Methods (procedure) and results of testing lubricants for determination of applicability in the process of rolling the copper tubes in the Cold Tube Rolling mills

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Abstract
Selection of the lubricants for using in the technological process of manufacturing the copper cold–rolled tubes by the way of rolling in the Cold Tube Rolling mills is a very important aspect of planning the technology of production, since the lubricant to be used exerts the huge influence on the energy and power parameters of the rolling, as well as on the quality of the final product. Examination of the lubricants by the way of the direct use of them in conditions of the cold die rolling is inexpedient in economic sense in view of the possible increase of the part of products of low quality and energy expenditures while manufacturing the mentioned products. The methods (procedure) of testing the lubricants described in the present article allows checking the lubricants for applicability to laboratory conditions of cold rolling the copper tubes with parameters close to those, which have place in zone of deformation while rolling tubes in Cold Tube Rolling mills. It is important that the economic expenditures at testing the lubricants according to the developed methods are minimal.
Key words: COLD DIE ROLLING, TECHNOLOGICAL LUBRICANT, COPPER TUBES, DEFORMATION, METHOD, TEST

Making the copper tubes is an important direction of manufacture in the field of metal and heavy industry. Cold–deformed tubes have the big specific weight in production of seamless tubes. Such tubes are notable for a great precision of geometric dimensions and high quality of the surface [9]. Tubes of copper and copper alloys find application in machine–building and power generating branches of industry. The world consumption of the cold–rolled copper tubes constitutes more than 5 mln. tons per year. The following countries take the leading positions in the copper tube production (Fig. 1). The statistic data are quoted as of 2012 [1].

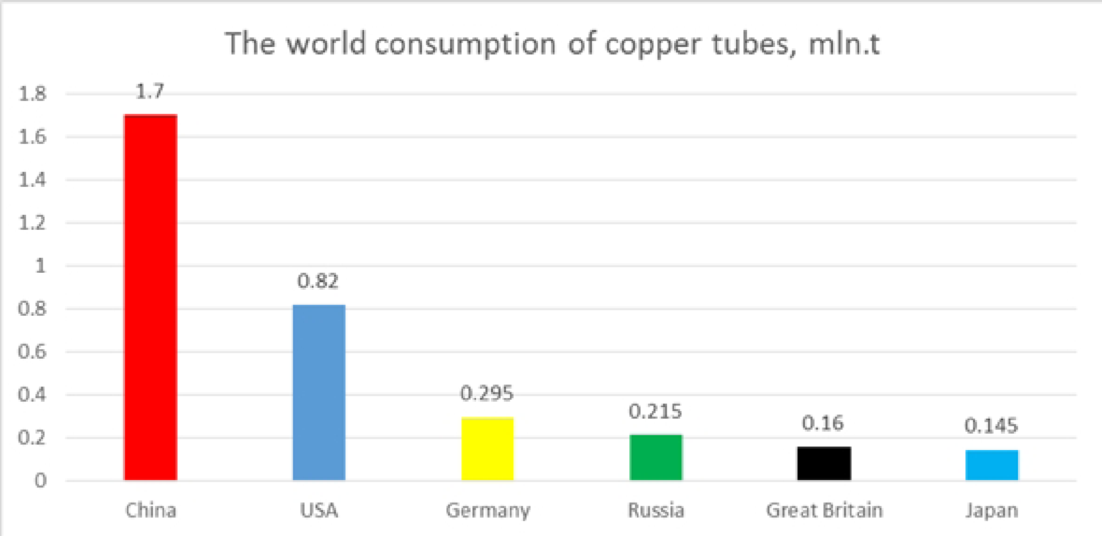

Figure 1. The world consumption of copper tubes
Development of the author

The classic scheme of manufacturing tubes of copper and copper alloys includes a number of the following stages of manufacture:

- extrusion of round ingots in hydraulic presses 1.5 MN and more;
- dressing of the round billet and cropping the ends;
- smearing of internal and external surfaces of the tube billet;
- rolling in CTR (Cold Tube Rolling) mills;
- cutting in measured lengths, annealing in shielding (protective) atmosphere (in the most of cases the copper tubes are annealed in nitrogen, nitrogen–hydrogen non–oxydizing medium) and transferred to the store or they are drawn in the chain or drum drawing mills.The requirements to tubes of copper and copper alloys are set forth in European (EN 12451:1999 – Seamless tubes of round section for the heat exchangers) and Interstate Standards (GOST- The State Standard – 21646 – 2003 – Copper and brass tubes for heat exchanging devices). The main requirements to seamless tubes of copper and copper alloys are the ultimate strength (kg force/square mm), relative elongation after rupture (%), geometric dimensions, grain size, chemical composition; there are also some additional requirements, such as requirement to the surface finish (GOST 21646 – 2003, p.4.5. External and internal surfaces should be without soiling hindering the inspection; EN 12451: 1999, p.6.4. External and internal surfaces should be clean and smooth) [5, 6, 7, 8]. Attainment of the high quality for seamless cold-rolled copper tubes is impossible without using lubricants. The leading world developers and manufacturers of technological lubricants (Chemetall, Shell, Mobil "Exxon", Bechem Lubrication, Q8 Oils, Fuchs) for cold metal forming, in particular, for rolling tubes, substantiate their recommendations as to application of lubricants with results of natural experiments. However, processes used in experiments do not always coincide with processes of industrial production. So, for example, Chemetall uses the process of drawing without mandrel and die-stamping of the cap in the press. Selection of lubricating materials immediately in the process of rolling without scientifically substantiated methods leads to the serious economic losses.

Using lubricants pursues usually a few aims what determines the basic functional requirements to technological lubricating materials [2]:

1. Decrease of friction forces on the contact.
2. Reduction of the instrument wear.
3. Maintenance of the cleanliness and optimal rough-

ness of products surface

4. Prevention of the metal sticking on the tool.

5. Decrease of the heat transfer between the metal under deformation and the tool.

6. Reduction of metal oxidizing.

7. Maintenance of the more uniform deformation distribution through the volume of the body to be deformed.

It is important to note that friction is one of the most important parameters, which the energy-power and kinematics parameters depend on. It follows from this fact that in the process of rolling the forces of external (contact) friction play the special part [3]. Friction influences the quality of the finished product surface, manufacturing cost of production and the output of metal forming process in indirect and sometimes in direct way [10].

The problem of testing and selecting the lubricating materials or their combinations, which are to be used in the process of the cold die rolling consists in necessity to replicate the friction conditions and contact stresses numerically close to those, which have place in deformation zone in the process of rolling in a CTR mill. In this connection, it is expedient to perform deformation of an alloy with lubricant to be investigated on the turning Bridgeman anvils (two vertically situated conic punches) in the capacity of simulating process (Fig. 2).

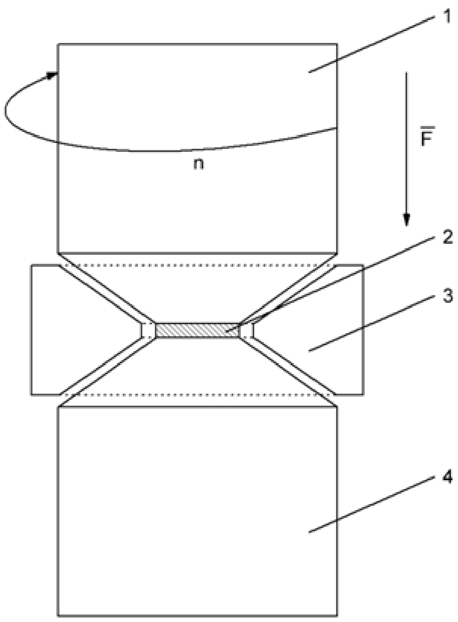

Figure 2. The scheme of disposition of the deforming tool and sample in Bridgeman anvils, where *F* is the vector of the applied force and *n* is the angle of turning (*1* is the upper turning punch; *2* is a sample; *3* is the thrust (stopping) ring limiting the diameter of sample to be deformed in horizontal plane; *4* is the lower stationary punch)
Developed by the author

Application of such system allows performing separation of deforming action for a vertically applied force and the force, which is necessary for turning the upper punch. To reproduce deformation zone, it is necessary to replicate the numerical values of deformation conditions, just as:

- contact stress;
- speed of relative displacement of metal over the tool;
- roughness of sample and tool.

Creation of such model will allow performing the comparative analysis of data obtained during testing the lubricants while rolling and deforming samples on the Bridgeman anvils. The method of simulation of the plastic deformation in Bridgeman anvils does not call for big volumes of metal.

