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RHEOLOGICAL AND TRIBOLOGICAL PERFORMANCE OF AN EXOPOLYSACCHARIDE USED AS CUTTING FLUID EXTRACTED FROM AN ALGAE

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Abstract. *Cutting fluids are commonly used for improving the cutting conditions in metal machining operations, in particular with low machinability materials such as austenitic stainless steel. However, the use of cutting fluids presents relevant problems related with pollution of soils, water and health issues. In this study an exopolysaccharide from an algae is used as cutting fluid, thereby presenting a biodegradable alternative. For this purpose the variation in the rheological properties of bio-cutting fluid extracted from an algae was analyzed using a rotational rheometer at steady state with 1° cone-plate geometry and 40 mm in diameter. Preliminary test were performed to determine the effect of shear stress on the viscosity of mixtures with different exopolysaccharide (EPS) concentration (4.5%, 2.5%,1%,0.25 % m/v). In addition, some rheological tests were carried out in 80°C, trying to simulate the temperature that achieves the tool under cutting conditions; as a result it was found that the concentration with 0,25% of EPS showed the best rheological performance. A tribological test that simulated the conditions of a cutting process was prepared, for this purpose austenitic stainless steel plates were machined using a drill of high speed steel lubricated with a solution of the EPS, and then the wear of the drill flanks was measured using image analysis. It was found that the EPS solution without any additive present a satisfactory performance respect to the commercial cutting fluid; so it could represent a viable alternative as a base for this kind of fluids in metalmechanic processes.*

Keywords: *Cutting fluid, Exopolysaccharide, Rheology, Metals, Friction, Wear*

1. INTRODUCTION

Cutting fluids are a type of lubricant commonly used in metal machining processes to reduce cutting forces, friction between parts and tools and the temperature in the cutting region; reducing energy consumption of the process, increasing the life of the tools and improving surface integrity (Madanchi, *et al*., 2015). Many cutting fluids are oil-based lubricants, generating harmful effects on the environment due to the mishandling of used lubricant, which contains toxic substances and has low biodegradability (Dixit, *et al*., 2012). On the other hand, it has been reported that about 80% of occupational diseases of the workers directly engaged in manufacturing metal cutting, are due to contact with cutting fluids (Shashidhara and Jayaram, 2010). Cutting fluids contain substances such as emulsifiers, stabilizers, corrosion inhibitors, biocides and extreme pressure additives, which can cause health problems such as dermatitis, asthma, bronchitis, irritation of the airways, breathing difficulties and long-term cancer lung (HSE, 2011). Despite its impact on the environment and human health, consumption of cutting fluids has increased due to its usefulness to increase productivity and quality of manufacturing operations. Reports indicate that about 35 million metric tons of mineral-based lubricants have been used in 2014 (Gosalia, 2015).

Some companies in the world have begun to use alternative lubricants. In large part this is due to the implementation of strict laws that can compel employers to use this type of lubricant, especially in regions located close to marine facilities, or forest reserves of fresh water (HSE, 2011; Shashidhara and Jayaram, 2010). In the European Union and The United States have carried out the most significant developments in the study and development of cutting fluids to plant-based feedstock using coconut, soybean, sunflower and canola (Shashidhara & Jayaram, 2010).

The aim of this paper is to present a biodegradable alternative to cutting fluids, from an exopolysaccharide extracted from an alga; for this purpose the rheological and tribological properties of an EPS concentration was analyzed, and then they were compared with the performance of a conventional cutting fluid and pure water.

2. METHODOLOGY

2.1 Rheological tests

The rheological tests were carried out using a rotational rheometer Bohlin Instruments C-VOR 200, a 1° titanium cone-plate measuring system (diameter 40mm) and a Peltier cell for controlling the temperature. Samples of water + 4.5%, 2.5%, 1%, 0.2 % m/v EPS were prepared. To obtain a colloidal dispersion, the lyophilized EPS was integrated into a solvent (deionized water) taking advantage of its great hygroscopicity and hydrophilicity and stirring at 1500 rpm. 0.5 ml of the sample was extracted and disposed between the bottom plate and the measuring cone with a gap of 30 microns. Two kinds of tests were performed; the first one at 25 °C and constant shear rate of 52 s^{-1} for 150 seconds, the second one was developed in 80°C, trying to simulate the temperature that achieves the tool under cutting conditions and with a shear rate sweep from 0 to 100 s^{-1} in 300 seconds.

