

The Influence of Degumming Process on Tribological Behaviour of Soybean Oil

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ABSTRACT

This paper presents experimental results for pointing out the tribological behaviour of two soybean oils (crude and degummed) in comparison to the transmission oil T90, with the help of tests on a four ball machine. The following parameters were analyzed: the friction coefficient, the average wear scar diameter (WSD) and the flash temperature parameter (FTP). The test parameters are: load 100, 200 and 300 N, sliding speed 0.461, 0.576 and 0.691 m/s, test time being 60 minutes. The friction coefficient was higher for the two vegetable grades, but its values kept in the range of 0.025 – 0.095 for these vegetable oils, suggest a mixed or boundary regime that could be practically accepted. The WSD was lower for these two vegetable oils under lower load. For 300 N, WSD was higher than 0.4 mm for all tested oils. Flash temperature parameter (FTP) was better for the two grades of soybean oil at tests with 200 N. Under higher load (300 N), this parameter is kept within the range 800 – 1000 N/mm^{1.4}, for all tested oils. The conclusion is that, for all tested speeds and loads, the soybean oils (crude and degummed) have a better tribological behaviour.

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1. INTRODUCTION

Industrial use of soybean oil has increased and researchers are interested in enlarging its applications, including those for lubrication [1-3]. Vegetable oils have potential to be used as base stock for lubricants when blended with proper additives [4-6] or/and with a test-confirmed evaluation for the actual regime. The long fatty acid chains and presence of polar groups in vegetable oil structures make them capable to be used as lubricants in mixed or boundary regimes [7,8]. Specialists are interested in testing vegetal oils on four ball

machine in order to compare them with mineral and synthetic oils [9-12]. The wear scar diameters of epoxidized soybean oil and high-oleic soybean oil are affected by additivation (ZDDP), temperature, speed, load and interactions with the contacting surfaces [13]. Zhao et al. [14] investigated the tribological behaviour of two types of polymerized oils with high viscosities, synthesized by nitrogen plasma polymerization of soybean oil. The load-carrying capacities of polymerized oils reached 940.8 and 1049 N, respectively, higher than that of conventional soybean oil (646.8 N). For the tests performed on four ball tribotester, for different

oil temperatures (55 – 125 °C) and ASTM conditions (load 392 N, speed of 1200 rpm and tests during 60 minutes) for jatropha, engine and hydraulic oils as base lubricant, the coefficient of friction and wear scar diameter increase with the increase of the oil temperature. The FTP decreases with the increase in oil temperature. Jatropha oil has higher anti friction and anti-wear ability than engine oil and hydraulic oil and the highest value for FTP was for jatropha oil [15]. Four ball test is also reliable for evaluating changes of tribological characteristics in case of contaminated, oxidated or aged oils [16]. The advantages of the soybean oil would be: even if the dynamic viscosity is lower than some commonly used lubricants, its viscosity is less dependent on temperature [17-19], thus, its viscosity index is bigger and their pressure coefficient for viscosity has intermediate values (10 – 20 GPa⁻¹) [20], low evaporation loss, a better lubricity (the oil behaviour in boundary regime makes the wear scar diameter smaller, even if the value of the friction coefficient is higher as compared to other oils), the flash point is higher, offering safer transportation and exploitation and, also, the costs are acceptable for obtaining the oil and the maintenance of the system it is introduced [17,21,22].

This paper presents experimental results for pointing out the influence of the degumming process of the soybean oil.

2. TESTED SOYBEAN OILS AND METHODOLOGY OF INVESTIGATION LUBRICATING CAPABILITY

The two grades of soybean oils (crude – Table 1 and degummed) were tested on a four ball machine and there were analysed the following parameters: the friction coefficient, the average wear scar diameter (WSD) and the flash temperature parameter (FTP). The degumming process of this soybean oil is done at Prutul SA Galati and prevent oil to form gum deposit and to ferment [23]. Figure 1 presents the four ball machine. The design allowing for a maximum load of 6000 N, in agreement with the standard SR EN ISO 20623:2004 [24]. The main elements are: electric motor (1), machine body (2), loading system (3), electric pannel for tuning and monitoring (4), support (5).

Table 1. Chemical composition in fat acids of the crude soybean oil (wt. %).

