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Effect of Nano Solid Lubricant in Automotive Brake Lining

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Abstract
Automotive brake pads consist of components that form materials such as binders, friction modifiers, reinforcing materials, lubricants and fillers. Factors such as particle size, morphologies, chemical and structural properties of the materials that make up the brake lining composites affect the stability and performance of the lining. In this study, effect of nano-sized graphite used as solid lubricant among brake lining materials on tribological properties was investigated. Three different specimens containing 3, 6 and 9 wt.% nano-sized graphite produced by powder metallurgy method. The specific wear rates and friction coefficients of specimens were obtained by using pin-on-disc type tribometer. The results showed that usage of nanomaterials in brake lining composites improved braking performance significantly. Additionally, it was observed that amount of graphite affected wear and friction properties of brake linings.

Keywords: brake lining, graphite, friction, wear,

1. Introduction

One of the most important parts of the brake system that affects the braking performance is the brake pad. Pads are widely used in automotive industry and other fields. The pads used in automotive brakes are made of a combination of many substances. Although the tribological properties of asbestos are very good, their use is prohibited due to their negative effects on human health. Today, friction materials that do not threaten human health are being produced [1, 2].

High friction coefficient and good abrasion resistance are among the required properties when determining friction material. However, friction materials must maintain a constant coefficient of friction under difficult conditions, such as high temperatures. It is also desirable that it forms a good friction pair does not damage the opposing material and exhibits a constant and high coefficient of friction under difficult thermal and mechanical influences [3,4,5].

Brake lining composites; multicomponent composites including binder materials, fibers (reinforcing elements), solid lubricants, friction regulators, abrasives and fillers. Graphite is a bright, soft material composed of layers of carbon atoms arranged in two-dimensional rings. Graphite can be easily machined, resistant to temperature and thermal shock, good thermal conductivity, resistant to almost all corrosive materials except strong oxidizing agents. A unique feature of graphite is its strength as temperature increases. Commonly used in low friction applications. The coefficient of friction between graphite and other materials depends on the counter material, surface roughness, shear rate, load and environmental conditions. Graphite, which has an important place in friction materials, keeps the percentage amount in the lining at appropriate values and ensures that the friction coefficient distribution is at the desired level [6].

Kim et al. [7] studied the tribological properties of asbestos-free organic brake pads containing graphite and antimony trisulfide (Sb_2S_3) in different volume ratios. Using a dynamometer for friction tests, they observed the effects of temperature, shear rate and applied pressure on the coefficient of friction according to the amount of both solid lubricants. As a result, they reported that the samples using both solid lubricants had better friction stability and lower speed accuracy than the sample containing a solid lubricant. They also emphasized that the lining sample containing high density graphite exhibited better feyd resistance than the others during the high temperature friction test.

Cho et al. [8] investigated the effect of three different solid lubricants (graphite, Sb_2S_3 and MoS_2) on the friction characteristics of brake friction materials. For this purpose, the other materials in the composition produced three different friction samples containing 10 vol.% graphite, 7 vol.% graphite + 3 vol.% Sb_2S_3 and 7 vol.% graphite + 3 vol.% MoS_2. They obtained tribological properties of friction materials using a brake dynamometer. As a result, they observed that friction materials containing Sb_2S_3 and graphite improve friction stability and fade resistance.

In this study, three different samples containing 3%, 6% and 9% nano graphite were produced while the other materials in the lining composition were fixed and their tribological properties were examined. The amount of graphite in the composition was found to affect the performance characteristics of the composite.

2. Materials and methods

2.1 Lining Production

In this study, the use of solid lubricant in nano sizes was investigated in the brake lining. Asbestos-free reinforcing materials were selected in the production of linings. During the production, the material ratio is based on the mass ratio. The powder contents of the lining sample are given in Table 1.

Table 1: Material content in the mixture (% by mass)

Lining additives	G3	G6	G9
Phenolic resin	20	20	20
Steel wool	5	5	5
Alumina	10	10	10
Brass shavings	6	6	6
Cu particle	8	8	8
Cashew	10	10	10
Graphite	3	6	9
Barite	38	35	32

The content of the samples was balanced with filler barite and coded as G3, G6 and G9 according to the amount of nano graphite. The materials used in the samples other than nano graphite and barite are constant.
The powder materials were weighed on a balance of 0.001 g before starting production. In order to ensure the homogeneity of the mixtures prepared in the ratios indicated in Table 1, the mixer was stirred at 300 rpm for 10 minutes. The prepared mixture was transferred to a 25.4 mm diameter mold and pre-formed by standing under 8 MPa pressure for 2 minutes. The samples were then pressed at 10 MPa pressure and 150 ° C for 10 minutes.

