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Tribological Properties of Some Fatty Acids

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Abstract. The tribological properties of commonly available fatty acids like Palmatic acid, Oleic acid, Myristic acid, Lauric acid and Steric acid were tested. The fatty acids significantly influence the friction and wear characteristics of vegetable oils. Four ball wear test apparatus was used to carry out tribological tests by varying the normal load. Oleic acid shows the lower coefficient of friction at 100N load because due to the formation of physisorbed layer at low loads. Among the tested fatty acids the descending trend of coefficient of friction shown is as follows: Lauric acid, Myristic acid, Palmitic acid and Stearic acid. Optical microscopy was used to study the wear scar. It was found that the coefficient of friction and wear scar diameter of fatty acids are influenced by chain length, degree of saturation and polarity of fatty acids.

1. Introduction

The Unwisely usage, spillage and improper disposal of mineral oil based lubricants leads to the environmental degradation. It was estimated that 50% of the lubricant throughout the world ends up in the environment [1]. Vegetable oils, due to their good biodegradability, renewability and low toxicity along with high viscosity index, flash point, fire point and good oiliness characteristic have the potential to replace the mineral oil based lubricants [2-11].The use of coconut oil in various industrial applications like metal cutting fluid, transformer oil, greases, engine oil etc. not only reduces the degradation of the environment but also adds value to agricultural activities [12].Vegetable oil contains the triglyceride molecules, which are triesters of the fatty acid and glycerin [6, 12-14]. Figure 1 shows the structure of triglyceride molecule. The long and polar fatty acid chain of triglyceride structure provides high strength lubricant films that interact strongly with metallic surfaces and reduces the friction and wear [13, 15, 16].
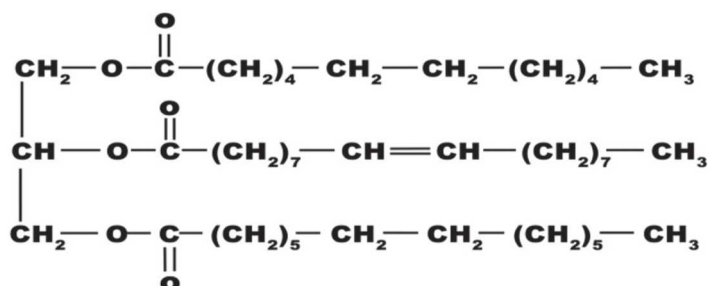

Figure.1 Structure of triglyceride molecule [13].

Apart from aforementioned good lubrication properties, vegetable oils also possess certain limitations like oxidation instability and poor pour point properties [5, 17, 18]. Experiments were conducted on oxidized coconut and palm oil taken from the four stroke engines, on the four ball tester. It was observed that with the oxidized oil, wear scar diameter increases due to the decrease in the viscosity of the oils [7]. Oxidative stability of vegetable oils is primarily limited by the degree of unsaturation. Unsaturated carbon–carbon bonds function as active sites for oxidation. A majority of triglyceride-based vegetable oils contain unsaturated fatty acids and are susceptible to oxidation. Oxidation of rapeseed oil generates other harmful acid products that may attack the metallic material and seals [19]. The oxidized vegetable oil has lower biodegradability than that of virgin vegetable oil [20]. Oxidation also leads to the reduction in the shelf life of the vegetable oils [5].The poor cold flow properties of the vegetable oils are due to the structure of triglyceride. The vegetable oils forms microcrystalline structure due to the stacking of triglyceride structures which reduces their mobility and ultimately oil gets freezes. Due to the poor cold flow properties, their use as industrial and automotive lubricants is restricted [6, 21]. Although the methods like chemical modifications, genetic modification and additive addition are used to overcome these limitations. But these methods have their own limitations [1, 22, 23].The aim of this research was to study the tribological behavior of fatty acids under the varying loads. Since there is a need to enhance the efficiency of vegetable oil based lubricants, it became important to undertake the experimental research in this field.

2. Methodology

Tribological properties of commonly available fatty acids like Lauric, Myristic, Palmitic, Stearic and Oleic fattyacids (CHEMSWORTH, Surat, India) along with Glycerin were tested. Some of the physiochemical properties of lubricant used for testing are listed in Table 1. The four ball wear test apparatus used for the experimentation was assembled at Department of Mechanical Engineering (IISc, Bangalore). The coefficient of friction was obtained by LUBE VIEW software. Figure 2 shows the four ball wear test apparatus. The optical stereo microscope (Leica Make) along with IMAGE J software was used for the determination of wear scar diameter. The standards followed for the experiment were ASTM D 5183 and D4172 for finding out coefficient of friction and wear preventive characteristics respectively.

