

Lecture Notes in Intelligent Transportation and Infrastructure  
Series Editor: Janusz Kacprzyk

Kasthurirangan Gopalakrishnan  
Olegas Prentkovskis  
Irina Jackiva  
Raimundas Junevičius *Editors*

# TRANSBALTICA XI: Transportation Science and Technology

Proceedings of the International  
Conference TRANSBALTICA,  
May 2–3, 2019, Vilnius, Lithuania

 Springer

# **Lecture Notes in Intelligent Transportation and Infrastructure**

## **Series Editor**

Janusz Kacprzyk, Systems Research Institute, Polish Academy of Sciences,  
Warszawa, Poland

The series "Lecture Notes in Intelligent Transportation and Infrastructure" (LNITI) publishes new developments and advances in the various areas of intelligent transportation and infrastructure. The intent is to cover the theory, applications, and perspectives on the state-of-the-art and future developments relevant to topics such as intelligent transportation systems, smart mobility, urban logistics, smart grids, critical infrastructure, smart architecture, smart citizens, intelligent governance, smart architecture and construction design, as well as green and sustainable urban structures. The series contains monographs, conference proceedings, edited volumes, lecture notes and textbooks. Of particular value to both the contributors and the readership are the short publication timeframe and the world-wide distribution, which enable wide and rapid dissemination of high-quality research output.

More information about this series at <http://www.springer.com/series/15991>

Kasthurirangan Gopalakrishnan ·  
Olegas Prentkovskis · Irina Jackiva ·  
Raimundas Junevičius  
Editors

# TRANSBALTICA XI: Transportation Science and Technology

Proceedings of the International Conference  
TRANSBALTICA, May 2–3, 2019, Vilnius,  
Lithuania

 Springer

*Editors*

Kasthurirangan Gopalakrishnan  
SRM University-AP  
Amaravati, India

Iowa State University  
Ames, IA, USA

Irina Jackiva  
Transport and Telecommunication Institute  
Riga, Latvia

Olegas Prentkovskis  
Vilnius Gediminas Technical University  
Vilnius, Lithuania

Raimundas Junevičius  
Vilnius Gediminas Technical University  
Vilnius, Lithuania

ISSN 2523-3440

ISSN 2523-3459 (electronic)

Lecture Notes in Intelligent Transportation and Infrastructure

ISBN 978-3-030-38665-8

ISBN 978-3-030-38666-5 (eBook)

<https://doi.org/10.1007/978-3-030-38666-5>

© Springer Nature Switzerland AG 2020, corrected publication 2020

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG  
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

# Contents


<b>The Survey of Transport Vehicle Delays at the Traffic Light Intersections of the Urban Arterial Streets</b> .....	1
Oleksandr Stepanchuk, Andriy Belyatynskiy, and Olexander Pylypenko	
<b>Supporting of Ecological Safety of Run-off from the Territory of Objects of Road Infrastructure, Contaminated by Petroleum Products</b> .....	10
Valentina Iurchenko, Oxana Melnikova, Larysa Mykhailova, Elena Lebedeva, and Nikolay Mikhalevich	
<b>Comparison of FRAM and CPN Approaches for Analysis of Incidents in Aerodrome Traffic</b> .....	18
Paulina Rutkowska, Malwina Okulicz, and Jacek Skorupski	
<b>Influence of the Information Disruptions in A-CDM System on the Time of Readiness for Take-off</b> .....	29
Malwina Okulicz, Paulina Rutkowska, and Jacek Skorupski	
<b>Degradation of Transport Infrastructure Under Breach of Drainage: Strain and Corrosion Damage</b> .....	40
Pavlo Maruschak, Andriy Sorochak, Denys Baran, and Olegas Prentkovskis	
<b>Images of Vibrations of a Passing Railway Vehicle</b> .....	47
Rafał Burdzik and Paweł Słowiński	
<b>Application of Modern Monitoring Measures in Lithuanian Dangerous Cargo Transportation</b> .....	57
Erikas Mazėtis and Nijolė Batarlienė	
<b>User Acceptance of Driverless Public Transportation: A Questionnaire-Based Study in Budapest</b> .....	67
Mohammad Maghrour Zefreh and Adam Torok	

