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RESEARCH

The Effect of Water on the Tribological Properties of Aviation Lubricants

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ABSTRACT

The influence of water and ice on the performance properties of lubricants is analysed. The tribotechnical properties of Era VNIINP 286M and AeroShell Grease 33 aviation lithium greases at low temperatures, in the presence of water in the grease, are presented. The research was conducted using a test rig simulating a block-on-ring sliding contact. AeroShell Grease 33 demonstrates high demulsifying properties in emulsions with a water content of up to 20 %, at temperatures ranging from -10 to +10 °C. Experiments showed that the presence of water in AeroShell Grease 33 does not reduce the wear resistance of the tribosystem under sliding conditions. The temperature variation in the tribotechnical contact was analysed in relation to the heat capacity of the emulsion, depending on the concentration of dissolved water in the lubricant. The mechanism of structural adaptation, based on the principle of the optimal mechanical scheme of contact interaction in sliding pairs lubricated with lithium grease emulsions, was identified. This mechanism involves the formation of a microrelief on the contact surfaces, increasing the relative bearing length of the profile to up to 25 % under conditions of effective demulsifying action of the grease. It was established that the microgeometric parameters of the structural adaptability of friction pairs are characterised by a reduction in both maximum profile height and equilibrium roughness.

1. INTRODUCTION

The reliability of mechanical systems is established at the design stage, ensured during production, and confirmed during operation. Lubricants play a crucial role in this process and are continuously developed to enhance their physical, chemical, and operational properties.

The primary function of modern lubricants is to reduce friction and wear in the tribological contacts of machines, mechanisms, and instruments used in various fields of technology [1]. In many cases, the reliability of friction pairs is determined by the quality of the lubricant; therefore, its properties must be considered on par with the properties of the materials used to manufacture the components when designing a friction unit. In practice, liquid, semi-solid (grease), and solid lubricants are widely used.

The issue of improving the efficiency of lubricant use is a complex scientific and technical task within the fields of tribology, materials science, and chemotology. As an element of a complex tribosystem, lubricants act as indicators of the operating modes and conditions of assemblies and their technical state. Thus, the reliability of friction components depends on the quality of the lubricants.

The production of aviation lubricants focuses on enhancing their physical, chemical, and operational properties to meet the ever-increasing demands of modern technologies, international regulations, and standards. When evaluating the quality of aviation lubricants, special attention should be given to monitoring their performance characteristics [2,3]. This ensures benefits such as extended service life of aircraft components, a reduced number of failures, and longer lubricant replacement intervals.

Water is one of the factors that can affect the effectiveness of lubricating properties. The ingress of water into lubricants may occur during transportation, storage, fuelling, and operational use [4].

During service, water in lubricants may exist in several states [5]: dissolved or chemically bound water, which cannot be removed by conventional methods and is practically harmless in concentrations up to 0.05%; and water in concentrations up to 2-3 %, forming emulsions with varying degrees of bonding to the lubricant components.

Water can be present in lubricants in the form of free, dissolved, or emulsified water. Due to their differing chemical properties, lubricants and water do not mix but rather separate into two distinct layers. Since water has a higher density than lubricants, free water accumulates at the bottom. However, depending on the base oil composition and the type of additives used, different lubricants can retain varying amounts of water in the dissolved phase (temperature and pressure also affect the amount of water a fluid can hold) [6].

Once the lubricant’s saturation limit is exceeded, water is present as either free water or an emulsion. An emulsion is a state in which water exists as fine droplets dispersed during agitation. The presence of emulsifying additives in the lubricant may also lead to emulsion formation. According to [7], emulsified and free water are the most harmful to bearings, as emulsions can reduce film strength, while free water can readily cause corrosive damage.

Water induces hydrolysis and degradation of additives in oils, leading to a decline in their lubricating, detergent, and neutralizing properties. It also increases corrosive effects and raises the risk of catastrophic failure of antifriction coatings in tribological pairs [8]. According to [9], the presence of water in oil facilitates the hydrolysis of additives with specific chemical compositions, which may result in severe corrosive-mechanical wear and scuffing of friction surfaces.

In addition, water causes intense coagulation of impurities and additives in the oil, resulting in sludge formation [10]. In the work [11], it was established that water negatively affects the properties of lubricants. When lubricants become water-contaminated, their alkalinity decreases, dispersing ability deteriorates, and corrosive aggressiveness increases. All of this leads to increased wear of component parts and also necessitates premature replacement of the lubricant in the event of water contamination, which significantly raises operating costs.

According to the data in [12], the addition of water and an increase in its concentration in CaS and Li-based lubricants lead to increased roughness of the friction surface profile as well as higher wear.

At low temperatures, water freezes and interferes with the normal operation of friction parts. Especially the processes of changes in the physical and chemical properties of lubricants due to their watering are characteristic of lubricants used in the lubrication of friction units in aircraft [13]. Specifically, aircraft can rapidly move between different temperature zones. For instance, an aircraft may take off in warm regions where the air temperature can reach +50 °C, and then remain in prolonged flight at altitudes of up to 9,000 m (≈ 29500 ft), where air temperatures can drop to between -40 °C and -57 °C. These changes in environmental conditions cause the lubricant to solidify quickly, and any water it contains may crystallise. During landing, the lubricant may not have enough time to thaw completely, leaving ice crystals present [14]. Under such conditions, the ice acts as an abrasive that enters the contact zone of the friction pairs. Accordingly, this can lead to catastrophic consequences.

