ISSN 1392–1207. MECHANIKA. 2014 Volume 20(4): 420–425

Experimental study of the tribological behaviour of materials of brake disc and pads

M. Djafri*, M. Bouchetara, C. Busch***, S. Weber******
**Faculty of Mechanical Engineering, University of Sciences and the Technology of Oran, L.P 1505 El -MNAOUER, USTO 31000 Oran, Algeria, E-mail: djafrimohammed@yahoo.fr*
***Faculty of Mechanical Engineering, University of Sciences and the Technology of Oran, L.P 1505 El -MNAOUER, USTO 31000 Oran, Algeria, E-mail: mbouchetara@hotmail.com*
****Laboratory of tribology ,University of Applied Sciences Zwickau Germany, E-mail: Christian.Busch@fh-zwickau.de*
*****Laboratory of tribology, University of Applied Sciences Zwickau Germany, E-mail: Simon.Weber.1@fh-zwickau.de*

crossref http://dx.doi.org/10.5755/j01.mech.20.4.6974

1. Introduction

The friction coefficient of brake friction material is an important parameter affecting brake performance and can be used to understand various braking phenomena such as stopping distance, fade, nose propensity, pedal feel, and brake-induced vibration [1]. Furthermore, the friction is not an intrinsic property of materials; in general it depends on the tribological system which includes materials, but also environmental conditions. Numerous experimental studies [2-6] show that the variation of the friction coefficient and the wear rate depends on interfacial conditions, such as the normal load, the sliding speed, the roughness of rubbing surfaces, the nature of material, the temperatures and the relative humidity. The procedure of braking refers to the complex wear mechanisms including abrasive wear, adhesives wear, fatigue wear and chemical reactions [7]. Gultekin et al [8] showed that the friction coefficient decreases with increasing applied normal load. Österle and Urban [9] investigated chemical and microstructural aspects controlling friction and wear of brake materials and they noticed that the main wear mechanism is a delamination of particles from the organic binder, supported by local degradation of the phenolic resin during asperity heating. Eriksson [10] gives an overview micro- and macroscopic of the wear process. Jankauskas [11] suggest that the steel abrasive wear can be predicted not only by the hardness, but also by the roughness. Hong et al [1] compared the friction and wear characteristics of three friction materials with different binder resins. In their study, the wear rate below a critical temperature showed a slow increase, but above it the wear rate increased rapidly so he shows that the wear rate depends on the temperature of friction independently of the material. The studies concerning the humidity effects on the tribological properties of relatively rough surfaces have been very limited. Gao and Kuhlmann-Wilsdorf [12] reported that humidity could enlarge the contact area of the rough surface during sliding and lead to stick-slip. Eriksson and Lord [13] suggested that addition of a fluid to the contact promoted the formation of larger contact plateaus which play an important role in friction and wear of brake materials. Another adopted approach for the analysis of the physical mechanisms of friction and wear bases on the notion of the third body which was introduced then developed by several authors [14, 15]. This notion is based on the tribological triplet, the tribological circuit and the mechanism of speed accommodation. In this paper, an experimental evaluation of the tribological behaviour of the brake materials sliding against pads material by varying various parameters such as the normal load, the sliding speed, and the relative humidity will be presented. The essays were realized by means of tribometer disc-pin SRV4.

2. Experimental procedures

2.1. Materials

Braking materials must ensure a stable friction with a high friction coefficient. The experiments were conducted with discs made of cast iron FG25 as a current materials of brake disc and chromium steel 100Cr6 used for comparative purpose. The simulated brake discs were 100 mm in diameter and thickness of 10 mm. The pad materials of automotive brakes are usually composites formed by hot compaction of coarse powder including many different components; also the current pad materials may contain phenolic resin, filler materials, fibers and phenolic particle. Fig. 1 shows the composition of the pad material by means of EDX, the main components are Fe and O. The pin is a cylindrical specimen 9.5 mm in diameter and 10 mm of height. The density of the pad material is 0.0025 g mm^{-3}.

