367. Use of liquid crystals for metal machining

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Abstract

The paper presents results of measurements of surface roughness of holes reamed in steel and cast iron workpieces, when mineral industrial oil with and without liquid crystals additives was used as coolant for reaming. Four types of twisted nematic liquid crystals (cholesterol esters) were tested: cholesterol valerate, cholesterol caproate, cholesterol stearate and cholesterol oleate. The concentration of the liquid crystals in oil was 0.5% by oil volume. The dependence of average roughness R_a of the reamed surface on coolant composition was established.

Keywords: liquid crystals, coolant, mineral industrial oil, reaming.

Introduction

Coolants are widely used for many metal machining operations. They perform three very important functions in the tool-workpiece interface zone: lubrication, cooling and washing. The first function results in reduced cutting force, temperature, tool wear and height of the roughness of machined surface. The second function results in reduced temperature in the cutting zone and tool wear. Finally, good washing properties are necessary for effective chip removal from the cutting zone. Therefore, improvement of properties of the coolants is one of the possible ways to increase the tool life, dimensional accuracy and surface quality of machined parts and reduce the production costs. That can be achieved by using coolant additives.

Liquid crystals are an interesting solution in this field for two main reasons. At first, it is known [1-4], that liquid crystals additives to the various lubricants can significantly reduce the friction coefficient of lubricated friction pairs (in separate cases, when twisted nematic liquid crystals are used as additives, maximum reduction of the friction coefficient of friction pairs reaches 5 times [1], wear of friction surfaces – 20 times [1] and friction zone temperature – 2 times [2] in comparison with pure lubricants). Next, many of liquid crystals (especially twisted nematic liquid crystals – cholesterol esters) are surface-active substances and they can strengthen the P. A. Rehbinder's effect [5] and reduce the deformation resistance of the surface layer of the workpiece.

Therefore, it may be presumed that liquid crystals can be used as effective additives for various coolants and can improve their lubrication properties, i.e. significantly reduce friction between tool and workpiece as well as tool wear, diminish temperature in the cutting zone resulting in improved quality of machined surface and extended tool lifetime. They can be particularly effective for multipoint tools (drills, reamers, taps, etc), when the tool-workpiece-chip contact area is comparatively large.

Research Object

The mineral industrial oil I-40A (Table 1) with and without twisted nematic liquid crystals (cholesterol esters) additives was selected as an object of research. Molecular formula of the tested liquid crystals is presented in Fig. 1, the main properties are presented in Table 2. The research covered homologous series of twisted nematic liquid crystals, i.e.: valerian acid cholesterol ester (Val), capron acid cholesterol ester (Cap), stearine acid cholesterol ester (St). Oleine acid cholesterol ester (Ol) also was used as additive of industrial oil.

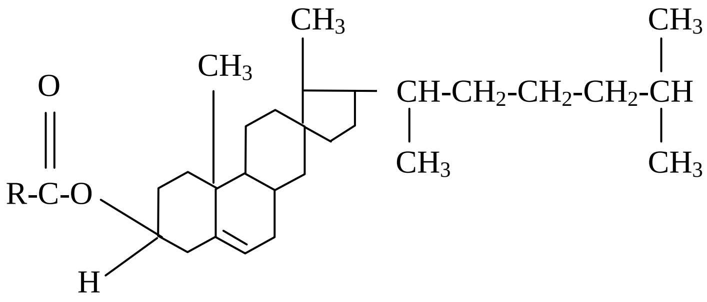

Fig. 1. The molecular formula of the studied twisted nematic liquid crystals: R is hydrocarbon radical of the saturated or unsaturated fatty acid (Table 2)

Table 1. Properties of industrial oil I-40A [6]

Property	Unit of measurement	Value
Density (20 °C)	[kg/m^3]	900
Acid number	[mg KOH/g]	0.05 (min.)
Kinematic viscosity (40 °C)	[mm^2/s]	61-75
Flash point	[°C]	220
Solidification temperature	[°C]	-15
Ash content	[%]	0.005

