Effect of fullerene-like nanoparticles on the tribological properties of industrial lubricants for steel rolling

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Abstract

The paper shows the results of studying the possibility of using fullerene-like nanoparticles as a lubricating additive in the composition of technological lubricant MT-216 M. The lubricity properties were evaluated on a laboratory rolling mill DUO-180 during cold rolling of strips of steel 08kp. The rolling force, the coefficient of friction in the deformation zone were measured, the values of the elongation coefficient and the parameter reflecting the costs of the rolling force per unit deformation of the metal were calculated.

Keywords: technological lubrication, cold rolling of steel, lubricating properties, fullerene-like nanoparticles

Introduction

Lubricating-cooling technological agents (LUTA), used in the processing of metals by pressure, are called technological lubricants (TL). The right choice of process lubricant helps to increase the productivity of rolling equipment, improve the quality of products. The technology of using the TL is also of great importance - i.e. a method of supplying lubricant to rolls and metal, determining the optimal lubricant consumption and improving lubrication systems.

Technological lubricants must meet a number of technical, economic and sanitary-hygienic requirements. Depending on the production conditions, the type of metalworking, the nature of the metal being processed, the parameters of the technological process, the list of requirements for lubrication may vary [1].

However, based on the fact that the performance properties of lubricants depend on many factors, taking into account the effect of lubricants on the quality of rolled products, as well as the variety of rolled products and the characteristics of rolling mills, it is possible to determine the main requirements for the TL for cold thin sheet steel rolling on modern high-speed mills:
• the ability to provide the lowest friction coefficient acceptable for this type of metalworking;
• ability to provide high adhesion to a metal surface;
• high cohesion in the film and its resistance to high pressure and shear resistance;
• ability to form polymolecular layers and provide a strong film;
• maximum resistance to temperature, improved adhesion and increased strength of the lubricating layers with increasing temperature;
• high viscosity index;
• stability of composition and properties;
• high lubricating properties;
• do not stick to the metal, do not degrade the quality of the surface;
• convenience of giving on rolls and metal;
• no harmful effects on metal and equipment (corrosion, contamination, etc.);
• non-toxicity, absence of an unpleasant smell.

Compliance of the TL with the above listed requirements is ensured by the component composition of the TL. The most important for the TL are lubricating properties. The technological environment used in the cold rolling of steel plays an important role in reducing the energy and power parameters of rolling, affects the productivity of the process, the consumption of rolls and bearings, the geometry and surface quality of the rolled strips [2].

Literature review

Studies show that the lubricating properties of TL are due to the complex effect of their component composition on the formation of boundary layers - surface protective films. Depending on the nature of the TL components, the chemical composition, structure, and properties of boundary surface layers can change significantly.

Currently, new carbon-based spatial nanostructures are considered as promising antiwear additives for lubricants. According to the recommendation of the International Union of Pure and Applied Chemistry (IUPAC), single- and multilayer closed spherical polyhedra consisting of carbon pentagonal and hexagonal faces (resembling a soccer ball in structure) are classified as fullerenes (or fullerene-like nanoparticles (FLN) [3].

The mechanism of action of FLN on the tribological characteristics of lubricants is explained by the deposition of fullerenes from the liquid phase on the contact surfaces during friction. It is assumed that a layer of ball-like fullerene nanoparticles formed on the friction surfaces transforms sliding friction into rolling friction with a decrease in the friction coefficient and minimization of wear [4, 5].

In accordance with such ideas, it should be expected that the positive effect of these additives on the tribological characteristics should increase as the contact surfaces are filled with fullerene particles. In turn, the precipitation of fullerenes accelerates with an increase in their concentration in the solution.

In V.P. Kukhar Institute of Bioorganic Chemistry and Pertochemistry of the National Academy of Sciences of Ukraine were developed methods for obtaining fullerene-like carbon nanoparticles (CNOs) by the plasma-chemical method and alkaline pyrolysis of vegetable carbohydrates (lignin, wood waste cellulose). The methods of atomic force and transmission electron microscopy, infrared and Raman spectroscopy were used to study the structural and dimensional features of the synthesized carbon nanoparticles.
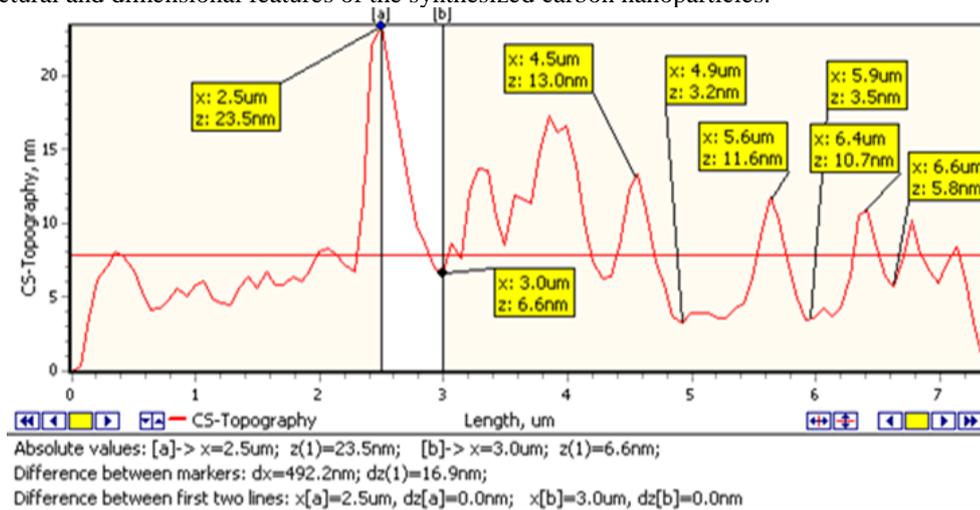