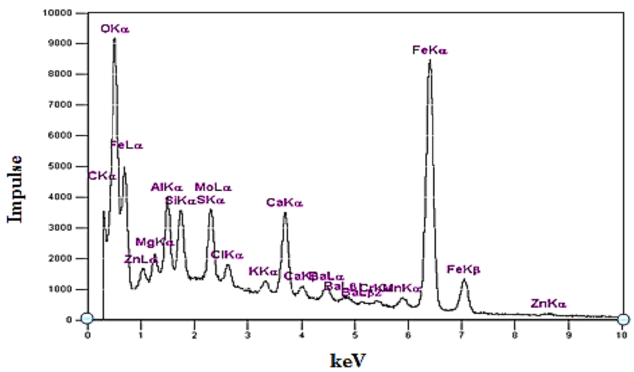


Fig. 1 Spectre EDX of the used pad material (pin)

2.2. Sliding tests

The essays on the tribometer allow an estimating of the tribological performance of dry sliding contacts on the scale of laboratory. The tribometer disc-pin type SRV4, as shown in Fig. 2, is composed by an essay chamber with disc-pin, a measurement unit with a display data panel (normal load F_n, rotation speed of the disc Ω, friction radius R, and initial temperature of the disc T_i) and an adjustment unit of test conditions (relative humidity H and ambient temperature T_c and a display screen. The sliding occurs between a fixed pin, pressed against a rotating disc. The frictional load and the wear depth monitored with an electronic sensors. From the values of the normal load applied on the pin F_n, and the frictional load F_r measured by the tribometer, the friction coefficient μ is calculated as follow:

$$\mu = F_r / F_n \qquad (1)$$

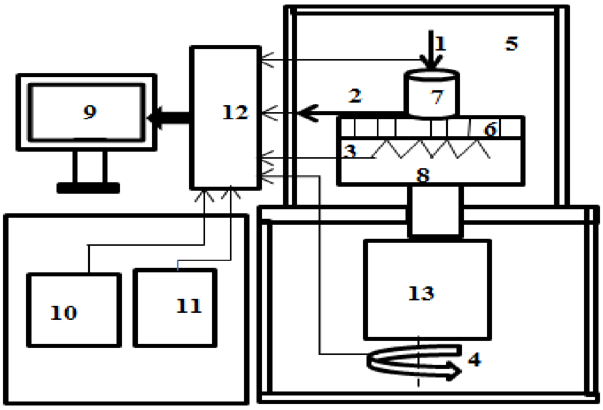


Fig. 2 Modelling of the sliding test of the couple disc-pin on the tribometer SRV 4: *1* - normal load F_n, *2* - friction load F_r, *3* - sensor of temperature of the disc T_i, *4* - rotational speed Ω, *5* - chamber of essay, *6* - disc ,*7* - pin, *8* - stand, *9* - screen, *10* - ambient temperature T_c, *11* - Humidity H, *12* - unit of measure, *13* - engine

To estimate the influence of the operating conditions on evolution of the wear of the pin, the weight loss was measured by means of an electronic balance with a precision of 1 x 10^{-4} g before and after essay, also the wear rate is calculated with the following formula [16]:

$$W_s = \Delta m / \rho L \qquad (2)$$

where W_s is the wear rate, $mm^3\ m^{-1}$; Δm is the mass loss, g; ρ is the density, g mm^{-3}; L is sliding distance, m.

In order to ensure a good parallelism of rubbing faces and good results of friction coefficient and wear, the essays will be repeated at least 5 times during 3 minutes for each condition of the test.

3. Influence of operating parameters on the tribological behaviour of the couple disc-pin

3.1. Evolution of the friction coefficient and the temperature according to the sliding time

The essay conditions on the tribometer are: F_n = 200 N, v = 3.76 m s^{-1} (Ω =1200 rpm), R =30 mm, T_i = T_c = 25°C and H = 25%. The used disc material is the cast iron FG25.