The disc-shaped samples of diameter 9 mm and thickness 0.8 mm were prepared for investigation. Roughness and hardness of samples should be close (different no more than for 3%) to parameters of the billet, which was used for rolling in the CTR mill. The chemical composition of alloy is the same as for rolling. Such approach in parameters will allow excluding the influence of certain factors, but the dimensional significance (value) of these factors is impossible to determine.

The important factor of carrying-out the experiment is its metrological provision (see the structural scheme of the latter in Fig.3). To obtain the maximum informativeness of the measurement, it is necessary that the measurements of parameters (the pressure applied to punch, the force applied for turning the punch) take place at the same time, not less than once in second; the survey of the primary meters (sensors) takes place once in 100 ms (the record presents the average significance (value) for 1 second). The absolute error in measuring the pressure and the force of the punch turning is no more than 1% of the indication. To exclude the influence of speed of data processing induced with operational system of the personal computer the recording was made on external digital block of recording the unified analog signals “OVEN SP270.” The primary transducers are: the sensor of pressure (“Honeywell”, P =0 - 400 bar, the output signal 4 – 20 mA, linear), force measuring sensor (“Keli”, m=0 – 100 kg, coefficient of signal transmission 2mV/V. The block of transformation “Microl. BPT-22 is used for transformation of the force measuring sensor signal into the unified analog signal with the range 4 – 20 mA.

In order to avoid the influence of the rests of lubricants on the process of deformation, punches and samples are degreased with alcohol before application of each new kind of lubricant. After experiment each sample was placed into a separate marked container. The turn of the upper punch was performed in 6 consistent turnings in 60º till the complete turn for 360º. The pressure to be set in the plunger of hydraulic press is 5 MPa, what makes up 1912 MPa (when the area of sample is 63.62 square mm). In such a way the tests of different lubricating materials were carried out in conditions of the plastic deformation, which is numerically compared with parameters in zone of deformation at the rolling in CTR mill.

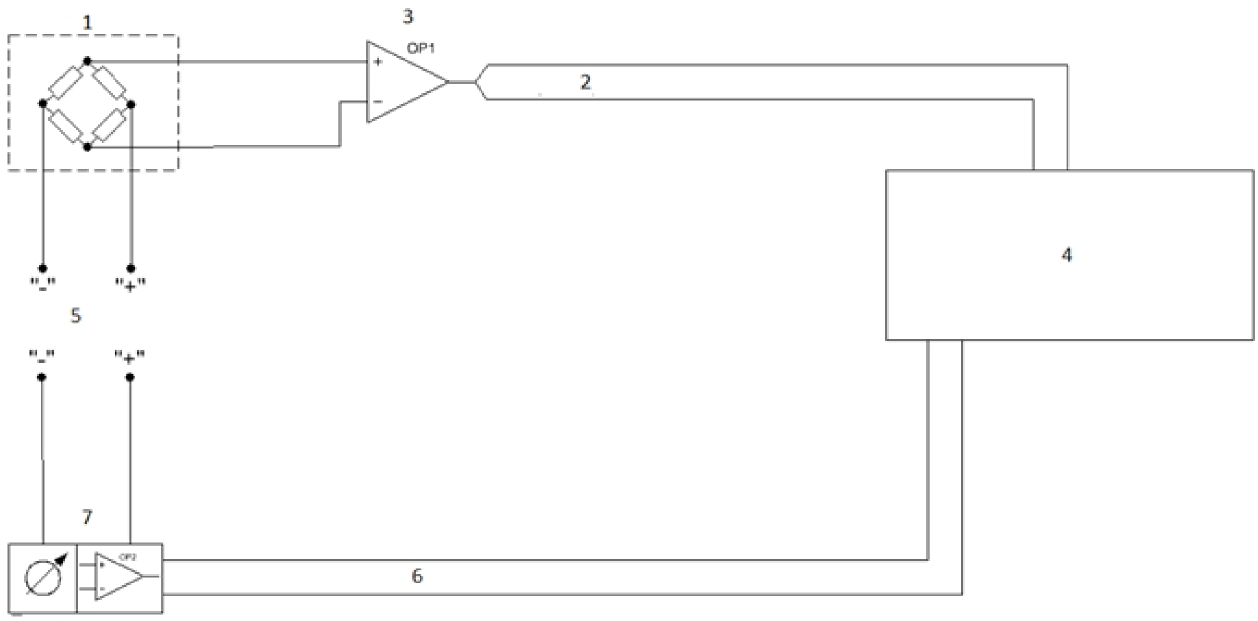

Figure 3. The scheme of the system for recording the experiment parameters
1 - force measuring sensor (transducer); 2 – unified analog signal 4-20 mA; 3 – normalizing amplifier of the unified analog signal; 4 – recording block of the unified analog signal, period of sampling 100 ms, period of recording numerical significances (value); 5 – 5V stabilizing power; 6 – unified analog signal 4 – 20 mA; 7 – pressure sensor (transducer) 0 – 400 kr-force / square cm.
Developed by the author

