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Article

New compositions of metal-working coolants for brass rolling

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Abstract: The efficiency of cold steel rolling depends mainly on the quality of the metal-working coolant (MWC) and its cost. In this connection, it is actual to search for new compositions of lubricants and emulsions, which provide the lowest values of the friction coefficients in deformation zone and are obtained by waste recycling in other industries. In this study we have developed new compositions of the MWC on basis of mono- and diglycerides and their esters of boric acid synthesized from the wastes of sunflower oil production. The new compositions of MWC were tested in DSEA on laboratory rolling mill 100x100 with a roll diameter of 100 mm. The efficiency of new MWC during cold rolling of brass L63 samples was determined by factor of metal stretch forming λ. We found the new metal-working coolants to show the most efficiency under higher cobbing that provides the highest metal stretch forming. The composition with 30 % of mono- and diglycerides is the most effective because it provides the minimum coefficient of friction that leads to increase of factor of metal stretch forming. Thereby the metal-working coolants on basis of mono- and diglycerides obtained from the wastes of sunflower oil production can be recommended for use in strip rolling of copper-zinc alloys because of a low cost, availability and high efficiency.

Keywords: metal-working coolants (MWC), lubricant, rolling, strip rolling, waste recycling, sunflower oil production.

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1. Introduction

The efficiency of cold steel rolling depends mainly on a quality of the metal-working coolant (MWC) [1–4]. Earlier we studied the influence of consistent medium- and high-temperature greases "Natol" [5], consistent anti-wear and metal-cladding greases [6], and metal-working coolants [7] on friction coefficient in still rolling on the laboratory rolling mill 100x100 (DSEA).

Friction conditions on a contact surface of metal and tool have an effect on energy-power parameters of metal forming processes and, in particular, rolling process. Besides, the friction defines quality of a surface of work metal and is a principal cause of deterioration of a working surface of the tool.

Growth of friction coefficient leads to growth of normal contact strains and reduces rolling accuracy especially for thin strips from considerable resilient flattening rollers. The friction has determinant influence on rolling result when the relation of arc length of contact l to an average thickness of a strip h_{avg} in the center of deformation is more than unit ($l/h_{avg} > 1$) [8,9].

Principal kind of a contact friction between metal and the tool is the sliding friction. It has two main characters: the presence of the pressure forces pressing the tool and metal to each other and an inequality of rates of the tool and metal on surfaces of contact.

Value of tangential stress τ in metal forming theory is more often defined with help of Amonton's law from physics:

$$\tau = \mu \cdot p, \tag{1}$$

where μ is coefficient of sliding friction (dimensionless quantity);

p is normal contact strain, Pa.

Value of μ is different in various points of contact, but it is assumed average value which is accepted constant for all surface contacts.

The major factors which have an influence on μ value are: parameters of a roughness of the tool and metal before rolling, a deformable material, pressure between the tool and metal, rate of deformations (rolling), metal temperature. Lubricating properties of the technological liquids used as lubricants have a special influence on value of friction coefficient μ.

In cold ferrous metal rolling a wide spectrum of metal-working lubricants is used. But for nonferrous metals and in particular for copper and its alloys, the assortment of metal-working lubricants could be better. Their efficiencies were wished to be the better to.

At the present time it is widely used the following metal-working lubricants. Emulsol «AZMOL OM», Emulsol «Viol» (TU 0258-011-23763315-2000), Concentrate VpCI-316 are used in cold copper alloy rolling. Oil Klubercut CO 6-102 is suitable for cutting and punching of nonferrous metals. Water-soluble cooling liquids "Rhenus", for example, Rhenus FSC-IHU, metal-working coolant «Smalta-3» (TU 0258-063-23763315-2008), Emulsol T «PM», lubricant-cooling agents «Universal-1 TC» (TU U 23.2-31023384.002-2004) and «ENTEKC-EM» (TU U 24.6-13450972.001-2002) are employed in rolling of ferrous and nonferrous metals.

The latter two metal-working coolants were taking as models for comparison in this study.