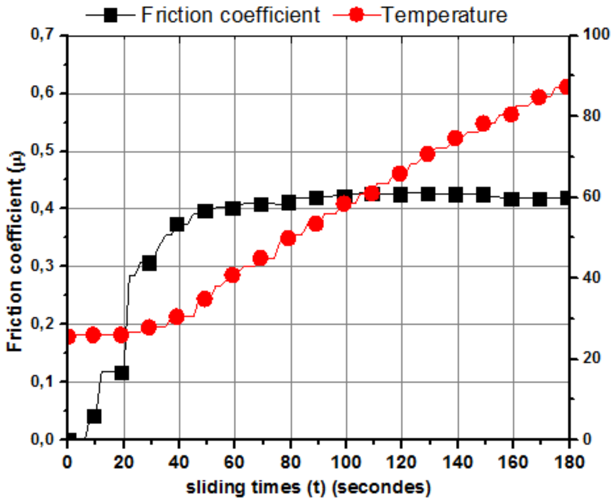
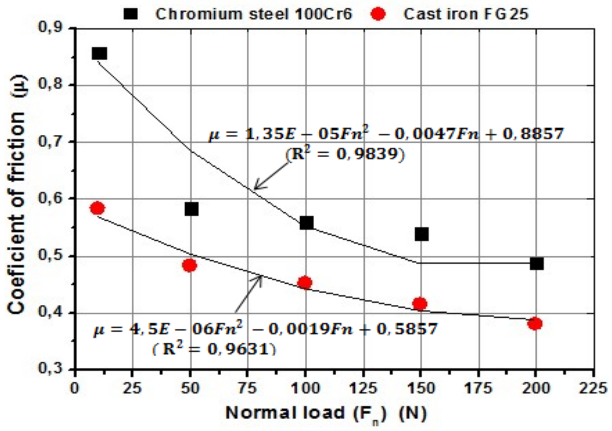


Fig. 3 Evolution of the friction coefficient and the temperature according to the sliding time

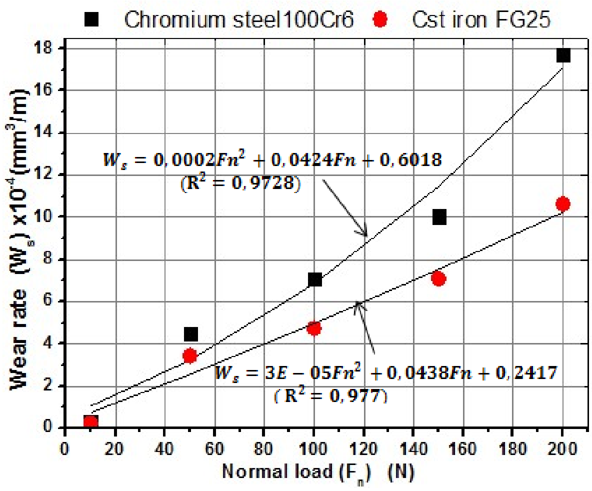
Fig 3 shows the evolution of the friction coefficient and the temperature according to the sliding time. To achieve the desired speed and load, the tribometer offers a preparation phase (20 s) during which the contact disc-pin is not established and the temperature did not vary. After this phase, the tribometer begins to establish the contact between the pin and the rotating disc during 20 s where the friction coefficient presents a fast rise from 0 to 0.37, because the size of the contact zone increases. After this phase, the friction coefficient becomes constant. Concerning the temperature due to the friction, it increases linearly with the sliding time after the preparation phase. There is a correlation between the friction and the contact temperature which confirms that the evolution of the temperature is governed by surface phenomena.