Table 1. Main Physiochemical properties of fatty acids used in study [24].

Sr. No.	Property	Lauric Acid	Myristic Acid	Palmitic Acid	Stearic Acid	Oleic Acid	Glycerin
1	Dynamic Viscosity at 100˚C(cP)	2.5	3.26	4.13	5.08	4.03	0.28
2	Melting point(˚C)	44	55	64	70	14	18
3	Density (kg/m^3)	880	862	853	941	895	1260
4	Molecular Weight (g/mol)	200.32	228.38	256.42	284.48	282.47	92.09

The material of balls used for the experiment purpose was conformed to AISI 52100 standard. These balls are made up of chrome steel. The hardness of the balls is very high about 700-900 HV or 60-67 HRC. This high hardness is required in order to shield the balls from getting deformed. The chemical composition of the balls, apart from Iron includes Carbon 0.95 - 1.10 %, Chromium 1.30 - 1.60 %,

Manganese 0.25 % Max, Silicon 0.15 - 0.30 %, Phosphor 0.03 % Max and Sulphur 0.025 % Max. The diameter of ball is 12.7 mm.
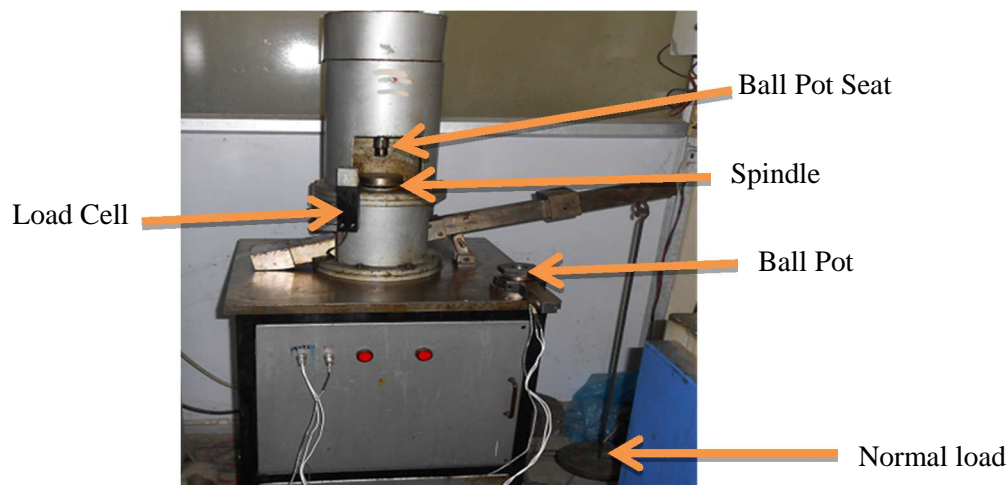
Figure 2. Four ball wear test apparatus and its various parts.

Experiments were performed by varying the Normal load from 100 N to 600 N. The temperature was kept at 75 ±2˚C whereas rpm was taken as 1200 ± 60. The duration of the each test was 1 hour. The temperature is measured with the help of Thermoresisitors. Four balls, collet (for holding the upper ball) and ball pot (for holding the three lower balls) were properly cleaned with the acetone and tissue paper such that there will be no trace of the solvent (acetone) left on the balls. The three balls were clamped in ball pot and fourth ball is tightened in collet and subsequently in the spindle of the four ball apparatus. 14 ml of lubricant to be tested is poured into the ball pot and then placed under the collet. Drive is setup for obtaining the spindle speed of 1200±60 rpm and timer is set for 60 minutes. Normal load is applied on the entire arrangement of four balls. While loading the arrangement shock loading was avoided. The heater is turn on and set to obtain a temperature of 75 ℃.

After the temperature stabilization, test was conducted. The value of coefficient of friction was obtained by the software. After one hour, drive motor and heater were switched off. Then ball pot is removed from the four ball wear apparatus. Balls were removed from the ball pot and cleaned. The optical microscope (magnification of 45X) was used for measuring the wear scar on the three balls of the ball pot. Two readings of each 3 scars were taken with the help of IMAGE J software. The two measurements were made diametrically at 90° to each other. Then the average of six readings was taken and reported as wear scar diameter in millimeters.