<b>Assessment of Crash Risks at Highway Access Points with Restricted Sight Visibility</b> .....	76
Sujata Basu and Pritam Saha	
<b>Basic Methods to Support City Bus Fleet Conversion Towards a 100% Electric Bus Fleet</b> .....	89
Krzysztof Krawiec	
<b>Analysis of Pedestrian Movements on Sidewalks: A Case Study in Kolkata, India</b> .....	99
Deotima Mukherjee, Soumyadip Das, Pritam Saha, and Sudip K. Roy	
<b>Simulation Processes of Construction of Optimal Routes for the Delivery of Goods by Road Transport on Urban Road Network in Mountainous Cities</b> .....	112
Viktor Danchuk, Talal Ameen, Olena Bakulich, and Vitaliy Svatko	
<b>Analysis of Quality of Car Rental Services Following Example of “Citybee”</b> .....	122
Kristina Čižiūnienė and Rolandas Vitkūnas	
<b>Assessment of the Interoperability of Railway and Maritime Transport in Lithuania</b> .....	132
Aldona Jarašūnienė, Vladislav Lagunovič, and Kristina Čižiūnienė	
<b>Modernizing of the Rail Transport Curriculum and Study Process</b> . . . .	139
Enno Lend and Wladimir Segercrantz	
<b>Comparison of Studies of Dangerous Cargo Flow Distribution Between Rail and Road Transport</b> .....	151
Gediminas Vaičiūnas, Olha Porkuian, and Jelena Nozhenko	
<b>Applying the Business Model Canvas to Increase Enterprise Competitiveness: A Case Study of Transport Company</b> .....	158
Virgilija Vasilienė-Vasiliauskienė, Aidas Vasilis Vasiliauskas, Monika Donculaitė, and Ieva Meidutė-Kavaliauskienė	
<b>Comparison of Railway Routes Enabling Freight Transportation from the Eastern Border of Poland to the West</b> .....	171
Wojciech Kamiński and Aleksander Śladkowski	
<b>The Impact of the Bioethanol Fuel on the Exhaust Gas Emission of a Two-Stroke Engine</b> .....	185
Keio Kūit, Risto Ilves, Arne Kūit, and Jüri Olt	
<b>Research of Mathematical Model of Movement of Six-Axle Locomotives with Controllable Wheelsets Installation</b> .....	193
Serhii Kliuiev, Dmytro Bobyr, Gediminas Vaičiūnas, and Stasys Steišūnas	

<b>Use of Container and Piggyback Services in International Railway Traffic</b> .....	521
Mykola Kurhan, Laura Černiauskaitė, and Dmytro Kurhan	
<b>Influence of Parameters of Electric Locomotive on its Critical Speed</b> .....	531
Irina Klimenko, Jan Kalivoda, and Larysa Neduzha	
<b>The Environment of Extremist Textual Content Threatening Transportation Systems</b> .....	541
Olga Zervina	
<b>Decision-Support Framework for the Urban Public Transport System Sustainable Planning: Riga Case Study</b> .....	552
Irina Yatskiv (Jackiva) and Evelina Budilovich (Budiloviča)	
<b>Study of Field Testing on Car Body Vibrations of Moving Passenger Car with Wheel Flat</b> .....	562
Stasys Steišūnas, Gintautas Bureika, Olha Porkuian, and Volodymyr Nozhenko	
<b>About Physical Aspects of Increasing Durability of Aluminum Alloys Due to Impact-Oscillatory Loading</b> .....	572
Mykola Chausov, Pavlo Maruschak, Elena Zasimchuk, Andrii Pypypenko, Roman Bishchak, and Iurii Burda	
<b>Special Aspects of Determining the Dynamic Load of the Tank Container During Its Transportation in an Integrated Train Set by a Railway Ferry</b> .....	581
Alyona Lovska, Juraj Gerlici, Oleksij Fomin, Kateryna Kravchenko, Yuliia Fomina, and Tomas Luck	
<b>Analysis of the Combustion Process of a Compression Ignition Engine Running on Diesel and Natural Gas</b> .....	591
Saulius Stravinskas, Alfredas Rimkus, and Donatas Kriaučiūnas	
<b>Anti-wear Properties of Jet Fuel with Camelina Oils Bio-Additives</b> . . . .	601
Anna Yakovlieva, Igor Trofimov, Sergii Boichenko, Hubert Kuszewski, and Kazimierz Lejda	
<b>The Model for Evaluating Criteria Describing the Internal Safety of a Railway Trip by International Train</b> .....	610
Lijana Maskeliūnaitė and Henrikas Sivilevičius	
<b>Analysis of Existing Train Lines and International Railway Transport Corridors of Ukraine</b> .....	622
Evgeniya Ugnenko, Anna Shevchenko, Oleksander Matviienko, Anatoliy Maliavin, Gintas Viselga, and Vytautas Turla	