3.2. Effects of normal load on the friction coefficient the wear rate and the temperature

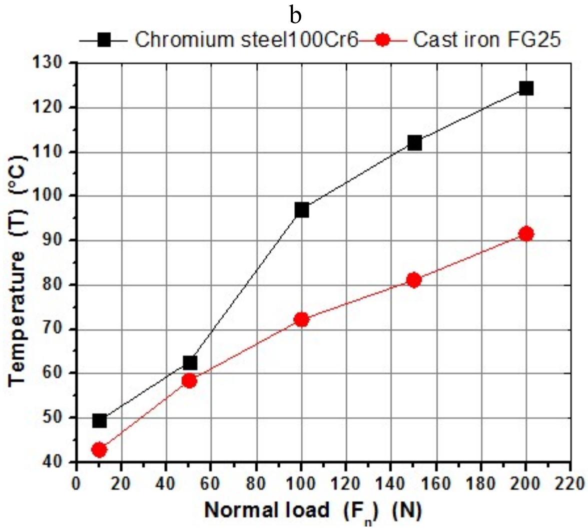
During this essay, the normal load applied by the tribometer on the pin was varied from F_n =10 N to 200 N by maintaining constant v = 3.76 m s^{-1} (Ω = 1200 rpm), T_c = T_i = 25°C and H = 25%. Two disc materials are used, the cast iron FG25 and the chromium steel 100Cr6. Fig. 4 shows respectively the evolution of the friction coefficient, the wear rate and the temperature according to the applied normal load. The friction coefficient decreases with increasing normal load for both tested materials, (Fig. 4, a). It is observed that at low applied normal load (F_n = 10 N), the friction coefficient has a high value. This is due to insufficient amount of tribo-layer formation between the sliding interfaces [4]. With increased applied load from 10 to 50 N, the friction coefficient of both materials decreased steeply. In the interval between 50 and 200 N, the coefficient of friction decreases weakly. However, an antagonist relation exists between the normal load and the measured friction coefficient, as described in [8]. In the Fig. 4, b, the wear rate increased with the normal load, this may be due to the quick plastic deformation of material in the friction surface, because the shear force between asperities and the ploughing force of asperities were continuously increased. The trend shows that the friction coefficient and the wear performance do not go together, if the friction behavior is good, wear performance is poor and vice versa [17]. From the Fig. 4, c, it observed that the friction temperature increased linearly with applied normal load. The temperature of the chromium steel is higher than the cast iron. For the interval of normal load between 10 and 50 N, the difference of temperature between both materials is constant, but it increased quickly after 50 N. For fixed normal loads of 100 N and 200 N, the differences of temperature between both tested materials are about 30°C and 35°C respectively.



a



b

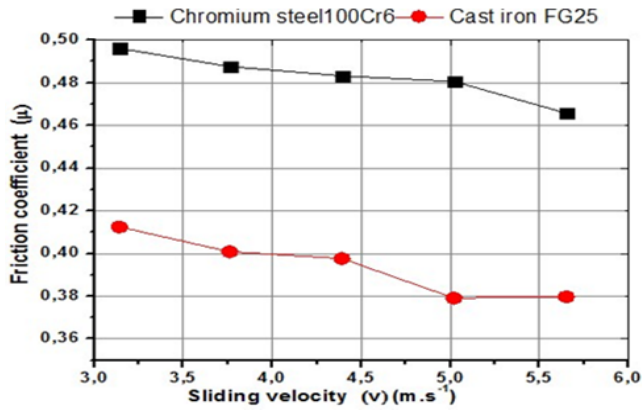


c

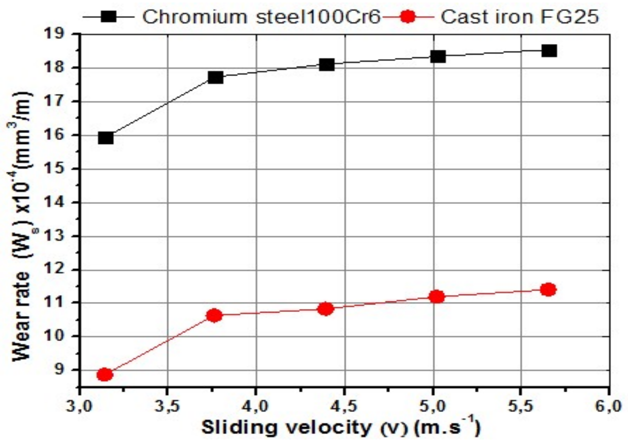
Fig. 4 Influence of normal load on friction coefficient (a), wear rate (b) and temperature (c)

