

Friction Process Control in Forging and Hot Stamping Technologies

E. G. Berdichevsky

Yaroslav the Wise Novgorod State University, ul. B. St. Petersburgskaya, 41, 173003
Veliky Novgorod, Russia

E-mail: bersev@mail.ru

Abstract. Theoretical and applied aspects of friction and lubrication process control in leading engineering technologies of metal forming have been considered. Innovative modifiers of friction for process lubricants in forging and hot stamping have been suggested. The efficacy of pyro- and nanomodifiers has been confirmed experimentally. Compositions of lubricants as well as the ways of studying tribological phenomena in hot metal deformation have been suggested.

1. Formulation of the problem

The purpose of the given paper is to determine scientifically the friction and lubrication process control in hot metal finishing. Our arguments are founded on modern tribological concept of multi-level area of frictional contact between an instrument and a product being deformed [1] as well as structural and energetic model of friction and wear-out processes [2].

There are three large-scale levels in an extremely heterogeneous contact friction area: macrolevel (10^3 m), mesolevel (10^6 m), nanolevel (10^9 m). Despite the fact that a distinct border between the levels is difficult to draw, each level possesses its own specific pattern. The interaction of processes taking place at different large-scale levels should not be excluded.

The influence of friction and technological lubricants (TL) is specific at each large-scale level. Table 1 gives the results of isolation of main TL properties, which determine the tribological effect at each large-scale level. Main functional TL properties are divided into two groups: individual and contact. Individual features characterize the physical and chemical properties of TL, which can be determined beyond the friction act and plastic deformation. These properties depend only on composition, structure and chemical nature of TL. The contact properties of TL manifest themselves interacting with the surfaces of participants of frictional and plastic contact.

We may suggest that an optimal TL is a composition demonstrating a positive effect at each large-scale level. The majority of TL used are intended to achieve a tribological effect at the macrolevel. However, the dispersity of TL components has often been ignored. For example, molybdenum disulfide or graphite preparations widely used in the processes of forging and hot stamping can demonstrate high antifrictional and anti-wear activities only in the colloidal state [3].

So, when choosing innovative TL, you should consider their tribological efficacy at three large-scale contact levels, in the first place - at meso- and nanolevels. Also, you should bear in mind that components producing necessary properties at any large-scale level may interact both antagonistically and synergistically [2].

Table 1. Main tribological TL properties demonstrated at different large-scale levels

Large-scale level	Individual properties	Contact properties
macro	density, viscosity, surface tension, pH and	contact angle of wetting, spreading,



	electrical conductivity (for water solutions), dielectric constant, thermal conductivity, thermal capacity, thermal diffusivity	heat transfer coefficient, thickness of original lubricant film
meso	volatility, solubility of gases, viscosity piezoelectric coefficient, thermal stability, chemical potential	microcapillary properties, adhesion work, adsorptive and chemisorptive activity, activation energy for formation of chemically modified layers, nanostructure of subtle layers at interfaces;
nano	dispersity of initial nanocomponents	activation energy of nanostructures

2. Experimental research

The variation of TL functional properties is easy to perform by means of so-called friction modifiers presented with additives for TL of various chemical and phase composition.

In Novgorod State University, we have isolated two kinds of friction modifiers for standard main bases of TL: pyromodifiers and nanomodifiers. In general, an optimal TL contains simultaneously both modifiers, provided that they are not antagonistic but, on the contrary, can interact synergistically.

Pyromodifiers of friction influence the process of thermal degradation (pyrolysis) of TL components in the area of plastic deformation during forging or hot stamping. As the result of pyrolysis, numerous volatile components are formed, producing high gas-static back pressure in microcavities of stamp (hammer) surfaces and billet. The pressure in the gas interlayer composed by volatile components can reach up to 100 mPa (Figure 1). In this case, within the processing area, normal and tangent tensions decrease significantly and so does the coefficient of plastic friction.