Fat acid	Symbol	Concentration
Miristic	C14:0	0.11
Palmitic	C16:0	12.70
Palmitoleic	C16:1	0.13
Heptadecanoic	C17:0	0.05
Heptadecenoic	C17:1	0.06
Stearic	C18:0	5.40
Oleic	C18:1	21.60
Linoleic	C18:2	52.40
Linolenic	C18:3	5.70
Arahidic	C20:0	0.25
Eicosenoic	C20:1	0.20
Behenic	C22:0	0.50
Erucic	C22:1	0.16
Lignoceric	C24:0	0.20



Fig. 1. The four ball machine.

The balls have a diameter of 12.7 mm (± 0.0005 mm) and $Ra = 0.02 - 0.03$ μm , were delivered by SKF. The test balls are lime polished, made of chrome alloyed steel (Table 2), with 64 – 66 HRC.

Table 2. Chemical composition (wt. %).

Material	C	Cr	Mn	Si	S	P
Steel grade EN31	1.0	1.3	0.5	0.35	0.05	0.05

The test parameters are: load 100, 200 and 300 N, sliding speed 0.461 m/s (1200 rpm), 0.576 m/s (1500 rpm) and 0.691 m/s (1800 rpm), test duration of 60 minutes.

3. RESULTS

This study included the following parameters: the wear scars diameters (a value of was obtained by averaging two diameters for each three fixed balls, one along the sliding and the other perpendicular to it), the friction coefficient and the flash temperature parameter. Four ball machine is intense used for characterizing lubricants as comparisons are easy to make and it is also convenient to point out difference in ranking lubricants, for improving additivation and limiting carrying capacities [5,7,25]. Rico et al. [26] obtained a very sharp increase of WSD, from 0.46 to 2.85 mm, when passing from 126 to 160 kgf for a mineral oil on a four ball tribotester. Jayadasa et al. [27] determined a WSD of 0.54 mm for coconut oil used as lubricant in a four ball tribotester, at 1236 N, higher than the rapeseed oil.

In this study, the smallest values for the WSD was obtained for the crude soybean oil, followed by the degummed soybean oil and the transmission oil T90 (Fig. 2). Comparing the values obtained for all three tested oils, the two vegetable oils produced lower values of WSD for low load (100 and 200 N). For the load of 300 N, WSD are all above 0.4 mm, for all tested oils. The crude soybean oil produced a WSD less sensitive to the speed for lower loads of 100 and 200 N, same behaviour was noted for the transmission oil T90 for $W = 200$ N and even for $W = 300$ N.

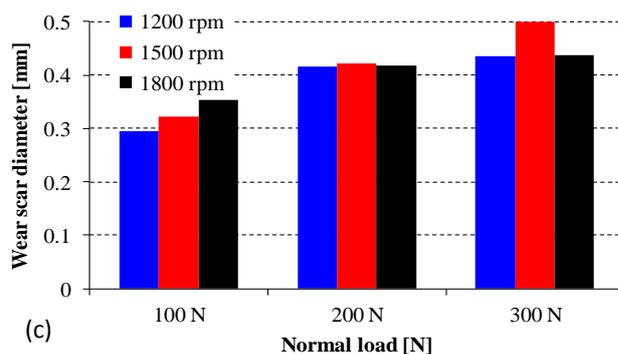
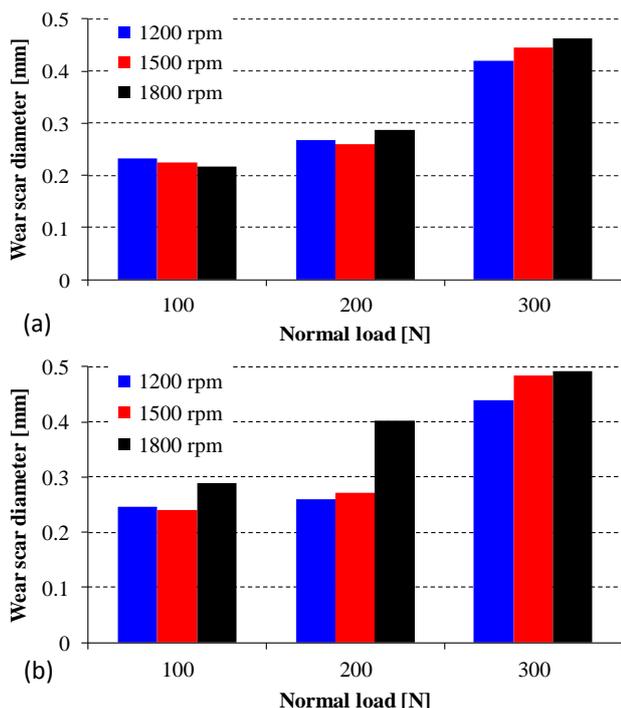