Studies investigating the effect of ice on friction processes demonstrate that the antifriction performance of a contact is dependent on both velocity and temperature [15]. Reference [16] reports that frictional heating and fluid film thickness increase with rising speed, resulting in reduced friction. At speeds below approximately 0.01 m/s, frictional heating is inadequate to maintain lubrication, causing frictional sliding dominated by deformation of surface asperities and micro-fractures.

The study presented in [17] investigates the friction processes of ice on resinous butadiene rubber filled with carbon. It was found that at low speeds and low temperatures, morphological features indicative of dry contact were observed. The high friction (friction coefficient $\mu \sim 1$) at low speeds and temperatures around -25 °C was attributed to internal friction. At higher temperatures and low speed, the formation of liquid films was observed due to the salt content in the ice.

The friction processes of ice samples sliding on steel were analyzed by studying the morphology of wear particles using low-temperature electron scanning microscopy [18]. High antifriction properties ($\mu < 0.1$) are observed at a high temperature (-3.4 °C) and low speed (0.02 m/s), as well as at a low temperature

(-25.1 °C) and high speed (0.30 m/s), which is due to the presence of liquid water that lubricates the sliding surface. Diagnostic morphological features of lubricated sliding surfaces include the presence of residual liquid in the wear grooves. A decrease in antifriction properties ($\mu > 0.15$) at a low temperature (-24.5 °C) and low sliding speed (0.03 m/s) is caused by insufficient lubrication at the sliding interface, which leads to plastic deformation. Under these conditions, diagnostics of contact morphology during plastic deformation reveal signs of abrasion on the wear surface and the accumulation of wear particles on the trailing edge of the wear surface.

Under operating conditions that lead to watering of lubricants, it is necessary to use lubricants with improved physical and chemical properties. This is achieved by introducing multifunctional additives and supplements into the base oil [19].

One of the most important tasks in the development of aircraft maintenance at the present stage is the development of measures aimed at improving the operational reliability and efficiency of their assemblies. The primary focus of research is increasing the durability and faultlessness of friction units through targeted enhancement of the properties of structural, functional, and composite materials, as well as improvement of their designs. However, operational experience with aircraft shows that insufficient attention has been paid to the effective selection of lubricants to ensure the reliability of aircraft tribosystems.

Unfortunately, there are few experimental studies assessing the tribotechnical properties of lubricants in the presence of water at low temperatures, where ice crystals form. Research in this area will enable the evaluation of the performance characteristics of water-contaminated lubricants at temperatures below 0 °C. The importance of such research lies in the fact that most modern lubricants, including aviation lubricants, are all-season and have a long service life. In case water enters the lubricant, special attention should be paid to its demulsifying properties (water-rejection ability), oxidation stability, and tribotechnical characteristics.

Thus, the quality of lubricants largely determines the durability and service life of friction units in aviation equipment as a whole.

2. PURPOSE OF RESEARCH

The purpose of this research is to determine the tribotechnical properties of aviation greases at low temperatures in the presence of water in the lubricant with conducting visually assessing qualitative changes in grease consistency and investigating changes in the microgeometry parameters of tribocontact during, friction.

3. METHODS AND MATERIALS USED IN THE RESEARCH

Lithium greases for aviation purposes, Era VNIINP 286M and AeroShell Grease 33, were studied as lubricating materials.

AeroShell Grease 33 is recommended for use as a universal lubricant for aircraft airframes, components and assemblies. It is formulated from a blend of synthetic hydrocarbon oil and esters, thickened with a lithium complex. The grease contains corrosion and oxidation inhibitors, as well as additives that enhance its load-bearing capacity [20]. Its operating temperature range is -73 to +121 °C. Effective operational properties of the grease include high anti-wear and anti-corrosion characteristics, increased resistance to washing out by water, anti-freezing fluids, and other liquids, as well as low additive depletion, which ensures a long service life. [21]. AeroShell Grease 33 has proven to be a versatile, general-purpose lubricant—except for wheel bearings operating above 121 °C and sliding friction pairs requiring molybdenum disulfide. It has received approval from Boeing and Airbus, as well as aircraft manufacturers such as McDonnell Douglas, BAe Regional Aircraft, Canadair, Lockheed, Embraer, Fokker, Gulfstream, and Antonov. Additionally, it meets the requirements of international standards BMS 3-33C, MIL-PRF-23827C (Type I), AIMS 09-06-002, COMAC QPL-CMS-OL-302, SAE AMS 3052, and NATO Code G-354 [22].

The main physical characteristics of AeroShell Grease 33 are presented in Table 1 [23].

Aviation grease "ERA" (VNIIINP-286M) (TU 38.101950-83, classified under DIN 51502 as grease type KP2-3K-60) is intended for use in aircraft components, such as rolling and plain bearings, gears of electrical mechanisms, and aircraft control systems. The grease has high mechanical stability, excellent antioxidant stability, good anti-corrosion, anti-wear, and anti-scuffing properties, and does not cause swelling of rubber products. The grease has low volatility and can be used in a wide temperature range from -60 to +120 °C.

Table 1. Typical physical and chemical characteristics of AeroShell Grease 33.

