Development and efficiency assessment of process lubrication for hot forging

S Kargin¹, Viktor Artyukh¹, I Ignatovich¹ and Varvara Dikareva²

¹Peter the Great St.Petersburg Polytechnic University, Polytechnicheskaya, 29, St. Petersburg, 195251, Russia
²Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia

E-mail: artiukh@mail.ru

Abstract. The article considers innovative technologies in testing and production of process lubricants for hot bulk forging. There were developed new compositions of eco-friendly water-graphite process lubricants for hot extrusion and forging. New approaches to efficiency assessment of process lubricants are developed and described in the following article. Laboratory and field results are presented.

1. Current state of the subject under consideration

Contact friction plays a major role in terms of efficiency increase of hot forging, that depends largely on the process lubricants composition [1, 2]. It is impossible to guarantee quality forge works and high durability of dies without development of the new compositions of grease lubricants and improvement of the lubrication technology. Problem of development of efficient process lubricants for hot forging becomes extremely important in recent times. This is due to the need to save expensive tool steels, improve working conditions by improving the atmosphere of the workshops. All this is largely due to the recent growth in the number of author's certificates and patents for inventions relating to process lubricants, both in Russia and Ukraine, and abroad [3, 4].

The final result of the development and creation of process lubricants is the production of a set of optimal lubrication parameters, in particular, operational ones [5]. In connection with the foregoing, it is of interest to attempt to develop an acceptable composition of the process lubricant and a way of assessing its efficiency. In order to improve sanitary and hygienic working conditions and increase the durability of dies in forging shops, water-graphite process lubricants Delta-144, OGV-75, graphitol V-2 [6, 7]. When the water-graphite lubricant is in contact with the heated die, the liquid constituents evaporate, cooling the die. The evaporated film lubricant covers the die surface and, to a certain extent, isolates contact with the hot work piece [8]. Graphite is usually used as antifriction filler in various smokeless process lubricants. Graphite has a complex structure and it is the most stable crystalline modification of carbon. Absorption of moisture with graphite helps to weaken the bonds between the layers and increase its lubricity. As temperature increases, the strength and modulus of elasticity of graphite increase respectively. High thermal resistance, oxidation temperature and adhesion to steel ensure the effectiveness of graphite as a high-temperature lubricant. In a number of cases, the weak dependence of frictional forces on graphite on the speed of movement can also be an advantage, which is explained by its high thermal conductivity and thermal stability. The valuable quality of graphite is its good ability to form films with metal oxides, which are components of a friction pair, in particular,
with iron oxides. An important indicator of the lubricant is the size and shape of the graphite particles obtained by grinding. Currently used methods of grinding graphite for its production are very labor intensive and unsatisfactory sanitary and hygienic working conditions.

2. Goal setting
The goal of the study is to develop composition of process lubricants and methods for their assessment under conditions close to manufactural, i.e. that kind of processes where lubrication will be implemented.

3. Methods and key laboratory findings
“Metal treatment under pressure” department of Pryazovskyi State Technical University in collaboration with “Hydraulics” department of Peter the Great St. Petersburg Polytechnic University developed, studied and implemented water-graphite process lubrication for hot forging (GFPO)

The composition of the GFPO lubricant includes:
- Graphite colloidal 18%
- Sodium tripolyphosphate 8%
- Ammonium lignosulphate (grain stillage) 8%
- Triethanolamine 0.3%
- Sawdust up to 4%
- Furacilin 0.01%
- Water up to 100%

Before use, the process lubricant requires dilution with water from 1:2 to 1:10, depending on the complexity of the forgings. It has been determined that the use of the GFPO lubrication does not cause corrosion of the die and the processed metal, does not disengage smoke and soot; lubrication is not toxic.

The introduction of wood dust (preferably pine), as containing rosin, allows to form a gas cushion between the die and the hot metal of the billet, due to the rapid combustion of the wood dust. In addition, carbon, that is formed in result of the combustion of wood dust, prevents welding to the die.