Fig. 2. Values of wear scar diameter as a function of load and speed: (a) crude soybean oil, (b) degummed soybean oil and (c) transmission oil T90.

Tests done on the four ball machine pointed out low values of friction coefficient as prove of a very thin lubricant film, at least for the test parameters (normal load 100 – 300 N and sliding speed, 0.461, 0.576 and 0.691 m/s) and acceptable values of WSDs (see Fig. 3).

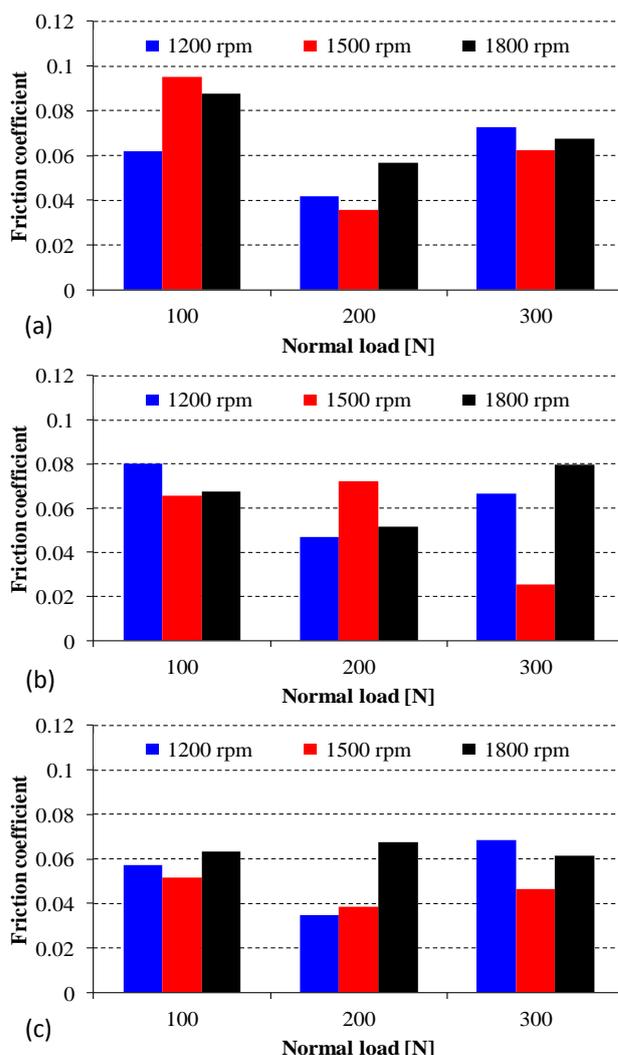


Fig. 3. Values of friction coefficient as a function of load and speed: (a) crude soybean oil, (b) degummed soybean oil and (c) transmission oil T90.

The FTP (flash temperature parameter) is used for ranking the lubrication capability of oils under high load that develop high temperatures in contact, but also for fluids involved in forming and cutting tools. Flash Temperature Parameter of a fluid is the lowest temperature that it can vaporize to form an ignitable mixture in air [28]. Higher FTP is a positive point of lubricant oils because they do not evaporate if temperature is low and their film thickness is still enough to reduce the heat flux generated by friction. In other words, low friction and temperature will exist even in a mixed or boundary regime. Analyzing all three parameters here presented, one may conclude that a combination of (low friction coefficient, low wear scar diameter and high flash temperature parameter) offers a highly reliable lubricant in contact. But this capability could be “transferred” to actual systems with prudence, as laboratory conditions (especially those for four ball tests) are well controlled.

The “flash-temperature” concept is a means of accounting for the local maxima of frictional heat flux. Several factors influence the surface temperature: rubbing time, speed, load, temperature of lubricant and environment and the configurations characterizing the friction couple, including size, shape, texture quality, and their physical and mechanical properties [29].

