Experimental Research on the Rheological Properties of Cutting Fluids

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Abstract. Cutting fluids are an important part of the machining and manufacture processes of almost all metal components and end products. The fluids are applied on the interface between the cutting tool and the work piece, and they are used in order to remove the heat generated during the process, reduce the friction, and help flushing the chips away. In this paper we are studying the rheological properties of four different types of cutting fluids, concerning the variation of the viscosity with the temperature. The tests were performed on a Brookfield Cap 2000+ viscometer, using cone plate geometry.

Keywords: rheology, cutting fluids, rheological properties.

1. INTRODUCTION

The cutting fluids are designed specifically to cool and lubricate both the instrument and work piece during the metalworking processes, such as machining and stamping. Various kinds of cutting fluids exist, such as gels, oils, oil-water emulsions, air, pastes, aerosols or other gases. It is known that they are made from animal fats, water and air, plant oils and mostly petroleum distillates or other raw ingredients. Machining and metalworking processes can benefit from the use of cutting fluids. Some materials such as cast iron and brass, can be machined dry, but they will still likely benefit from the use of a cutting fluid (Osorio, 2015).

Those properties are sought after in a good cutting fluid:

- Keep the temperature of the work piece stable, which is crucial when we are working in close tolerances. Warm is acceptable, but extremely hot or cold are avoided.
- Extend the life of the cutting tip, reducing tip welding by lubricating the work edge.
- Prevent rust on the cutting tools, machine parts and work piece.
- Ensure safety for the machine operator and environment.

The main functions of the cutting fluids are cooling and lubrication.

1. 1. Cooling

Metalworking processes generate heat due to friction and the energy used to deform the material. Rather than stopping production while the tools are cooling, the use of a liquid coolant decreases the heat significantly and more rapidly, and it is proven to also speed the cutting, reduce friction and tool wear.

1. 2. Lubrication

Cutting fluids are also used to lubricate the interface between the cutting edge of the tool and the chip. By preventing this friction, the generated heat is less. The lubrication is also helping to prevent welding of the chips onto the tool, which leads to smoother surface (Mamidi, 2012).

There are three types of liquid cutting fluids: mineral, synthetic and semi-synthetic.

The petroleum-based mineral oils, first were used in cutting applications in the late 19^{th} century. They vary from the light and clear oils to the dark, thick cutting oils that are used in the heavy industry.

Semi-synthetic coolants, are an emulsion of water with mineral oil. They were first used in the 1930s. The typical Computer Numerical

Control (CNC) machines are usually using emulsified coolant, consisted of small amounts of oil emulsified into a large amount of what through the use of a detergent.

Synthetic coolants first saw use in the 1950s. They are usually water-based. The usual technique to measure the concentration of the oil in the cutting fluid is: 100ml of the fluid under test is titrated with a 0.5M HCI solution to an end-point of pH 4 and the volume of titrant used to reach pH 4 is used to calculate the concentration of the oil. Another way to determine the mix ratio of water-soluble coolants is with a hand-held refractometer, that estimates the oil concentration from the sample refractive index which is measured in the Brix scale, but the sample contamination reduces the accuracy of the measurement (Meister, 2002).

The rheological properties show if the fluid will be effective enough to sustain large amount of stress and maintain low enough viscosity so the pumping can be efficient. The rheological properties determine if the fluid is Newtonian or not.

The present paper proposes to study the rheological properties of four different type of cutting fluids, as function of their chemical and physical characteristics.

The experimental stand is a Brookfield cone-plate viscometer. The tested liquid is placed between a rotating cone and immobile disc. The viscometer is suitable for digital data acquisition and offers the possibility to determine the variation of shear stress versus shear rate.

2. DATA

The tests were performed on the following four liquids:

- INSA Rezinol C-22;
- INSA Emulsol;
- Prista Emulsol B;
- Prista Emulsin Extra.

In Table 1. the physical and chemical properties of the fluids are presented.

TABLE 1. Physical and chemical properties of the cutting fluids used in the research.

	INSA Rezinol C-22	**INSA Emulsol**	**Prista Emulsol B**	**Prista Emulsin Extra**
Physical state	Liquid	Liquid	Liquid	Liquid
Colour	Light brown	Light brown	Brown	Brown
Odour	Characteristic	Characteristic	Characteristic	Characteristic
Flash point, °C	> 175	> 160	160	> 140
Auto - ignition temp., °C	> 300	-	> 315	> 315
Solubility	Water miscible	Water miscible	Water miscible	Water miscible
Kinematic Viscosity at 40 °C, mm^2/s	19,8 - 24, 2	19,8 - 24,2	45	130
Density at 20 °C, g/ml	0,868 - 0,874	0,868 - 0,874	0,884	0,987
Freezing point, °C	-15	-15	-15	-

3. METHODOLOGY

The dependency of shear stress versus shear rate has been studied for four different types and brands of fluids: INSA Rezinol C-22, INSA Emulsol, Prista Emulsol B and Prista Emulsin Extra.

