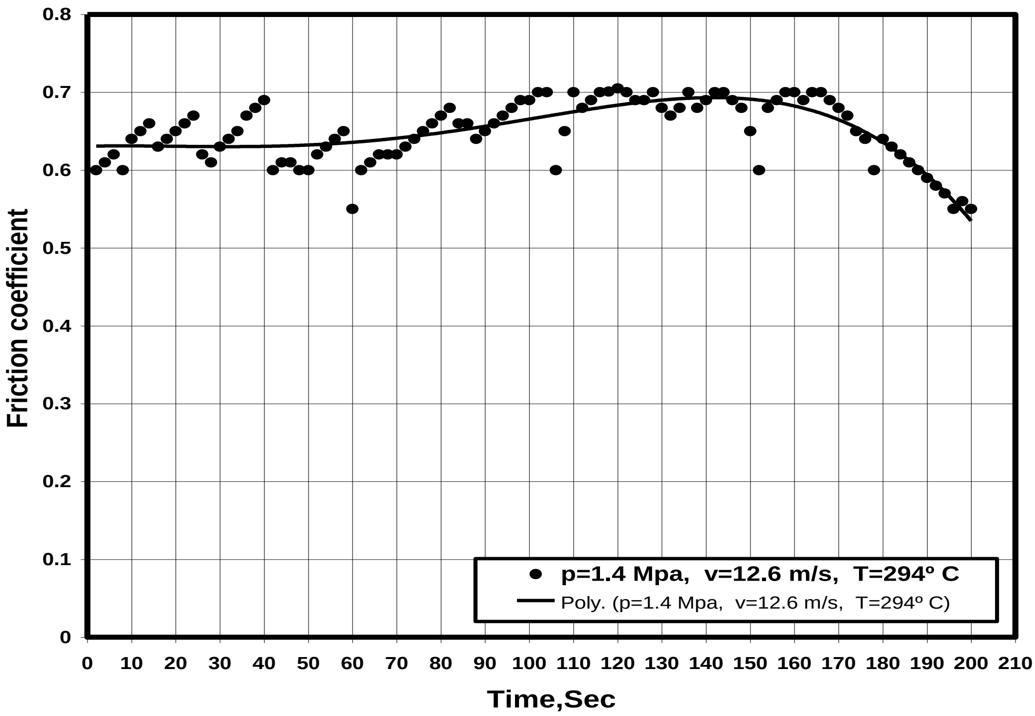

Fig. 10 Friction coefficient versus time for composites containing 15 % palm fibres and 10 % Cu copper powder.

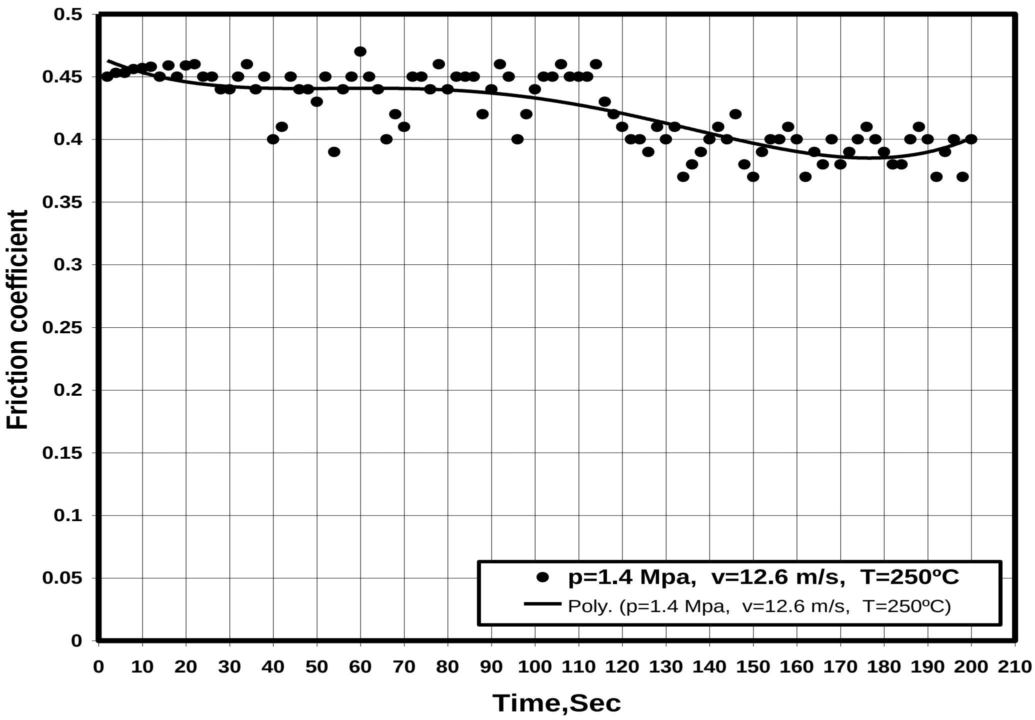

Fig. 11 Friction coefficient versus time for composites containing 25 % palm fibres and 10 % Fe iron powder.