# Anti-wear Properties of Jet Fuel with Camelina Oils Bio-Additives

Anna Yakovlieva<sup>1</sup>, Igor Trofimov<sup>1</sup>, Sergii Boichenko<sup>2</sup>,  
Hubert Kuszewski<sup>2</sup>, and Kazimierz Lejda<sup>2</sup>

<sup>1</sup> National Aviation University,

Kosmonavt Komarova ave. 1, Kiev 03058, Ukraine

anna.yakovlieva@nau.edu.ua, trofi@ukr.net

<sup>2</sup> Rzeszow University of Technology, Powstancow Warszawy ave. 8,  
35-959 Rzeszow, Poland

chenmotology@ukr.net, {hkuszews, klejda}@prz.edu.pl

**Abstract.** Anti-wear properties of conventional jet fuel, fatty acids ethyl esters bio-additives derived from camelina oil and their blends were investigated experimentally. Anti-wear properties were estimated on a four-ball tester by the value of the scuffing load, friction torque, friction coefficient and the scuffing load applied to the friction pair operating in a tested fuel sample. The state of friction pairs' surfaces was studied using the system for tribological characteristics of fuels and lubricants investigation by comparing microphotographs of friction pairs' surfaces. It was determined that lubricity of bio-additives is intensively higher comparing to conventional jet fuel. Bio-additives derived from camelina oil provide formation of better oxidative film on friction pairs' surface with higher elasticity. It is stipulated by the chemical composition of fatty acids ethyl esters: high polarity of molecules stipulate its' good adsorption at the surface of friction pair. Adding bio-additives into jet fuel provides strengthening of boundary film and thus improves anti-wear properties of fuel blends.

**Keywords:** Jet fuel · Alternative fuel · Bio-additive · Fatty acids ethyl esters · Camelina oil · Wearing · Lubricity · Scuffing load · Friction surface

## 1 Introduction

Studies described within this paper relate to transport, aviation and machinery constructing industries. In a result of stream rising of prices for natural resources, improvement and studying of exploitation properties of fuels and lubricants became a relevant research-technical problem.

That's why the question of studying and improving anti-wear properties of modern fuels for road and air transport is one of the key questions during considering the priority directions in provision of reliability and durability of mechanisms and tribotechnical systems operation.

## 2 Literature Overview

Modern air transport is equipped with complex hydraulic systems, which perform important functions concerning operation of air and ground vehicles. Reliability of fuels and hydraulic constructions mainly depend on operability of precision friction pairs. In a result of strong wearing, destruction and jamming of friction pairs the breakdown of hydraulic systems can take place. Thus, it will require replacement of worn details. The most common defects include jamming of plunger pumps, laminose, spool and sleeve pairs, destruction of roll bearings, wear of plunger axial bearings etc. Peculiarity of these friction pairs requires critical approach in the question of application of lubricating mediums, mechanical properties of materials, roughness of contacting surfaces, speed of its relative movement.

From the previous studies it is known that modern world tends to introducing alternative energy sources in all spheres of industry and air transport in particular [1, 2]. Taking into account wide variety of new alternative fuels and feedstock for its production, much studies have to be done in order to discover operational properties of new fuels. One of the issues to be studied is influence alternative aviation fuels on reliability and durability of aircraft equipment, which is strongly determined by lubricating properties of fuels. From the studies [1–5] it is known that alternative fuels produced from plant oil esters possess high lubrication properties. However, most of the studies are devoted to researches of plant oil esters during application in diesel engines (biodiesel fuel) [4–6].

Taking into account the existing data about lubricating properties of plant oil esters it is necessary to study its impact on anti-wear properties of jet fuels.

Durability and reliability of aircraft equipment, mainly fuel system friction pairs strongly depends on anti-wear properties of jet fuels [2, 7–9]. These pairs work in a regimes of rolling friction, sliding friction and combined friction at different loads, temperatures, pressure, speed of relative movement in conditions of liquid or boundary friction. It is known that fuel lubricating properties are determined by complex of physical and chemical parameters [2, 7, 10]. In case of semi-liquid friction the anti-wear properties of jet fuels are determined by fuel viscosity and presence of surfactants in fuel that form high strength absorption layer at the wearing surface [2, 9, 10].

