International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 22 (2017) pp. 12362-12368
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Development of New Lubricants for Reducing the Wear of the Elements of the Path and Running Parts of Rolling Stock

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Annotation

The article offers a new lubricant composition based on chemical production wastes on the basis of low-molecular polyethylene. As the liquid component, which imparts to lubricant composition the desired consistency, we used oil or other petroleum refining products. To evaluate the properties of lubricating compositions, data of protective properties of developed lubricating compositions are presented. The results of testing are given. We got approximating dependences, determining every-component influence of the lubricating composition on the wear, that allow to accurately predict the wear in pair of wheel-rail friction, depending on the content of the lubricant composition.

To evaluate the tribological properties of the proposed lubricating compositions, the data of the protective properties of the developed lubricating compositions are presented, that were identified in vitro using a friction machine AI 5018, with respect to the conditions of interaction of the rolling stock wheels with rail. Calculated and shows the values of the relative reduction of wear by lubrication.

The composition is offered to prevent wear in wheel-rail friction tandem, which consists of cheap, available components, can be easily applied on the rail, has high efficiency and has minimal impact on man and the environment. Obtained approximating dependences allow to accurately predict wear in wheel-rail friction tandem, depending on the content of the lubricant composition.

Keywords: lubricating composition, modeling, chlorlignin, properties of the compositions, wear, polymer.

INTRODUCTION

Lubricants used in rail transport must meet a certain number of requirements [1- 4]: have high lubrication efficiency; easy to apply in the contact place and retained on the friction surfaces; be accessible and inexpensive; maintain its quality during storage and transport; be nontoxic; be without side effects, such as corrosion of metal parts, rotting of sleepers, rail corner losing; meet the requirements of fire safety, etc.

In view of the above requirements, it is developed new lubricating composition based on chemical production wastes on the basis of low-molecular polyethylene. The low molecular polyethylene (LMPE) - production waste of high-tonnage product - high-pressure polyethylene. As the liquid component, which imparts to lubricant composition the desired consistency, we used oil or other petroleum refining products.

Prior to our studies, in Irkutsk State Transport University lubricant composition was developed to prevent the wear in the pair of wheel-rail friction, comprising: (% wt.); 10-20 of petroleum coke, 15-25 of waste diesel oil and the rest (to 100) - a low molecular polyethylene (LMPE).

The disadvantage of this composition is the need to use dispersed petroleum coke with the particle size less than 0.100 mm, which is difficult to achieve in a production environment.

MODELLING AND RESULTS

The above drawback eliminated in developed lubricant composition based on low molecular polyethylene, where the anti-friction components are the wastes of wood processing on hydrolysis and pulp and paper mills – lignin, and also chlorlignin. Using this waste, lubricating composition of the following composition is proposed (% wt.):

a) hydrolysis lignin - 15-25;

b) waste diesel oil - 10-25;

c) LMPE - the rest (to 100).

Mixed components of the composition in the required ratio form a stable dispersion, which is a consistent grease of dark brown color.

In this grease composition, it was also introduced polysulfide polymers, antiseize effect of which had been investigated previously. Lubricating compositions, containing LMPE, waste diesel oil and other components, prepared by heating the LMPE to about 90 ° C and adding with vigorous stirring to a preheated (about 70 ° C) diesel oil. The other components was added to the resulting homogeneous mixture. LMPE ratio: Waste diesel oil (WDO) was chosen so as to provide the necessary lubrication consistency.

Using lignin, partially modified by chlorination, the developed composition was with the following consist [5]:

a) hydrolysis chlorlignin - 15-25;

b) waste diesel oil - 10-25;

c) LMPE - the rest (to 100).

To evaluate the tribological properties [3] of the proposed lubricating compositions, the data of the protective properties of the developed lubricating compositions are presented (Table 1), that were identified in vitro using a friction machine AI 5018, with respect to the conditions of interaction of the rolling stock wheels with rail.

As the samples, we used standard size rollers, which were made of steel marks used for the production of rails (R-65) and wheels (mark 1). Rollers wear was determined by gravimetry method - by weighing on analytical scales with accuracy of 0.001 g.

The test results are shown in Table 1. As can be seen from the data, reduction of lignin content below 15 (% wt.) decreases the protective effect of the lubricant, and the increase of its content above 25 (% wt.) leads to the formation of thick grease, which is difficult to be applied in the contact zone.