Properties	**Method**	**Requirements by specifications BMS 3-33C AIMS 09-06-002 SAE AMS3052A**	**AeroShell Grease 33**
Oil type		Synthetic Hydrocarbon / Ester	Synthetic Hydrocarbon / Ester
Colour		Blue-green	Green
Thickener type		Lithium Complex	Lithium Complex
Base Oil viscosity at, mm^2/s	ASTM D445		
-40°C		-	1840
40°C		-	14.2
100°C		-	3.4
Operating temperature, °C		from -73 to +121	from -73 to +121
Dropping point, °C	ASTM D556	205 min	227
Worked penetration at 25°C	ASTM D217	from 265 to 315	297
Oil separation at 100°C in 30 hrs., %m[1]	ASTM D6184	8 max	2
Water Washout at 79°C, %m	ASTM D1264	7,5 max	<6
Evaporation loss 500 hrs. at 121°C, %m	ASTM D2595	10 max	<10
Anti-friction performance at 121°C, hrs	ASTM D3336	1000 min	>1200
Load Carrying Capability LWI[2] at 27°C, kg	ASTM D2596	60 min	>60
Copper corrosion in 24 hrs. at 100 °C	ASTM D4048	1B max	-

[1] – Percentage of weight loss in accordance with the accepted standard;
[2] – Load Wear Index in accordance with ASTM D2596

Era grease (VNIINP-286M) is produced by thickening a mixture of hydro isomerization and hydrocracking oils with hydrogenated castor oil acids and stearic acid lithium soap, along with additional extreme pressure and antioxidant additives. The grease exhibits high antioxidant and anticorrosive properties and is characterized by high mechanical stability. Effective extreme pressure and wear characteristics have been established during operation.

The main physical characteristics of VNIINP-286M are presented in Table 2.

The study was conducted for three cases:

1. Commercial greases Era VNIINP 286M and AeroShell Grease 33, which, according to the quality certificate, do not contain water;
2. Emulsions of grease (Era VNIINP 286M or AeroShell Grease 33) and water with a water concentration of 10%;
3. Emulsions of grease (Era VNIINP 286M or AeroShell Grease 33) and water with a water concentration of 20%.

Table 2. Standardization of ERA Grease Quality Indicators (VNIINP-286M).

Properties	**Standard**	**Test method**
Dropping point, °C, not less than:	180	Under GOST 6793
Penetration at 25 °C, ×10-1 mm	210-250	
Viscosity at 0 °C and 10s-1, Pa·s, not more than:	110	
Effective viscosity, Pa·s, determined by a capillary viscometer at a temperature of −50 °C and an average strain rate gradient of 10 s^{-1}, not more than:	900	Under GOST 7163
Colloidal stability at a 3N load, %, not more than:	22	Under GOST 7142
Shear strength at 20 °C, Pa, within:	500-600	
Shear strength at 50 °C, Pa, within:	200-350	Under GOST 7143, Method Б
Mass fraction water	None	Under GOST 2477
Mechanical impurities content	None	Under GOST 6479
Corrosive effects on metals	Withstands	Under GOST 9.080 with the addition of clause 4.3
Colloidal stability, %, not more than:	35	
Mass fraction of free alkali in terms of NaOH, %, not more than:	0,1	Under GOST 6707
Evaporation loss 150°C in 1 hrs., % masses, not more than:	5,0	Under GOST 9565

After thorough mixing, the samples were placed in a freezer at a temperature of minus 10 °C.

Oil-water emulsions were prepared in a transparent container. First, the lubricant was poured into the container and weighed on a precision balance to the nearest 0.1 g. Then, the appropriate mass of water was added to achieve the required mass percentage. The components were mixed with a spatula for 10–15 minutes. The quality of mixing and emulsion formation was then visually assessed using an optical microscope. After preparation, a sample was taken for testing.

To study aviation greases and emulsions under sliding conditions, tests are carried out on a full-scale setup that simulates a cylinder-to-flat contact. The control unit allows for the management of the setup and, during testing, displays the current rotational speed of the movable sample and the torque. The rotational speed is measured using a Hall effect sensor, which registers parameters on the shaft driven by a belt transmission connected to the machine's main rotating shaft. The setup is equipped with a system of Pt100 thermoresistive sensors, enabling the monitoring of both the research objects' and the ambient temperatures.

According to the methodology, two test samples are placed at diametrically opposite points of the counter-sample (Figure 1).

The maximum pressure (p_{max}) in the contact is determined based on the theory of contact deformation in an elastic body, which assumes a linear initial contact of the tested samples [24,25] as shown in formula (1):

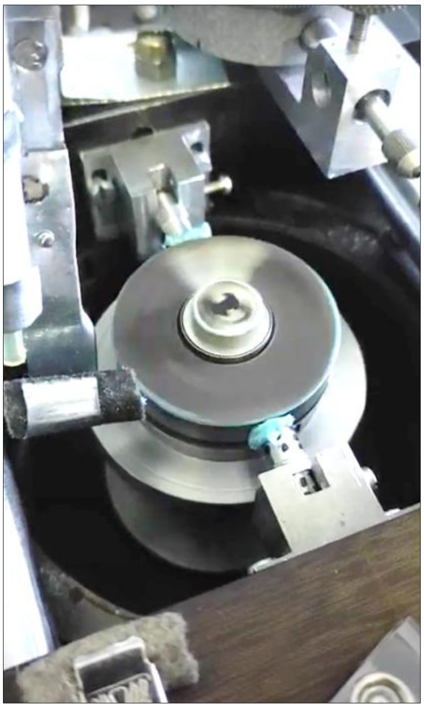
$$p_{\max} = 0.564\sqrt{\frac{N_l}{\Theta_\Sigma r}}, \text{ [MPa]}. \quad (1)$$

Where N_l is the normal load per unit length, r is the radius of the cylindrical body, and $\Theta_\Sigma = \Theta_1 + \Theta_2$ is the elastic constant for the case of two deformable bodies.