This single number (FTP) expresses the critical flash temperature above which a given lubricant will fail under given conditions [30].

According to equation (1), there exist an inverse proportionality between FTP and wear scar diameter, under constant load:

$$FTP = \frac{W}{d^{1.4}} \quad (1)$$

where: W is the load on the machine axle in N, and d is the WSD in mm; thus, the unit of FTP being $N/mm^{1.4}$ in this paper.

A higher value of FTP number means the lubricant stability in a particular condition of exploitation. The lower values causes breakdown of lubricant film, hence WSD increases. Masjuki et al. [25] proposed a mathematical model, including speed and test duration, but the equation (1) is more used to express the lubricating contact capability, this will be used in this paper for evaluating the three tested oils.

In this study, at lower load ($W = 100$ N and $W = 200$ N), the highest values were obtained for the crude soybean oil; for the degummed soybean oil the values were just a little bit lower, but for all tests (Fig. 4).

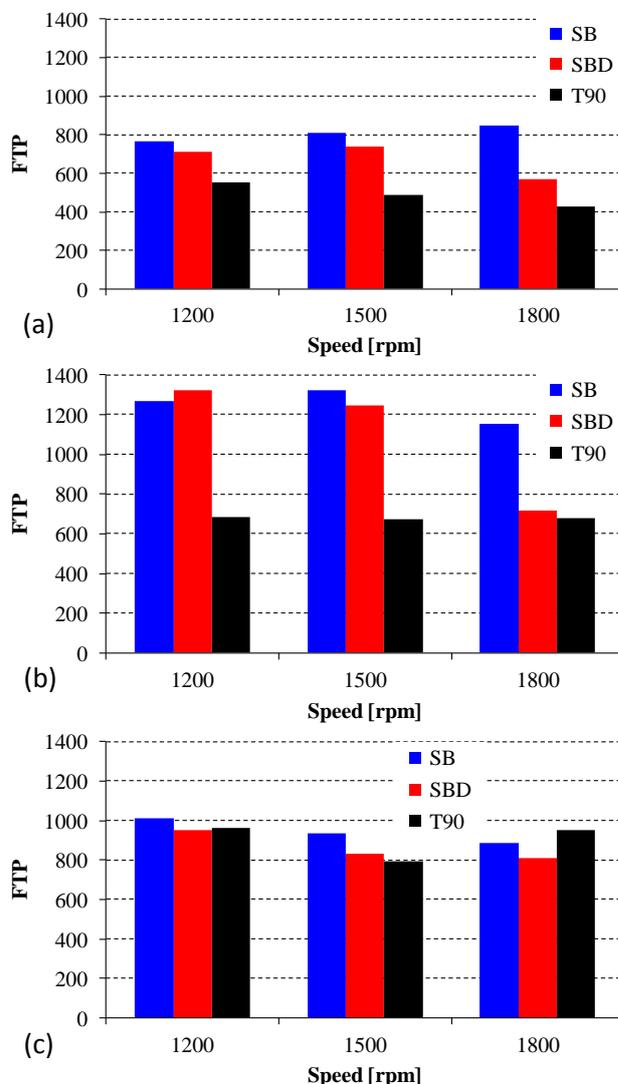


Fig. 4. FTP for the tested oils, for different rotational speeds and load: (a) 100 N, (b) 200 N and (c) 300 N.

Under load $W = 100$ N, the difference in this parameter could be acceptable for actual applications, one may notice that the increase of the load to $W = 200$ N differentiate the transmission oil to the vegetable oils. Only under the highest tested speed, FTP of the degummed soybean oil is slightly higher than that of the transmission oil, suggesting that low loads and high speed could be a solution for using this grade of soybean oil. Under $W = 300$ N, the difference in values of FTP is lower and all are kept above $800 N/mm^{1.4}$, the values being only with 20 % over $800 N/mm^{1.4}$, indifferently of

speed. For these soybean oils, larger values than 1000 N/mm^{1.4} were obtained for the intermediate value of load ($W = 200$ N), especially for 1200 and 1500 rpm. The transmission oil has a more pronounced tendency of increase the FTP with load and less with speed. This difference in the behaviour of these two categories of oils (mineral and vegetable) points out the necessity of testing the lubricating capabilities and not estimating by general tendency of a lubricant class.