Friction coefficient displayed by composites containing 25 % palm fibres and 10 % iron powder decreased from 0.44 to 0.37 at a temperature rise of 250º C, Fig. 11. These composites displayed friction coefficient reduction (fade) lower than that displayed for commercial brake linings due to its low temperature rise. Figure 12 shows friction coefficient displayed by composites containing 25 % sugar fibres and 20 % copper powder. Friction coefficient decreased from 0.53 to 0.32 at a temperature rise of 384º C. The reduction in friction may be due to the high temperature which burnt the bonding material and fibres, so that a carbon film covered the surface of the contact area causing reduction in friction coefficient. Besides, it seems that sugar bar fibres released relatively high heat during friction causing remarkable temperature rise.

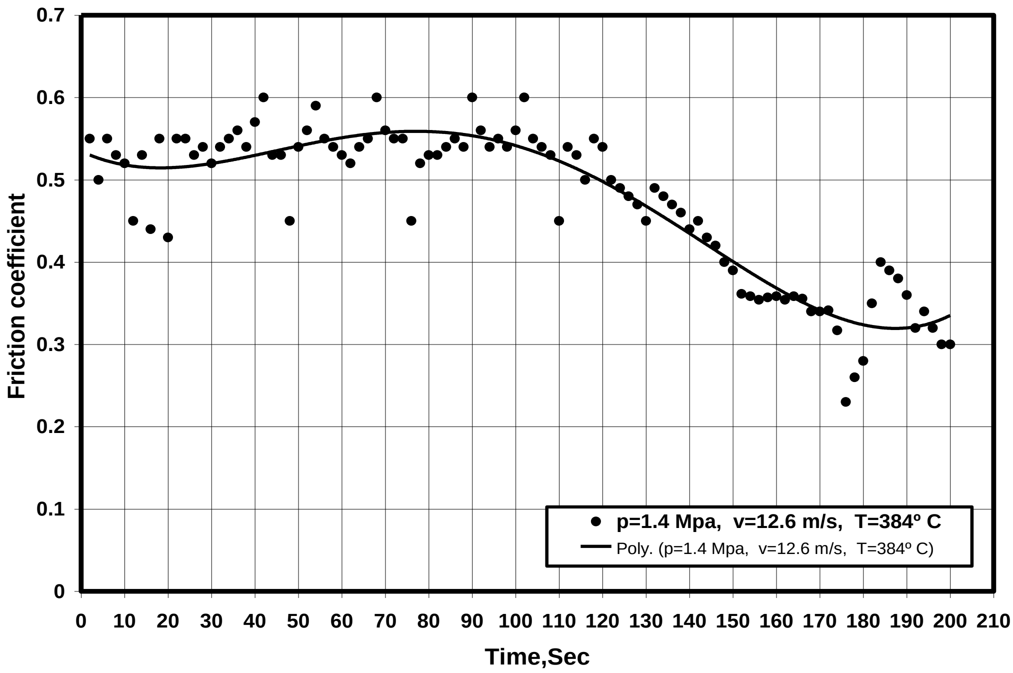

Fig. 12 Friction coefficient versus time for composites containing 25 % sugar bar fibres and 20 % Cu copper powder.