2.2 Tribological tests

Tribological tests were carried out in an A FEXAC milling machine. AISI 304 austenitic stainless steel plates with 1.52 mm thick were machined using a drill of high speed steel of 6,35mm (diameter) lubricated with a solution of the EPS. Perforation processes were carried out with 500 rpm and 22mm/s feed motion and each drill was used until its failure. The same operation was performed using a commercial cutting fluid and pure water with the aim of having a positive control. Tool wear were registered using a stereoscope Nikon (SM) SMZ 1000; for this purpose photographs with a resolution of 640 pixels x 480 pixels were capture every 20 holes. Areas of the flank and tip were compared in its initial state and after cutting using the sotware ImageJ and was expressed in mm2 (24025 pixels / mm2), this measurement was repeated three times and then takes an average wear. This method was bases in the work of Patiño (2004).

3. RESULTS AND DISCUSSION

3.1 Rheological performance

Figure 1 shows the effect of the shear rate on viscosity with different EPS concentration at temperature of 25°C. Initially it is observed a short region of shear-thinning, which varies for each of the concentrations of EPS, after this zone, it can be seen an asymptotic behavior for each concentration.

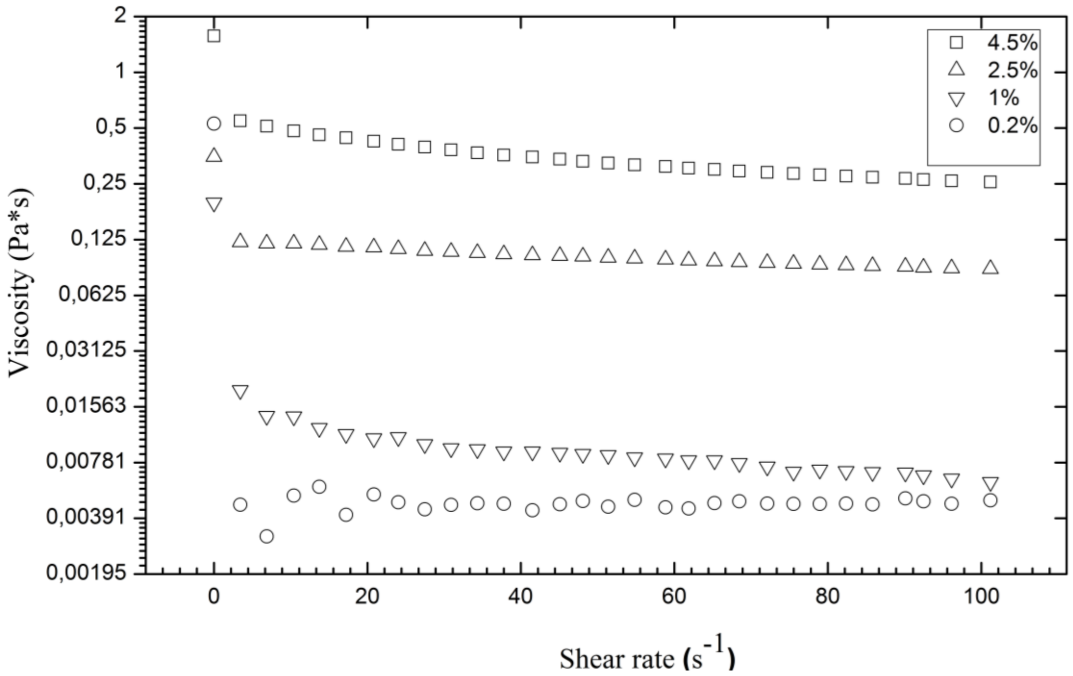

Figure 1. Effect of the shear rate on the viscosity of fluids with different EPS concentrations at 25°C

