

COMPARATIVE ANALYSIS OF THE PERFORMANCE BETWEEN CONVENTIONAL CUTTING FLUIDS AND CHEMICALLY MODIFIED GLYCERIN FLUID IN THE TURNING OF 1020 STEELS

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Abstract. *In this work, the performance of different types of commercial cutting fluids (mineral, vegetable and semi-synthetic) was compared with two fluids made using glycerin chemically modified. The purpose of this work is to investigate the behavior of glycerin, after physical-chemical transformation, used as cutting fluid in turning operation. For this, the effect over the roughness of the 1020 steel was analyzed after turning operation using six different kind of fluid. These fluids were: water, commercial fluid 100% vegetable based, commercial fluid 100% mineral based, semi-synthetic, two fluids, non-commercial, made of glycerin chemically modified. Three different cut depths were used, $a_p = 0,5$ mm, $a_p = 1,0$ mm, $a_p = 1,5$ mm, machined length of $l = 50$ mm. The initial diameter of the steel bars was $\varnothing = 28$ mm and the feed rate used $f = 0,122$ [mm/rev]. The turning operations were performed on a turning CNC, Romi brand, model Centur 30D. The roughness tests (R_a and R_z) were performed with a cut-off = 0,80mm and length $l = 4,00$ mm. The equipment used was a Taylor Hobson rugosimeter, model Suntronic s128 and the tests were performed inside the machining laboratory of the Pontifical Catholic University of Minas Gerais - PUC-MG. Results showed that the fluid made of glycerin chemically modified presented similar performance when compared to the commercial fluids, in some conditions the results were even better. This work indicated the possibility of formulating a cutting fluid with complementary additives using modified glycerin. Subsequently, complementary studies shall be carried out with this new fluid to evaluate the physico-chemical behavior of this new product in order to guarantee the quality of the product.*

Keywords: turning operation, machining, cutting fluid, glycerin, 1020 steel

1. INTRODUCTION

The production of biodiesel is made by the transesterification process (vegetable oil, methanol and catalysts), generating biofuel, as well as glycerol, also known as crude glycerin. In the last decade, with the significant increase in biodiesel production, there has been also a dizzying increase in the generation of glycerin as co-product of this process. It was estimated that from 2008 to 2010, glycerol production around the world has practically doubled to 250,000 tons, making it unfeasible to absorb this product in the market due to oversupply. Currently, the most destination of this glycerin is to be discarded in rivers (Vera et. al., 2011) or be burned in blast furnace (Cordoba, 2011), generating relevant environmental impact (D'Avino et. al., 2015).

An alternative idea for the destination of this glycerin would be using it as vegetable base for the development of cutting fluids used in machining operations. The cutting fluids are liquid or gaseous elements and perform several specific functions, being the four principals: lubrication, refrigeration, anti-oxidation and removal of chips. Costs associated with the use of these inputs typically range from 7 to 17% of total costs production. It is a significant amount if compared, for example, to the 4% of tool costs (King et. al, 2001).

Cutting fluids role, a very important play in machining operations, what has already been widely studied and supported by the abundant bibliography available for the subject. They influence not only the quality of the produced pieces, but also the tool set (Machado et. al., 2009). The fluids help to lubricate bearings and prevent the deposition of tailings between the rolling parts of the machine, thus preventing its premature wear. Inside the factory of Fiat Chrysler Automobiles – FCA it could be determined that dry machining accelerates the machine's wear increasing maintenance time. Cutting fluids are also relevant for the surface integrity of the machined piece (Lawal et. al., 2014) and in some cases, can be the determinant in quality of a process.

Using glycerin as an input for the production of cutting fluid can be feasible both economically and technically. Marius et al. successfully used glycerol as Metal Fluid Working – MFW on a grinding machine process (Winter et. al,

2012). D'ávino et. al. (2015) searched environmental benefits of crude glycerin, co-product in biodiesel production, in metal working fluid formulation. Since crude glycerin is actually a reject being discarded as a waste, it could be a good input for producing MFW, with a high potential to serve as base, raw material, to produce an environmental friend MWF, having economic advantages, especially because of its low market value. In this way, the main objective of this work is to evaluate how a chemically modified glycerin, made by the *Grupo de Tecnologias Ambientais- GUTAM* of the *Universidade Federal de Minas Gerais - UFMG* behaves during a machining operation. Based on the preliminary results of this study, further works will be done with the main goal to use the crude glycerin to develop a new MWF in the near future. The procedures adopted to make this evaluation are described below.

2. MATERIALS AND METHODS

2.1 MATERIALS AND EQUIPMENTS

For the accomplishment of this work, the following materials were used:

- 1) Six different cutting fluids: mineral water (I), commercial fluid, 100% vegetable based (II), 100% mineral based (III), semisynthetic (IV), synthesized from glycerin, "A" (V) and "B" (VI). The difference between the fluids V and VI are because of the chemical process used to make them.
- 2) Six 1020 steel bars with total length of $l=185\text{mm}$, initial diameter $\phi = 28,00\text{mm}$.
- 3) Six inserts Kyocera, M type, TNMG160404MS.