3. Results

3.1. Coefficient of friction
In Figure 3, glycerin is showing the highest value of coefficient of friction at all six loads as compared to the tested fatty acids. This is due to the fact that the fatty acids are having higher polarity and structural linearity than that of alcohols, hence surface coverage of glycerin is less whereas interaction zone of opposing adsorbate surfaces is deeper [17, 21, 25-27].The highest coefficient of friction shown by the glycerin is 0.092 at 300 N, whereas the lowest value of 0.062 was shown at 100 N. Further it was observed that among various fatty acids, the oleic acid is showing the lower coefficient of friction at 100 N. This is due to the formation of physisorbed layer at lower loads. At higher loads, due to the presence of double bond, oleic acid will give the higher coefficient of friction. The double bond contributes in the increment of the coefficient of friction due to the oxidation and irregularities in the stacking of the

physisorbed layer [26]. The lowest and the highest value of coefficient of friction shown by oleic fatty acid is 0.015 at 100 N and 0.057 at 600 N respectively.
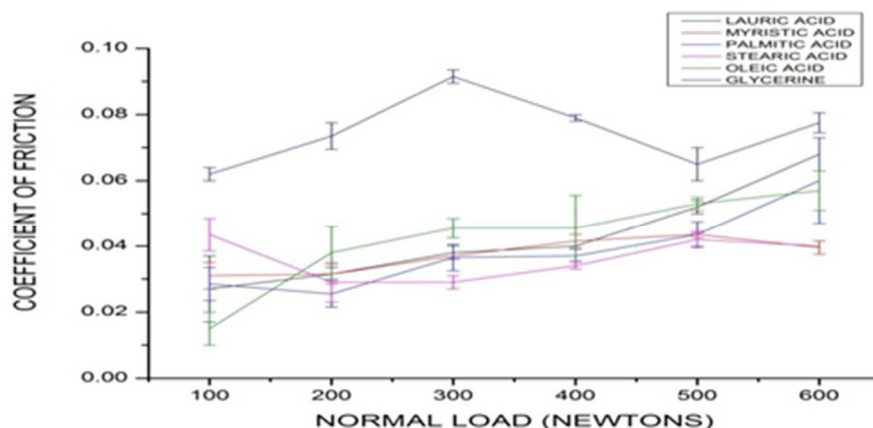
Figure 3. COF for glycerin, saturated fatty acid and a monounsaturated fatty acid at different loads.

Among various tested saturated fatty acids, the general trend in the descending order of their coefficient of friction is as follows- Lauric acid, Myristic acid, Palmitic acid and Stearic acid. The highest value of coefficient of friction for the Lauric acid is 0.068 at 600 N, whereas the lowest value is 0.027 at 100 N. The Lauric acid was followed by the Myristic fatty acid. This acid gave the least variation in coefficient of friction with respect to the applied normal load. The lowest value of coefficient of friction for the Myristic acid is 0.031 at 100 N whereas the highest is 0.044 at 400 N. The Myristic acid is followed by the Palmitic acid. The lowest and the highest value of the coefficient of friction for the palmitic fatty acid is 0.029 at 100 N and 0.060 at 600 N respectively. Stearic acid showed the lowest value of the coefficient of friction among all saturated fatty acids because its chain has higher number of carbon atoms. Due to this the molecular weight increases and so the Vander Waal forces also got increased. The size of physisorbed layer formed by fatty acids is of 2 nm [17].Highest coefficient of friction shown by the stearic acid is 0.044 at 100 N of normal load whereas the lowest value of coefficient of friction is 0.029 at 200 N and 300 N. Table 2 shows the values of coefficient of friction of various tested lubricants under different loads.