2. Materials and Methods

In the present work we offered the new metal-working coolants on the basis of products of waste treatment in sunflower oil production that is very actual in Ukraine. Mono- and diglycerides, and their esters of boric acid were synthesized from wastes of sunflower oil production in Ukrainian State University of Chemical Technology. Compositions of new metal-working coolants included calcium stearate or barium carbonate which were good fillers for metal-working coolants and improved their properties in metal rolling and stretch forming. The mixture of chlorinated paraffin wax XP-470 and industrial spindle oil was used as medium for metal-working coolant. The quantities of mono- and diglycerides, and their esters of boric acid in compositions of metal-working coolants were 10, 20 and 30% (Table 1). Percentages of chlorinated paraffin wax, calcium stearate, and barium carbonate were equal 20%. To determine the influence of mono- and diglycerides, and their esters of boric acid on metal rolling we created metal-working coolants without these components (Table 1, compositions 13 and 14).

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Table 1. Compositions of new metal-working coolants (MWC) for metal rolling

Number of MWC	Table of component contents, %					
	boric acid esters of mono- and diglycerides*	mono- and diglycerides*	industrial spindle oil	chlorinated paraffin wax XP-470	calcium stearate	barium carbonate
1	20	-	40	20	20	-
2	-	20	40	20	-	20
3	10	-	50	20	20	-
4	-	10	50	20	-	20
5	30	-	30	20	20	-
6	-	30	30	20	-	20
7	20	-	40	20	-	20
8	-	20	40	20	20	-
9	10	-	50	20	-	20
10	-	10	50	20	20	-
11	30	-	30	20	-	20
12	-	30	30	20	20	-
13	-	-	50	25	25	-
14	-	-	50	25	-	25

Note. * These components were synthesized in Ukrainian State University of Chemical Technology (Dnipro, Ukraine).

In the present work we did not task to define the exact values of friction coefficient for these metal-working coolants. It is a subject of another research.

However the efficiency of application of these coolants is easy established: it is necessary to carry out rolling of identical samples with various coolants and without them (in dry rollers) with constant gap between the rollers. It is obvious that in case of more effective coolant the friction coefficient μ is less. That decreases contact pressures τ and p and rolling force and consequently elastic deformation of elements of a roll mill stand. And we can obtain thinner strip on output.

The tests with various coolants were carried out on the laboratory rolling mill 100x100 in Donbas State Engineering Academy (Fig. 1).

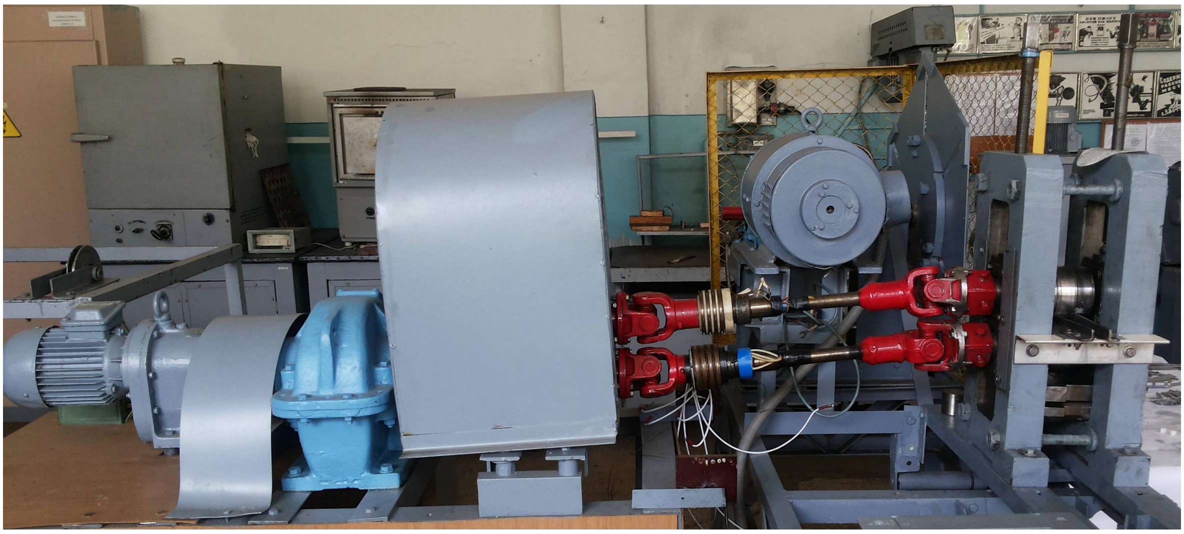

Figure 1. General view of experimental assembly

Work rollers were produced from a steel 9X and had following parameters: diameter was 97 mm, hardness of forming surfaces of roll body was equal 80HS, and roughness was 0.32 microns. The samples were produced from brass L63 (brass state is annealed) and had initial thickness h_0=0.77

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mm and width b=26 mm. Rolling rate was 0.05 m/s with three levels of cobbing ε_{avg}: ε_{avg}≈18% (first level), ε_{avg}≈31% (second level), ε_{avg}≈47% (third level).