Fig. 1. Evaluation by atomic force microscopy of the size of fullerene-like nanoparticles obtained by carbonization of wood waste
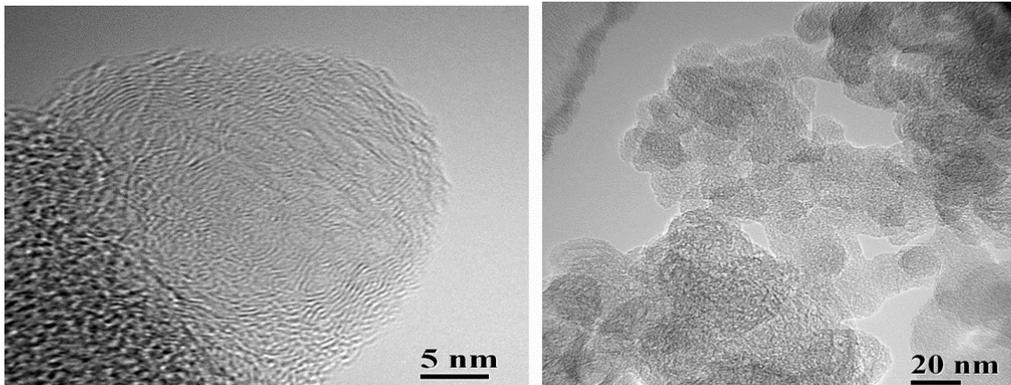

Fig. 2. Transmission electron microscopy image of fullerene-like nanoparticles obtained by carbonization of wood waste

Figure 1 shows images of the synthesized FLN obtained by atomic force, and in Figure 2 - transmission electron microscopy. The average size of individual synthesized nanoparticles is in the range of 15–25 nm.

Purpose

The authors studied the possibility of using spherical carbon nanoparticles obtained by carbonization of bio-raw materials as a lubricant additive in the composition of TL. The object of the study was a Ukrainian-made technological lubricant MT - 216 M produced by "Chemical Investment Company LTD".

Results

Technological lubricant MT-216 M is a balanced composition of synthetic esters of fatty acids and polyhydric alcohols, vegetable oils, emulsifiers, corrosion inhibitors and other multifunctional additives that give it a set of necessary performance properties. TL MT-216 M is designed for use in high-speed cold rolling of carbon and alloy steels, pipe rolling and drawing, wire drawing, stamping and cutting of carbon and alloy steels. Physical and chemical requirements for technological lubricant MT-216 M are given in Table 1.

Table 1

Physical and chemical requirements for TL MT-216M

| №	The name of indicators	Norm according to Specifications 20.5-32734997-003:2016	Test Methods
		A. Concentrate	
1	Appearance and color	Homogeneous oily liquid from yellow-red to brown	GOST 6243
2	Density at 20°C, kg/m^3 within	920-1000	ASTM D 1298
3	Kinematic viscosity at 50°C, mm^2/s (cSt), within	30-70	ASTM D 2196
4	Flash point in an open crucible, °C, min	180	ASTM D 92
5	Pour point, °C, max	minus 5	ASTM D 97
6	Acid number, mg KOH/g, max	20	ASTM D 664
7	Saponification number, mg KOH/g, min	210	GOST 17362 or GOST 21749
8	Mass fraction of water, %, max	0,5	ASTM D 6304
9	Storage stability	Withstands	GOST 6243
10	Ash content, %, max	0,05	GOST 1461
11	Mass fraction of mechanical impurities, %, max	0,03	ASTM D 189 or ASTM D 524
12	Corrosive effect on metals: steel 10	Withstands	ASTM D 130
13	pH value, within	6,0 -8,0	GOST 6243
14	Emulsion stability: oil release is allowed within 1 hour,%, max	2,0	GOST 6243
		B. 5% emulsion prepared according to GOST 6243	
16	pH value, within	6,0 -8,0	GOST 6243
17	Emulsion stability: oil release is allowed within 1 hour,%, max	2,0	GOST 6243
18	Corrosive effect on metals: steel 10	Withstands	GOST 6243

Experimental study of the effectiveness of the lubricating properties of fullerene-like nanoparticles in the composition of technological lubricants during cold strip rolling

An alcoholic solution of fullerene-like nanoparticles was prepared by extracting a dry CNOs-Br powder with absolute ethanol with a content of nanoparticles of 0.4862 g/l of the solution.