To determine the dependency a type of test “speed ramp” was used at standard temperature of 20 °C, rotation from 100 to 1000 rpm and different soaking times (the time necessary to homogenize the sample) for each of the fluids.

The experimental results corresponding to the determination of the rheological parameters were numerically treated assuming the validity of power law rheological model:

$$\tau = m\left(\frac{du}{dy}\right)^n \qquad (1)$$

where: τ – shear stress;

m – consistency index (equivalent to viscosity);

n – flow index (equal to 1 if the fluid is Newtonian);

$\left(\frac{du}{dy}\right)$ – shear rate.

The experimental research has been performed in the tribological laboratory of the POLITEHNICA University of Bucharest, Romania. A Brookfield viscometer was used for the purpose of our research.

The BROOKFIELD CAP 2000+ Series Viscometers (Fig. 1) are medium to high shear rate instruments with Cone Plate geometry and integrated temperature control of the test sample material.

Fig. 1 Image of the Brookfield CAP 2000+ Viscometer.

Technical parameters of the CAP 2000+ viscometer are (see BROOKFIELD CAP 2000+, Viscosimeter, Operational manual):

- rotational speed selection ranges from 5 to 1000 rpm;
- viscosity measurement ranges depend upon the cone spindle and the rotational speed;
- temperature control of sample is possible between 5°C and 75°C;

The viscometer uses a CAPCALC32 software for complete control and data analysis. The cone plates used by the viscometer are shown in Table 2.

Fig. 2 Testing cones 3, 5, 6 and 8, used by the Viscometer.

In Table 2 are shown the parameters of the testing cones.

TABLE 2. Geometry and viscosity range of cones.

Cone Number	Cone Radius, mm	Cone angle, degree	Viscosity Range, Pa.s
3	9,53	0,45	0,083 … 1,87
5	9,53	1,8	0,333 … 7,50
6	7,02	1,8	0,833 … 18,7
8	15,11	3	0,312 … 3,12

In order to optimize the measurement the tests were performed under the following testing conditions used on the Capcalc 32 software:

1. Type of test –Speed ramp up & down.
2. Temperature 20 °C.
3. Cone number 8.
4. Range of rotation speed – 100-1000 rpm.
5. Soaking time – 10 seconds on each speed.

6. Number of points collected – 20 up & 20 down.

4. EXPERIMENTAL RESULTS

We studied variations of the shear stress versus shear rate with different testing conditions for the 4 different types of fluids.

The results are shown in Fig. 3, 4, 5 & 6. The comparison between the results of the two brands is shown in Fig. 7 & Fig. 8.

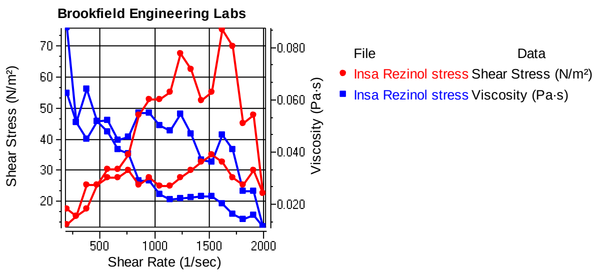

Fig. 3 Rheogram for INSA Rezinol C-22.

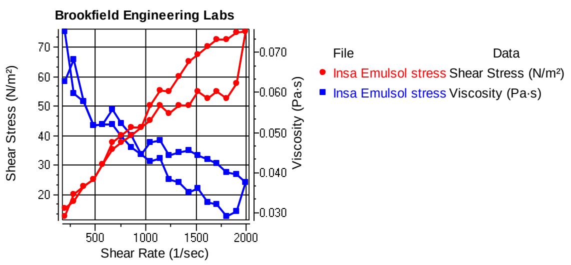

Fig. 4 Rheogram for INSA Emulsol.

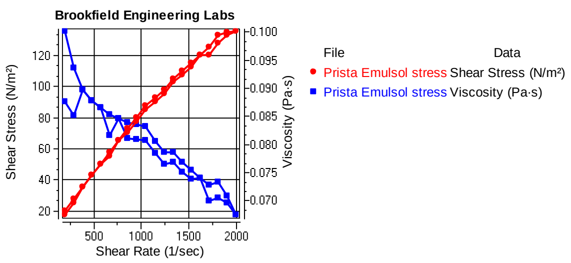

Fig. 5 Rheogram for Prista Emulsol B.

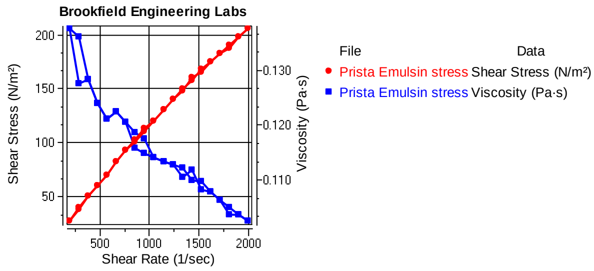

Fig. 6 Rheogram for Prista Emulsin Extra.