Before rolling the uniform layer of the coolant was spread on a strip. After every test the rollers were carefully degreased with solvent 647 (TU U 24.3-14215951.004 - 2004).

To increase the accuracy of estimation in every case we determined the cobbing level with help of factor of metal stretch forming λ as relation of distances between lines, marked preliminary on a strip (l_0=100 mm), before and after rolling (l_1), that is $\lambda = l_1/l_0$.

The approximate average value of a friction coefficient for every coolant was determined by method of forward slip [10]. That was to determine the experimental value of forward slip S as an index of relative sliding of metal on a roller surface in output from the deformation center in steady-state process. After this with help of the experimental value of forward slip S the friction coefficient was calculated by Fink and Ekelund-Pavlov formulas which established linkage between forward slip, friction coefficient, roller diameter, and strip thickness on output from rollers.

3. Results

In the present work the forward slip was determined by method of core marks [5]. For this the roller body was preliminary marked by labels at certain distance l_0' (in our case l_0' = 100 mm), which dinted on a strip surface at distance l_1'. With help of this distance on samples rolled with various coolants, the forward slip was calculated under the formula:

$$S = (l_1' - l_0')/l_0'. \quad (2)$$

Results of experimental tests are shown in Table 2 and graphic on the Figure 2, 3, 4 and 5.

Table 2. Results of experimental study of efficiency of metal-working coolants in cold rolling of brass L63 with use of various coolants

Metal-working coolant	h_1 [mm]*	l_1 [mm]	l_1' [mm]	λ
1[st] level of cobbing (ε_{avg}≈18%)				
0**	0.64	120	102	1.2
1	0.63	125	102	1.25
2	0.63	124	102.5	1.24
3	0.64	124	102	1.24
4	0.63	126	102.5	1.26
5	0.63	126	102	1.26
6	0.63	127	103	1.27
7	0.63	126	102.5	1.26
8	0.63	126.5	102	1.265
9	0.64	127	102.5	1.27
10	0.63	126	102.5	1.26
11	0.63	127	102.5	1.27
12	0.63	126	102	1.26
13	0.64	126	102	1.26
14	0.63	126	103	1.26
15***	0.64	125	102.5	1.25
16***	0.63	126	103	1.26
2[nd] level of cobbing (ε_{avg}≈31%)				
0**	0.53	152	103	1.52
1	0.52	153	102.5	1.53
2	0.53	153.5	102.5	1.535
3	0.53	154	102.5	1.54
4	0.53	154	103	1.54
5	0.52	154	102	1.54
6	0.53	154	103	1.54
7	0.51	153	102	1.53

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Metal-working coolant	h_1 [mm]*	l_1 [mm]	l_1' [mm]	λ
8	0.53	153	102.5	1.53
9	0.54	152	102.5	1.52
10	0.52	151	102	1.51
11	0.53	153	102.5	1.53
12	0.53	152	102.5	1.52
13	0.53	151	102	1.51
14	0.53	151	103	1.51
15***	0.53	150	102.5	1.50
16***	0.53	152	103	1.52
3rd level of cobbing (ε_{avg}≈47%)				
0**	0.42	184	102	1.84
1	0.41	190	102	1.90
2	0.40	190	102	1.90
3	0.41	191	102	1.91
4	0.43	187	102	1.87
5	0.41	193	101.5	1.93
6	0.42	189	102	1.89
7	0.40	191	102	1.91
8	0.41	196	102	1.96
9	0.43	185	102	1.85
10	0.40	192	102	1.92
11	0.40	191	101	1.91
12	0.39	198.5	101	1.99
13	0.42	190	101.5	1.90
14	0.41	192	102	1.92
15***	0.42	190	103	1.90
16***	0.43	185	102.5	1.85

Note. * h_1 is a strip thickness after rolling. ** Without coolant (dry rolling). *** The lubricant-cooling agents «Universal-1 TC», TU U 23.2-31023384.002-2004 (№ 15) and «ENTEKC-EM», TU U 24.6-13450972.001-2002 (№ 16) were used as models for comparison.