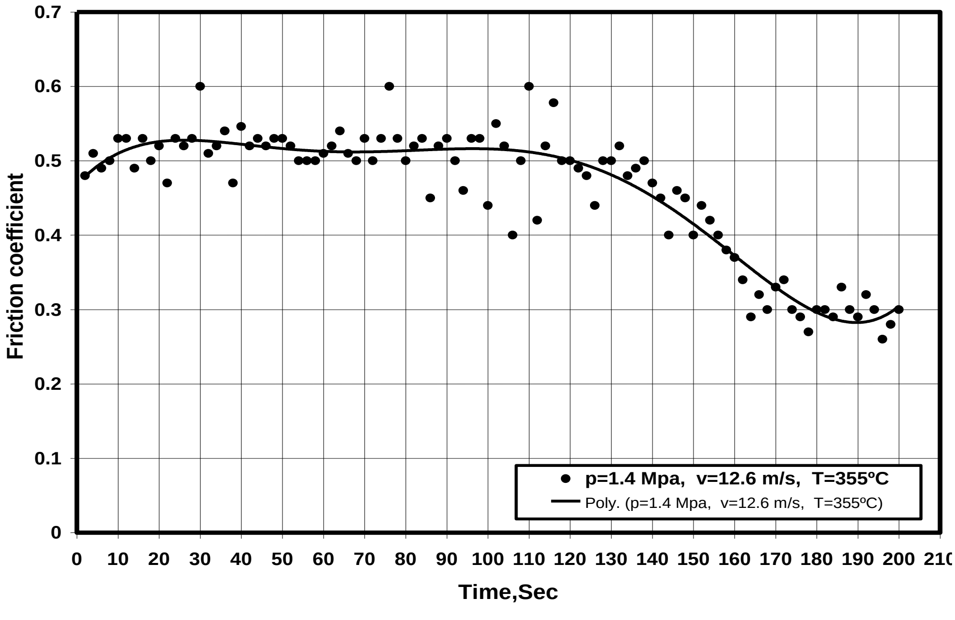

Fig. 13 Friction coefficient versus time for composite containing 25 % sugar bar fibres and 20 % Fe iron powder.

Friction coefficient displayed by composites containing 25 % sugar fibres and 20 % iron powder is shown in Fig. 13. The friction coefficient decreases from approximately 0.51 to 0.38 at a maximum temperature rise of 355° C. Temperature is one of the most important parameters influencing the tribological properties of the friction materials. However, since it is also affected by the materials, it is a key factor that helps to understand the actual contact conditions and interface interactions. Temperature was measured using digital thermometer with thermocouple for continuous test after 60 seconds at contact pressure of 1 MPa and velocity of 12.6 m/s. Figure 14 shows the temperature rise for composites containing corn fibres and 10 % aluminum powder. Brake linings A, B and C showed 233 and 300 and 180 ºC temperature rise. Among the tested composites, brake lining B showed the highest value of temperature rise (300 ºC).

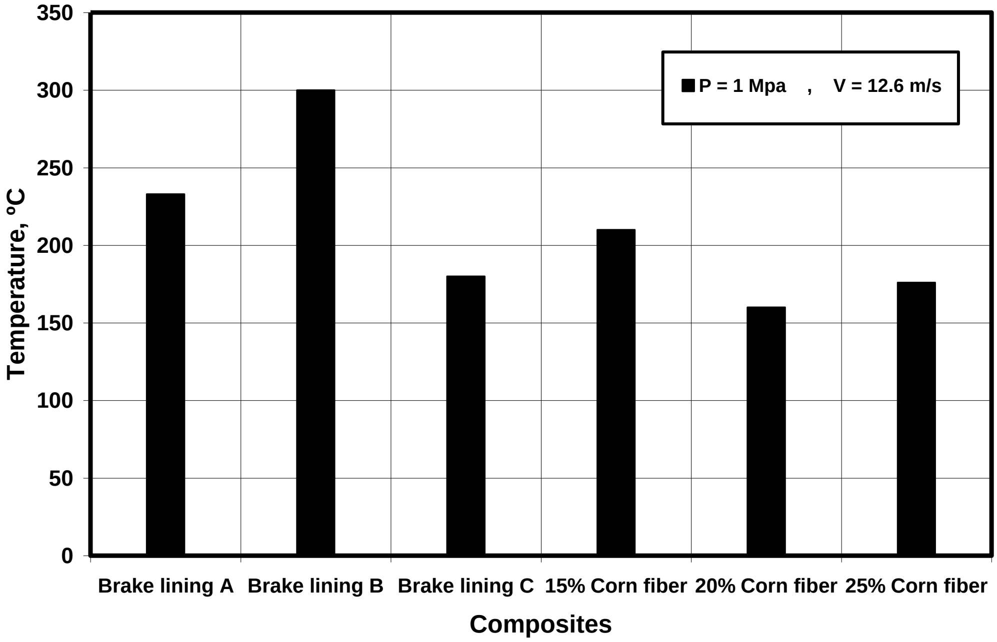

Fig. 14 Temperature rise of composites containing corn fibres and 10 % Al aluminum powder.