The ratio between the content of diesel oil and LMPE determines grease consistency and depends on climatic conditions of the composition application. Reducing the amount of diesel oil lower than 10 (% wt.) make thick grease, its components are difficult to mix with each other, and its increasing higher than 25 (% wt.) leads to the formation of the liquid composition, which, nevertheless, has a high viscosity and poorly applied in the friction zone.

Except lignin we used, as compositions component, the product obtained by injecting chlorine in lignin. For that hydrolysis lignin in an aqueous suspension is treated with chlorine or hypochlorite. The obtained lignin contains 3-5 (% wt.) of chlorine, organic compounds of which are used as anti-wear additives to lubricants. Compositions 9 and 10 (see. Table 1) instead of lignin contain chlorlignin, which contributes to a more long-term effect of the applied grease.

Table 1 shows the values of the relative reduction of wear by lubrication, which is calculated by the formula:

$$\Delta = \left(\frac{I_{without} - I}{I_{without}} \right) * 100\ \%$$

Where I, I*without* - the value of wear with and without grease.

Table 1: Wear of test rollers

№ of grease	Content of lubrication composition, %			Wear I, y		Δ, %	
	Diesel oil, x	LMPE, y	chlorlignin, z	Movable roller (MR)	Non-movable roller (NR)	MR	NR
1	15	65	20	0,054	0,145	96,597	90,954
2	15	70	15	0,098	0,198	93,824	87,648
3	15	75	10	0,153	0,203	90,359	87,336
4	20	55	25	0,126	0,136	92,060	91,515
5	25	55	20	0,085	0,097	94,644	93,948
6	28	52	20	0,181	0,201	88,594	87,461
7	10	75	15	0,146	0,196	90,800	87,772
8	15	67	28	0,187	0,207	88,216	87,086
9	15	65	20	0,053	0,135	96,660	91,578
10	15	70	15	0,099	0,187	93,761	88,334
11	Without the grease $I_{бс} =$			1,587	1,603		

As can be seen from Table. 1, lubrications number 1, number 5 and number 9 reduce wear on 94.6 - 96.7% for the moving roller at 90.9 - 93.9% for the fixed roller.

Experimental results (excluding experiments 9 and 10) were treated in the Stat-graphics Plus package. We got approximating dependences, determining every-component influence of the lubricant composition content x, y, z on wear Ip. Statistical criteria of regression dependences reliability are presented in Table. 2.

For MR:

$$I_p = 1{,}5253 - 0{,}1526x + 0{,}00381x^2\,; \tag{1}$$

$$I_p = 1{,}5872 - 0{,}0470y + 0{,}00037y^2\,; \tag{2}$$

$$I_p = 1{,}5136 - 0{,}1506z + 0{,}00381z^2\,. \tag{3}$$

For NR:

$$I_p = 1{,}5442 - 0{,}1467x + 0{,}00358x^2\,; \tag{4}$$

$$I_p = 1{,}6019 - 0{,}0483y + 0{,}00040y^2\,; \tag{5}$$

$$I_p = 1{,}5311 - 0{,}1440z + 0{,}00356z^2\,. \tag{6}$$

Analysis of the dependences allowed to offer the following multiple regression equations that predict the amount of wear on the component composition of the lubricant:

For MR:

$$I_p = 1{,}5750 - 0{,}8264(xyz)^{0{,}0563}, \qquad (7)$$

For NR:

$$I_p = 1{,}57183 - 0{,}000225xyz + 1{,}04 \cdot 10^{-6}(xyz)^{1{,}5}. \qquad (8)$$

Table 2: Criteria of regression dependences reliability

Formula number	Determination coefficient, %	The criterion of the Durbin-Watson	Standart error, S	Avg. abs. error, г
(1)	95,14	1,83	0,124	0,076
(2)	99,37	2,00	0,045	0,026
(3)	94,74	1,78	0,129	0,078
(4)	95,62	1,79	0,116	0,069
(5)	99,54	2,75	0,038	0,025
(6)	94,83	1,94	0,126	0,076
(7)	98,68	1,84	0,065	0,045
(8)	97,55	1,45	0,086	0,060

Thus, the proposed lubricant compositions № 1, № 5 and № 9 to prevent wear in pair of wheel-rail friction, which consist of cheap, available components, easily applied to the rail, are highly effective and have a minimal environmental impact.