## 3 Aim and Scope of the Study

The aim of this article is to study the anti-wear properties of blended jet fuels containing bio-additives based on camelina oil. Thus one of the tasks of the study was comparison of anti-wear properties of blended jet fuels and conventional jet fuels.

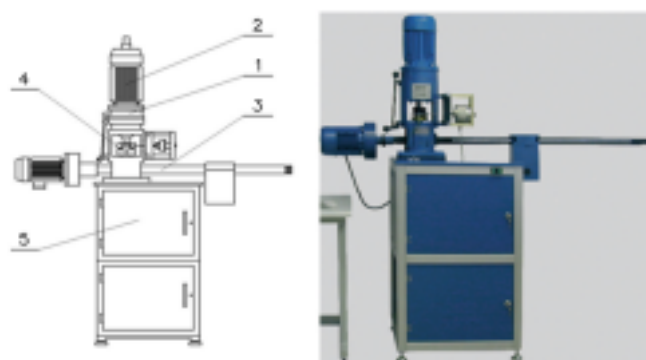
Analysis of literature sources [1–4, 7, 8, 11, 12] have shown the interest of authors in experimental and theoretical researches related to improving of anti-wear properties of precision friction pairs and studying influence of various components of fuels and oils on anti-wear. One of the ways for prolongation of exploitation period and renewal of tribocouplings is a tribomodification of friction surfaces due to the formation of stable oxidative films. This may be achieved by applying of modified or energetically changed fuels and lubricating materials.

Lubricity of jet fuel, camelina oil bio-additive and its blends with jet fuel was investigated during the experiment. Conventional oil-derived jet fuel of grade Jet A-1 that meets the requirements of ASTM D1655 [13] was used for testing. Fatty acids ethyl esters (FAEE) of camelina oil were used as bio-additive. Bio-additive was added to fuel blends in quantity: 10%, 20%, 30%, 40% and 50% (vol.).

Usually anti-wear properties of jet fuels are determined according to the value of wear of certain friction pair. Wear in the medium of certain fuel of one friction pair can't characterize lubricating properties of this fuel completely. The change of details material, testing regimes and other factors may significantly influence on wearing of friction pairs. Because of that estimation of anti-wear properties have to be fulfilled in a strictly regulated conditions [7, 10, 14, 15].

Considering the practice worldwide, anti-wear properties of jet fuels are estimated according to the ASTM D5001. Ball-on-Cylinder Lubricity Evaluator – BOCLE. This device imitates oxydation-corrosive type of wearing. Anti-wear properties are estimated quantitatively by the value of wear scar diameter. At the same time another device SLBOCLE was developed and proposed. It is intended for estimating and forecasting anti-scuffing properties of fuels by determining scuffing load. During the last 40 years number of other mechanical stands was developed for determining lubricating properties of jet fuels. However, most of them are not able to imitate the most important type of wearing, which takes place in fuels systems of aircrafts [3, 8].

Anti-wear properties of fuel samples were investigated using a T-02U four-ball tester that consists of the testing device presented at Fig. 1 and a metering-control system. The friction pair installed in testing device is given at Fig. 2 [2, 14].



**Fig. 1.** Four ball tester T-02U: 1 – body; 2 – power train; 3 – friction pair load bearing drive; 4 – ball cup assembly; 5 – base.

The composition of the friction pair, its assembling and characteristics as well as principle of four-ball tester operation are described in details in previous studies of authors [2, 14].

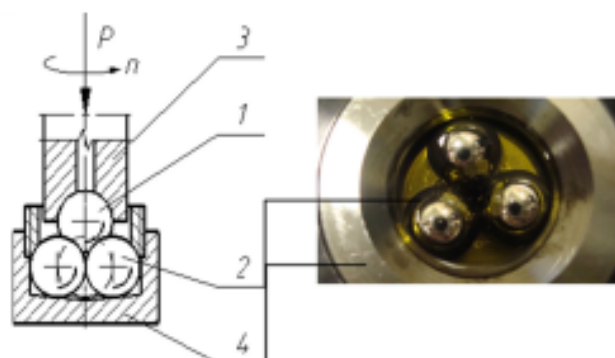


Fig. 2. Four ball tester friction pair: 1 – top ball; 2 – bottom balls; 3 – spring clamp; 4 – balls cup.

The studies were fulfilled under the following conditions of the four-ball tester:

- rotation speed during tests – 500 rpm,
- load increase rate of 409 N/s,
- initial temperature of the fuel sample at the start of the test run –  $20 \pm 1.0$  °C.