Table 2. Coefficient of friction for various fatty acids and glycerin at different loads

Load(N)	Lauric	Myristic	Palmitic	Stearic	Oleic	Glycerin
100	0.027	0.031	0.029	0.044	0.015	0.062
200	0.032	0.032	0.026	0.029	0.038	0.074
300	0.038	0.037	0.037	0.029	0.046	0.092
400	0.040	0.042	0.037	0.034	0.046	0.079
500	0.052	0.044	0.044	0.042	0.053	0.065
600	0.068	0.040	0.060	0.040	0.057	0.078

3.2. Wear Scar Diameter
Figure 4 shows that the maximum wear scar diameter was observed in the case of glycerin as compared to other fatty acids until the 400 N loads. This behavior of the glycerin is due to the low polarity and branched structure than that of fatty acids which subsequently leads to poor surface coverage. Hence this leads to higher wear scar diameter [21, 25]. The highest wear scar diameter of 1.5 mm was shown by glycerin at 600 N whereas lowest wear scar diameter of 0.5 mm was shown at 100 N. Among the

various fatty acids, the trend of wear scar diameter in descending order follows- oleic, Myristic, Lauric, palmitic and stearic acid upto a load of 400 N. In the case of the oleic acid, the high wear scar diameter is attributed to the presence of double bond, which is responsible for non-uniform stacking between the nonpolar chains due to bent and oxidation. Whereas in the case of saturated fatty acid, with increase in chain length wear scar diameter get reduced.

Among the fatty acids the wear scar diameter increases abruptly after the 400 N of the load. This is due to the fact that after this loads the physisorbed layer breaks, thus leading to higher coefficient of friction and wear scar diameter [28]. This load is called as the critical load [17]. This is evident from wear scar diameter at a load of 600 N in Figure 6. At 600 N of load, severe abrasive wear can be observed which occurs due to the result of breaking of the physisorbed layer. Among the fatty acids, the trend of wear scar diameter at 600 N in descending order is as follows – Palmitic acid (2.17mm), oleic acid (1.93 mm), Myristic acid (1.90 mm), Lauric acid (1.81) and stearic acid (1.77 mm). Table 3 shows the wear scar diameter for the various tested lubricants at different loads.

Table 3 Wear scar diameter (mm) for the various fatty acids and glycerin at different loads.

| Load (N)	Lauric	Myristic	Palmitic	Stearic	Oleic	Glycerin
100	0.27	0.26	0.25	0.26	0.29	0.5
200	0.33	0.34	0.31	0.29	0.41	0.61
300	0.41	0.4	0.34	0.33	0.55	0.89
400	0.52	0.61	0.46	0.47	0.88	1.13
500	0.58	1.51	1.51	1.4	1.66	1.22
600	1.81	1.9	2.17	1.77	1.93	1.5