The basic stages of investigation of the got samples are:

- analysis and comparing of recorded parameters of the press pressure and force of the turn in dynamics of the time changing;
- analysis of the surface microstructure by means of optical microscope;
- measurement of the surface roughness by means of profilometer.

The comparative analysis of parameters (numerical significances (values) of parameters) allowed establishing the mechanism of the influence of lubricants on the power parameters of the process bringing off and the quality of surface at the deformation in Bridgeman anvils and, as a consequence, at the die tube rolling. Juxtaposition of the numerical significances of parameters obtained while deforming samples with application of different lubricants allows revealing the lubricant, which reduces the friction forces in zone of deformation with maximum effectiveness and improves the quality of surface.

Experiments in deformation of samples were carried out in Bridgeman anvils in the laboratory of technologic designing department of NMAU on the 100 tons-forces press.

According to the developed procedure, the comparative analysis of pressure had been performed on the press plunger with the force of turning the upper punch (Figures 4 – 8).

The temperature in the laboratory during the experiment was +18ºC.

Recording of indications was performed on the flash-accumulator using the developed measuring system.

Each of the lubricants to be investigated was poured out into a separate marked container.

Roughness of samples (Ra) before deformation was 0.9 micron +/- 5%.

Results of the change in specific pressure on the surface of samples and in the force of the punch turning on 5 investigated lubricants are presented on Figures 4, 5, 6, 7, 8.

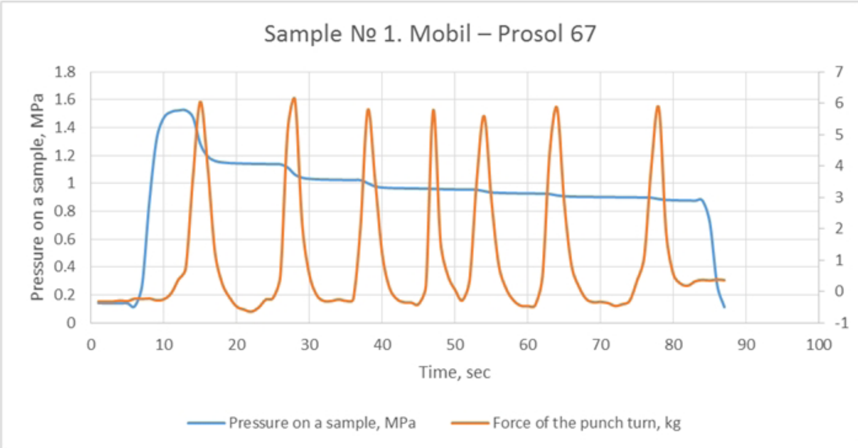

Figure 4. The plot of the change in the specific pressure on the surface of a sample and of the change in the force during the punch turn (Sample No 1. Lubricant Mobil – Prosol 67)
Developed by the author

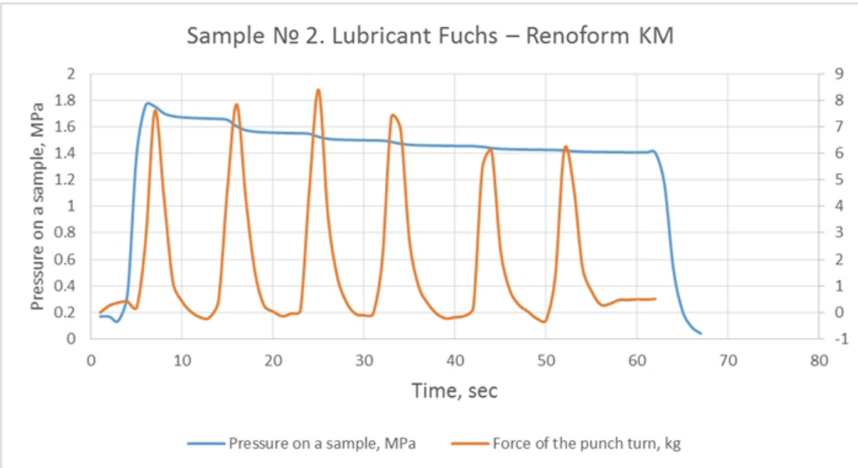

Figure 5. The plot of the change in the specific pressure on the surface of a sample and of the change in the force during the punch turn (Sample No 2. Lubricant Fuchs – Renoform KM)
Developed by the author