The maximum pressure (p_{max}) in the contact is:

$$p_{\max} = 0.564\sqrt{\frac{N_l}{\Theta_\Sigma r}} = 0.564\sqrt{\frac{30/20}{8.46\times10^{-6}\times25}}$$

$$= 47.5 MPa$$



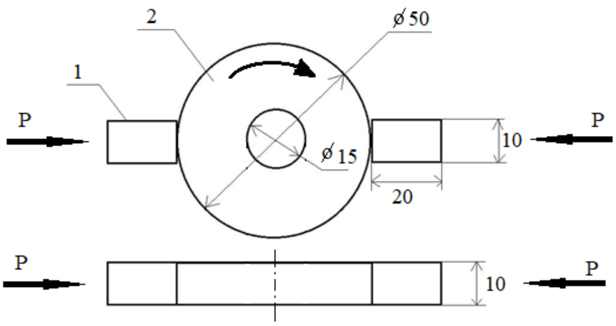


Fig. 1. Diagram of roller-cylinder contact on a full-scale setup: 1 – test samples; 2 – counter-sample.

The sliding speed was 1.1-1.15 m/s. During the study, the friction torque, temperature of the sample and the counter-sample were determined. The duration of the tests on the full-scale setup was 20 minutes, corresponding to the complete thawing time of the frozen water added to the lubricant test samples, which were previously frozen at −10 °C.

The weight wear of the samples was measured using Axis ANG200C scales of class 2 accuracy with a resolution of 0.0001 g.

Each series of experiments was conducted three times. The measurement errors of the investigated parameters are within 5% at a confidence level of P = 95% and a significance level of α = 5%. The standard deviation of the friction coefficient is 0.01, and that of the weight wear is 0.005 g.

For the study, a counter sample and samples made of 30KhGSA steel were selected. This steel grade is a structural alloy of chromium, silicon, and manganese as shown in Table 3 [26].

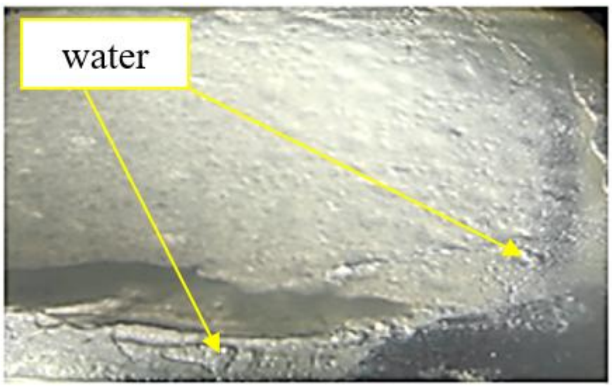
Table 3. The chemical composition in % of the material is 30ChGSA.

C	0.28 - 0.34
Si	0.9 - 1.2
Mn	0.8 - 1.1
Ni	< 0.3
S	< 0.025
P	< 0.025
Cr	0.8 - 1.1
Cu	< 0.3

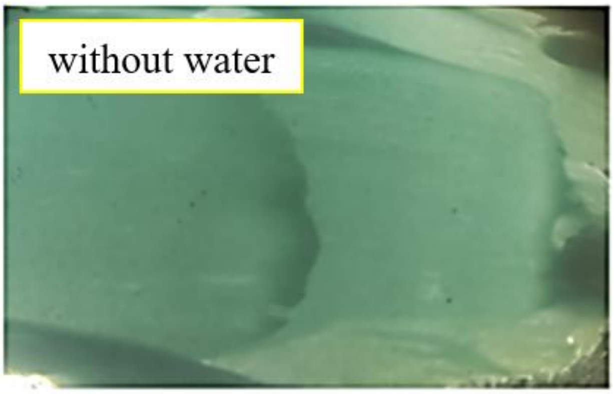
The microgeometric characteristics of the initial surface of 30ChGSA steel and the surface formed via structural adaptation during friction were analyzed using a laser scanning differential-phase microscope-profilometer for surface quality assessment [27].

4. RESEARCH RESULTS

Visual inspection of the grease-water emulsions revealed significant differences in the degree of water dissolution among the lubricants tested (Figure 2).



(a)