3.3. Effects of the sliding speed on the friction coefficient , the wear rate and the temperature

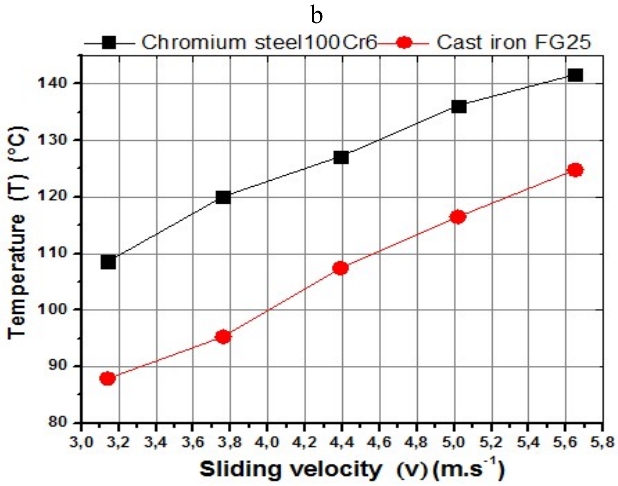
The sliding speed was varied from $v = 3.14$ m s^{-1} ($\Omega = 1000$ rpm) to $v = 5.56$ m s^{-1} ($\Omega = 1800$ rpm) by maintaining constant $F_n = 200$ N, $R = 30$ mm, $T_c = T_i = 25$°C and $H = 25$%.The results for both tested materials show that the friction coefficient decreases weakly with increasing sliding speed (Fig. 5, a), as described in [3]. In Fig. 5, b, the wear rate increased steeply with the sliding speed from $v = 3.14$ m s^{-1} until $v = 3.56$ m s^{-1}, afterward it increased weakly. The difference of the wear rate between the both materials remains constant during all essays.



a



b



c

Fig. 5 Influence of sliding speed on friction coefficient (a), wear rate (b) and temperature (c)

The increase in sliding speed is accompanied by an increasing of entering heat flux and sliding distance.This verified the linear increasing of temperature with the sliding speed (Fig. 5, c). The difference of the temperature between both materials is constant.

3.4. Effcts of relative humidity on the friction coefficient, the wear rate and the temperature

To investigate the effect of the relative humidity on the tribological characteristics of the couple disc-pin, the relative humidity was varied from $H = 20\%$ to $H = 90\%$ increment of 10% in the conditioning chamber of the tribometer and keeping constant the other parameters, $F_n = 200$ N, $v = 3.76$ m s^{-1} ($\Omega = 1200$ rpm), $R = 30$ mm and $T_i = T_c = 25$°C.The experimental results presented in Fig. 6, a, showed that for the cast iron (FG25), with increased humidity from 20% to 40%, the coefficient of friction increased, afterward it decreased weakly. Concerning the chromium steel (100Cr6), the friction coefficient decreased weakly with increased humidity and it is higher than that of cast iron. Fig. 6, b shows that the wear rate of the pin follows the same law for both materials. The wear decreases strongly with increasing relative humidity, so that no influence of the applied normal load was found at high humidity, due to the formation of a water film on the sliding interface [5]. In Fig. 6, c, it is observed that the humidity has no influence on the friction temperature and the difference of temperature between both materials is constant. According to the previous figures, the cast iron FG25 is characterized by friction coefficient, wear rate and temperature less important than the chromium steel 100Cr6.

4. Micrographs of worn surfaces

Given that the increasing of the applied normal load has big effect on the wear, macroscopic observations of worn tracks were realized after the essays on the tribometer at $F_n = 200$ N, $v = 3.76$ m s^{-1} (Ω =1200 rpm), $T_i = T_c = 25$ °C and $H = 25\%$. Numerous tracks resulting from the ploughing of asperities were observed in the contact area of the disc in chromium steel (100Cr6) and in grey cast iron (FG25). The chromium steel disc presents a rather uniform surface with not much deformation, (Fig. 7, a). Parallel grooves were observed due to the abrasion. The wear grooves show the evidence of severely plastic flow in the form of grooves parallel to the sliding direction. Some pulverulent fragments are observed at the edges of the track of the disc. In Fig. 7, b, the disc in cast iron shows a clear mechanism of abrasion with parallel grooves generated by abrasive action in the sliding direction, as well as numerous pulverulent fragments and obviously oxidized and collected in the track of friction of the disc. In comparison between the two previous figures, we notice that a great deal of abrasive particles (debris) coming from the pin penetrate into a shallow surface layer of the chromium steel (100Cr6) than the cast iron (FG25) This explains why chromium steel is characterised by higher values of friction coefficient and wear rate than the grey cast iron.