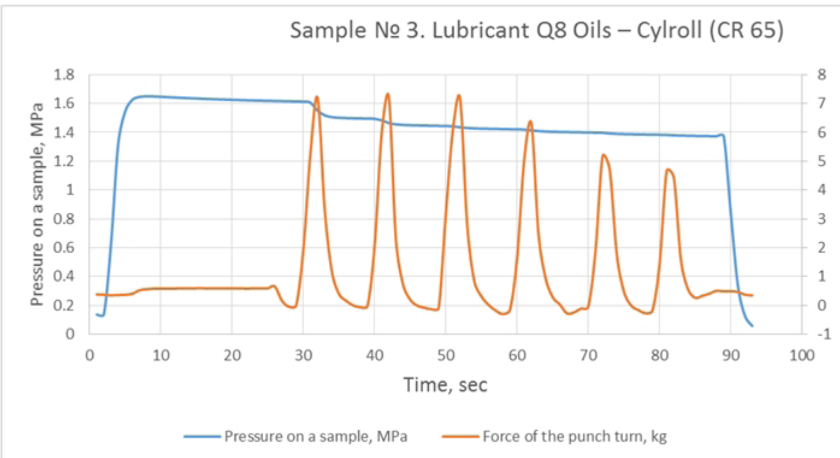

Figure 6. The plot of the change in the specific pressure on the surface of a sample and of the change in the force during the punch turn (Sample No 3. Lubricant Q8 Oils – Cylroll (CR 65)
Developed by the author

Analysis of behavior (character) of the mutual influence of the normal specific pressure and the force of the punch turn, which characterizes the process of the metal surfaces shift along the tool in the presence of the concrete lubricant allows drawing following conclusions:

- the more effective is the lubricant, the bigger is the difference between the normal and shifting force, till two times;
- the more effective is the lubricant, the greater is reduction of the normal pressure (30%), at the equal values of the shifting force.