2.2 Test Equipment

The experimental set shown in Fig. 1 was used to determine the coefficient of friction-time of the samples. Experiment set; friction coefficient, brake force, hydraulic system pressure, pad surface temperature values can be transferred to the computer during the experiment.

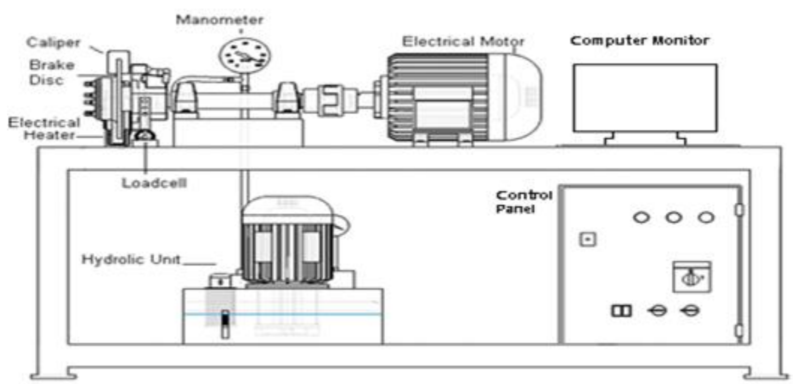

Fig 1: The brake lining test device [9]

In the test apparatus, a load cell is used to measure the frictional force between the lining and the brake disc during rotation. Thus, due to the frictional force arising from the pressure applied to the brake lining during the rotation of the disc, the rotation force of the lining is also measured electronically, considering the desire of the lining to rotate with the disk. In the test set, an inverter is available to use the brake disc at the desired speed. In order to carry out the tests in accordance with the standards, a non-contact (IR) thermometer, which can receive data every second to determine the disk surface temperature, can be operated at -50 to 1000 °C. 116 HB (41.86 HRA) hardness and 280 mm diameter gray cast iron brake disc was used in the test operations [9].

2.3 Test Conditions

The produced linings were placed on the tester and operated at 0.7 mPa pressure at a speed of 3 m/s to ensure that the friction surfaces overlap until 95% of the sample surface touches the disk surface. Experiments were carried out at 1.05 MPa lining surface pressure and 6 m/s speed. The friction coefficient and time values taken during the experiments are the arithmetic mean of the values obtained from the three samples produced with the same mixture and properties. The friction coefficient for each sample was recorded for 700 seconds at a pressure of 1.05 MPa at a speed of 6 m/s.

2.4 Friction Coefficient and Wear Tests

The friction coefficient was calculated with the formula given in equation (1) according to TS 555 considering the force applied to the linings and the friction force obtained from the test device [10].

$$\mu = \frac{f_s}{f_n} \qquad (1)$$

where; fs is the friction force and fn is the normal force applied to the lining surface and is calculated according to equation (2):

$$f_n = P \times A \qquad (2)$$

In equation (2); P is the applied pressure (MPa), and A is the friction surface area of the lining (mm2). The masses of each sample were determined before and after the friction test and the specific wear rate was calculated using the formula given in equation (3) according to TS 555 [10]:

$$V = \frac{1}{2.\pi.R} \cdot \frac{m_1 - m_2}{n.f_s.\rho} \quad (3)$$

where; the specific wear rate V (cm3/Nm), the distance between the center of the pad l and the center of the disc (m), m1 and m2 respectively the pre-test and post-test mass of the pad (g), n the total number of rotations of the disc during the test, ρ the density of the pad (g/cm3) and fs mean friction force (N). Friction stability (%) of the samples was calculated according to equation (4) [11].

$$FS = (\mu_{ort}/\mu_{maks}) \times 100 \quad (4)$$

Where, FS is the friction stability (%) of the sample, µort average friction coefficient, and µmax is the maximum friction coefficient obtained during the test.