Fig. 7, c shows the surface state of the pin with zones very altered of agglomerated material, sit of intense mechanisms of adhesion separated by zones where it seems that the contact was only partial. The presence of the third body is composed of plateaus of powder and characterized by very smoother zones called patches. The plateaus of powder, trapped in the contact along cutting fibers by the friction, accumulated and compacted to form patches. These patches participate in the transmission of the load and the accommodation of speed between the disc and the pin [11].

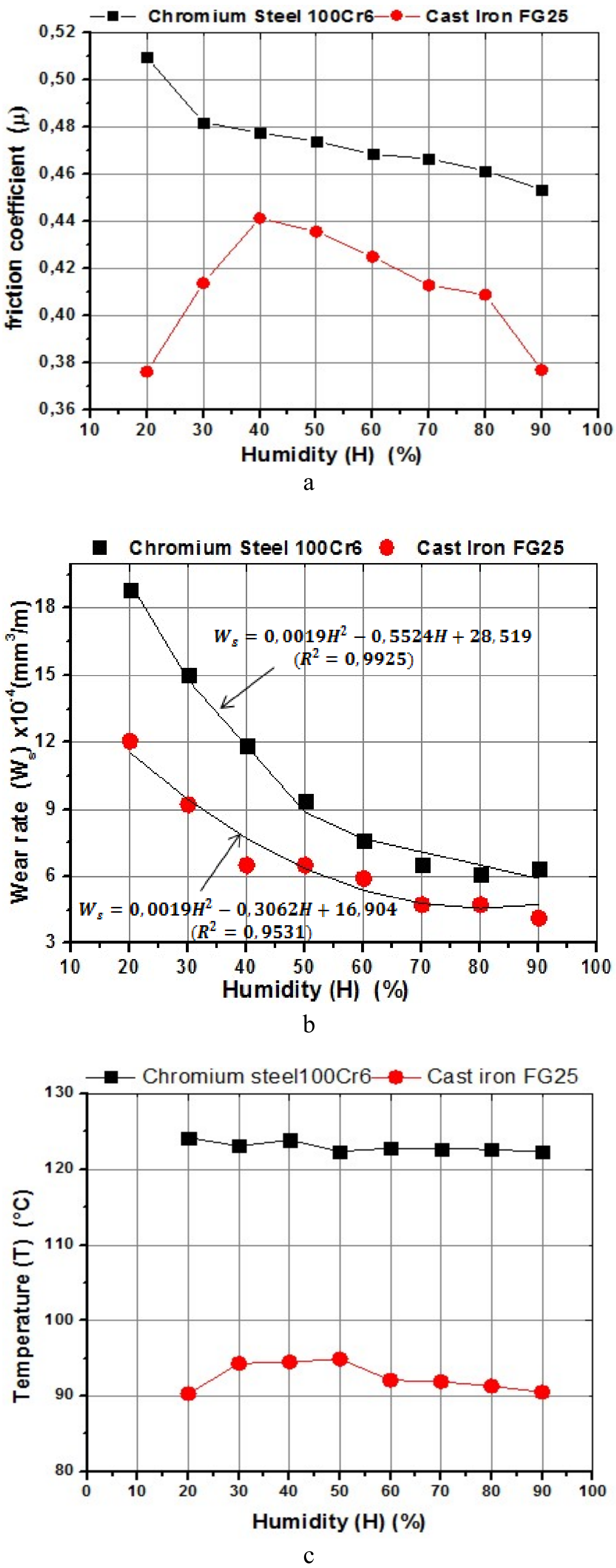


Fig. 6 Influence of humidity on friction coefficient (a), wear rate (b) and temperature (c)