Within the production process of the TFPO lubrication, a method for graphite wet grinding on a hydrodynamic activator was adopted. A fundamentally new method was suggested and studied, which is based on a cavitational physical phenomenon arising when a suspension flow moves with a certain speed and pressure through a hydrodynamic activator (Figure 1, 2) [9-13].

![Figure 1. The hydrodynamic experimental stand. Setup diagram](image-url)
Suspension stream creates cavities in the activator, which later disintegrate into cavitation bubbles. When the cavitation bubbles collapse, cumulative micro streams are formed, which cause disintegration of the solid particles of the suspension.

A significant advantage of graphite hydrodynamic grinding is the disintegration of the latter into particles of plate-like shape, which is impossible to achieve when grinding is conducted in ball grinders. When grinding graphite in ball grinders, the graphite particles become rounded.

Theoretical studies and practical experiments of suspension sedimentation processes have shown that the speed of sedimentation of suspension particles in liquid media, in addition to many factors (particle size, fluid viscosity, etc.) depends on the shape of the particles.

The sedimentation rate of graphite particles of plate-shaped form in a liquid medium is 1.74 - 1.8 times smaller than the sedimentation rate of rounded ones. Since the sedimentation rate of graphite particles in the liquid phase of suspension is directly related to the stability index of the lubricant, it can be concluded that the hydrodynamic grinding method can achieve a higher degree of stability of the lubricant compared to grinding by ball grinders.

The quality of process lubricants is characterized, in addition to other parameters, by the ash content. High ash content of the lubricant adversely affects the durability of dies when hot metal is treated with pressure (HFM - hot-forming method). The method for hydrodynamic grinding of graphite, unlike ball grinders, does not increase the ash content in the lubricant due to the absence of friction between grinding elements (metal elements of ball grinders).

Two methods to assess the efficiency of process lubricant for hot forging were developed and investigated.

3.1 Method 1
Determination of the process lubricants efficiency in hot forging, which includes deformation in the die of identical blanks with the use of process lubricants, pushing forging pieces from the die and determining the efficiency of the used lubrication [14]. The method is characterized in that the application of process lubricants is carried out by applying them to a die with a deep cavity, and as a controlled parameter, the total height of the forging ($H_{\text{max}}$) is used after deformation, over which the filling of the die cavity is judged. At the same time, the greater efficiency of the process lubricants corresponds to its greater value (and vice versa).

Studies on the efficiency of the process lubricants for hot forming by this method were carried out in the laboratory of “Metal treatment under pressure” department of Pryazovskyi State Technical University.
The studies were carried out on the basis of a crank press with a force of 2.5 MN of the KA9534 model. OGV-75 was used as a based lubricant according to TU 21-25-147 standard, which is used for steel hot forging. Ten samples of steel 35 of height $H = 38.0 \pm 0.5$ mm, diameter $D = 45.0$ mm and weight 0.15 kg were used. In Fig. 3 a general drawing of the forgings is shown.

Heating of the blanks prior to deformation was carried out in an electric furnace of the SShOŁ to a temperature of $t = 1150 \, ^\circ C$ with an exposure in the furnace for 30 minutes. Before deformation, the die was heated to a temperature of $200 \, ^\circ C$. The time of transfer of the blank from the furnace to the press was 5 s. The tested lubricant was applied to the surface of the die before each operation by spraying.

It is established (Fig. 4) that the most efficient process lubricants are GFPO and GFP, since the most depth of filling of the die cavity is observed when these lubricants were used. The suggested method for determining the efficiency of process lubricants can be applied directly to hot forging.

![Figure 3. Forging general drawing](image)

3.2 Method 2

Determination of the efficiency of process lubricants for bulk forging involves deformation in a die of identical by weight and dimensions of blanks using various process lubricants [15]. The method is characterized in that forgings are extracted from the die by extrusion, with the least efficient extrusion force corresponding to the most efficient process lubrication. The suggested method for determining the process lubricants efficiency for bulk forging makes it possible to simplify the determination of the efficiency of a process lubricant and to determine it directly in bulk forging.