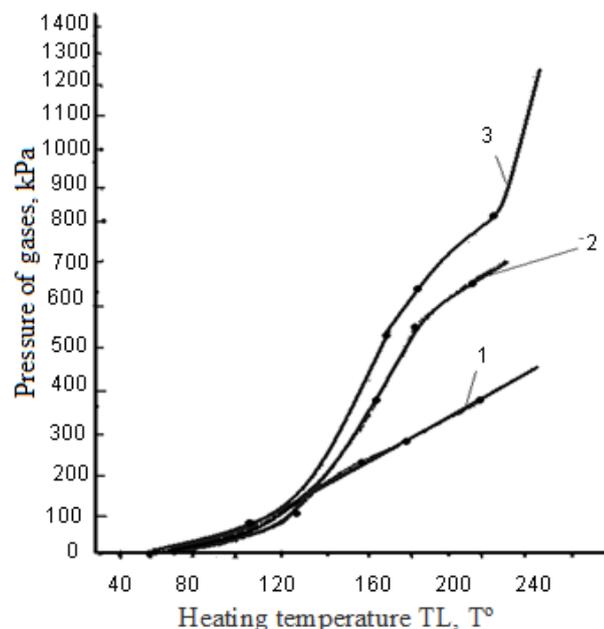


Figure 1. Investigation of the gaseous ability of lubricants:
1 – Aluminol, 2 – Pressol KF, 3 – Grafitol E21

Volatile components of pyrolysis possess high chemical activity as they result from thermodestruction of high-molecular chains. They are instantly adsorbed by resultant fresh-exposed microareas of contact surfaces produced by friction, the formation of a protective layer following.

Solid coke-like sediment produced by pyrolysis can play the role of a solid lubricating film shielding the working surface of a stamp (hammer). The forming of a solid coke-like film during the TL pyrolysis is influenced by the nature of metallic contacting surfaces. By their ability to form a film, metals can be ranked as follows: Fe>Ni>Ti>Zr>Cu>W. Now it is clear why stamping of stainless steels containing significant amount of chromium is followed by high wear-out of the stamp and low efficacy of standard TL.

We suggest using MCC-1 microcellulose and technical cellulose of various brands as a friction pyromodifier.

The laboratory testing of pyrolytic activity of MCC-1 microcellulose has shown that it can significantly soften severe contact friction regimes, if it is added into synthetic solutions and emulsions (through emulsol) in the form of powder. Bearing capacity of the lubricating layer increases by 40%, its ultimate strength – by 80%. Load wear index increases by 14%. Combined with 2% MCC-1 microcellulose, antifrictional properties of compositions change insignificantly. An optimal result can be obtained when a standard antifrictional additive – colloidal graphite (2%) with microcellulose (2%) – is used in a standard emulsion. In this case, a synergistic effect between the components is evident (Table 2).

Table 2. Tribological characteristics TL with pyrolytic active components

TL	P _K , H (critical load)	P _c , H (welding load)	I _z (index tease)	Coefficient of friction
Aqueous dispersion of graphite – 3%	63	126	36	0,177
Aqueous dispersion of graphite (3%) and MCC-1 (2%)	92	240	68	0,163
Aqueous dispersion of MCC-1 – 2%	85	200	52	0,171
Aqueous dispersion of emulsol – 3%	56	105	44	0,155

The next group of friction modifiers is that of nanomodifiers sprung to life by achievements of nanotechnologies. Nanomodifiers are successfully used as the components of motor and transmission oils. We can also remember the positive influence of TL enriched by nanoproducts in the processes of hot stamping.

Specific features of nanoproducts include small dispersion determining their high chemical and responsive activities. Nanoparticles can play the role of catalysts of unique chemical reactions proceeding with superhigh speed. This characteristic gives unpredictable properties to nanomaterials. For example, under certain conditions nanomaterials can organize themselves, i.e. atoms act together to form regulated structures [4-8].

Nanoclustered carbon materials, such as fullerenes, fullerene soot and fullerene black, carbon nanotubes, nanofibers, etc., may be applied practically.

Fullerenes, a new form of carbon, underlie the majority of technical nanomaterials. The most common is fullerene C₆₀, a molecule composed of 60 carbon atoms forming a closed spherical surface made up of regular hexa- and pentagons. The main characteristic of fullerenes is their increased responsive activity. They catch atoms of other substances easily and form materials with completely new attributes.

Considering the high cost of fullerene C₆₀, manufactured in Russia, fullerene soot (FS) and fullerene black (FB) have been tested as TL nanomodifiers for hot stamping. There is a concept that suggests inhibiting friction and wear-out at all three large-scale levels without fail. In order to prove this, a complex of oil additives IS-12 was tested. The oil was alloyed with nanomodifiers as well as standard additives: graphite, molybdenum disulfide, chloroparaffin and zinc dialkyldithiophosphate (DF-11).

The results of tribological and bench tests are given in table 3.

3. The discussion of the results

The table demonstrates that the tribological efficacy of fullerene black gives little to that of fullerene soot. P_k (critical load) and P_c (welding load) of fullerene black and molybdenum disulfide combined exceed largely the indices of the oil with fullerene soot only. Welding load is impacted by nanocarbons most of all. FS and FCh additives literally break off the catching of balls. Frictional characteristic of oils alloyed with nanocarbons almost doubles that of oils with graphite, and is 80 % higher than that of oils with molybdenum disulfide.