From Figure 5 it can be observed that the wear scar diameter is highest in the case of glycerin. The fine, linear grooves in wear scar indicate that the wear is due to the mild abrasion [17]. In the case of all the saturated fatty acids, the wear scar is having the linear grooves thus indicating that the wear is primarily due to the abrasion. It can be seen from the Figure 6 that the wear scar diameter increases with the increase in the load. It can also be noticed that the wear scar observed in case of fatty acids, shows some traces of the adhesive wear with severe abrasion. By this it can be said that after a critical load (400 N), due to the increase in the localized pressure, temperature increases. Due to the increment in temperature, surface energy reduces leading to the breakdown of physisorbed layer [17, 21]. Thus the abrupt increase in the wear scar diameter after 400 N of load in Figure 4 can be justified.
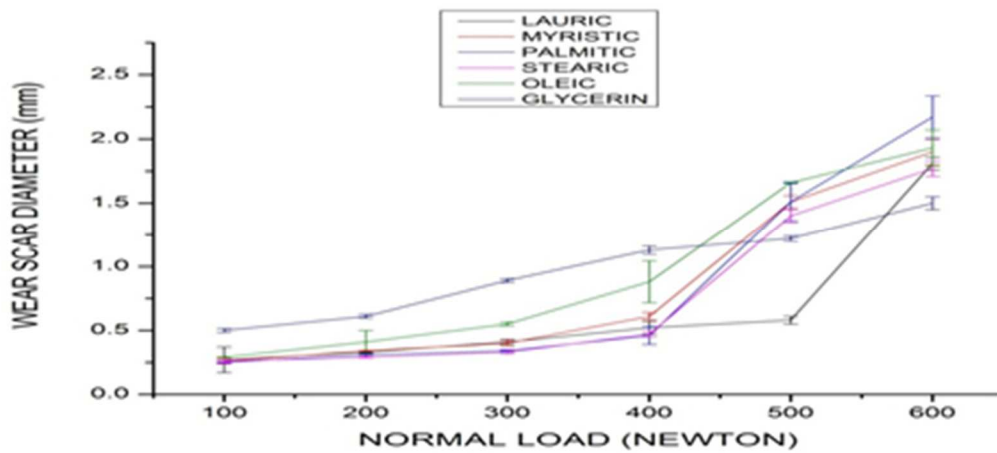
Figure 4. Wear scar diameter for glycerin, saturated, monounsaturated fatty acids at different normal Load
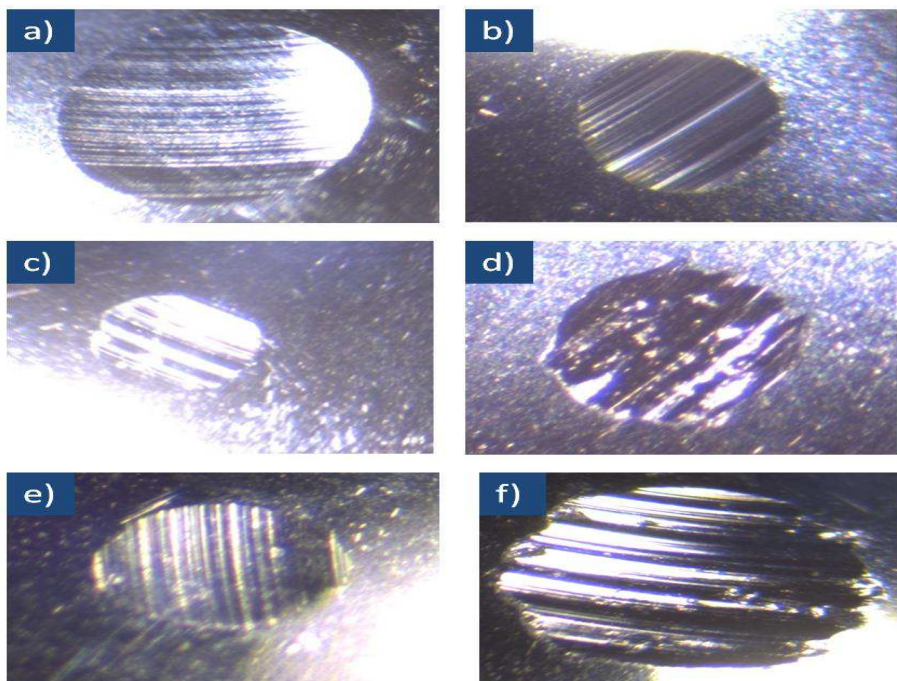
Figure 5. Wear scar for a) Glycerin (30X) b) Lauric acid (45X) c) Myristic acid (45X) d) Palmitic acid (45X) e) stearic acid (45X) f) oleic acid (45X) at 400 N.
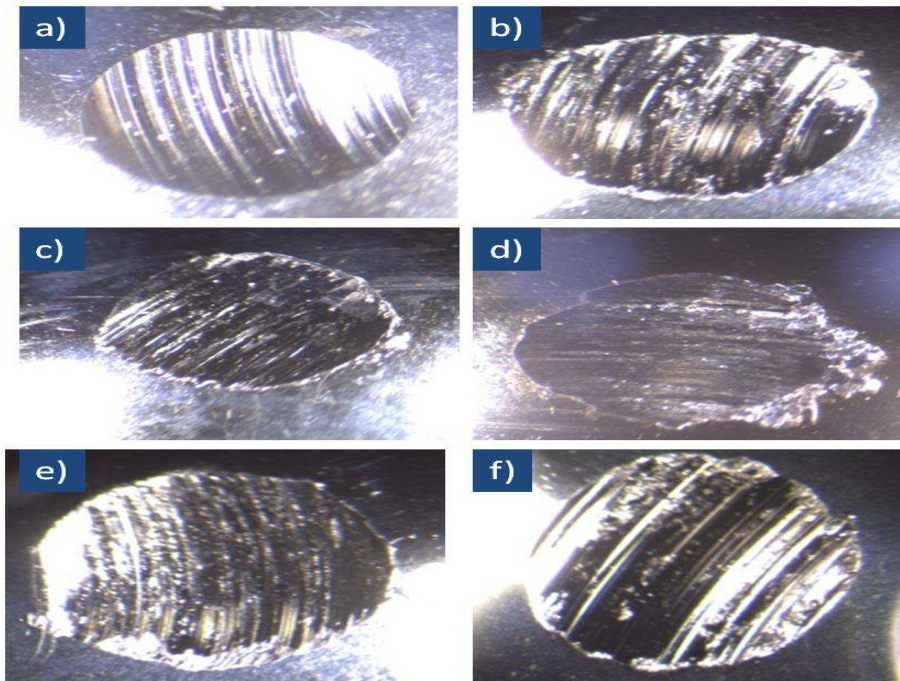
Figure 6. Wear scar for a) Glycerin (30X) b) Lauric acid c) Myristic acid   d)Palmitic acid e)