Fullerene-like nanoparticles were introduced into the TL MT-216 M in the form of an alcohol solution in an amount of 0.01% wt; 0.10% wt; 1.00% wt. Experimental studies were carried out on the basis of the A.P. Chekmarev Department of Metal Forming of the Ukrainian State University of Science and Technology (National Metallurgical Academy of Ukraine) (DMF USUST (NMetAU).

Studies of antifriction efficiency were carried out during cold rolling of thin strips 0.5 mm thick ($l/h_{av} > 3-5$), which, according to A.P. Grudev [6], is the most favorable condition for such experiments. The samples were a strip in a roll of 08kp steel in the annealed state ($\sigma_{t.init.}=260$ N/mm^2) with a width b=200.5 mm and an initial thickness $h_0=0.5$ mm. The study was carried out for 15 samples with a length of $l_0=540$ mm, based on 3 pcs. for each sample of the investigated lubricant, and 3 pcs. for rolling without lubrication.

TL studies were carried out on a laboratory two-roll mill "duo"-180 of the Department of DMF USUST (NMetAU). The mill is equipped with rolls with a diameter of 180 mm, the rotation speed of which is 0.264 m/s. A general view of the rolling stand is shown in fig. 3.
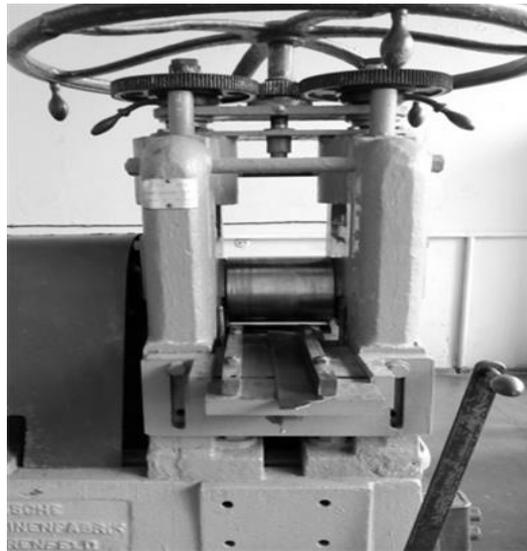
Fig. 3. General view of the stand of the laboratory mill 180-"duo" of the Department of DMF USUST (NMetAU)

Before rolling, the prepared strips were cleaned and degreased with "Kalosha" gasoline-solvent (Nefras S2-80/120). Also, the rolls and the receiving table of the mill stand were subjected to cleaning and degreasing.

The degree of compression of steel samples was preliminarily chosen, the value of which is equal to 12% of the initial height of the sample. At the first stage of experimental studies, 3 samples were rolled without lubrication, which will later serve as a standard for comparing the power parameters of rolling samples with lubrication. Lubricants were generously applied with a brush to the surface of each strip along the entire length. Before rolling each strip, the rolls and the receiving table of the mill stands were degreased with the solvent indicated above. Fig. 4 shows a sample of the indicated length with lubrication applied.

Fig. 4. Initial sample with applied lubricant (top view)

After rolling, changes in their geometric parameters were measured on the test samples: thickness h_1 (10 measurements were made along the length of the strip on each strip, the average value is indicated in the table), width and length of the samples b_1, l_1. The elongation ratio, which is an indirect method for determining the lubricity properties of TL during rolling, was calculated from the ratio of the sample cross section before and after rolling.

$$\lambda = \frac{F_0}{F_1} = \frac{h_0 b_0}{h_1 b_1} , \qquad\qquad (1)$$

were

F_0 is the sample cross section before rolling,
F_1 is the cross section of the sample after rolling,
h_0 is the sample thickness before rolling,
h_1 is the sample thickness after rolling,
b_0 is the sample width before rolling,
b_1 is the width of the sample after rolling.

During the rolling of the specimens, the rolling force was measured using pressure gauges installed under the pressure screws. Mesdoses were previously calibrated. The value of the rolling force (the previously used expression "pressure of the metal on the rolls") was taken from the molds, and with the help of an ADC device (analogue-to-digital converter) was transmitted to a computer. The research data on the effect of TL on the rolling force are presented in Table 2. The obtained data on the rolling force of steel specimens indicate the effect of technological lubricants on the rolling force. The most effective lubricant in this case is MT-216M +

1.00% fullerene-like nanoparticles (FLN), the other lubricant samples showed approximately the same result of force measurements.