As it was shown by the results of the research, the GFPO lubrication has the lowest friction coefficient, which corresponds to the smallest extrusion force. Two methods for the efficiency assessment of process lubricants with hot bulk extrusion were developed and investigated.
3.3 Method 1
By changing the length of the extruded rod. The goal is achieved by the fact that in the suggested method [16], blanks of the same mass are used to assess the efficiency of lubricants, and as the controlled parameter of the rod part of the forgings, the full length of this part is used, in addition, the greater value of the length of the rod part corresponds to the greater efficiency of the lubricant, and vice versa.

The method is carried out in the following way: samples of the same mass are selected, the rod is extruded out using the base lubrication, the length of the forging is measured. A similar action is performed with forgings obtained using the lubricants under study. A longer length indicates the use of a more efficient lubricant. The grades of the tested process lubricants and the results of the tests are given in Table. 1 and on the histogram of Figure 5. 10 blanks were deformed using one lubricant.

**Table 1. Test results**

| №  | Lubrication  | Rod length, l, mm |
|----|--------------|-------------------|
| 1  | Ukrinol 7²   | 130               |
| 2  | Effektol 1   | 115.5             |
| 3  | Coolant MMI  | 118.5             |
| 4  | Graphitol 1  | 117               |
| 5  | Graphitol № 8 ¹ | 127               |
| 6  | Graphitol № 9 ¹ | 123               |
| 7  | Graphitol № 10 ¹ | 121              |
| 8  | GFPO (smokeless) | 130              |

Notes:

1 – Samples of oil-based lubricants of the State Institute of Applied Chemistry, St. Petersburg.
2 – Oil-Graphite lubricant according to TU 21-25-106-73.

![Histogram of Experiment Results](image)

**Figure 5.** Experiment results

It can be seen from the histogram (Figure 5) that lubricants No. 8 - GPFO and No. 1 - Ukrinol-7 are the most efficient, since the valves obtained with the use of these lubricants are the longest. But preference should be given to the GPFO, as this lubricant with all other factors held equal is smokeless.

3.4 Method 2
By changing the diameter of the extruded rod. The goal is achieved by the fact that in the suggested method [17], blanks of the same mass are used to assess the efficiency of the lubricant, and, the diameter of the rod is used as the controlled parameter of the rod part of the forging (Figure 6).
The method is conducted in the following way. The forging is extruded out in the form of a rod using the base lubrication. The diameter of the output end of the rod $d_2$ is measured with a micrometer. Then the diameter at the base of the rod $d_1$ is measured. Using a caliper, the distance $l$ between $d_1$ and $d_2$ is measured. From the obtained data, the tangent ($\tan \alpha$) of the angle of inclination of the bar is calculated: $\tan \alpha = (d_1 / d_2) / 2l$.

Similar actions are carried out with forgings obtained using the lubricants under study. The smaller value of the tangent of the angle of inclination of the bar generates the use of a more efficient lubricant.

The efficiency of the following lubricants was determined: Ukrinol-7, Effektol, Graphitol No. 8, Graphitol No. 9, Graphitol No. 10 and GFPO.

**Figure 6.** Valve general drawing

Among the tested lubricants, the GFPO lubricant was preferred as having the least thinning of the lubricating layer or the minimum tangent of the angle of inclination of the rod. Therefore, the method makes it possible to determine a more efficient lubrication with respect to the minimum value of the tangent of the angle of inclination of the rod.

4. Main results of the field tests

Field test were carried out at the production association "Taganrog Combine Plant". The forging "wheel axis" No. MK 23. M03.653 is manufactured on the automatic line "Hosenklever" on the basis of a crank press with the force of 63 MN. The annual program of production is 40000 pieces. Forging material is Steel 40X. Weight of the forgings is 41 kg. The temperature of forging is 1150-1100 °C. The forging rate is 140 pieces / hour. The process is carried out for 4 junctions with 2 press strokes: 1 stroke - extrusion and final forging (1st and 3rd junction); 2 stroke - extrusion and trimming (2 and 4 transitions).