Table 2. Properties of the tested twisted nematic liquid crystals

Liquid crystals	R=C_mH_n (Fig. 1)	Melting point, [ºC]	Molecular mass
Valerian acid[1] cholesterol ester (Val)	C_4H_9	93.0	470.8
Capron acid[1] cholesterol ester (Cap)	C_5H_{11}	99.5	484.8
Stearine acid[1] cholesterol ester (St)	$C_{17}H_{35}$	83.0	653.1
Oleine acid[2] cholesterol ester (Ol)	$C_{17}H_{33}$	48.0	651.1

[1]saturated fatty acid; [2]unsaturated fatty acid

Research Methods

Experiments were performed on vertical drilling machine. Steel 45 and cast iron СЧ-15 specimens were machined. First, the hole was drilled by twisted drill, then enlarged by core drill and finally, reamed by machine reamer (Table 3). Thus, in total 16 holes were machined in every workpiece: 1 hole, when no coolant was used for reaming, 3 holes, when pure industrial oil was used as coolant for reaming and 12 holes, when industrial oil with liquid crystals additives (Table 2) was used as coolant for reaming (3 holes × 4 types of the tested liquid crystals).

The concentration of liquid crystals in industrial oil was 0.5 % by oil volume. Industrial oil and liquid crystals mixtures were prepared as follows: industrial oil and liquid crystals were heated above melting temperature of the liquid crystals (Table 2), then melted liquid crystals were added to oil (0.5 % by oil volume) and, finally, the mixture was prepared and cooled down to room temperature. Subsequently it was poured into vessel and left for 3 days on purpose to examine the solubility of liquid crystals in oil, then tested as coolant for reaming in the low pressure flood application system of the drilling machine.

The average roughness of the reamed surface R_a was chosen as an output parameter in the research. The R_a values of reamed holes were established by roughness indicator Talysurf 4 (Taylor & Hobson), and then average R_a value was calculated for every coolant.

Table 3. Cutting conditions

Workpiece material	Operation component	Tool	Feed, [mm/rev.]	Cutting speed, [m/min]	Rotational speed, [rev./min]	Machine time, [min]
Steel 45	Drilling	Twisted drill ∅13	0.28	30.0	710	0.12
	Core drilling	Core drill ∅15.75	0.56	17.6	355	0.12
	Reaming	Machine reamer ∅16H9	1.12	2.26	45	0.46
Cast iron СЧ-15	Drilling	Twisted drill ∅13	0.28	30.0	710	0.21
	Core drilling	Core drill ∅15.75	1.12	24.7	500	0.08
	Reaming	Machine reamer ∅16H9	1.6	6.3	125	0.21

Results of Research

Results of experiments are presented in Fig. 2 and Fig. 3 as relationships of average roughness of the reamed surface R_a on coolant composition.

It should be mentioned, that all the tested twisted nematic liquid crystals completely melted in mineral industrial oil. 3 days after mixing all the oil and liquid crystals mixtures were clear and free from micelles of molecules of the liquid crystals, the visible changes of viscosity of mixtures were not observed.