Let's construct a forward-looking assessment of wear at the next change in the lubricant composition. Confidence intervals of prediction $I_p \pm tS$ (t = 1,895 - student criterion $S = \sqrt{\frac{\sum_{i=1}^{n}[I_{\text{э}}(i) - I_p(i)]^2}{n-3}}$ - the standard error (see Table 2) for the regression models (7), (8) for a significance level of 0.10 and the number of freedom degrees n-3 = 7.

Table 3: Forward-looking assessment of wear at the changes in the lubricant

Roller, regression equation	The composition is close to the experiment №	x	y	z	Wear forecast, I_p, г	Lower border $I_p - tS$,	Upper border $I_p + tS$,
MR, (7)	4	21	56	23	0,1070	–0,0161	0,2301
MR, (7)	5	26	56	18	0,0437	–0,1192	0,2066
NR, (8)	8	16	68	16	0,0437	–0,1192	0,2066
NR, (8)	5	26	56	18	0,0980	–0,0649	0,2609
NR, (8)	4	21	56	23	0,1124	–0,1605	0,2752

Analysis of Table 3 and Table 1 shows that the experimental value of the wear enters the forecast intervals, specified by lower and upper boundaries.

We also did analysis of anti-seize additives based on polysulfide polymers [6], the impact of their structure on the protective properties of the lubricant.

The friction that occurs between the wheel flange and the side surface of the rail head, is characterized by high specific loads, frequency and unsteadiness. In the contact zone there are sharp momentary increases of pressure and temperature. As a result of these influences molecules, included in the lubricating compositions, undergo chemical reactions and reaction products are adsorbed more easily on rubbing surfaces [6].

As an anti-seize agent in the composition for lubrication of rails we proposed and used sulfur-containing polymer products, derived from the production of epichlorohydrin waste, produced for the synthesis of epoxy resins.

The dispersed polymers of this type are easily mixed with lubricating composition, proposed for the lubrication of rails based on the low molecular polyethylene, finely milled petroleum coke or chlorlignin and locomotive waste diesel oil.

Table 4 shows the results of laboratory tests of lubricant compositions on the friction machine containing polysulfide polymers with varying percentages of sulfur.

To evaluate the effect of anti-seize additives from thiokol on this tribological system, the wear of rollers was determined several times during a single experiment. First, rollers worked 6 hours in the presence of grease that was applied in the contact area every 10 minutes. Then lubricate was cleaned from the rollers using gasoline and rags, measured result of wear, and tests were carried out for another three hours (in the absence of lubrication). After that the wear of rollers was measured, and experiment was continued again for another three hours.

Test results indicate that the introduction in the lubricant of polymer additive, containing sulfur, not only retains and enhances the protective effect of lubrication, but also contributes to strengthening of the surface in the friction zone, because protective effect persists after the removal of grease.

This allow to suggest that the sulfur-containing polymers will reduce the wear of rail side surface and wheel flange when passing the curved sections not only by direct lubricant location in the friction zone, but some time after its complete removal.

Table 4: Influence of the polysulfide polymer composition on the lubricant protective properties

The number of working hours with lubricant	1 hour				2 hours				3 hours				4 hours				6 hours			
The number of working hours without lubricant	3 hours		6 hours		3 hours		6 hours		3 hours		6 hours		3 hours		6 hours		3 hours		6 hours	
	MR	NR	MR	NR	MR	NR	MR	NR	MR	NR	MR	NR	MR	NR	MR	NR	MR	NR	MR	NR
Lubricant № 1 (polymer from Na_2S_1)	**0,603**	**0,610**	**1,203**	**1,387**	**0,510**	**0,612**	**1,234**	**1,318**	**0,383**	**0,401**	**1,117**	**1,107**	**0,123**	**0,161**	**0,712**	**0,694**	**0,118**	**0,123**	**0,535**	**0,561**
Lubricant № 2 (polymer from Na_2S_2)	**0,583**	**0,602**	**1,223**	**1,294**	**0,555**	**0,543**	**1,162**	**1,158**	**0,471**	**0,462**	**1,087**	**1,010**	**0,264**	**0,247**	**0,853**	**0,871**	**0,189**	**0,183**	**0,394**	**0,437**
Lubricant № 3 (polymer from Na_2S_3)	**0,412**	**0,434**	**0,812**	**0,796**	**0,357**	**0,371**	**0,732**	**0,741**	**0,303**	**0,298**	**0,619**	**0,627**	**0,261**	**0,257**	**0,463**	**0,482**	**0,194**	**0,187**	**0,417**	**0,386**
Lubricant № 4 (polymer from Na_2S_4)	**0,342**	**0,361**	**0,707**	**0,723**	**0,276**	**0,275**	**0,672**	**0,663**	**0,217**	**0,210**	**0,575**	**0,563**	**0,195**	**0,199**	**0,401**	**0,384**	**0,183**	**0,171**	**0,293**	**0,287**