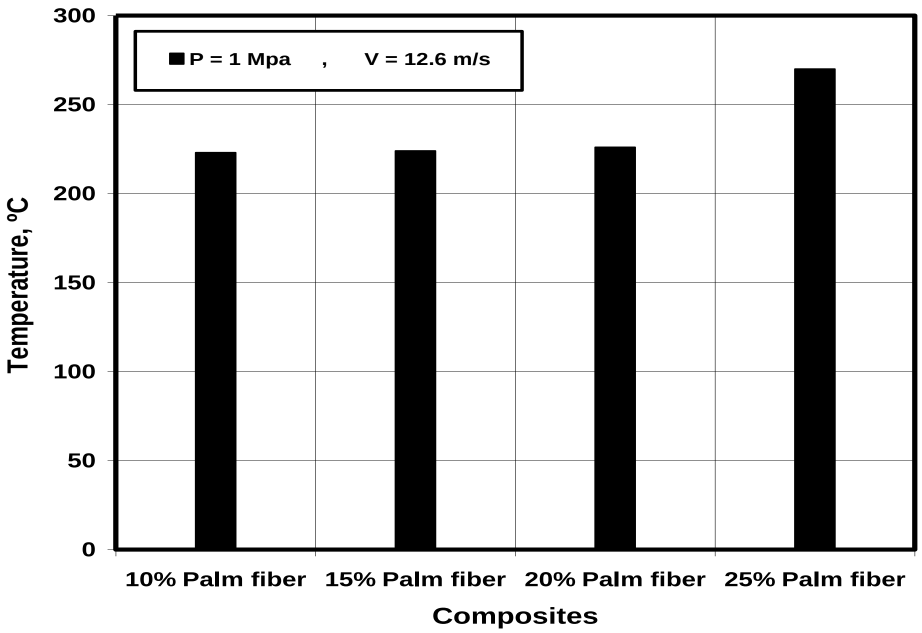

Fig. 15 Temperature rise of composites containing palm fibres and 20 % Cu copper powder.

With respect to Fig. 15, composites containing 20 % palm fibres and 30 % copper powder displayed higher temperature among the tested composites, while low temperature was observed for composites containing 10 % palm fibres. It can be noticed that the temperature increased with increasing fibres content. Composites containing 10 % sugar bar fibres and 30 % iron powder showed the highest temperature rise (310 ºC), while low temperature was obtained for composites containing 15 % sugar bar fibres, Fig. 16. The reduction of bonding material caused the increase of temperature as shown for composites containing 10 % sugar bar fibres.

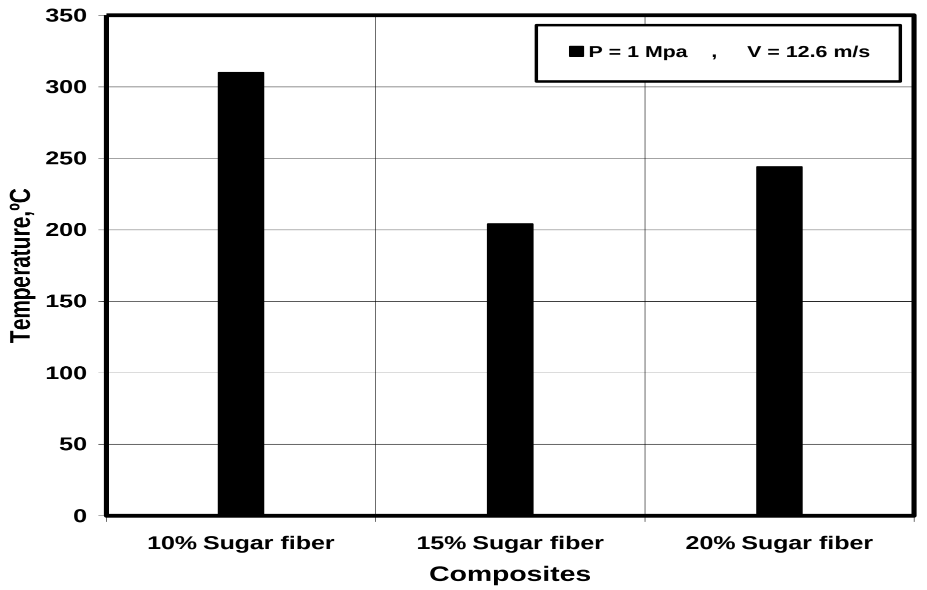

Fig. 16 Temperature rise of composites containing sugar bar fibres and 30 % Fe iron powder.