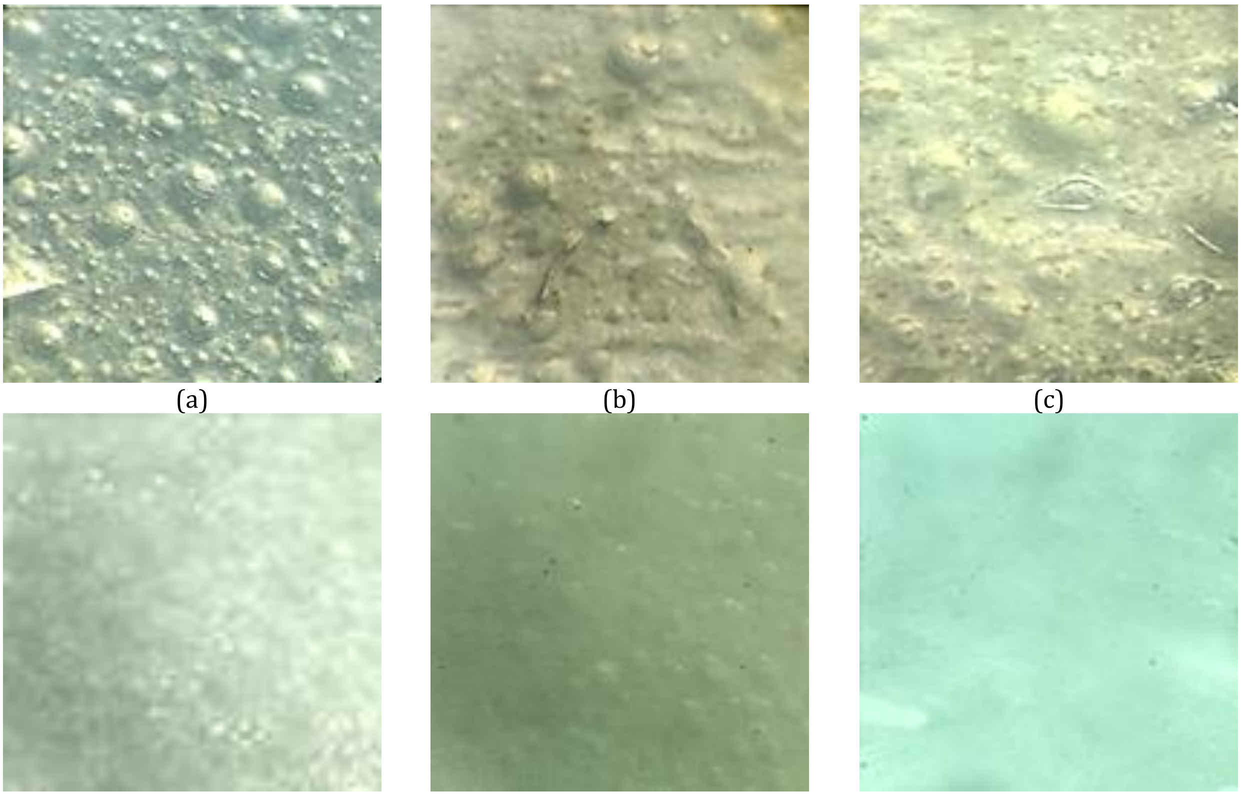


(b)

Fig. 2. Grease-water emulsions in the cooled state at -10 °C with a water concentration of 20% in Era VNIINP-286M grease (a) and AeroShell Grease 33 (b), (×4.8).

For Era VNIINP-286M grease, a high affinity for water was observed – water at a concentration of 10% is homogeneously distributed throughout the grease at room temperature. When cooled to -10 °C, water crystallization is predominantly observed. However, at a water concentration of 20 %, single structures of bound, uncrystallized water occupy 10 % of the observation area (Figure 3. a, b, c).

When 10% water is added to VNIINP-286M grease, a homogeneous emulsion is formed; however, when the water concentration is increased to 20%, partial separation of the emulsion is observed, with up to 5 % of free water separating. Thus, VNIINP-286M grease forms a stable emulsion with water at concentrations of up to 15%.



(a) (b) (c)

(d) (e) (f)

Fig. 3. Visual inspection of the oil-water emulsion at -10 °C: Era VNIINP-286M commercial grease (a), emulsions with 10 % (b) and 20 % (c) water; AeroShell Grease 33 commercial grease (d), emulsions with 10 % (e) and 20 % (f) water, (×32).

Regardless of the water concentration, AeroShell Grease 33 exhibits effective demulsifying properties. Within 1–3 minutes, the emulsion completely separates into oil and water. When cooled, the consistency of the grease remains homogeneous, with water crystallizing in the lower part of the container (Figure 3. d, e, f).

When the cooled emulsions are heated to +10°C, delamination is observed in VNIINP-286M grease, while AeroShell Grease 33 exhibits a homogeneous texture (Figure 4).

Let's analyse the tribotechnical characteristics of the emulsions. For VNIINP-286M-water emulsions, a 10 % increase in the coefficient of friction was observed in contact, regardless of the operating time, compared to the commercial lubricant (Figure 5).

(a)

(b)

Fig. 4. Grease-water emulsions (20%) after cooling at -10°C and subsequent heating to +10°C: (a) Era VNIINP-286M grease, (b) AeroShell Grease 33 (×32).

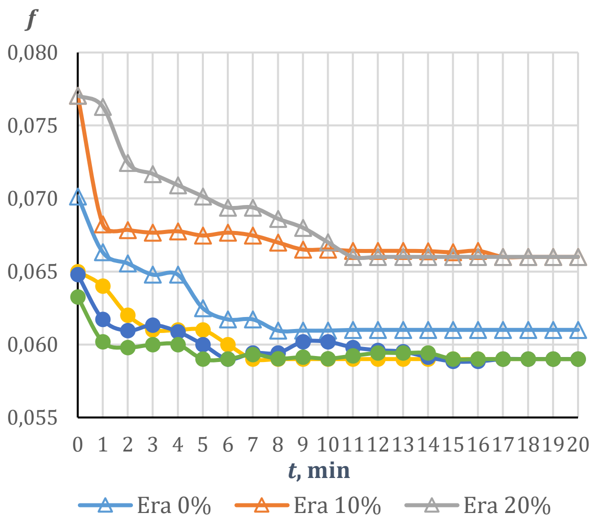


Fig. 5. Changes in the coefficient of friction during operation for commercial greases Era VNIINP-286M and AeroShell Grease 33, and their emulsions with water: 0%, 10%, and 20% water concentration.