To estimate the aftereffects of lubricant compositions, it is given the modeling of lubricant compositions aftereffects in the wheel-rail system.

For a quantitative description of the influence of sulfur and chlorine in the polymer additives under-wear, we obtained regression equations of general form $I_p = f(t)$, where I_p - wear for *x* hours of work without lubrication, and t – hours of preliminary work with lubrication. Table 5 shows the obtained regression equations, the reliability criteria of which are shown in Table. 6. When choosing approximating dependencies, we came from the maximization of determination criteria R^2. If the difference in R^2 values for the non-linear and linear regression was small, then we selected linear regression [7].

On Fig. 4, as an example, the calculation results are compared by the model (16) with experimental data.

The actual value $I(t_i)$ for the argument t_i can be represented as:

$$I(t_i) = I_p(t_i) + e_i$$

where I_p - wear value, calculated according to the equation (16) for the time of work without lubrication t_i, *i* - number of experiences, $e_i = I_э(t_i) - I_p(t_i)$ - the value of the remainder, random, unobserved variable. Fig. 6 shows the dependence e_i from $I_p(t_i)$.

As can be seen from Fig. 4-6, the regression equation (16) accurately describes the experimental data.

Table 5: Regression equations of wear model

Roller	№ lubricant	$x = 3$ working hours without lubricant	$x = 6$ working hours without lubricant
MR	1	$I_p = 0{,}8484 - 0{,}2550t + 0{,}0166t^2$ (9)	$I_p = 1{,}2860 + 0{,}1115t - 0{,}1424t^{1{,}3}$ (10)
NR	1	$I_p = 0{,}8533 - 0{,}1946t + 0{,}0114t^2$ (11)	$I_p = 1{,}6033 - 0{,}1844t$ (12)
MR	2	$I_p = 0{,}6940 - 0{,}0880t$ (13)	$I_p = 1{,}4880 - 0{,}1700t$ (14)
NR	2	$I_p = 0{,}7011 - 0{,}0918t$ (15)	$I_p = 1{,}4984 - 0{,}1701t$ (16)
MR	3	$I_p = 0{,}4445 - 0{,}0435t$ (17)	$I_p = 0{,}8790 - 0{,}0845t$ (18)
NR	3	$I_p = 0{,}4673 - 0{,}0494t$ (19)	$I_p = 0{,}8874 - 0{,}0878t$ (20)
MR	4	$I_p = 0{,}4301 - 0{,}0971t + 0{,}0093t^2$ (21)	$I_p = 0{,}8184 - 0{,}0902t$ (22)
NR	4	$I_p = 0{,}43554 - 0{,}1090t + 0{,}0104t^2$ (23)	$I_p = 0{,}8241 - 0{,}0938t$ (24)

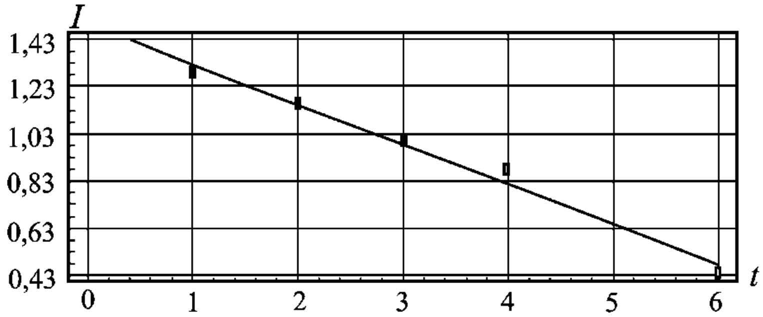

Figure. 1: Dependence of wear I from working time t without lubrication: points - experimental data, line - regression equation