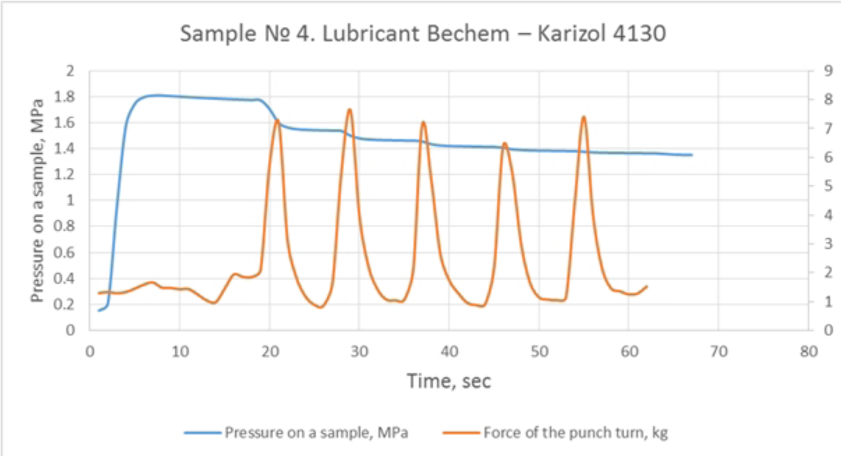

Figure 7. The plot of the change in the specific pressure on the surface of a sample and of the change in the force during the punch turn (Sample No 4. Lubricant Bechem – Karizol 4130)
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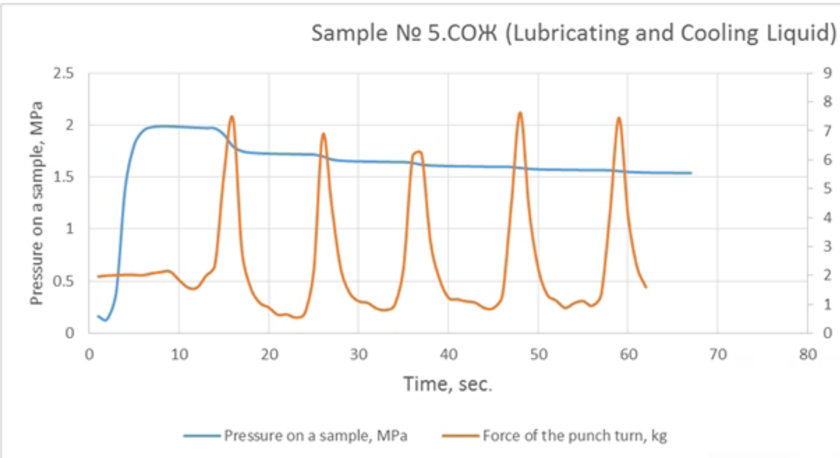

Figure 8. The plot of the change in the specific pressure on the surface of a sample and of the change in the force during the punch turn (Sample No 5. Lubricant СОЖ (in Russian) – Lubricating and Cooling Liquid
Developed by the author

In order to carry out the analysis, the optimal version will be a sample of 3 maximum values from themassive of data got during each experiment. Results are put down to the Table 1 (Developed by the author).

The average value, presented in the Table 1, is calculated by the way of choice of confidence interval using Kornfeld method (the average arithmetical between minimal and maximal measured value).

One may suppose from the values presented in the Table 1 that at the relatively equal forces of deformation, the most optimal processes of friction take place while using the lubricant Mobil – Prosol 67. But the final conclusions can be made only after analyzing the macrostructure of the surface and measuring the roughness of samples surface.

Measurement of the roughness (Ra) (device for measuring is the profilometer "Hommel Tester T500 Jenoptic Germany", works number - 82904, state calibration - 02.11.15) was carried out thrice in different diametric directions (displacement of the axis of each measurement for 120º for each sample with calculation of the average arithmetic value (Table 2. Developed by the author. In connection with the small area of sample, the stroke of planimeter test prod was set as 1.5 mm.

Table 1. The results of the optimal version of measurements

Lubricant	1		2		3		Average value	
	Force of the turn, kg	Pressure on a sample, MPa	Force of the turn, kg	Pressure on a sample, MPa	Force of the turn, kg	Pressure on a sample, MPa	Force of the turn, kg	Pressure on a sample, Mpa
Mobil – Prosol 67	6.113	1.4	6.049	1.2	5.857	1	5.985	1.2
Fuchs – Renoform KM	8.395	1.7	7.85	1.6	7.6	1.55	7.9975	1.616667
Q8 Oils – Cylroll CR65	7.22	1.53	7.185	1.5	7.169	1.48	7.1945	1.503333
Bechem – Karizol 4130	7.901	1.6	7.637	1.56	7.407	1.49	7.654	1.55
LCL (lubricant-cooling liquid)	7.633	1.62	7.451	1.57	7.421	1.52	7.527	1.57

Table 2. The results of measurement of the roughness

Name of lubricant	Roughness, Ra, мкм			The average arithmetical value Ra, micron
	The first measurement	The second measurement	The third measurement	
Mobil – Prosol 67	0.25	0.22	0.27	0.25
Fuchs – Renoform KM	0.76	0.69	0.82	0.76
Q8 Oils – Cylroll CR65	0.42	0.31	0.38	0.37
Bechem – Karizol 4130	0.63	0.55	0.58	0.59
СОЖ (LCL)	0.43	0.47	0.46	0.45

Proceeding from the data obtained during investigation of roughness of samples it may safely be said that the best quality of surface was obtained while using the lubricant Mobil – Prosol 67 and the worse one – while using Fuchs – Renoform KM.

The aim of samples investigation with optical microscope is determination of the state of surface macrostructure (Figures 9 – 12).

The surface of all samples includes defects of different dimensions. It is important to note, that the state of the surface in Fig. 9 and 11 (lubricants Mobil – Prosol 67 and Q8 Oils Cylroll CR65) differs from the state in Fig. 10 and 12 (lubricants Fuchs Renoform KM and Bechem Karizol 4130).