The obtained friction coefficient vs. running-in time dependencies presented in Figure 5 were analysed using trendlines based on polynomial functions. The quality of approximation was evaluated using the coefficient of determination (R^2). For example, the following polynomial functions were obtained:

For the emulsion of grease ERA VNIINP-286M with 20% water:

$y = 4E\text{-}05x^2 - 0{,}0014x + 0{,}0763$ ($R^2 = 0{,}9698$);

for the commercial grease AeroShell Grease 33:

$y = 3E\text{-}05x^2 - 0{,}0008x + 0{,}0641$ ($R^2 = 0{,}9143$);

for the emulsion of AeroShell Grease 33 with 20% water:

$y = 2E\text{-}05x^2 - 0{,}0005x + 0{,}0628$ ($R^2 = 0{,}7438$).

While the friction coefficient for the commercial grease stabilized at 0.061 after 7-8 minutes, for the emulsions, this parameter stabilized after 11-12 minutes of operation. The analysis of the temperature change kinetics in tribotechnical contact is also noteworthy. By the end of the experiment, the temperature increase in the contact was +13 °C, +11 °C, and +10 °C, respectively, for the commercial grease and emulsions with 10 % and 20 % water (Figure 6).

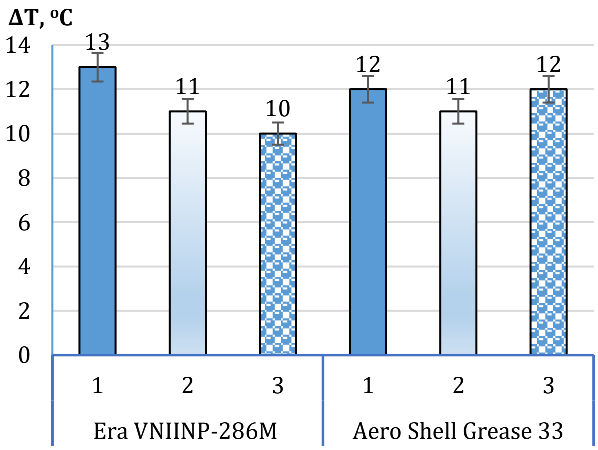


Fig. 6. Temperature increase in the contact zone after 20 minutes of operation: 1 - commercial lubricants; 2 - emulsion with 10 % water; 3 - emulsion with 20 % water.

Thus, the intensity of temperature rise in the tribotechnical contact is reduced by 15% and 23% when lubricated with emulsions containing 10% and 20% water, respectively. We suggest that the mechanism behind this process lies in the thermophysical properties of water, which differ significantly from those of oils. In particular, the specific heat capacity of water is 4200 J/ (kg·°C), which is approximately twice as high as that of a lubricant; the thermal conductivity of water is 0.58 W/ (m·°C), which is three times higher than that of a lubricant. These thermophysical properties determine a lubricant's ability to remove heat from the contact zone, thereby reducing thermal stress in the tribosystem. In our case, an increase in the concentration of dissolved water in the emulsion results in a less intense temperature rise in the tribotechnical contact, due to the increased heat capacity of the emulsion compared to the commercial lubricant.

Unlike VNIINP-286M grease, the addition of water to AeroShell Grease 33 does not degrade its antifriction characteristics. During the initial period of operation, the coefficient of friction for both commercial AeroShell Grease 33 and its emulsions with water is 0.065, which is 8% lower than for VNIINP-286M grease and 15% lower than the coefficient of friction for VNIINP-286M-water emulsions. Stabilization of the friction coefficient at 0.059 occurs after 5 minutes of operation, compared to VNIINP-286M grease. AeroShell Grease 33 reduces the friction coefficient 3% more effectively, and by 11 % compared to the emulsions. The temperature increase in the contact after 20 minutes of operation is 11-12 °C for both the commercial grease AeroShell Grease 33 and its emulsions with water (Figure 7).

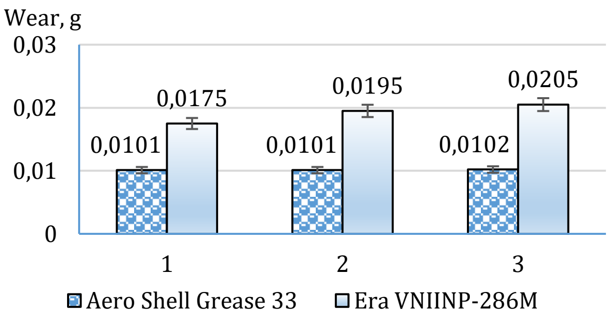


Fig. 7. Weight wear of 30KhGSA steel when lubricated with commercial lubricants (1), and emulsions of lubricants with water at concentrations of 10% (2) and 20% (3).

Thus, due to the effective demulsifying properties of AeroShell Grease 33, the separation of the emulsion into oil and water ensures that the ingress of water into the grease does not affect its antifriction characteristics.

Let's analyse the effect of water on the anti-wear properties of the lubricants under study. Emulsions of VNIINP-286M with 10 % and 20 % water lead to an increase in tribosystem weight wear by 11 % and 15 %, respectively (Figure 7).

The use of AeroShell Grease 33 results in a 1.75-fold reduction in wear of 30KhGSA steel, and a 2-fold reduction in wear for emulsions with 20% water, compared to VNIINP-286M grease. The presence of up to 20% water in AeroShell Grease 33 does not affect the wear resistance of the tribosystem under the experimental conditions studied.