Table 2

Comparison of rolling force

Lubricant	Force at the initial capture of the strip (P_3), кN	Average force at steady state (P_c), кN	Minimum rolling force (P_{min}), кN
Without lubrication	26,8	25,5	24,0
MT-216 M	27,4	24,5	22,6
MT-216M + 0,01 % FLN	24,5	24,5	22,6
MT-216M + 0,10 % FLN	26,8	24,5	19,6
MT-216 M+1,00 % FLN	29,4	22,6	20,6

The second criterion for evaluating the lubricating properties of lubricants is the determination of the average coefficient of friction in the deformation zone (f). The calculated dependence for determining the coefficient of friction during cold strip rolling, proposed by A.P. Grudev [7]:

$$f = k_l \frac{1}{1+0.25\sqrt{v_{50}}-0.005v_{50}}[1+(0.4+\varepsilon)R_z] \cdot \left[0,07 - \frac{0.1V_r^2}{2(1+V_r)+3V_r^2}\right] \qquad (2)$$

where k_l is a coefficient that takes into account the nature of the lubricant; v_{50} is the kinematic viscosity of the lubricant at a temperature of 50 °C, mm^2/s; ε is the partial relative reduction of the strip during cold rolling, fractions of a unit; R_z is the height of microroughnesses on the surface of work rolls, μm; V_r is the circumferential speed of the work rolls during rolling, m/s.

According to A.P. Grudev coefficient k_l is equal to: for vegetable oils – 1.0, for mineral oils – 1.4. When rolling with emulsions from emulsols based on mineral oils, the viscosity of the corresponding mineral oils is taken as the calculated value of v_{50} [7].

The geometric dimensions of the samples after rolling, the values of the elongation coefficient, as well as the calculated values of the friction coefficient are shown in Table 3. Also, as mentioned above, to indirectly determine the lubricating properties of the TL during rolling, the values of the elongation coefficient and the parameter K (kN/%), reflecting the cost of rolling force per unit of metal deformation were calculated.

Table 3

Geometric dimensions of specimens, elongation coefficient and coefficient of friction during rolling of steel specimens on a laboratory mill 180 "duo"

Lubricant	Final strip thickness h_1, mm	Relative compression, ε, %	Strip width after rolling b_1, mm	Relative drawing, λ	Roll speed m/s	Medium contact stress p_m, N/mm^2	Friction coefficient, f	K, кN/%
Without lubrication	0,46	8	20,15	1,079	0,264	473	0,229	3,187
MT-216	0,44	12	20,1	1,131	0,264	372	0,097	2,043
MT-216 M + 0,01 % FLN	0,44	12	20,1	1,131	0,264	372	0,077	1,879
MT-216 M + 0,10 % FLN	0,44	12	20,1	1,131	0,264	372	0,062	2,043
MT-216 M+1,00 % FLN	0,44	12	20,1	1,131	0,264	342	0,058	2,043

Analysis of the data given in Table 3 showed that when rolling without lubrication, large values of the friction coefficient are observed and the cost of force per unit of deformation of the metal K increases. The lowest values of the friction coefficient f were obtained when rolling strips using TS MT-216 M + 1.00% wt. FLN.

Conclusions

An analysis of the obtained data shows that the addition of fullerene-like nanoparticles to the composition of the technological lubricant MT-216M improves the lubricating properties. The lubricating effect is manifested at a concentration of 1.00% FLN in the composition of the lubricant, which is mainly due to the deposition of fullerene nanoparticles on the surface and, to a lesser extent, to the effect on the structure of the liquid phase.

In the future, to study the lubrication efficiency, it is possible to conduct experiments to determine the advance during rolling as an indirect parameter of the TL efficiency, as well as to study the thickness of the lubricating layer by the drop method.

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І.М. Картун, О.А. Ремез, О.О. Гайдай, О.А Спаська, О.Б. Янченко, В.С. Пилявський, Є.В. Полункін. Вплив фулереноподібних наночастинок на трибологічні властивості технологічних мастил для прокачування сталі

В роботі показані результати дослідження можливості застосування фулереноподібних наночастинок як змащувальна присадка у складі технологічного мастила МТ-216 М. Оцінка змащувальних властивостей проводилася на лабораторному прокатному стані ДУО-180 при холодній прокатці смуг зі сталі 08кп. Були виміряні сила прокатки, коефіцієнт тертя в осередку деформації, розраховано значення коефіцієнта витяжки і параметра, що відображає витрати сили прокатки на одиницю деформації металу.

Ключові слова: технологічне змащення, холодна прокатка сталі, змащувальні властивості, фулереноподібні наночастки