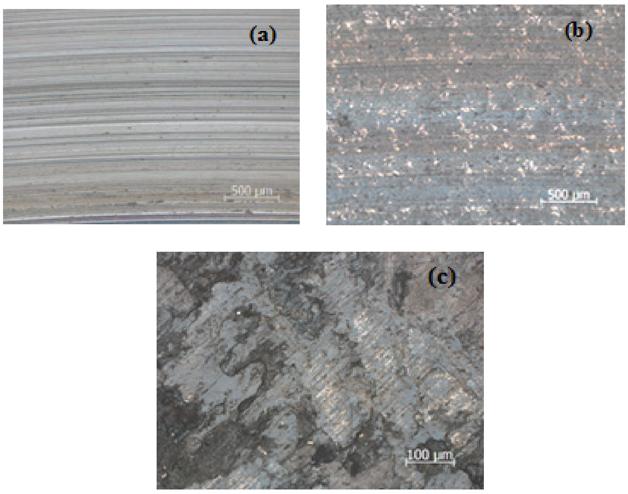


Fig. 7 Micrographs of worn surfaces: a - Chromium steel (100Cr6), b - Cast iron (FG25), c - Pad material

5. Conclusions

This study was dedicated to the development and the essay implementation of tribology for the experimental evaluation of the tribological behaviour for materials of the couple disc/pads. The experimental investigations revealed that the friction coefficient of both tested materials (cast iron FG25 and chromium steel 100cr6) decrease linearly with the increasing normal load applied on the disc by the pin. The increased sliding speed is accompanied by decreased friction coefficient for both materials. The effect of the relative humidity on the friction coefficient depends on the tested materials. For the cast iron, it is high at low humidity. The results also show that the normal load has an important effect on the wear rate than the sliding speed. An opposite trend exists between the wear rate and the relative humidity, and it decreased steeply with increased relative humidity while it observed a formation of water films at the sliding interface. The friction temperature depends on the normal load, the sliding speed and the nature of material. The humidity does not affect the friction temperature. This study clearly showed that the cast iron (FG25) used as braking material is characterized by values of wear and temperature lower than the chromed steel disc (100Cr6).

References

1. **Hong, U.S.; Jung, S.L.; Cho, M.H.; Kim, S.J.; Jang, H.** 2009.Wear mechanism of multiphase friction materials with different phenolic resin matrices, Wear 266: 739-744.
http://dx.doi.org/10.1016/j.wear.2008.08.008.
2. **Uyyuru, R.K.; Surappa, M.K.; Brusethaug, S.** 2007. Tribological behaviour of Al–Si-SiC$_p$ composites /automobile brake pad system under dry sliding conditions, Tribology International 40: 365-373.
http://dx.doi.org/10.1016/j.triboint.2005.10.012.
3. **Blau, P.J.; McLaughlin, J.** C. 2003. Effects of water films and sliding speed on the frictional behavior of truck disc brake materials, Tribology International 36: 709-715.
http://dx.doi.org/10.1016/S0301-679X(03)00026-4.
4. **Natarajan, N.; Vijayarangan, S.; Rajendran, I.** 2006. Wear behavior of A356/25SiCp aluminium matrix composites sliding against automobile friction material, Wear 261: 812-822.
http://dx.doi.org/10.1016/j.wear.2006.01.011.
5. **Kchaou, M.; Sellami, A.; Elleuch, R; Singh, H.** 2013. The influence of humidity on the sliding friction of brake friction material, Materials and Design 52: 533-540
http://dx.doi.org/10.1016/j.wear.2013.01.014.
6. **Jankauskas, V.; Kreivaitis, R.** 2008. Research of abrasive erosion wear for Fe-C-Cr-B hard layers, Mechanika 4(72): 71-76.
7. **Müller, M.; Ostermeyer, G.P.; Graf, M.** 2009. Towards an explicit computation of wear in brake materials. SAE Technical. Paper 01-3048.
8. **Gultekin, D.; Uysal, M.; Aslan, S.; Alaf, M.; Guler, M.O.; Akbulut, H.** 2010. The effects of applied load on the coefficient of friction in Cu-MMC brake pad/Al-SiCp MMC brake disc system, Wear 270: 73-82.
http://dx.doi.org/10.1016/j.wear.2010.09.001.
9. **Österle, W.; Griepentrog, M.; Gross, T.; Urban, I.** 2001. Chemical and microstructural changes induced by friction and wear of brakes, Wear 250-251: 1469-1476.
http://dx.doi.org/10.1016/S0043-1648(01)00785-2.
10. **Eriksson, M.; Bergman, F.; Jacobson, S.** 2002.On the nature of tribological contact in automotive brakes. Wear, 252(1-2): 26-36.
http://dx.doi.org/10.1016/S0043-648(01)00849-3.
11. **Jankauskas, V.; Skirkus, R.** 2013 .Steel abrasive wear forecasting by wearing surfaces micro geometric parameters, Mechanika 19(4): 486-490.
http://dx.doi.org/10.5755/j01.mech.19.4.5049.
12. **Gao, C.; Kuhlmann-Wilsdorf, D.** 1991. Adsorption films, humidity, stick-slip and resistance of sliding contacts, IEEE Transactions on: Components, Hybrids, and Manufacturing Technology 14: 37-44.
http://dx.doi.org/10.1109/33.76508
13. **Eriksson, M.; Lord, J.; Jacobson, S.** 2001. Wear and contact conditions of brake pads: dynamical in situ studies of pad on glass, Wear 249: 272-278.
http://dx.doi.org/10.1016/S0043-1648(01)00573-7.
14. **Rabinowicz, E.** 1995. Friction and Wear of Materials. John Wiley and Sons. New York.
15. **Chattopadhyay, R.** 2001. Surface wear analysis treatment and prevention. USA. ASM-International.
16. **Daoud, A.; Abou El-khair, M.T.** 2010. Wear and friction behaviour of sand cast brake rotor made of A359-20 vol%SiC particle composites sliding against automobile friction material, Tribology International 43: 544-553.
http://dx.doi.org/10.1016/j.triboint.2009.09.003.
17. **Gurunath, P.V.; Bijwe, J.** 2007. Friction and wear studies on brake-pad materials based on Newly Developed Resin, Wear 263: 1212-1219.
http://dx.doi.org/10.1016/j.wear.2006.12.050.