The surface of samples deformed with lubricants Mobil – Prosol 67 and Q8 Oils Cylroll CR65 shows the circular scratches and “microcavities”. But the main area of deformation has no cracks and traces of non-uniformity in distribution of deformation forces over the contact surface. An important element of samples in Fig. 9 and 11 is the presence of the clear picture and tracks at the torsion of sample.

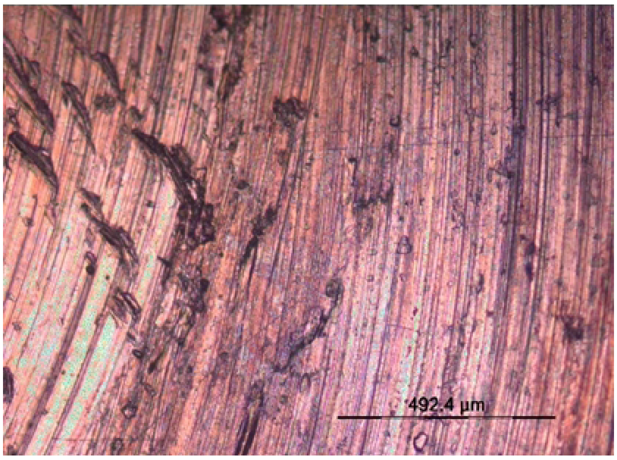

Figure 9. Structure of surface (increase 20X) of a copper sample deformed in Bridgeman anvils using the technological lubricant Mobil – Prosol 67
Developed by the author

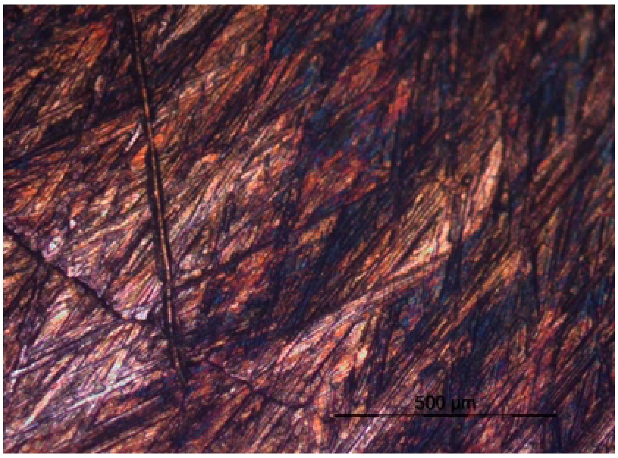

Figure 10. Structure of surface (increase 20X) of a copper sample deformed in Bridgeman anvils using the technological lubricant Fuchs – Renoform KM
Developed by the author

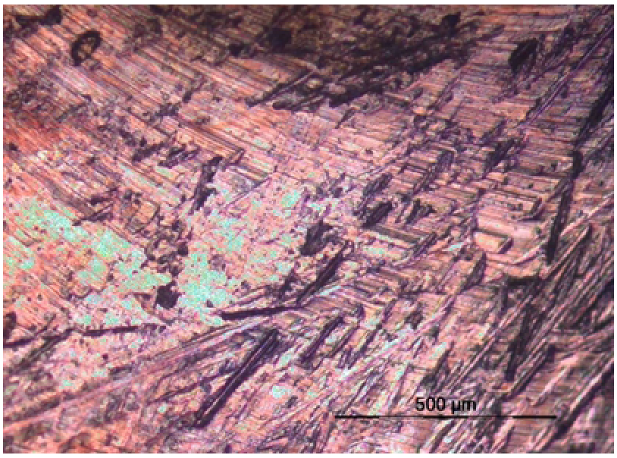

Figure 11. Structure of surface (increase 20X) of a copper sample deformed in Bridgeman anvils using the technological lubricant Q8 Oils Cylroll CR65
Developed by the author

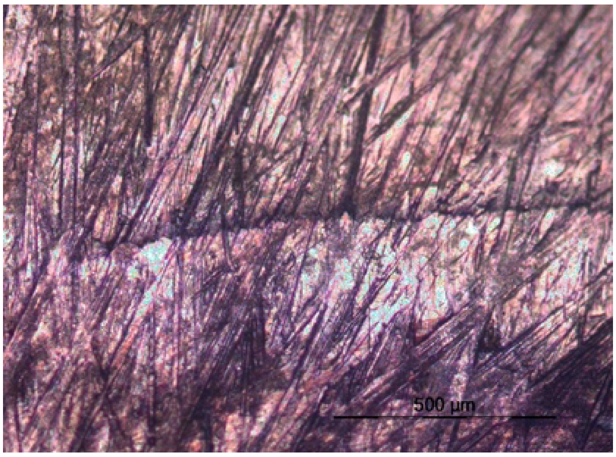

Figure 12. Structure of surface (increase 20X) of a copper sample deformed in Bridgeman anvils using the technological lubricant Bechem Karizol 4130.
Developed by the author