According to the methodology of this test a friction pair scuffing occurs when boundary friction torque  $M_T$ , of 10 Nm is exceeded. This value is determined by the durability of the top ball shank in the friction pair. The friction torque  $M_T$  and the linearly increasing friction pair load  $P$  were recorded during testing [2, 14].

The following Fig. 3 depicts the principle of the method of determining scuffing load applied to the friction pair [2, 14]. Load  $P$ , at point 1, where the friction torque value quickly increases is denoted as scuffing load  $P_S$ . Point 2 is a point of scuffing. At this moment the boundary friction torque  $M_T$  equal to 10 Nm is reached. The load at point 2 is called seizure load.

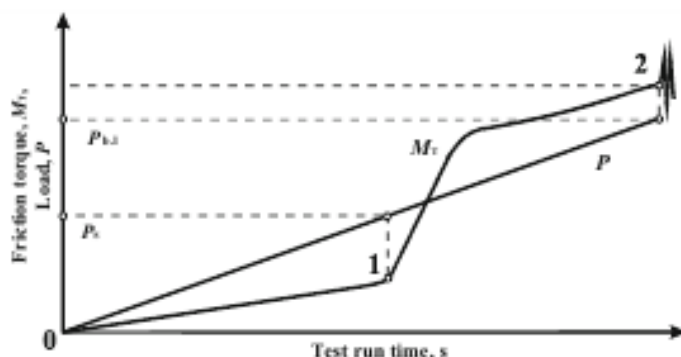


Fig. 3. The method for determining the scuffing load  $P_S$ : 1 – the point of scuffing initialization; 2 – point of scuffing.

Thus, it can be concluded that the fuel with the highest value of applied scuffing load possesses the highest anti-wear properties. It can be said that the boundary film of this fuel has demonstrated the highest durability to damage [2].

Also, the state of friction surfaces was additionally studied using the system for tribological characteristics of fuels and lubricants investigation that was developed by authors [16]. Technical conditions of the system provide possibility to make photographs and video recording of surface transformations in dynamic regime.

The friction joint is a transparent glass plate made of photographic glass that passes light without refraction. Microscope objective is mounted in front of the sample, whose surface contacts with glass. The light is focused through the system of lenses into the camera of "PC Camera" type with standard software for processing and fixation of photographs at the monitor and possibility to record the obtained data about friction surfaces. The described system allows fulfilling studies in the sphere of determining the mechanism of oxidation films formation at the surface of metals independently on the impact of contacting material.

The studies were fulfilled according to the friction scheme "finger-surface"; material of samples GCr15 steel – photographic glass,  $\theta = 0.30$ ;  $0.630$  m/s,  $P = 5$  N. Dimensions of the finger-sample are: diameter – 4 mm, length – 25 mm.

## 4 Results and Discussion

The following Figs. 4 and 5 present the friction torque, friction pair load and friction coefficient that were checked during tests. The scuffing load that describes the criteria for anti-wear properties estimation is marked.

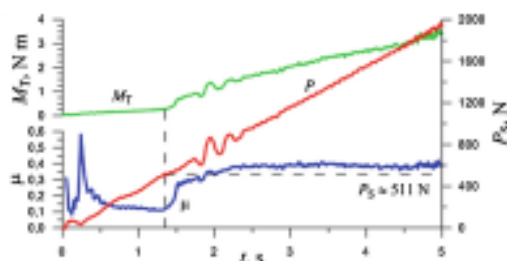
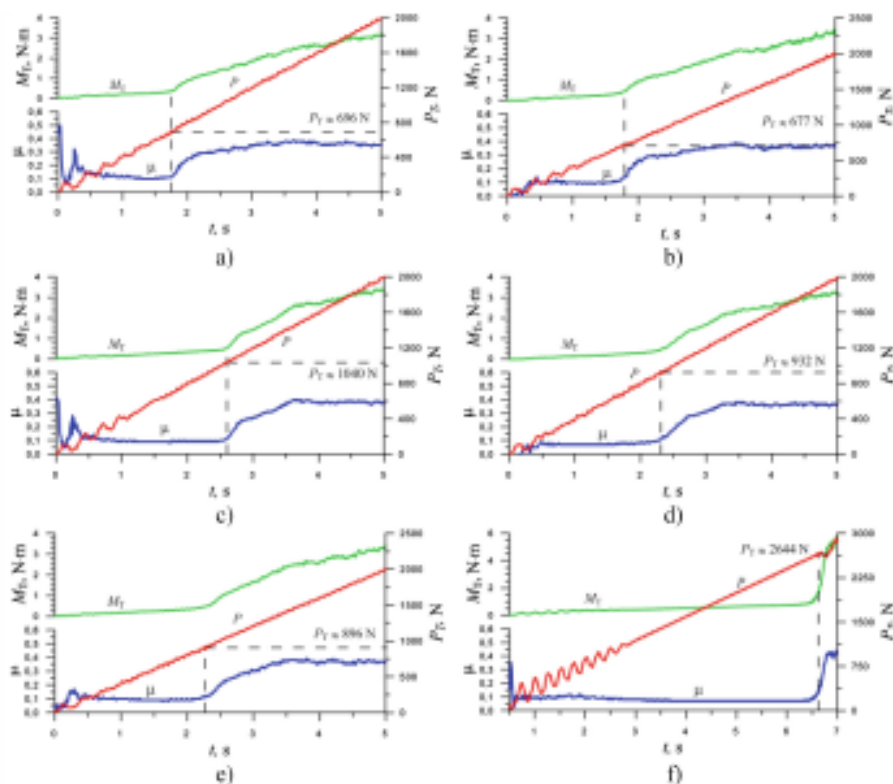