The lubricant "Sumidera" (Germany) is used in the extrusion process. The lubrication is fed through the nozzles of the branded unit into each of the 4 die impressions. The problem is that when using the "Sumidera" lubricant, a flame, smoke and unfavorable sanitary and hygienic conditions are formed, which has been repeatedly reflected in the acts. In addition, this lubrication is quite expensive (1 kg costs 4 euros).

There was set a task to create a smokeless process lubricant, which did not come short to the "Sumidera" lubricant in terms of efficiency. A new smokeless water-graphite grease V1 was developed, manufactured and introduced [11, 18], the composition of which is given below (Table 2).

**Table 2.** Composition of V1 lubricant

| №  | Component name                  | Content, % | Notes                                      |
|----|--------------------------------|------------|--------------------------------------------|
| 1  | Graphite                       | 10 – 12    | Content of the component is in weight units.|
| 2  | Sodium triopolyphosphate       | 1 – 2      |                                            |
| 3  | Triethanolamine                | 0.2 – 0.3  |                                            |
| 4  | Ethnas                         | 3 – 4      |                                            |
| 5  | Spent sulfite-alcohol liquor   | 6 – 8      |                                            |
| 6  | Pine rosin                     | 0.8 – 1.5  |                                            |
| 7  | Water                          | до 100     |                                            |
Table 3. Composition of “Sumidera TR 199” lubricant

| №  | Component name                                      | Content, % |
|----|-----------------------------------------------------|------------|
| 1  | Content of the rape oxidized oil                    | 89         |
| 2  | Content of the graphite with dispersion of 1-6 microns | 8          |
| 3  | Wetting and stabilizing agents                      | 3          |

The efficiency of V1 and "Sumidera" lubricants (Table 3) was assessed from the value of the maximum force required to extrude the "wheel axis" forging. The test results showed that the extrusion force with the use of these lubricants is almost the same. It should be noted that smoke, soot, flames are absent when water-graphite V1 lubricant is used; Forgings had a clean surface, a clear design, easily removed from the matrix. The V1 lubricant was introduced and recommended for hot extrusion of steel.

At the Lugansk Automobile Valve Plant, lubricants based on oils and fuel oil (graphite-oil mixtures, Ukrinol-7, fuel oil 100, etc.) are generally used for hot extrusion of valves. At the same time, the air environment is contaminated with oil aerosol, products of thermooxidative destruction, carbon monoxide and carcinogenic substances, among which the majority is benzapyrene. In the absence of individual ventilation on the press and the use of fuel oil as a lubricant, 100 the content of benzapyrene in the air is 3 times higher than the maximum allowable concentration (MAC), and when using the lubricant Ukrinol-7, the content of nitrides in the air exceeds the MAC 2 times. Thus, the use of such technological lubricants is unacceptable from the environmental point of view.

The criterion for the efficiency assessment of the developed GFPO lubricant was the matrix resistance [19-24]. The tests were carried out on a crank hot-forging press mod. KA-864 with 10 MN force when extruding automobile valves. All forgings are of the same type, made by direct hot extrusion of the rod in the first die impression with the subsequent design of the valve plate in the second one.

The material of valve is steel 40X9C2. The blank with diameter of 25 mm and a height of 32 mm was heated in an inductor to 1150 °C. The diameter of the valve rod is 9.6 mm, and the length is 123 mm, the draw-down ratio is 9.41.

The material of the puncheons and matrices is 4X4BMФC (DI-22) steel. The GFPO lubricant was fed to the cavity of the matrix in the same way as Ukrinol-7. The amount of lubricant fed was regulated by the feeding time and was 6-8 g per forging for Ukrinol-7 and 18-20 g per forging for GFPO.

The test results of the GFPO and Ukrinol-7 process lubricants showed that the durability of the matrices is approximately the same (1300 ... 1400 forgings). When using the GFPO water-graphite lubrication, smoke, soot is eliminated, so is air pollution.

The developed new GFPO water-graphite lubrication can be used instead of oil graphite Ukrinol-7. At the same time, sanitary and hygienic conditions are significantly improved.