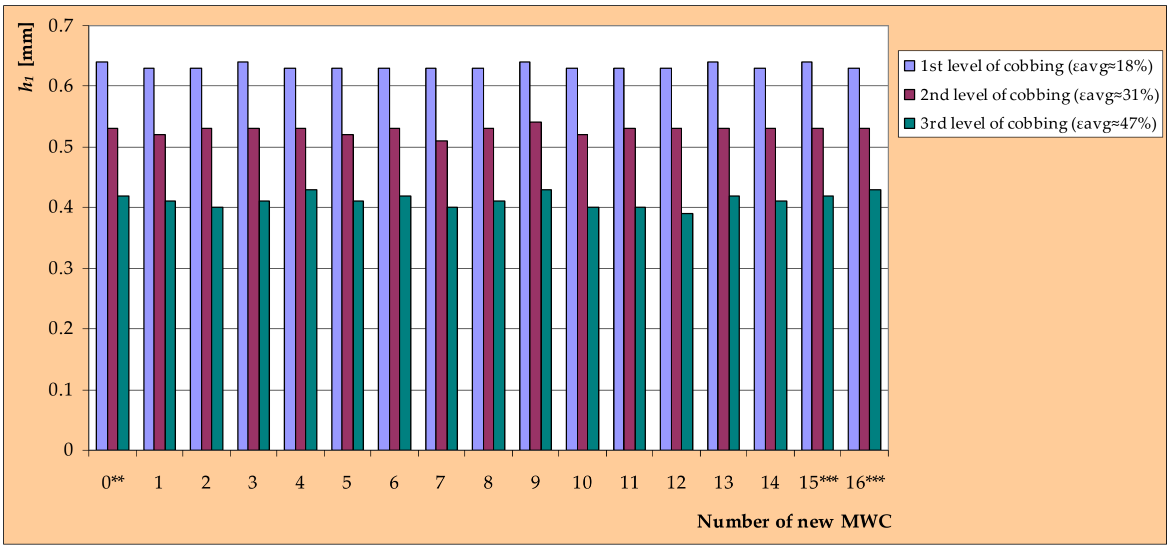

Figure 2. Graphic representation of values of strip thickness after rolling (h_1) [mm] for different number of new metal-working coolant (MWC)

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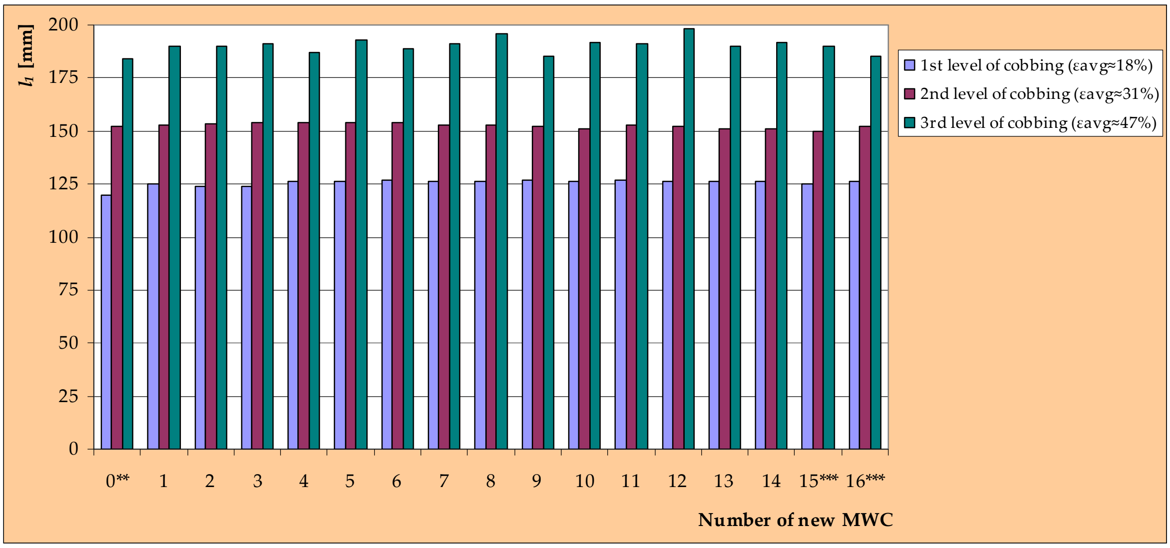

Figure 3. Graphic representation of values of distance between before and after rolling (l_1) [mm] for different number of new metal-working coolant (MWC)