Fig. 4. Dependence of friction pair loading force  $P$ , friction torque  $M_T$  and friction coefficient  $\mu$  on testing run time  $t$  for jet fuel of grade Jet A1 fuel:  $P_s$  – scuffing load.

We can see from the graph at Fig. 5a that testing of jet fuel blended with 10% of FAEE bio-additive results in friction coefficient  $\mu$  varying from 0.3 to 0.5 and friction torque  $M_T$  varying from 0.5 to 3 Nm.

From the graph at Fig. 5b we can see that testing of jet fuel blended with 20% of FAEE bio-additive results in friction coefficient  $\mu$  varying from 0.1 to 0.3 and friction torque  $M_T$  varying from 0.5 to 3 Nm.



**Fig. 5.** Dependence of friction pair loading force  $P$ , friction torque  $M_\gamma$  and friction coefficient  $\mu$  on testing run time  $t$  for samples of jet fuel blended with camellina oil bio-additives: (a) Jet A-1 +10% FAEE; (b) Jet A-1+20% FAEE; (c) Jet A-1+30% FAEE; (d) Jet A-1+40% FAEE; (e) Jet A-1+50% FAEE; (f) FAEE;  $P_S$  – scuffing load.

Analogously, comparing the graph at Fig. 5e, describing test of jet fuel blended with 50% of FAEE bio-additive, we observe values of friction coefficient  $\mu$  within a range of 0.15 to 0.4 and values of friction torque  $M_\gamma$  within a range of 0 to 3 Nm.

Thus from the graphs on Fig. 5 we can conclude that anti-wear properties of jet fuels blended with FAEE bio-additives are better comparing to anti-wear properties of conventional jet fuel of grade Jet A-1.

Values of scuffing load  $P_S$  for each tested fuel sample were taken as a key parameter to evaluate anti-wear properties. They are depicted and compared at Fig. 6.

The results given at Fig. 6 allow us concluding that conventional jet fuel of grade Jet A-1 presented the lowest value of scuffing load – 511 N. At the same the highest value of scuffing load was found for camellina oil bio-additive – 2,644 N. Considering conventional jet fuel as a base-line we can assume that use of camellina oil esters positively influences the anti-wear properties of jet fuels. In general obtained results indicate that increasing portion of bio-additive in jet fuel improves its anti-wear properties.



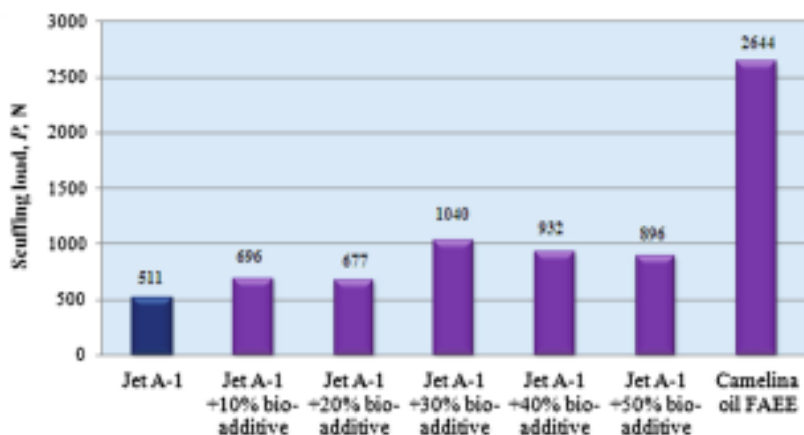


Fig. 6. Friction pair scuffing load  $P$  for each of the tested fuel samples.