2.5 Hardness and Density Measurements

In the hardness measurement process, the Rockwell hardness tester with a steel ball tip with a diameter of 2.5 mm was used. The applied load was taken as 62.5 kgf (612.9 N). Hardness measurements were made on the friction surface of the samples. It was calculated by taking the values from the middle and near edges of the sample surface. The arithmetic mean of three sample results with the same content was taken for each sample. Density measurements of samples were determined by Archimedes principle [9].

3. Results & Discussion

Three different composite linings were produced, containing 3%, 6% and 9% nano graphite. In the experiments, the arithmetic mean of the results obtained from five test samples with the same content was taken and fifteen samples were produced. The time dependent friction coefficient graphs of the samples are shown in Fig. 2, Fig. 3 and Fig 4.

One of the most important characteristics of the brake pads is that the change in the coefficient of friction is minimal due to the increase in interface temperature caused by friction during braking [12,13]. The friction stability (%) value should be as high as possible and close to 100, while the slope and fluctuations of the obtained curve should be minimum [11]. When the graphs are examined, the lowest friction coefficient is given as G3 coded sample containing 3% nano graphite with 0.3334 and the highest friction coefficient is G9 coded sample containing 0.415 with 10% nano graphite by mass. In the literature, it is emphasized that the coefficient of friction (µ) ranges from 0.1 to 0.7 depending on the friction force and disc-pad interface temperature [14].

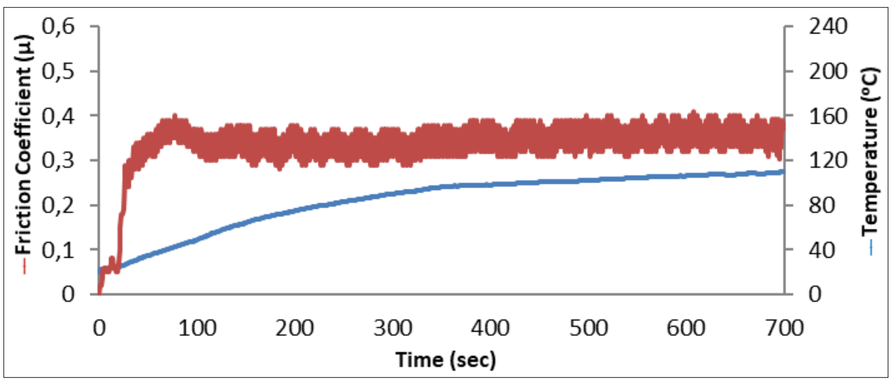

Fig 2: Time dependent friction coefficient graph of sample containing 3% nano graphite

Fig. 2 shows the change in coefficient of friction over time of an G3 coded sample containing 5% nano graphite by mass. The minimum temperature of the lining and disc interface is 22 °C and the maximum is 110 ° C. The average coefficient of friction is 0.33 and the friction stability is 80.48%.

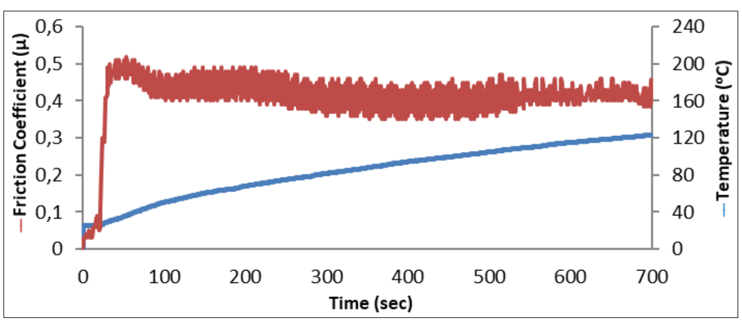

Fig 3: Time dependent friction coefficient graph of sample containing 6% nano graphite

Fig. 3 shows the change in coefficient of friction over time of the sample coded G6 containing 6% nano graphite by mass. The temperature at the disc interface with the lining is 25 °C minimum and 123 °C maximum. The mean coefficient of friction was 0.40 and the friction stability was 78.4%.