M. Djafri, M. Bouchetara, C. Busch, S. Weber

EKSPERIMENTINIS STABDŽIŲ DISKŲ MEDŽIAGŲ IR JŲ KALADĖLIŲ TRIBOLOGINĖS SĄVEIKOS TYRIMAS

R e z i u m ė

Slydimo kontakte sąveikaujančių stabdžių disko-kaladėlės fizinio mechanizmo suvokimas reikalauja eksperimentinio disko-atraminės plokštelės modeliavimo priimant dėmesin tokius parametrus, kaip disko ir kaladėlės medžiagos rūšis, normalinės apkrovos dydis, slydimo greitis, kontaktavimo plotas ir aplinka. Šio tyrimo uždaviniu yra sukurti eksperimentinį disko-plokštelės poros eksperimentinį modelį tikslu geriau suprasti termo ir tribologinės sąveikos ypatumus. Tribometro SRV4 dėka gauti eksperimento rezultatai rodo, kad normalinė apkrova labai įtakoja stabdžių medžiagų tribologines savybes. Dilimo intensyvumas kinta priklausomai nuo medžiagų ir bandymo sąlygų. Drėgmė neturi jokios įtakos trinties temperatūrai. Sutinkamai su atliktais bandymais, chrominis plienas 100Cr6 yra charakterizuojamas trinties koeficientu ir temperatūra aukštesne nei ketaus FG25.

M. Djafri, M. Bouchetara, C. Busch, S. Weber

EXPERIMENTAL STUDY OF THE TRIBOLOGICAL BEHAVIOUR OF MATERIALS OF BRAKE DISC AND PADS

S u m m a r y

The understanding of the physical mechanisms involved in sliding contact disc - pads requires an experimental simulation represented by the couple disc-pin, taking into consideration a number of parameters such as the nature of the material of the disc and the pin, the applied normal load, the sliding speed, the contact area and the environment. The objective of this study consists to realize an experimental simulation model of the couple disc - pads in order to understand the evolution of the thermal and tribological behaviour. The experimental results obtained by means of the tribometer SRV4 show that the normal load has a significant effect on the tribological behaviour of the brake materials. The wear rate varies according to the materials and the essay conditions. The humidity has no influence on the variation of the friction temperature. According to the carried tests, the chromium steel 100Cr6 is characterized by a friction coefficient and temperatures higher than the cast iron FG25.

Keywords: Brake disc; friction material; wear rate; humidity.

Received March 18, 2014
Accepted August 20, 2014