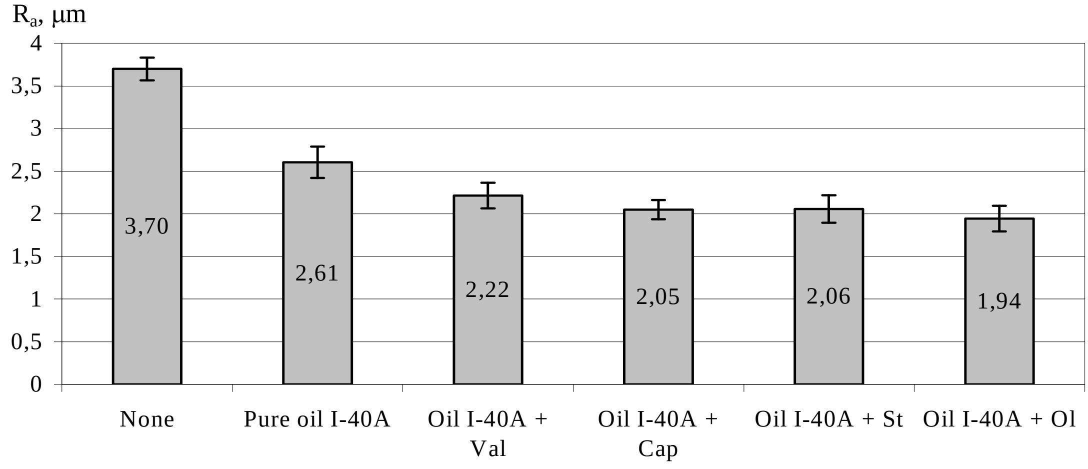

Fig. 2. Average roughness R_a of reamed cast iron surface as function of coolant composition (presented average values of 9 R_a measurements (3 different measurement positions inside the hole × 3 reamed holes) when any coolant was used and average value of 3 R_a measurements (3 different measurement positions inside the hole × 1 hole) when no coolant was used for reaming)

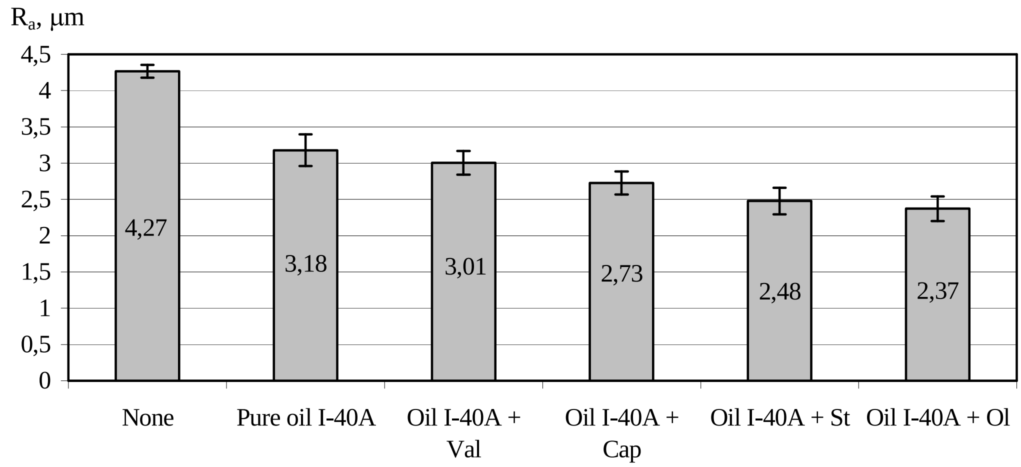

Fig. 3. Average roughness R_a of reamed steel surface as function of coolant composition (presented average values of 9 R_a measurements (3 different measurement positions inside the hole × 3 holes) when any coolant was used and average value of 3 R_a measurements (3 different measurement positions inside the hole × 1 hole) when no coolant was used for reaming)

Conclusions

1. All tested twisted nematic liquid crystals positively influence the properties of coolant. Liquid crystals with the biggest molecular mass (stearine acid cholesterol ester and oleine acid cholesterol ester) are particularly effective. When they were used as industrial oil additives, the reduction of the R_a of reamed steel surface reached approx. 1.3 times as compared with additive-free oil. In case of cast iron workpiece, reduction of the average roughness was similar.
2. All the tested twisted nematic liquid crystals are completely soluble in industrial oil at concentration of 0.5 % by oil volume. This fact is very important for application of the liquid crystals in the coolant systems of the machines.
3. Attempt to establish the dependence of the average roughness of reamed surface on the molecular mass of used liquid crystals was only partially successful since the measuring errors were comparative with the variations of the R_a values. It can be only assumed that the dependence exists and as the molecular mass of the used liquid crystals increases, the average roughness of reamed surface slightly decreases.

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