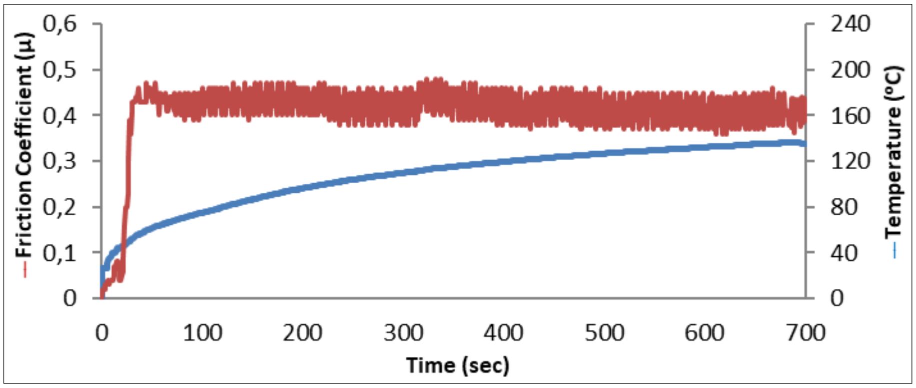

Fig 4: Time dependent friction coefficient graph of sample containing 9% nano graphite

Fig. 4 shows the change in coefficient of friction of G9 coded sample containing 9% nano graphite by time. The minimum temperature of the lining and disc interface is 26 ° C and the highest is 136 °C. The average coefficient of friction is 0.41 and the friction stability is 85.41%.
Ostermeyer [15] in his study of the dynamics of the coefficient of friction stated that the coefficient of friction will decrease depending on the increase in interface temperature.
When the graphs are analyzed, there is a continuous change in the friction coefficient. Anderson [16] stated that this was due to the periodic continuous change of heat into the contact areas on the disk surface during friction. This effect results in a constant change in the coefficient of friction. Moreover, Stachowiak and Batchelor [17] explain this situation by the coalescence and growth of the roughness on the surface of the friction pairs. In this case, a release state of adhesion is repeated continuously, which results in a continuous increase and decrease in the coefficient of friction.

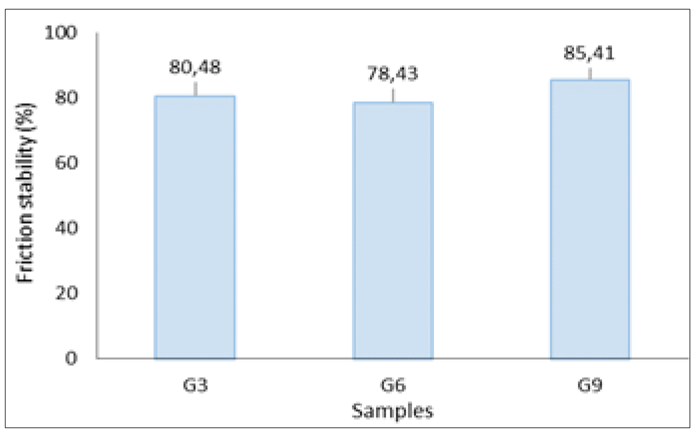

Fig 5: Friction stability of samples containing nano graphite (%)

When the friction test results were examined, it was seen that the temperature occurring at the interface between the pad and the disc directly affected the stability of the friction. It is desirable to have high friction stability in brake lining materials. The highest friction stability value was observed in the sample containing 9% nano graphite by mass.

Average friction coefficient, friction stability, density, hardness, specific wear rate and standard deviation values of brake lining samples are given in Table 2. Three different composite brake linings were produced containing 3%, 6% and 9% nano graphite.

Table 2: Typical characteristics of the brake lining used in this study

Sample code	Friction coefficient [μ]	Specific wear ratio [$cm^3 \times Nm^{-1}$]	Density [$g \times cm^{-3}$]	Rockwell hardness [HRL]	Friction stability [%]	Standard deviation
G3	0,33	0,144 $x10^{-6}$	1,77	85	80	0,059
G6	0,40	0,189 $x10^{-6}$	1,95	87	78	0,075
G9	0,41	0,214 $x10^{-6}$	2,12	89	85	0,073

The friction coefficient and specific wear rate of the brake friction materials are important parameters that affect the brake performance. In terms of braking performance, it is desired that the friction coefficient is high and the specific wear rate is low. According to TS 555 standard, the friction coefficient of brake linings should not be less than 0.25 [10]. When Table 2 is examined, it is seen that the sample with the highest friction coefficient is the G9 coded sample containing 9% nano graphite by mass. In addition, it was found that there is a direct correlation between the hardness and density of the samples. The relationship between hardness and density is consistent with the literature.