Table 3. Tests of nano-containing lubricating components

Lubricating composition	Tribological characteristics			
	P_k , H (critical load)	P_c , H (welding load)	Wear Scar Diameter, mm	Coefficient of friction
Aqueous dispersion of graphite – 3% Aerosol spray	220	310	5,2	0,38
Aqueous dispersion FS – 3% Aerosol spray	280	450	4,6	0,32
Aqueous dispersion FCh – 3% Aerosol spray	270	420	4,7	0,32
Aqueous dispersion of FCh (2%) and graphite (3%) Aerosol spray	310	480	4,1	0,28
Oil IS–20 +5% MoS ₂	450	730	3,7	0,28
Oil IS–20 +5% graphite	410	640	3,9	0,32
Oil IS–20 +3% FS	630	920	2,8	0,22
Oil IS–20 +3% FCh	600	990	2,9	0,24
Oil IS–20 +3% FCh + 3% MoS ₂	710	1100	1,7	0,18
Oil IS–20 +3% FCh + 3% MoS ₂ +2% chlorparaffin + 2% DF–11	780	1220	1,5	0,12

In the aqueous dispersions, nanocarbons do not influence significantly the coefficient of friction (an exception is the composition of FCh + graphite), but they increase largely the welding load. Frictional characteristics of the compositions are improved markedly, when standard lamellar additives are replaced with nanocarbons. FS and FCh in aqueous dispersions are practically interchangeable.

Since FCh is much cheaper than FS, it can be considered to be more promising and up-to-date friction modifier. The composition of molybdenum disulfide, fullerene soot, chlorparaffin and complex phosphate has been proved to be extremely effective in severe regimes of boundary friction. This composition can serve as a base for developing a series of innovative technological lubricants.

Since FS and FCh powders are unstable and tend to agglutinate, they have been supposed to be used in a microcapsular form. When being tested in industry, microcapsules were manufactured by means of phase separation in a gelatinous shell with 300-500 mcm diameter. Dispersion from microcapsules can be easily performed with a standard aerosol spray. Microencapsulation allows saving up to 30 % of nanocarbon materials.

References

- [1] Berdichevskij E 2011 *Trenie i smazka pri plasticheskoj obrabotke metallov* (Velikij Novgorod) (Friction and lubrication in metal plastic finishing).
- [2] Pogodaev L and Kuz'min V 2006 *Strukturno-energeticheskie modeli nadezhnosti materialov i detali mashin* (Sankt-Peterburg: Akademiya transporta Rossijskoj Federacii) (Structural and energetic models of material reliability and machine details).

- [3] Berdichevskij E 2010 Modifikatory treniya kak osnova smazochnyh kompozicij dlya metalloobrabotki *Fundamental'nye i prikladnye problemy tekhniki i tekhnologii* **5** pp 43-46 (Friction modifiers as base of lubricating compositions in metal finishing *Theoretical and applied problems of technics and technology*).
- [4] Bokarev D, Bakunin V, Kuz'min G and Parenago O 2004 Vysokooehffektivnye modifikatory treniya na osnove nanorazmernyh materialov *Himiya i tekhnologiya topliv i masel* **4** pp 28-30 (Highly effective friction modifiers based on nanoscale materials *Chemistry and technology of fuels and oils*).
- [5] Malushin I N N, Valuev D V, Il'jaschenko D P, Gizatulin R A, Nekrasov R Yu 2018 Improvement of Research Procedures into the Highly Rigid Welded Metal Using Thermal Microscopy Facilities *J. Materials Science Forum* **927** 148-152
- [6] Valuev D V, Danilov V I, Ivanov V I 2007 On the causes of formation of non-optimal structures in a pressure-treated low-carbon steel *J. Russian Physics Journal* Issue **10 (50)** 964-968.
- [7] Kryukov R E, Kozyrev N A, Galevsky G V, Bendre Y V, Goryushkin V F, Valuev D V 2015 Some aspects of oxidation-reduction reactions under carbon-bearing flux welding *IOP Conference Series: Materials Science and Engineering*. **91**
- [8] Malushin N N, Valuev D V, Valueva A V, Serikbol A 2014 Kinetic study of the effect of plasticity and its role in stress relaxation in the weld speed steel during the martensitic transformation *Applied Mechanics and Materials* **682** 58-63