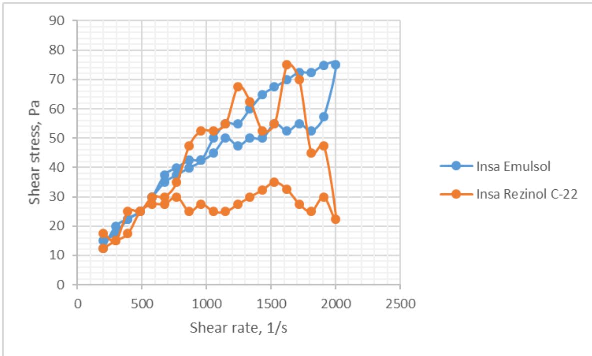

Fig. 7 INSA Emulsol and INSA Rezinol compareson.

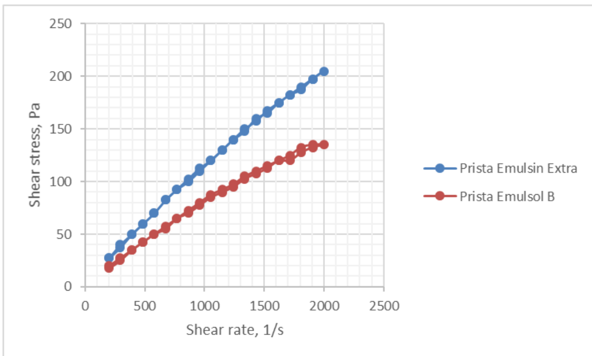

Fig. 8 Prista Emulsin Extra and Emulsol B comparison.

TABLE 3. Rheological parameters for the Power law model.

Fluid	Power law model		
	Consistency index (m), Pa·sn	Flow index (n)	Correlation Coeff. (%)
Insa Rezinol C22	1.39	0.46	72.1
Insa Emulsol	0.344	0.703	92
Prista Emulsol B	0.192	0.872	97.4
Prista Emulsin Extra	0.265	0.878	98.8

The parameters of the power law model for the four used types of fluids are shown in Table 3. The consistency index (m) and the flow index (n) are graphically displayed in Fig 9 & Fig. 10.

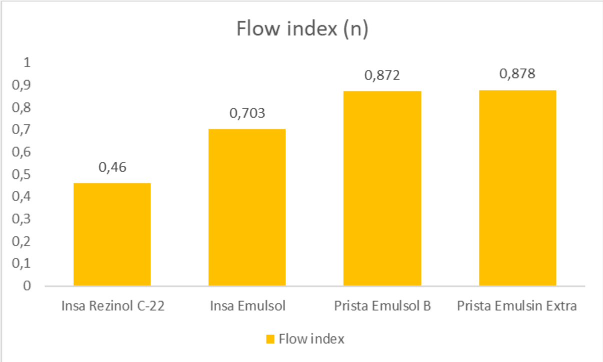

Fig. 9 The variation of the Flow index (n) parameter for the different types of fluids.

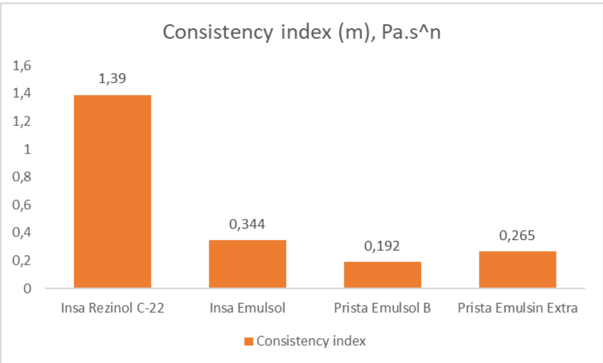

Fig. 10 The variation of the Consistency index (m) parameter for the different types of fluids.

5. COMMENTS AND CONCLUSIONS

In this paper was performed a study of the rheological properties and the variation of the shear stress versus shear rate for four different types of fluids: INSA Rezinol C-22, INSA Emulsol, Prista Emulsol B and Prista Emulsin Extra.

1. The cutting fluids from the company INSA oil, show important thixotropy behaviour, so they have reduced stability during machining and are not as homogeneous compared to Prista Emulsol B and Emulsin Extra. From rheological point of view it is recommended to use the INSA fluids in common cutting processes, without very intense cutting regimes. The cutting fluids from the company INSA oil, show thixotropy behaviour, so they have reduced stability during machining.
2. By analysing the rheological properties of the cutting fluids we observe that the cutting fluids from the company Prista oil have almost no hysteresis or thixotropy. From rheological point of view it is recommended that they are used for intensive cutting processes, with high surface quality requirements. Those fluids are much more homogeneous and stable, which means they are more likely to optimize the cutting process.
3. All of the cutting fluids can be modelled with Power law rheological model, but with different correlation coefficients.

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