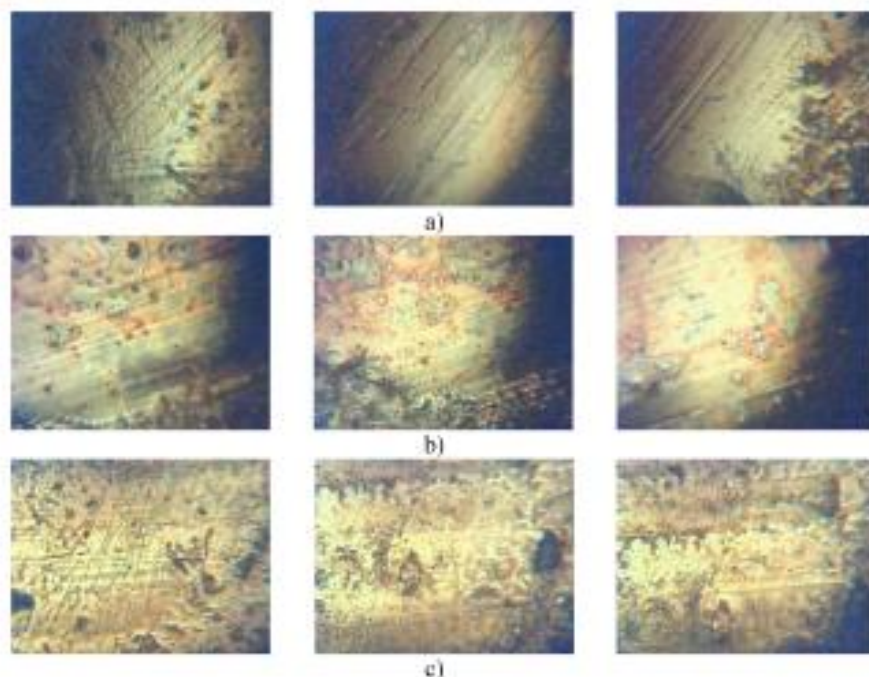
As it was mentioned previously, fuel's surfactants provide ability of fuel or its components to absorb at the surface of metal, create the boundary film and thus protect dry friction of details [2]. Hydrocarbons in conventional jet fuels are non-polar and can not prevent wear of friction pairs [5, 10]. On the contrary, molecules of bio-additives are fatty acids esters and act as natural surfactants [5, 17]. Presence of oxygen atom in carboxyl group in molecules stipulates strong polarity of esters. Such structure provides ability to absorb on surfaces of solid bodies and thus, ability to form polymolecular film – boundary layer.

Such view on lubricating properties of fatty acids esters allows us explaining obtained experimental results: regular improvement of anti-wear properties of jet fuel with increasing content of bio-additives. During blending jet fuel with bio-additives the total content of surfactants in fuels rises. In a result the boundary film between friction pair become stronger.

Taking into account the abovementioned we may conclude that addition of bio-additive into composition of blended jet fuels provides increasing of surfactants quantity and finally strengthening of boundary film between friction pair [2].

Figure 7 depicts microphotographs of friction pairs' surfaces, which were obtained after operation in medium of conventional jet fuel, camelina oil bio-additive and jet fuel blend with 20% of bio-additive. Microphotographs were done at the device for studying anti-wear properties of fuels and lubricants according to the method described in work [16]. The sliding distance for all the fuel samples was 8 km.

Comparing friction surfaces we can observe that friction surfaces of samples operated in camelina oil bio-additives (Fig. 7b, 7c) are more uniform than friction surfaces of samples operated in conventional Jet A-1 fuel (Fig. 7a). Oxidative films are thinner and more elastic. These results give explanation to smaller values of friction coefficient and values of wearing in equal conditions of sliding distance. Moreover, boundaries of oxidative films on samples are clearly seen at the Fig. 7b. During the



**Fig. 7.** Microphotographs of friction pairs' surfaces (200 times magnification): operation in a medium of (a) Jet A-1; (b) FAEE; (c) Jet A-1+20% FAEE.

process of operation, samples' films (operation in camelina oil bio-additive medium) become longer and wider comparing to films of sample operated in conventional jet fuel medium. More contrast coloring speaks that sample's friction surface at Fig. 7b has smaller thickness and it is more elastic.