stearic acid f) oleic acid at 600 N and resolution of 25X.

4. Conclusion

- Surface coverage, polarity, chain length and degree of saturation of lubricant, influences the coefficient of friction and wear scar diameter of fatty acids.
- With the increase in the load whereas keeping the temperature and speed constant, the coefficient of friction and wear scar diameter for the fatty acids, molar solutions and vegetable oils generally increases.
- Fatty acids, their molar solution and tested vegetable oils in this study shows abrupt change in the wear scar diameter after the normal load of 400 N

References
[1]. Reeves C J, Menezes P L, and Jen T C 2015 *Tribology International* **90** 123–134.
[2]. Bartz W J 1998 *Tribology International* **31(1–3)** 35–47.
[3]. Wilson B 1998 *Industrial lubricant and tribology* **50 (1)** 6-15.
[4]. Norrby T 2003 *Industrial Lubrication and Tribology* **55 (6)** 268-274.
[5]. Mannekote J K, Kailas S V 2009 *Lubrication Science* **21(9)** 355–365.
[6]. Erhan S Z, Sharma B K, Adhvaryu A, Liu Z, 2006 *Journal of the American oil chemists' society*, **82 (2)**, 129-136.
[7]. Mannekote J K, Kailas S V 2011 Tribology *online* **6(1)** 76-82.
[8]. Stefanescu I, Calomi C R, Chirita G, University of Galati, Romania.
[9]. Robinovich G S K, Gresham I, Hakim S M, Krzanowski J, Veldhuis S C 2014 Lubricants **2** 113-123.
[10]. Weller D E Jr, Perez J M 2000 Lubrication engineering **56(11)** 39-44.
[11]. Alves S M, Barros B S, Trajano M F, Ribeiro K S B, Moura E 2013 *Tribology international*, **65**, 28-36.
[12]. Jagadeesh K. Mannekote and Satish V. Kailas, Department of Mechanical Engineering, IISc Bangalore.

[13]. Mannekote J K, Kailas S V 2012 *Journal of Material Research and Technology* **1(2)** 91-95.

[14]. Ishida S, Tsuboi R, Sasaki S 2012 *15th International Conference on Experimental Mechanics.*

[15]. Adhvaryu A, Erhan S Z, Perez J M 2004 *Wear* **257(3)** 359-367.

[16]. Syahrullail S, Zubil B M, Azwadi C S N, Ridzuan M J M 2011 *International Journal of Mechanical Sciences*, **53**, 549-555.

[17]. Stachowiak G W, Batchelor A W 2004 *Butter worth and Heinemann publications.*

[18]. Erhan S Z, Asadaurks S 2000 *Industrial crops and products* **11** 277-282.

[19]. Fox N J, Stachowiak G W, 2003 *Lubrication Engineering* **59(2)** 15–20.

[20]. Jayadasa N H, Nair K P 2006 *Tribology International* **39** 873–878.

[21]. Rudnick L R, 2009 *Chapter 16 second edition, CRC press London.*

[22]. Wagner H, Luther R, Mang T 2001 *Applied Catalysis A General* **221(1)** 429-442.

[23]. Jelsøe E 1997 **387(6638)** 845-7.

[24]. Noureddini H, Teoh B C, Clements L D 1992 **69** 1189-1191.

[25]. Simic R, Kalim M 2013 *Journal of mechanical engineering* **59 (12)** 707-718.

[26]. Bhushan B 1999 *John Wiley & Sons, Inc. New York.*

[27]. Cao Y, Yu L, Liu W 2000 *Wear* **244** 126–131.

[28]. Bowden F P, Tabor D 1964 *Oxford: Clarendon Press*.