Figure 2 shows the same variables presented in Fig. 1 but at 80°C. It is noted that the variation in the viscosity values are most noticeable at higher concentrations, tending to a pseudoplastic behavior, which implies that an increment in the shear rate generates a reduction in the viscosity (Mezger, 2006). Similarly, it is observed that concentrations of 4.5% and 2.5% EPS show greater sensitivity to the effect of temperature, since a significant decrease in viscosity for these concentrations is observed in comparison with those obtained at 25 ° C.

On the other hand, Fig. 1 and Fig. 2 reported similar viscosity values for concentrations of 1% and 0.2%, at 25°C and 80°C. This is a very significant result for this research since considering the application in cutting operations, it is important that the viscosity does not present significant changes when the temperature or the rate deformation increases (Mezger, 2006).

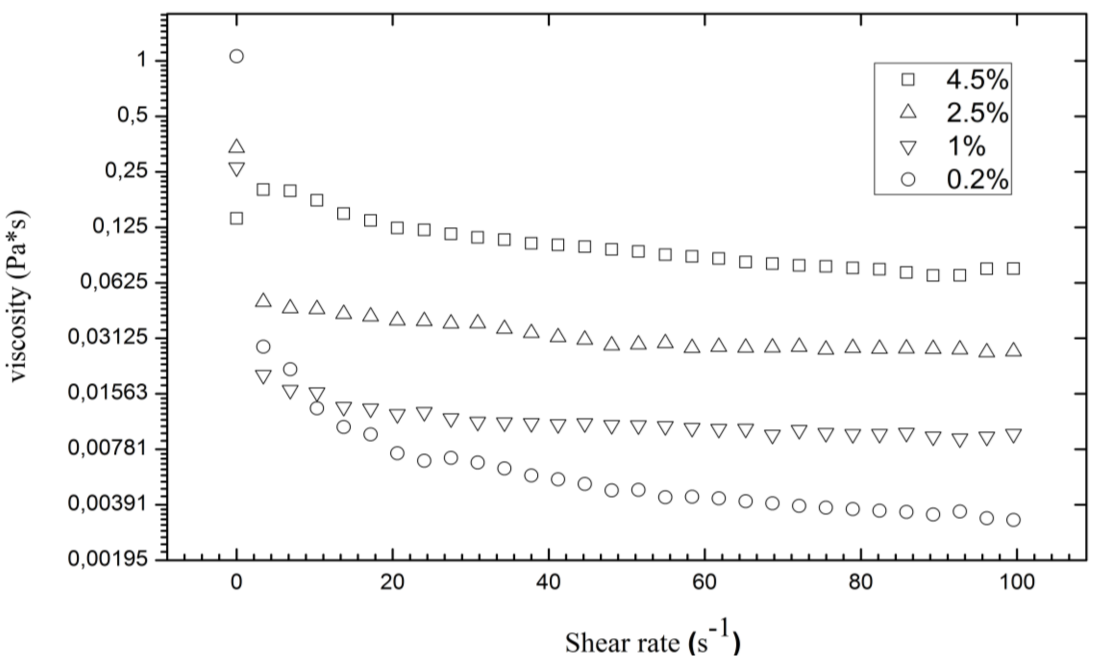

Figure 2. Effect of the shear rate on viscosity of fluids with different EPS concentrations at 80°C

Figure 3 shows that the viscosity of the fluid does not vary with time at a constant shear rate, this effect can be desirable during cutting operations, in order to assure the fluid remain in the contact zone, minimizing the amount of friction and tool wear in the process (Rizvi, 2009)