Table 6: Criteria of regression dependences reliability

Formula number	Determination coefficient, %	The criterion of the Durbin-Watson	Standart error, S	Avg. abs. error, г
(9)	91,872	2,680	0,089	0,051
(10)	89,282	2,730	0,146	0,083
(11)	88,737	2,511	0,112	0,063
(12)	91,819	2,719	0,122	0,081
(13)	91,834	2,745	0,058	0,040
(14)	93,736	1,369	0,098	0,067
(15)	92,136	2,882	0,060	0,038
(16)	98,589	1,861	0,045	0,030
(17)	98,442	1,454	0,012	0,008
(18)	92,199	2,357	0,054	0,034
(19)	96,958	1,449	0,019	0,014
(20)	96,240	2,551	0,038	0,023
(21)	99,672	3,465	0,005	0,003
(22)	95,410	2,650	0,044	0,031
(23)	98,398	2,880	0,014	0,007
(24)	95,566	2,756	0,045	0,029

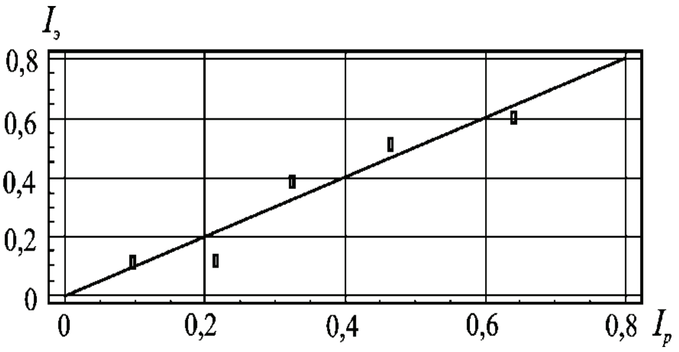

Figure. 2: Dependence of the experimental values of wear $I_э$ from predicted by equation (16) Ip values

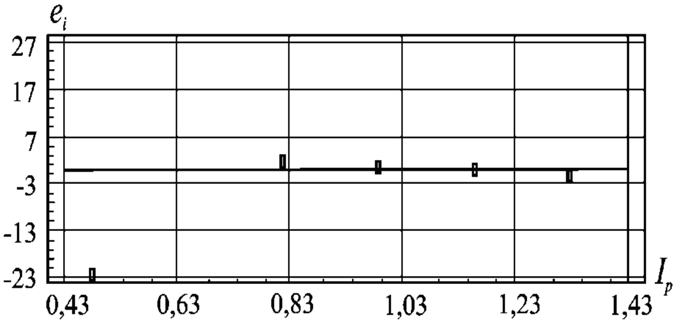

Figure 3: Dependence of the residues from the predicted Ip values, calculated by the regression equation (8)

The resulting equations allow not only predict the wear value at expenditure of lubrication, but also explains the mechanism of the protective effect of polymeric additives, containing sulfur and chlorine.

Despite the fact that the approximation by polynomials of 2, 3 and 4 orders of magnitude describe better the experimental data, their prognostic characteristics (forecast to increase work with lubrication for more than 6 hours) have no physical meaning. For a second-order equation wear becomes negative, and for polynomials of 3 and 4 orders wear increases sharply after working time increase with lubrication over 6 hours, although aftereffect of lubrication (formation of a plastic protective layer on the metal surface) should either increase or remain at 6 hours work level with lubrication.

In general, the protective effect of lubrication is best described by an exponential dependence of the wear from working time of friction machine with lubrication (y = ae-bx), coefficient b has a large absolute value for the models, corresponding to three clock running without lubricant, which indicates that the protective layer formed on the surface during 3 hours of near-fully protect the metal surface from wear even in the absence of lubrication.

Note, that the quality of the lubricant significantly affects the parameters of movement of the rolling stock and the safety of the transportation process and modeling of the compositions allows to achieve the optimal motion parameters [8-10].

Thus, a composition is offered to prevent wear in wheel-rail friction tandem, which consists of cheap, available components, can be easily applied on the rail, has high efficiency and has minimal impact on man and the environment. Obtained approximating dependences allow to accurately predict wear in wheel-rail friction tandem, depending on the content of the lubricant composition.

CONCLUSION

The mathematical models of lubricant compositions aftereffect in the wheel-rail system are complied. Approximating dependences allow to accurately predict wear in wheel-rail friction tandem, depending on the content of the lubricant composition.

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