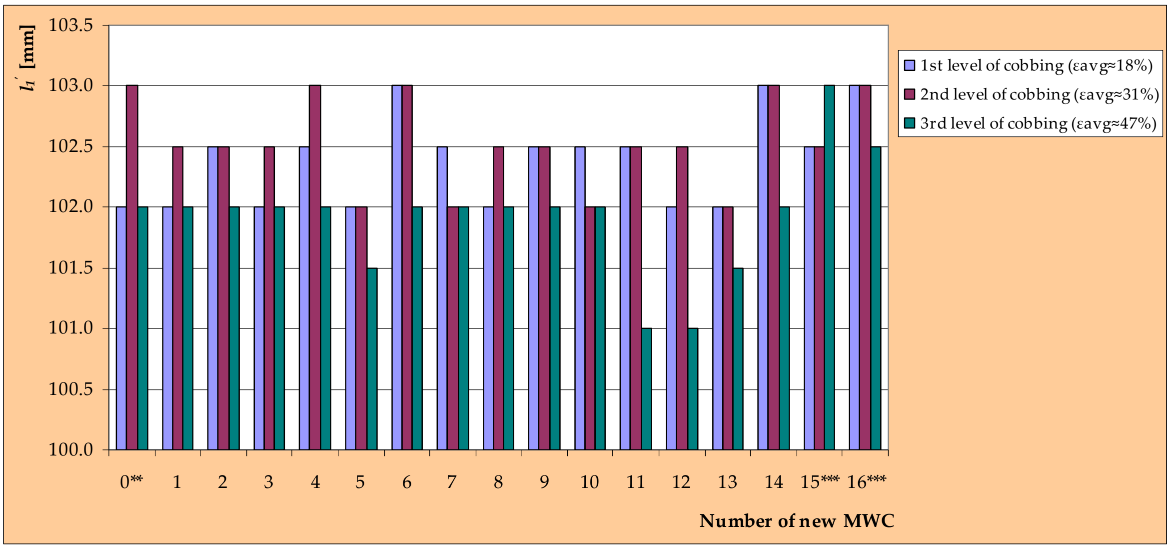

Figure 4. Graphic representation of values of strip surface at distance (l_1') [mm] for different number of new metal-working coolant (MWC)

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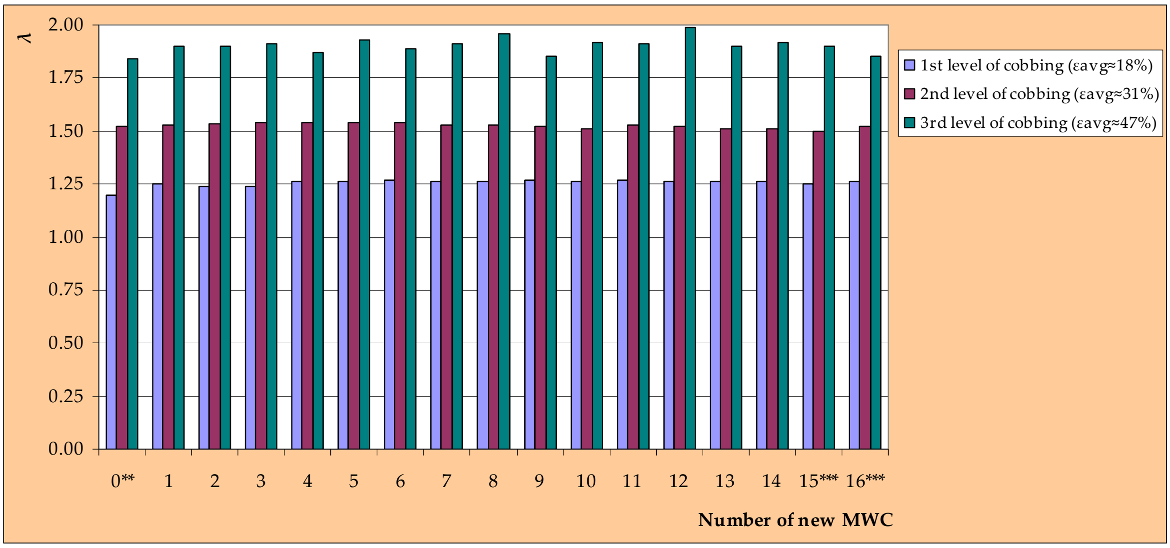

Figure 5. Graphic representation of values of factor of metal stretch forming (λ) for different number of new metal-working coolant (MWC)

The value of factor of metal stretch forming (λ) characterizes the value of a friction coefficient (μ) therefore it can be used in definition of efficiency of metal-working coolants.