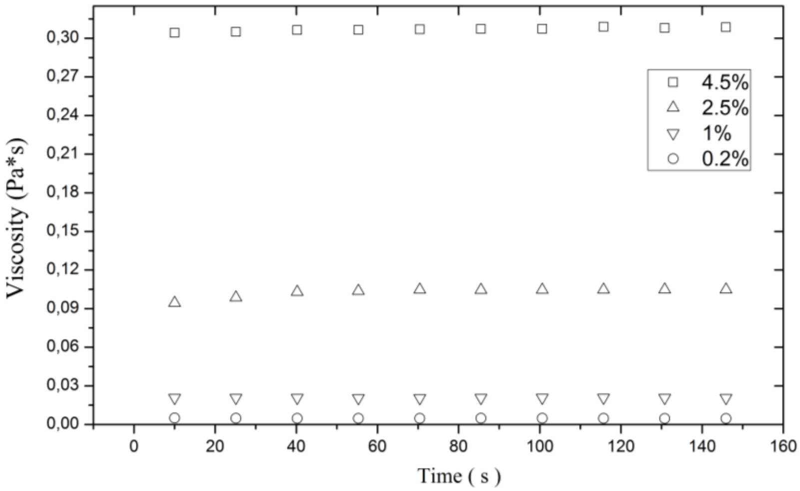

Figure 3. Variations of viscosity of fluids with different EPS concentrations at a constant shear rate of 52 s^{-1}.

3.2 Tribological performance

A solution with 0.2% EPS was selected for tribological tests due to its high stability when subjected to temperature and shear rate changes, besides a reduction in the necessary quantity of EPS for having a lubricant effect.

Figure 4 shows the wear pattern of the drills when the number of holes increases. Column **A** corresponds to wear pattern after a drilling test performed with the conventional cutting fluid, the next column (**B)** It is the result of using 0.2% EPS lubrication, and finally de column **C** presents the drill wear pattern that results of lubricating with water. The rows represent the number of drilled holes, the first row corresponds to 20 holes, the second one is for 40 holes and the third row corresponds to 60 holes. The corresponding figure with pure water 60 holes is not shown in this paper due to the tool failure that occurred around 45 holes.

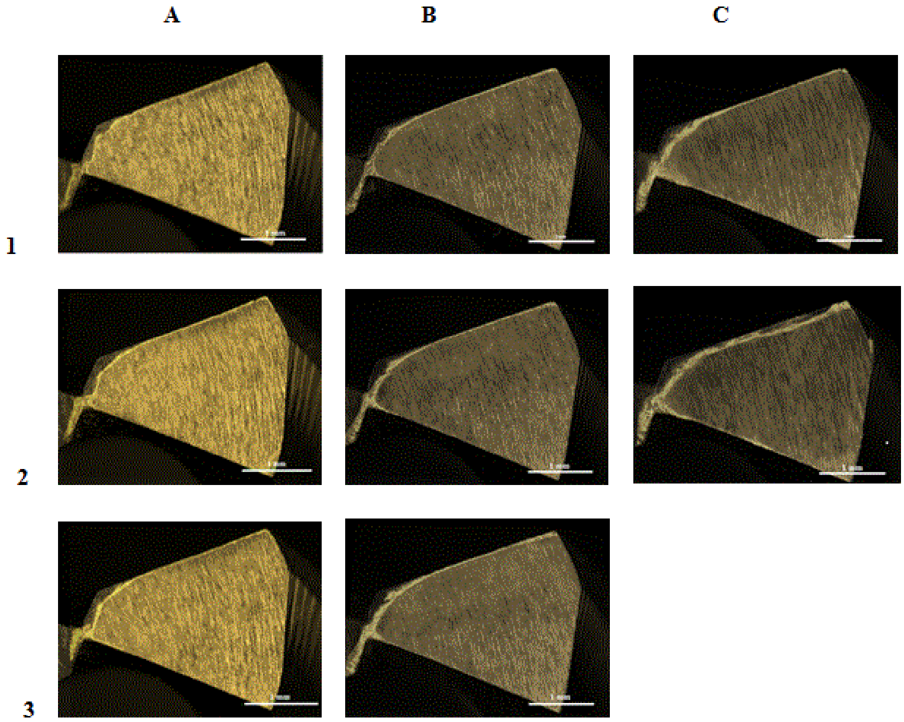

Figure 4. Wear pattern of the drills lubricated with commercial cutting fluid (A), 0.2% EPS biodegradable alternative (B), and pure water (C)