5. Conclusions
1. A new composition of ecologically pure water-graphite process lubricant for hot bulk forging of steel with the conventional name of GFPO (graphite-phosphate preparation) was developed and tested.
2. A new composition of ecologically pure water-graphite fuel for hot extrusion of steel with the conventional name V1 was developed and tested.
3. Four new methods for efficiency assessment of process lubricant were developed and investigated (two methods for hot bulk forging and two methods for hot bulk extrusion).
4. The field tests confirmed the efficiency of the developed process lubricants (GFPO and V1).
References

[1] Maksimenko O P 2005 Osnovi tribologii: navchal'nij posibnik Maksimenko O P, Lejko O S (Drinpodzerzhinsk'k) 192 p

[2] CHichinadze A V 2003 Trenie, iznos i smazka. Tribologiya i tribotekhnika (Moscow, Mashinostrojenie) 576 p

[3] Sorochan E, Artyukh V, Melnikov B and Raimberdiyev T 2016 Mathematical Model of Plates and Strips Rolling for Calculation of Energy Power Parameters and Dynamic Loads MATEC Web of Conferences 73 04009

[4] Nabeel S Gharaibeh, Mohammed I Matarneh and Artyukh V G 2014 Loading Decrease in Metallurgical Machines Research Journal of Applied Sciences Engineering and Technology 8(12) pp 1461–1464

[5] 2009 Novaya technologicheskaya smazka Beruform STO 1268. Anspruchsvolle Umformprozesse ohne Ghlor realisizen. Maschinenmarkt 50 p 49 1 il. Nem.

[6] Kargin B S 2004 Sovershenstvovanie kuznechno-shtampovochnogo proizvodstva za chet primeneniya ehffektivnyh technologicheskih smazok B S ZH Kargin Mir tekhniki i tehnologij 2 p 52-53.

[7] Kukhar V, Artyukh V, Serduik O and Balalayeva E 2016 Form of Gradient Curve of Temperature Distribution of Lengthwise the Billet at Differentiated Heating Before Profiling by Buckling Procedia Engineering 165 pp 1693–1704

[8] Gluesing H 1972 Ohne wasser geht es nicht «M.M. – Industrie» 78 20

[9] Patent 4622798/26 SSSR, MPK S 01 V 31/04 (1991)

[10] Patent 2043966, MPK S 10 V 31/02 (1995)

[11] Patent 2039792, MPK S 10 M 173/02 (1991)

[12] Patent 2048508, MPK S 10 M 173/02 (1995)

[13] Patent 51190 Ukraina, MPK B 21 J 3/00 (2009)

[14] Patent 46174 Ukraina, MPK B 21 J 3/00 (2009)

[15] SSSR, MPK B 21 J 3/00, G 01 N 33/26 (1993)

[16] Patent 1648616 SSSR, MPK B 21 J 3/00 (1988)

[17] Patent 13443 Ukraina, MPK S 10 M 103/02 (2000)

[18] Patent 1467082 SSSR, MPK S 10 M 173/02 (1989)

[19] Kargin B S 2012 Issledovanie ehffektivnosti tehnochnologicheskih smazok pri shtampovke avtomobil'nyh klapanov na «LZAK» (Lugansk) Universitetskaya nauka : mezhdunarodnaya nauchno-tenh. Konf (Mariupol' : PGTU) p 271–272

[20] Kargin B S 2000 Progressivnye metody povysheniya efektivnosti tehnologicheskih processov kovki-shtampovki Metall i lit'e Ukrainy 3/4 p 37–39

[21] Kargin B S 1989 Issledovanie efektivnosti tehnologicheskih smazochnyh materialov pri shtampovke klapanov Kuznechno-shtampovochnoe proizvodstvo 3 p 19 – 20

[22] Mazur V, Artyukh V, Artyukh G and Takadzhi M 2012 Current Views on the Detailed Design of Heavily Loaded Components for Rolling Mills Engineering Designer 37(1) pp 26–29

[23] Kitaeva D, Rudaev Y and Subbotina E 2014 About the Volume Forming of Aluminium Details in Superplasticity Conditions METAL 2014 - 23rd International Conference on Metallurgy and Materials Conference Proceedings pp 347-352