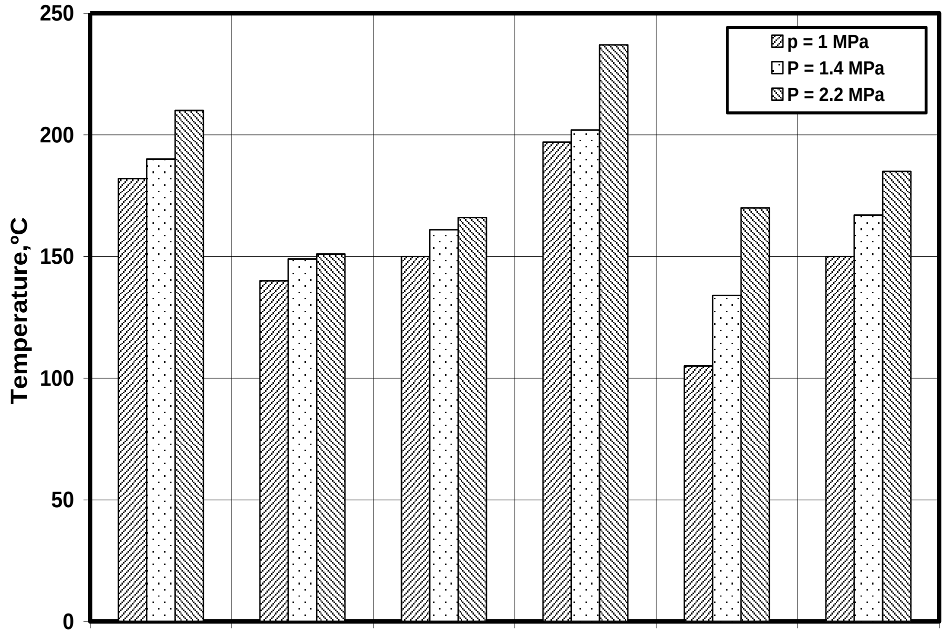

Fig. 17 Temperature rise of commercial brake linings and composites containing corn fibres and 10 % Al aluminum powder.

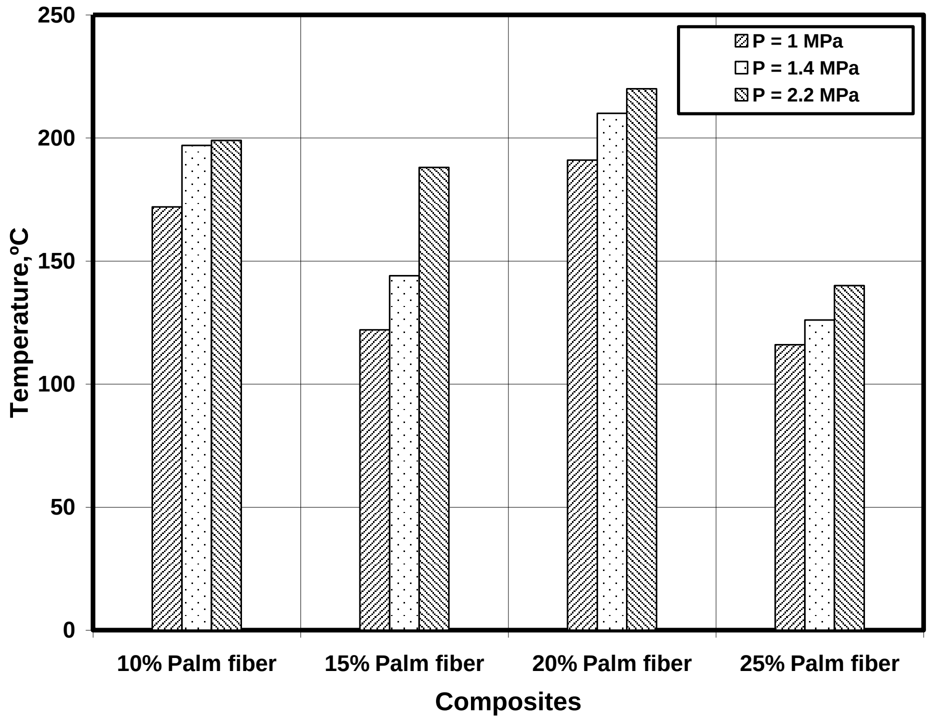

Fig. 18 Temperature rise of composites containing palm fibres and 20 % Cu copper powder.