4. CONCLUSIONS

Both grades of soybean oil had exhibited a good behaviour as lubricant, for smaller ranges of speed and load, as compared to the transmission oil T90.

Values for friction coefficient were higher for the two vegetable grades, especially with load of 100 N and for the crude soybean oil, meaning the regime is either a mixed or a boundary one. The WSD was lower for these two vegetable oils under loads of 100 and 200 N. For a load of 300 N, WSD was higher than 0.4 mm for all tested oils. Flash temperature parameter (FTP) was better for the soybean oils, its values exceeding 1200 N/mm^{1.4} for these oils under 200 N. For $W = 100 - 200$ N, FTP for the transmission oil was in the range 550 – 680 N/mm^{1.4}. Under higher load ($W = 300$ N), this parameter is kept within the range 1000 – 1200 for all tested oils, only for speeds of 0.461 m/s (1200 rpm) and 0.576 m/s (1500 rpm).

A synthesis conclusion is that these two vegetable oils could be used in mild regimes (load and speed), and the degumming process does not affect in a significant manner the tribological behaviour of the soybean oil, at least for the tested conditions. Of course, tests have to continue on how these oils keep the lubricating capabilities in time. The test duration of 60 minutes is far to be the duration of an actual application. But the results obtained for the soybean oils are promising as they have not been additivated, yet.

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REFERENCES

- [1] S.Z. Erhan, *Industrial Uses of Vegetable Oils*. Peoria: AOCS Press, 2005.
- [2] A. Campanella, E. Rustoy, A. Baldessari and M. Baltanas, 'Lubricants from chemically modified vegetable oils', *Bioresource Technology*, vol. 101, pp. 245-254, 2010.
- [3] P. Nagendramma and S. Kaul, 'Development of ecofriendly/biodegradable lubricants: An overview', *Renewable and Sustainable Energy Reviews*, vol. 16, pp. 764-774, 2012.
- [4] L.A. Quinchia, M.A. Delgado, C. Valencia, J.M. Franco and C. Gallegos, 'Viscosity modification of different vegetable oils with EVA copolymer for lubricant applications', *Industrial Crops and Products*, vol. 32, pp. 607-612, 2010.
- [5] F.A. Gebig, B. Helman, Y. Gebig and H. Haefke, 'A comparative study of the tribological properties of vegetable oils', in *Proceedings of 2nd World Tribology Congress*, 03-07.09.2001, Vienna, Austria, Paper A-21-08-159.
- [6] H.M. Mobarak and M. Chowdhury, 'Tribological performance of hydrogenated amorphous carbon (a-C: H) DLC coating when lubricated with biodegradable vegetal canola oil', *Tribology in Industry*, vol. 36, no. 2, pp. 163-171, 2014.
- [7] A. Adhvaryu, S.Z. Erhan and J.M. Perez, 'Tribological studies of thermally and chemically modified vegetable oils for use as environmentally friendly lubricants', *Wear*, vol. 257, no. 3-4, pp. 359-367, 2004.
- [8] D. Dowson, M. Priest, C.M. Taylor, P. Ehret and T.H.C. Childs, *Lubrication at the Frontier. The Role of the Interface and Surface Layers in the Thin Film and Boundary regime*. Amsterdam: Elsevier Science B.V., 1999.
- [9] M. Shahabuddin, H.H. Masjuki, M.A. Kalam, M.N.K. Bhuiya and H. Mehat, 'Comparative tribological investigation of bio-lubricant formulated from a non-edible oil source (jatropha oil)', *Industrial Crops and Products*, vol. 47, pp. 323-330, 2013.
- [10] S. Syahrullai, F.H. Ani, I. Golshkhouh: *Wear resistance characteristic of vegetable oil*, in: *Proceedings of the 2nd International Conference on Sustainable Materials Engineering*, 26-27.03.2013, Penang, Malaysia, pp. 44-47.
- [11] M. Habibullah, H.H. Masjuki, M.A. Kalam, A.M. Ashraful, M.A. Habib and H.M. Mobarak, 'Effect of bio-lubricant on tribological characteristics of steel', *Procedia Engineering*, vol. 90, pp. 740-745, 2014.
- [12] C. Boshui, Z. Nan, L. Kai and F. Jianhua, 'Enhanced biodegradability, lubricity and corrosiveness of