The analysis of results showed that depending on a level of cobbing within 18-47 % and consequently on pressure in point of contact of metal and tool, the friction coefficient μ decreases from 0.077-0.08 (for $\varepsilon_{avg}\approx$18 %) to 0.046-0.063 (for $\varepsilon_{avg}\approx$47 %) practically for all metal-working coolants. Decrease in a friction coefficient μ with increase in deformation degree ε up to 31-47 % can be explained by consideration of the scheme of contacting surfaces of rollers and metal. At small cobbing the microasperities on a metal surface pierce through layer of metal-working coolant that leads to direct point contact of metal surfaces in the deformation center. In this case the friction coefficient has higher value. With increase of cobbing the microasperities on a metal surface are rolled over and as result the conditions for formation of coolant layer on a contact surface improve that promotes reduction of a friction coefficient [6].

Thus, the most efficiency of new metal-working coolants is revealed in the conditions of higher cobbing. Therefore it is possible to consider the new metal-working coolants provide the highest metal stretch forming 1.92-1.985 (the third level of cobbing) and are more effective.

Comparison of the received results has shown the calcium stearate is more effective filler. In all cases with the identical content of mono- and diglycerides or boric acid ethers of mono- and diglycerides the use of calcium stearate gave higher λ in comparison with barium carbonate (compare, for example, compositions 3 and 4 in Table 2). Only at absence of mono- and diglycerides or boric acid ethers of mono- and diglycerides in composition of metal-working coolant the composition with barium carbonate is more effective (see Table 2, compositions 13 and 14). When the content of mono- and diglycerides or their ethers of boric acid was 10 % the value of λ was higher in the case of mono- and diglycerides (see Table 2, compositions 3 and 10). So the efficiency of metal-working coolants with mono- and diglycerides are higher in comparison with compositions with boric acid ethers of mono- and diglycerides. The same results are observed and for compositions containing 20 % and 30 % of these components (compare results for compositions 1 and 8, 5 and 12 in Table 2).

4. Discussion

Thus the compositions of metal-working coolants with mono- and diglycerides on basis of wastes of sunflower oil production are more perspective in comparison with compositions containing boric acid ethers of mono- and diglycerides because the letter are more expensive from additional stage of treatment.

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The best results were received for composition 12 containing 30 % of mono - and diglycerides. It is possible to surmise the higher content of mono - and diglycerides can give higher efficiency of metal-working coolant in brass rolling.

In the present study we have tested the new compositions of metal-working coolants in comparison with widely used lubricant-cooling agents «Universal-1 TC» (Table 2, № 15) and «ENTEKC-EM» (Table 2, № 16). We found that in these conditions the lubricant-cooling agent «ENTEKC-EM» is not effective (λ is 1.85), and efficiency of lubricant-cooling agent «Universal-1 TC» is middle (λ is 1.90).

5. Conclusions

In the result of this investigation it is developed the new compositions of metal-working coolants on basis of mono- and diglycerides of wastes of sunflower oil production and also on basis of their esters of boric acid.

Compositions of metal-working coolants were tested on laboratory rolling mill 100x100 (DSEA) in brass L63 rolling.

The analysis of results has shown that depending on a level of cobbing the friction coefficient decreases from 0.077-0.080 (for $\varepsilon \approx$ 18 %) to 0.046-0.063 (for $\varepsilon \approx$ 47 %) for many new compositions of metal-working coolants.

New metal-working coolants showed the most efficiency under higher cobbing that provides the highest metal stretch forming and therefor these coolants are more effective.

The composition of metal-working coolant, containing 30 % of mono- and diglycerides on the basis of wastes of sunflower oil production, is the best effective (λ is 1.99).

In steel rolling the MWC on basis of boric acid esters of mono- and diglycerides are more effective than ones on basis of mono- and diglycerides [11]. MWC with 100 % concentration of boric acid esters of mono- and diglycerides is the most effective.

Author Contributions: Avdeenko A.P. created the compositions of coolants, analyzed the results, and wrote the paper; Fedorynov M.V. designed a technique of experiments, carried out the tests of metal-working coolants, and analyzed the results; Dašić P.V. analyzed the results and wrote the paper; Turmanidze R. analyzed the results; Burmistrov K.S. designed experiments and synthesized mono- and diglycerides from wastes of sunflower oil production, analyzed the results; Toropin N.V. synthesized esters of boric acid of mono- and diglycerides from wastes of sunflower oil production, analyzed the results; Konovalova S.A. created the compositions of coolants, analyzed the data, and wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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