The surface microrelief was assessed for sample 1 (Figure 2), comparing the original surface and the friction surface after 20 minutes of operation when lubricated with emulsions of the studied lubricants containing 20% water (Figure 8).

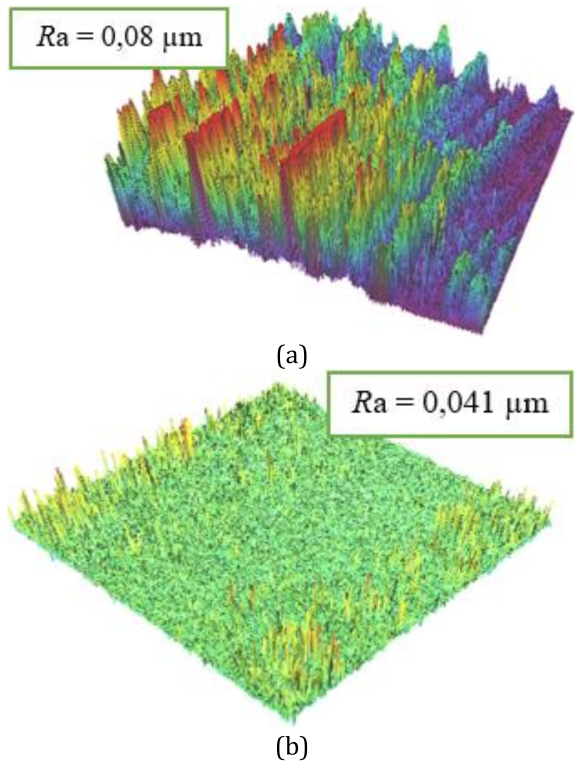


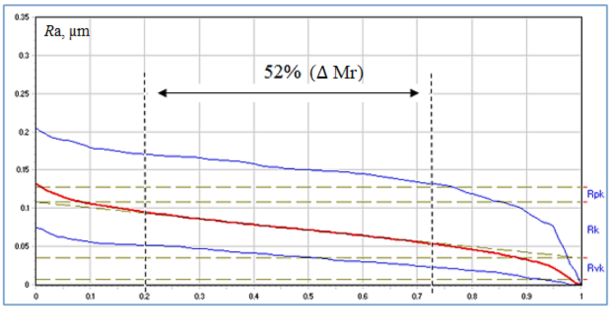
Fig. 8. The initial surface of 30KhGSA steel (a) and the friction track after running-in (b) when lubricated with a VNIINP-286M water-20% emulsion.

The presented images show the 3D state and configuration of the friction surfaces, obtained using a profilometer microscope with height sensitivity up to 1 nanometer.

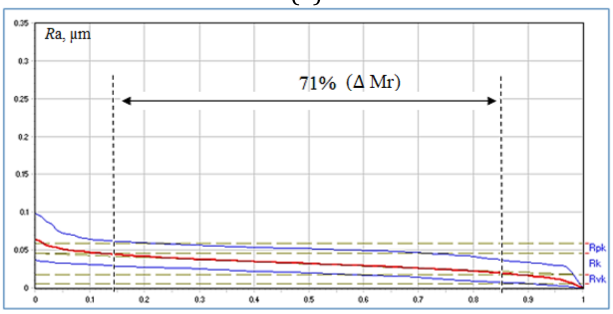
The quality of the steel surface layer was assessed based on the parameters presented in Table 4 and (Figure 9).

Table 4. Microrelief parameters of the surface layer of 30KhGSA steel.

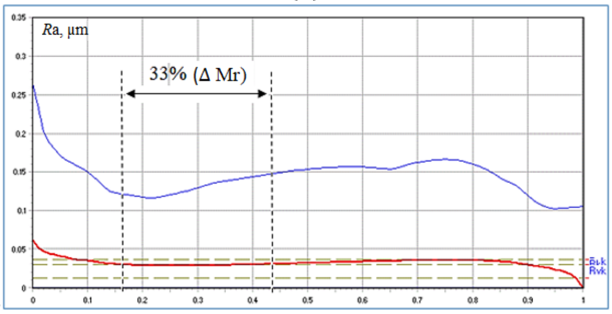
Properties	Initial surface	Friction track* (lubrication with a VNIINP-286M water-20 % emulsion)	Friction track* (lubrication with a AeroShell Grease 33 – water-20 % emulsion)	Friction track* (lubrication with a Grease 33)
R_a, µm (arithmetic mean deviation of the profile)	0.08	0.041	0.038	0.038
R_{max}, µm (maximum profile height)	0.21	0.26	0.1	0.11
R_{pk}, µm (average height of the protrusions)	0.022	0.1	0.018	0.016
R_k, µm (central height of micron irregularities)	0.078	0.021	0.03	0.033
R_{vk}, µm (adjusted depth of the indentations)	0.03	0.017	0.018	0.02
Δ Mr,% – proportion of the central area of the profile according to DIN 4776	58	33	71	73
* - contact zone between the test samples and the counterbody (Figure 1).				



(a)



(b)



(c)

Fig. 9. Determination of the central region share of the profile (ΔMr) of the 30ChGSA steel surface according to the Abbott curve: (a) - initial surface, (b) - after friction with an emulsion based on AeroShell Grease 33, (c) - after friction with an emulsion based on VNII NP-286M grease.