In samples in Fig. 10 and 12, on the contrary, microcracks are present (in the Fig. 10 the crack is situated in the lower left corner; in the Fig. 12 the crack is situated over the center, in parallels to horizontal axis). Such cracks can be the evidence of the non-uniform distribution of the contact between the tool and sample in the presence of given lubricant during rotation of the punch, in consequence of different speeds of metal sliding over the tool. The deep scratches lead to speeded up formation of oxydations on the surface of samples. For more detailed analysis of samples deformed with lubricants Fuchs Renoform KM (Fig.13) and Bechem Karizol 4130 (Fig. 14), the surface of samples was etched with solution of hydrogen peroxide 3% and citric acid. The treatment with low-active etching solution allowed removing the most part of the formed oxidations without harming the macrostructure of the surface.

The Fig. 13 confirms that the microrelief of the surface is characterized with the presence of strips directed in different directions. These strips are the evidence of stretching actions (effects) caused by non-uniform contacts of the tool with sample, what leads to the high speed of surface oxidation. Such conclusions are confirmed with increased roughness of sample (the average value Ra=0.76 micron).

The surface of sample in the Fig.14 shows the big quantity of points harmed with oxidation. After etching one can trace direction and track of the punch rotation.

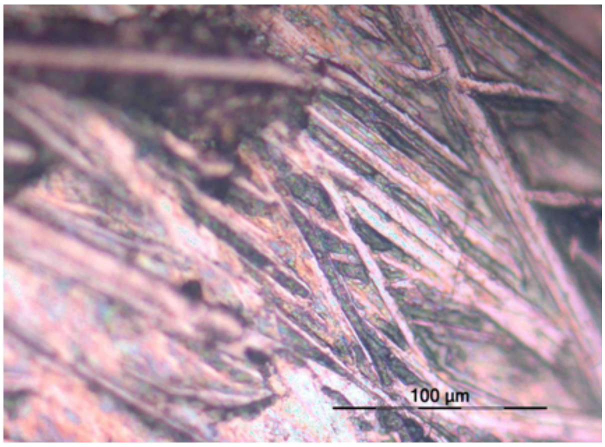

Figure 13. The surface of a sample deformed with putting the lubricant Fuchs – Renoform KM, after etching (increase 100X)
Developed by the author

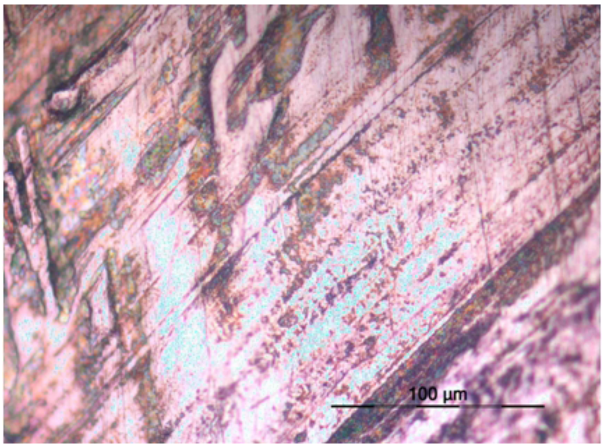

Figure 14. The surface of a sample deformed with putting the lubricant Bechem Karizol 4130, after etching (increase 100X)
Developed by the author

Conclusions

1. A method (procedure) has been developed for evaluation of the effectiveness of technological lubricants for the cold die rolling with using Bridgeman anvils.

2. Results of experimental investigations with division of the force action of metal for normal pressure and the force of turning allowed establishing the importance of the influence of relative metal sliding on quality of the surface.

3. The best lubricant among investigated materials, which assures the minimal force of deformation and the minimal roughness (the best quality) of the surface is Mobil – Prosol 67.

4. The proposed procedure for evaluation of effectiveness of technological lubricants does not practically demand expenditures for materials to be investigated (lubricant, metal).

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