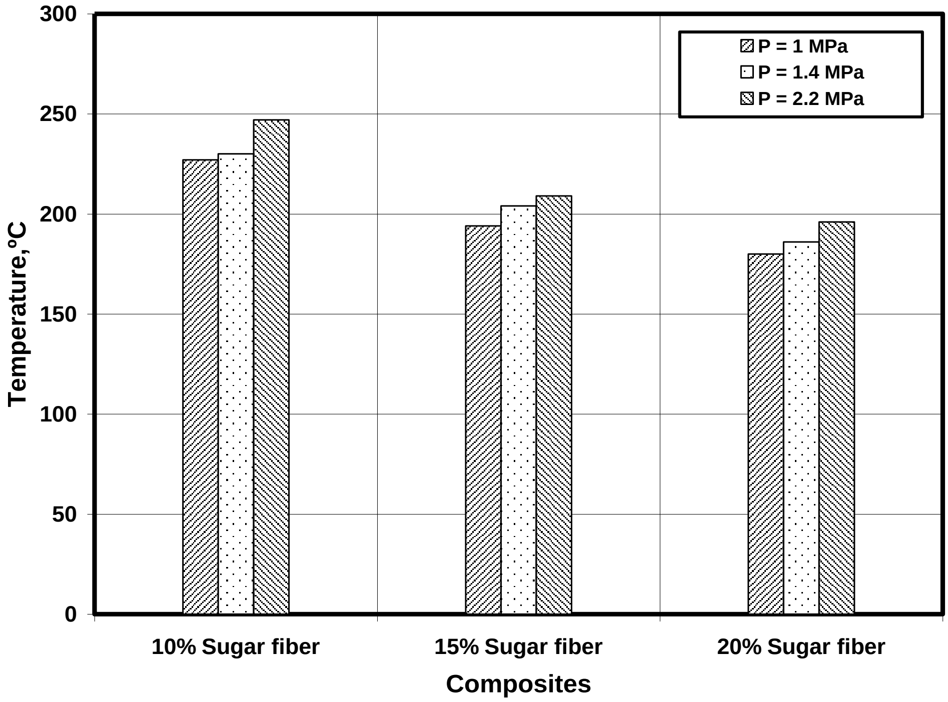

Fig. 19 Temperature rise of composites containing sugar bar fibres and 30 % Fe iron powder.

In starting – stopping test the friction of the proposed composites was investigated at different values of contact pressure. The temperature rise of starting – stopping test was measured for composites at different contact pressure 1, 1.4 and 2.2 MPa to obtain the effect of pressure on temperature rise. Figure 17 showed the temperature rise for commercial brake linings and composites containing corn fibres and 10 % aluminum powder. It can be seen that the temperature increased with increasing contact pressure. Composites containing 15 % corn fibres showed the highest temperature among composites tested at 1, 1.4 and 2.2 MPa. Composites containing 20 % corn fibres showed lower temperature at 1 and 1.4 MPa than that displayed by commercial brake linings. Referring to Fig. 18, composites containing 25 % palm fibres and 20 % copper powder experienced the lowest temperature among composites shown, while the highest temperature was displayed by composites containing 20 % palm fibres at different contact pressure 1, 1.4 and 2.2 Mpa. It can be noticed that the temperature increases with increasing the contact pressure. Composites containing 10 % sugar bar fibres and 30 % iron powder displayed relatively the highest temperature among composites, Fig. 19 at different contact pressures. The reduction of bonding material caused the increase of temperature as shown for composites containing 10 % sugar bar fibres. It can be noticed that temperature increased with increasing the contact pressure. The lowest temperature was observed for composites containing 20 % sugar bar fibres.

CONCLUSIONS

Based on the experiments carried out in the present work, the following conclusions can be withdrawn:

1. The best fade resistance was displayed by composites containing 25 % palm fibres and 10 % iron powder.
2. The presence of aluminum and copper powders inside the composites provided lower value of fade due to their high thermal conductivity.
3. Composites containing sugar bar fibres released relatively high heat during friction and consequently increased the temperature rise.
4. At continuous test, composites containing corn fibres with iron powder gave the lowest temperature rise during friction test.
5. The temperature rise of composites increased with increasing the contact pressure at starting – stopping test.

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