Numerous experimental studies have shown that lubricant significantly affects the process of structural adaptation in tribological elements, with the key aspect being the formation of the microrelief on contact surfaces during the running-in process [28,29].

A comparative analysis of the microgeometric characteristics of the initial surface and the friction raceway has established a more effective structural adaptability of contact surfaces when lubricated with an emulsion based on AeroShell Grease 33 compared to an emulsion based on VNIINP-286M grease, according to the following criteria:

1. Both the equilibrium roughness and the maximum height of the surface layer profile during the running-in process are reduced by a factor of 2;
2. The proportion of the base material, which determines the relative bearing length of the profile, increases by 26 % (Figure 9).

It should be noted that the presence of water in AeroShell Grease 33 does not affect the microgeometric parameters of the structural adaptability of friction pairs within the studied time interval. However, we believe that longer studies are needed to assess the effect of water in lubricant-water emulsions. The negative consequences of water in the lubricant may include the dissolution and leaching of additives, leading to intensified oxidation and wear of friction pairs. This part of the research focused on assessing the effect of water at temperatures below 0°C. The experiments were short-term, as no additional cooling equipment was used in the tribocontact; only pre-cooled lubricant was used.

Comparing the antifriction properties of the commercial grease AeroShell Grease 33 at +10°C and in a cooled state at -10°C, it was found that the friction coefficient during the initial operating period increases by 1.4 times for the cooled grease. Upon stabilization, f is 1.27 times higher than at +10°C (Figure 10 (1, 2)).

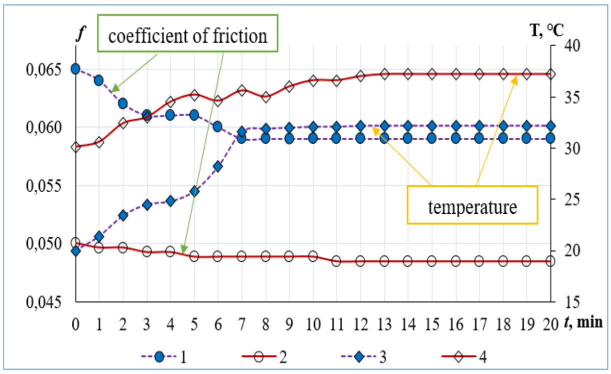


Fig. 10. Kinetics of changes in the coefficient of friction (f) and temperature in the tribological contact (T) during lubrication with AeroShell Grease 33: 1 - f at grease temperature of -10 °C; 2 - f at grease temperature of +10 °C; 3 - initial grease temperature -10 °C; 4 - initial grease temperature +10 °C.

After 20 minutes of tribosystem operation, the temperature increase in the contact zone is 7°C and 13°C, respectively, for grease with an initial temperature of -10°C and +10°C (Fig. 10 (3, 4)).

Based on the data on changes in the coefficient of friction and temperature for AeroShell Grease 33, the following lubrication mechanism for grease–water emulsions is assumed: when water enters the grease, it is effectively demulsified, preventing it from reaching the friction zone. This is evidenced by the stability, consistency and lack of variation in the antifriction and anti-wear properties of commercial grease, the parameters of the microrelief of the surface layer of 30KhGSA steel with structural adaptability in the friction process under conditions of water ingress into the grease. The high hydrophobic properties of this grease prevent the onset of corrosion processes during operation.

Further research may focus on improving the testing methodology to better simulate real flight conditions of aircraft. This could include expanding the temperature range for testing lubricants and their water emulsions, as well as conducting cyclic freeze–thaw tests of the lubricants and their emulsions.

5. CONCLUSION

AeroShell Grease 33 has demonstrated high demulsifying properties: the emulsion of this grease with water, at concentrations of up to 20% and temperatures ranging from -10 to +10 °C, completely separates, and preventing water from entering the contact zone. In contrast, Era VNIINP-286M grease forms a stable emulsion with water at concentrations of up to 15%.

It was found that the presence of water in AeroShell Grease 33 does not affect its antifriction characteristics. The coefficient of friction is 15% and 11% lower, respectively, during the initial running-in period and when the parameter stabilizes in contact, compared to the emulsions of Era VNIINP-286M.

The mechanism for reducing the temperature rise in the sliding pair contact when lubricated with Era VNIIINP-286M grease emulsions has been established. It involves an increase in the heat capacity of the emulsion due to the dissolved water, which has higher thermophysical properties compared to the grease, resulting in a decrease in the thermal stress of the tribosystem.

AeroShell Grease 33 is characterized by high anti-wear properties, reducing the weight wear of 30KhSA steel by 1.75 times compared to Era VNIINP-286M. The presence of water in the grease does not lead to an increase in steel wear, unlike Era VNIINP-286M, where emulsions containing 10% and 20% water cause an increase in steel weight wear by 11% and 15%, respectively.

A more effective structural adaptation of local contacts in sliding pairs lubricated with AeroShell Grease 33 and its emulsions was observed, in contrast to Era VNIINP-286M grease and its emulsions. This is manifested by a two-fold reduction in equilibrium roughness, a 1.6-fold decrease in the maximum profile height, and a 26% increase in the relative reference length of the profile. Such changes in microgeometric characteristics during friction facilitate the formation of an optimal microroughness of the tribological pairs during running-in.

The presented methodology for evaluating the tribotechnical properties of lubricants with varying water content (percentage) was applied during laboratory testing of the flap lift actuator gearbox, model 148.00.5737.000.000, used in AN-148 aircraft.

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