Figure 5 shows the average wear for both flank and tip of each drill. This wear was obtained from measurements performed in the images of Fig. 4. It is observed that the average wear using pure water has the highest rate of wear showing exponential growth; the biodegradable alternative analyzed in this paper 0.2% EPS shows that wear increases linearly with the number of holes, this behavior can be also observed for the conventional cutting fluid, but the latter has a lower slope than the other two alternatives. However it is clear that the conventional cutting fluid has additives that improve its properties, that is not the case of the biodegradable alternative, that has no any additive or modification.

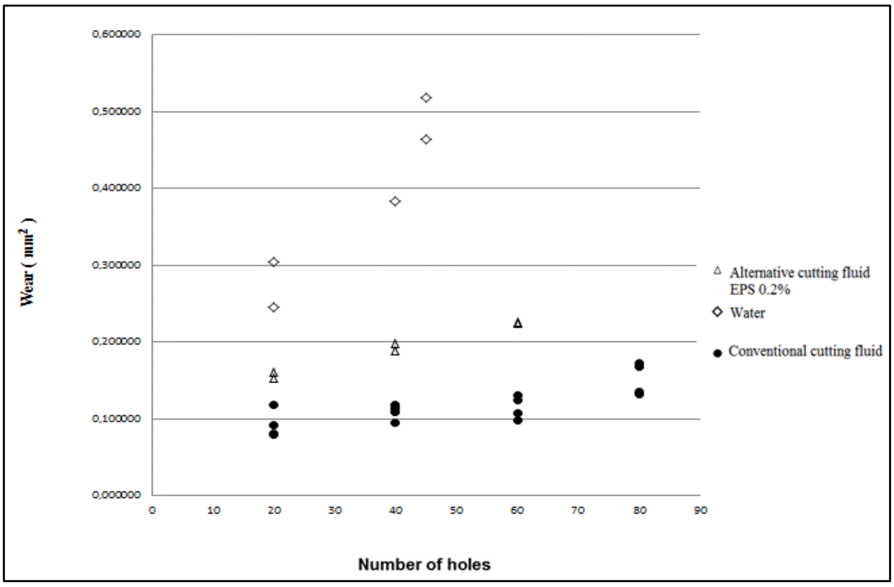

Figure 5. Wear of the drills as a function of the number of holes

The wear measurements of drills lubricated with the biodegradable cutting fluid showed a mechanism dominated by abrasive wear on the tip of the tool relative to the wear pattern observed with the commercial cutting fluid, this result can be related the lack of additives or an additional mechanism that protect the tool against extreme pressure (Stachowiak, 2014); however, wear of the flanks for both types of cutting fluids is very similar. On the other hand, wear observed in tools lubricated with water samples, shows a significant wear both the tip and flanks, which is due to a water cooling effect and not lubrication.

The protection of the tool obtained with the biodegradable cutting fluid can be related with the formation of a colloidal dispersion formed by long carbohydrate molecules with a very small change in internal energy, presenting a certain flexibility of movement and rotation (Xu et al., 2013), and allowing the matrix of polysaccharides behave as a distributed system or mobile network layers that protect the surface of the tool.

These results are promising, but are necessary further studies for to know the lubrication mechanism of polysaccharide.

4. CONCLUSIONS

A 0.2%EPS concentration was found adequate for using as a base of a cutting fluid.

The rheological results show that this polysaccharide tested in 25 and 80o C has a shear-thinning initial region which is prolonged by higher concentrations of EPS and higher temperatures.

Concentrations below 1% EPS not exhibit significant variation in the values of viscosity when subjected to temperature increases or shear rate; that result can be useful for applications in metal mechanic processes.

The tribological characterization shows that the polysaccharide has a good performance compared to a commercial cutting fluid, besides this, it confirms that pure water has cooling properties but not anti-wear properties.

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6. RESPONSIBILITY NOTICE