- lubricating oil by oleic acid diethanolamide phosphate', *Tribology in Industry*, vol. 34, no. 3, pp. 152-157, 2012.
- [13] K. Cheenkachorn, 'A study of wear properties of different soybean oils', *Energy Procedia*, vol. 42, pp. 633-639, 2013.
- [14] X. Zhao, J. Yanga, D. Taob and X. Xua, 'Tribological study of nitrogen plasma polymerized soybean oil with nitrogen heterocyclic structures', *Industrial Crops and Products*, vol. 51, pp. 236-243, 2013.
- [15] I. Golshokouha, S. Syahrullail and F.N. Ani, 'Influence of normal load and temperature on tribological properties of jatropha oil', *Jurnal Teknologi*, vol. 71, no. 2, pp. 145-150, 2014.
- [16] M.A. Kalam, H.H. Masjuki and L.A. Memon, 'Wear and friction characteristics of waste vegetable oil contaminated lubricants', in *Proceedings of National Tribology Conference Rimba Ilmu*, 04-05.05.2009, University of Malaya, Paper NTC-2009-019.
- [17] L.C. Solea, 'Contributions in studying the rheological and tribological behavior of biodegradable lubricants with vegetable oils as stock base oil', *PhD thesis*, "Dunarea de Jos" University, Galati, 2013.
- [18] N. Yilmaz, 'Temperature-dependent viscosity correlations of vegetable oils and biofuel-diesel mixtures', *Biomass and Bioenergy*, vol. 35, pp. 2936-2938, 2011.
- [19] R. Wang and T.P. Schuman, 'Oxidation and low temperature stability of polymerized soybean oil-based lubricants', *Thermochimica Acta*, vol. 601, pp. 9-16, 2015.
- [20] G. Biresaw and G.B. Bantchev, 'Pressure viscosity coefficient of vegetable oils', *Tribology Letters*, vol. 49, pp. 501-512, 2013.
- [21] C. Ting and C. Chen, 'Viscosity and working efficiency analysis of soybean oil based bio-lubricants', *Measurement*, vol. 44, pp. 1337-1341, 2011.
- [22] Z. Liu, B.K. Sharma, S.Z. Erhan, A. Biswas, R. Wang and T.P. Schuman, 'Oxidation and low temperature stability of polymerized soybean oil-based lubricants', *Thermochimica Acta*, vol. 601, pp. 9-16, 2015.
- [23] E.M.J. Deffense, *From organic chemistry to fat and oil chemistry*, Oléagineux Corps Gras Lipides/OCL, Vol. 16, pp. 14-24, 2009.
- [24] EN ISO 20623 *Petroleum and related products. Determination of the extreme-pressure and anti-wear properties of fluids. four ball method (European conditions)*, 2003.
- [25] H.H. Masjuki, M.G. Saifullah, M. Husnawan, M.S. Faizul and M.G. Shaaban, 'Flash temperature parameter number prediction model by design of tribological experiments for basestock mineral oil containing palm olein and aminephosphate additives', in *Proceedings of WTC2005, World Tribology Congress III*, 12-16.09.2005, Washington, USA, Paper WTC2005-63193.
- [26] E. Fernandez Rico, I. Minondo and D. Garcia Cuervo, 'The effectiveness of PTFE nanoparticle powder as an EP additive to mineral base oils', *Wear*, vol. 262, pp. 1399-1406, 2007.
- [27] N.H. Jayadasa, K. Prabhakaran Nair and G. Ajithkumar, 'Tribological evaluation of coconut oil as an environment-friendly lubricant', *Tribology International*, vol. 40, pp. 350-354, 2007.
- [28] H. Blok, 'The flash temperature concept', *Wear*, vol. 6, no. 6, pp. 483-494, 1963.
- [29] W.D. Marscher, 'A Critical Evaluation of the Flash-Temperature Concept', *ASLE Transactions*, vol. 25, no. 2, pp. 157-174, 1982.
- [30] E. Fernández Rico, D. García Cuervo and A. Hernández Battez, 'Tribological behaviour of polyalphaolefins: wear and rolling contact fatigue tests', *Journal of Synthetic Lubrication*, vol. 19, no. 4, pp. 315-325, 2003.