## 5 Conclusions

A four-ball tester and system for studying tribological characteristics of fuels and lubricants were used for estimating lubricating and anti-wear properties of conventional jet fuel and its blends with bio-additives based on camelina oil FAEE.

The research of fuel samples has shown that camelina oil FAEE have better tendency for permanent boundary film creation comparing to conventional jet fuel within. The reason for this effect is surface activity of camelina oil FAEE molecules and its high viscosity. The results of the tests have shown that increasing of bio-additive content in fuel blend causes strengthening of boundary film of surface of friction pair. Camelina oil bio-additives positively affect lubrication properties of conventional jet fuels and may be used for improving anti-wear properties of jet fuels.



## References

1. Chuck, C.J., Donnelly, J.: The compatibility of potential bioderived fuels with Jet A-1 aviation kerosene. *Appl. Energy* **118**, 83–91 (2014)
2. Iakovlieva, A., Boichenko, S., Lejda, K., Vovk, O., Kuszewski, H., Jakubowski, M.: Experimental study on antiwear properties for blends of jet fuel with bio-components derived from rapeseed oil. *Eastern-Eur. J. Enterp. Technol.* **5/8(77)**, 20–28 (2015)
3. Marunich, V.S., Melnichenko, O.I., Kharuta, V.S.: Passenger transportation: reliable information support. *Int. Acad. J. Web Scholar* **9(18)**, 31–35 (2017)
4. Yanovskii, L., Dmitrenko, V., Dubovkin, N., et al.: *Fundamentals of aviation chemmology*. MATI, Moscow (2005)
5. Hu, J., Du, Z., Li, C., Min, E.: Study on the lubrication properties of biodiesel as fuel lubricity enhancers. *Fuel* **84**, 1601–1606 (2005)
6. Nagomov, S.A., Dvoreckiy, D.S., Romancova, S.V., Tarov, V.P.: *Technics and technologies of production and processing of plant oils*. TGTU Publishing, Tambov (2010)
7. Dubovkin, I., Yanovskiy, L., Shigabaev, T., Galimov, F., Ivanov, V.: *Engineering methods of analysis of physical-chemical and exploitation properties of fuels*. Master-line, Kazan (2000)
8. Alves, S.M., Barros, B.S., Trajano, M.F., Ribeiro, K.S.B., Moura, E.: Tribological behavior of vegetable oil-based lubricants with nanoparticles of oxides in boundary lubrication conditions. *Tribol. Int.* **65**, 28–36 (2013)
9. Bratkov, A.A., Serigin, Ye.P., Gorenkov, A.F.: *Chemmtology of jet fuels*. Himia, Moscow (1987)
10. Yakovleva, A., Boichenko, S.V., Lejda, K., Vovk, O.A., Kuszewski, Kh.: Antiwear properties of plant—mineral-based fuels for airbreathing jet engine. *Chem. Technol. Fuels Oils* **53(1)**, 1–9 (2017)
11. Trofimov, I.L.: Improvement of anti-wear properties of fuels and lubricants by electric field. *Questions chem. Chem. Technol.* **2**, 54–58 (2013)
12. Aksenov, A.F., Chernova, K.S., Spirkin, V.G., Klimov, S.G., Borodin, A.E., Belyanskii, V.P., Terekhin, V.I., Nekipelov, Y.G., Shepel', A.Ya.: Effect of jet fuel chemical composition on antiwear properties. *Chem. Technol. Fuels Oils* **8(2)**, 133–137 (1972)
13. An American National Standard ASTM D1655 Standard Specification for Aviation Turbine Fuel
14. T-02U. Four-ball tester – operation manual. Instyute of Technology and Exploitation Publishing, Radom (2011)
15. Coordinating Research Council. <https://crao.org>. Accessed 15 Oct 2018
16. Svyryd, M.M., Parashchanov, V.G., Onishchenko, A.V.: Complex for studying tribotechnical parameters of friction joint. *Probl. Friction Wear* **45**, 204–209 (2006)
17. Xu, Y., Wang, Q., Hu, X., Li, C., Zhu, X.: Characterization of the lubricity of bio-oil/diesel fuel blends by high frequency reciprocating test rig. *Energy* **35(1)**, 283–287 (2010)