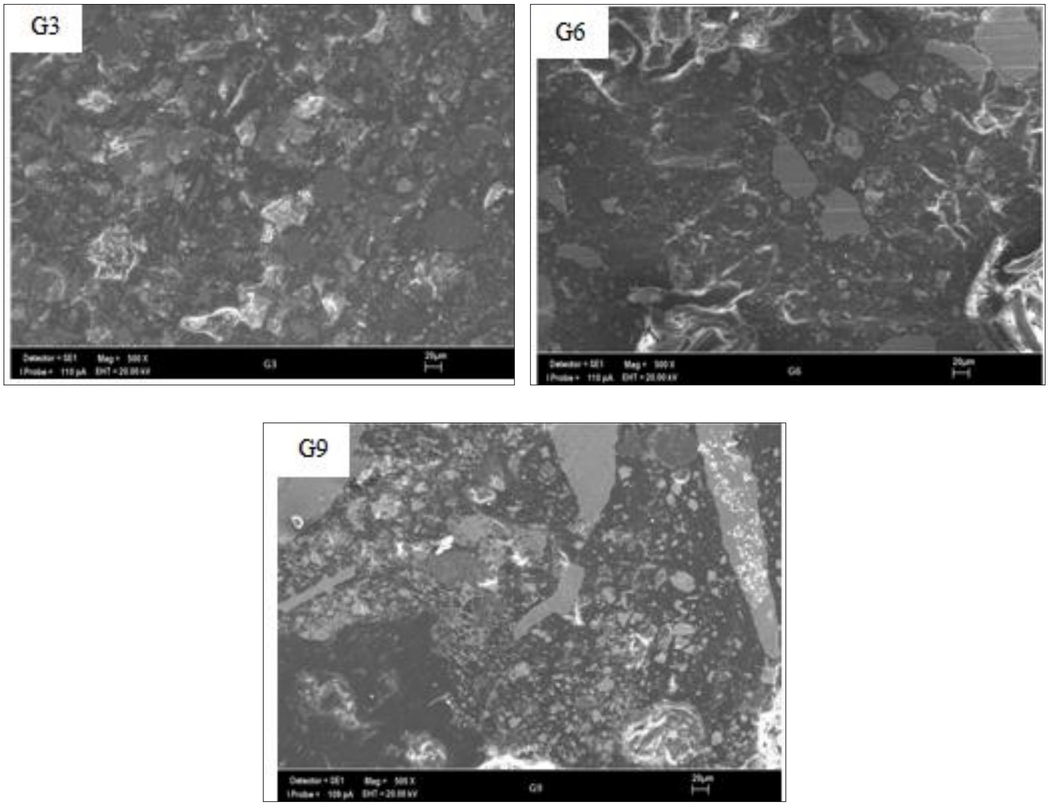

Fig 6: SEM morphologies of frictional surface of G3, G6 and G9 coded samples

SEM micrographs of the friction surface of braking pads are shown in the Fig. 6. On the macro and micro scale, the wear and friction characteristics of brake lining/disc depend on the formation, growth and disintegration of contact plateaus, shape adaptation and thermal-induced deformation [18, 19, 20]. When the SEM images of the friction surfaces are examined, it is seen that there are micro cracks, micro and macro cavities, coated friction layers showing adhesive wear and scratched friction marks showing abrasive wear. Compression of wear residues on the friction surface is the cause of friction film formation [21]. The lines in the slip direction on the lining surface indicate the presence of the friction film. It is also understood that the materials forming the lining content on the friction surfaces are actively involved in the friction. Compression of wear residues on the friction surface is the cause of friction film formation. The lines in the slip direction on the lining surface show the formation of the friction film. It is also understood that the materials forming the lining content on the friction surfaces are actively involved in the friction.

4. Conclusions

In this study, the effect of nano graphite on lining performance was investigated. In this context, 3%, 6% and 9% nano graphite was added to the lining content. Important findings obtained from this study;

- All samples produced according to the results obtained from friction and abrasion tests can be applied in industry, comply with the literature and comply with TS 555 standard.
- As the amount of graphite increased, the coefficient of friction increased. The highest coefficient of friction was found in the sample containing 9% nano graphite.
- The sample with 9% nano graphite showed the highest friction stability with 85%.
- There was a direct correlation between the hardness and density of the samples.
- The use of nano-sized graphite in the lining had a positive effect on the lining performance.

5. References

1. Khoni NAA, Ghazali CMR, Abdullah MMAB. Characterization of palm slag/waste tire dust reinforced polyester brake pad composite. Journal of Applied Physics, 2018, 2030(1).
2. Idris UD, Aigbodion VS, Abubakar IJ, Nwoye CI. Eco-Friendly Asbestos Free Brake-Pad: Using Banana Peels. Journal of King Saud University - Engineering Sciences. 2015; 27(2):185-192.
3. Bijwe J, Aranganathan N, Sharma S, Dureja N, Kumar R. Nano-abrasives in friction materials-influence on tribological properties. Wear. 2012; 296(0043-1648):693-701
4. Sugözü B. Friction and Wear Behavior of Fiber Reinforced Polymer-Matrix Composites Containing Ulexite and Pinus Brutia Cone Dust. European Mechanical Science. 2019; 3(3): 92- 96.

5. Hee KW, Filip P. Performance of ceramic enhanced phenolic matrix brake lining materials for automotive brake linings, Wear. 2005; 259(7–12):1088-1096.
6. Stadler Z, Krnel K, Kosmac T. Friction and wear of sintered metallic brake linings on a C/C-SiC composite brake disc. Wear. 2008; 265(3–4): 278-285.
7. [7] Seong, Jin, Kim., Min, Hyung, Cho., Keun, Hyung, Cho., Ho, Jang., (2007). Complementary effects of solid lubricants in the automotive brake lining. Wear, vol. 40, ISSN 0043-1648 p. 15-20.
8. [8] Min Hyung, Cho., Jeong , Ju., Seong Jin, Kim., Ho Jang., (2006). Tribological properties of solid lubricants (graphite, Sb2S3, MoS2) for automotive brake friction materials. Wear, vol. 260, ISSN 0043-1648 p. 855-860.
9. [9] Sugozu, I., Mutlu, I., Sugozu, B., (2018). The effect of ulexite to the tribological properties of brake lining materials. Polymer Composites 39(1): 55–62.
10. [10] TSE 555, (1992). Highway Vehicles-Brake System-Brake Pads for Friction Brake. Ankara, Turkey.
11. [11] Bijwe, J., Aranganathan, N., Sharma, S., Dureja, N., Kumar, R. (2012). Nano-abrasives in friction materials-influence on tribological properties. Wear, vol. 296, ISSN 0043-1648 p. 693-701.
12. Kim SJ, Jang H. Friction and wear of friction materials containing two different phenolic resins reinforced with aramid pulp, Tribology International. 2000; 33:477-484
13. M Eriksson F Bergman, S Jacobson. On the nature of tribological contact in automotive brakes, Wear. 2002; 252:26–36.
14. Moore DF. Princippless and Application Tribology, Oxford, Pergamon Press, 1975, 109-156.
15. Ostermeyer GP. On the dynamics of the friction coefficient, Wear. 2003; 254:043-1648, 852-858.
16. Anderson AE. Friction and Wear of Automotive Brakes, USA, Friction, Lubrication and Wear Technology ASM Handbook, 1992.
17. Stachowiak GW, ve Batchelor AW. Adhesion and adhesive wear, In: Engineering Tribology, Eds, A.B.D: Butterworth-Heinemann, 2001, 533-553.
18. EL Tayeb NSM, Liew KW. On the dry and wet sliding performance of potentially new frictional brake pad materials for automotive industry, Wear. 2009; 266:275-287
19. Eriksson M, Bergman F, Jacobson S. On the nature of tribological contact in automotive brakes,Wear, 2002; 252:26–36.
20. Sugozu I, Mutlu I, Sugozu B. The Effect of Colemanite on The Friction Performance of Automotive Brake Friction Materials. Industrial Lubrication and Tribology. 2016; 68(1): 92-98.
21. Shin MW, Cho KH, Lee WK, Jang H. Tribological Characteristics of Binder Resins for Brake Friction Materials at Elevated Temperatures. Tribology Letters. 2010; 38(2):161-168.