The operations were performed on a CNC turning, Romi brand, model Centur 30D. The concentration of the emulsifiable fluids (II, III and IV), as well as of the bases synthesized from the glycerol (V and VI), were adjusted in 10% and measured using a Atago bench refractometer, serial number 80017. R_a roughness criteria were measured using a digital rugosimeter, Taylor Hobson brand, model Suntronic s128.

2.2. EXPERIMENTAL METHODS

As methodology for this work the turning of 1020 Steel was performed with cutting speed, $v_c = 339 \text{ m/min}$. The feed rate was determined at $f = 0,122 \text{ mm/rev}$. A pass with length $l = 50\text{mm}$ was performed, varying the depth of the cut defined in: $a_{p1}=1,5\text{mm}$, $a_{p2}=1,0\text{mm}$ and $a_{p3}=0,5\text{mm}$, according to the scheme of Fig. 1.

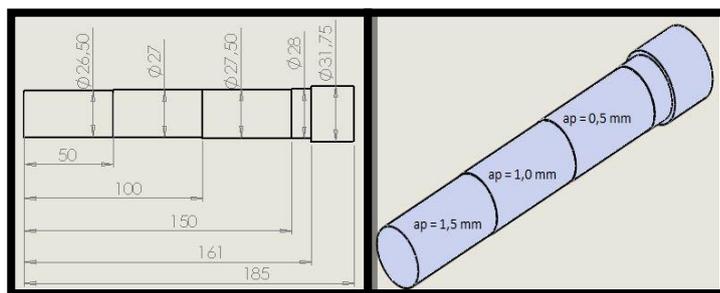


Figure 1. Final diameter of the 1020 Steel bars (left) and depths of cut (right.)

Each one of the six bars were machined using one of the fluids (I to VI). Emulsifiable fluids (II, III and IV) were adjusted at a concentration of 10% and the synthesized bases (V and VI) were mixed in water in a ratio of 10% of base with 90% of fresh water. After the turning operations, the roughness R_a were measured with a digital rugosimeter and using the following parameters: $cut-off=0,80 \text{ mm}$ and $l=4,00 \text{ mm}$. For each distinct depth of cut (a_p), three roughness measurements were taken separated by an angle of 120° , in order to avoid false results. The mean of the three values for each a_p was calculated. The fluid was applied using gravity flow and to ensure constant flow rate, the same quantity was putted inside the bottle. Figure 2 shows the way that fluid was applied. Tab. 1 shows main operation parameters.



Figure 2. Schematic for applying cutting fluid over the tool edge

Table 1. Turning operation parameters

Cutting Speed Vc [m/min]	Feed rate f [mm/min]	Diameter Ø [mm]
339	0,12	28

3. RESULTS AND ANALISYS

Tab. 2 to 7 shows the roughness (R_a and R_z) obtained from the tests.

TABLE 2 - TURNING - 1020 STEEL - H2O

	Ap (0,5 mm)		Ap (1,0 mm)		Ap (1,5 mm)	
	Ra [µm]	Rz [µm]	Ra [µm]	Rz [µm]	Ra [µm]	Rz [µm]
H2O (I)	1,32	6,77	1,29	7,01	1,52	7,65
	1,19	6,41	1,44	7,11	1,21	6,39
	1,45	7,39	1,41	6,93	1,31	7,10
AVERAGE	1,32	6,86	1,38	7,02	1,35	7,05

TABLE 3 - TURNING - 1020 STEEL - 100% MINERAL

	Ap (0,5 mm)		Ap (1,0 mm)		Ap (1,5 mm)	
	Ra [µm]	Rz [µm]	Ra [µm]	Rz [µm]	Ra [µm]	Rz [µm]
100% MINERAL (III)	1,43	7,71	1,74	9,06	1,57	7,88
	1,29	6,71	1,52	8,82	1,94	9,28
	1,81	8,91	1,55	7,70	2,44	10,60
AVERAGE	1,51	7,78	1,60	8,53	1,98	9,25

TABLE 4 - TURNING - 1020 STEEL - (SEMI-SYNTHETIC)

	Ap (0,5 mm)		Ap (1,0 mm)		Ap (1,5 mm)	
	Ra [µm]	Rz [µm]	Ra [µm]	Rz [µm]	Ra [µm]	Rz [µm]
SEMI- SYNTHETIC (IV)	1,35	7,13	1,43	7,22	1,57	7,23
	1,43	7,42	1,82	8,65	1,96	9,72
	1,48	8,01	1,51	8,08	1,4	7,99
AVERAGE	1,42	7,52	1,59	7,98	1,64	8,31

TABLE 5 - TURNING - 1020 STEEL - 100% VEGETAL

	Ap (0,5 mm)		Ap (1,0 mm)		Ap (1,5 mm)	
	Ra [µm]	Rz [µm]	Ra [µm]	Rz [µm]	Ra [µm]	Rz [µm]
100% VEGETAL (II)	1,28	6,91	1,71	8,54	1,46	7,44
	1,27	7,2	1,52	8,21	1,62	8,3
	1,37	7,53	1,6	8,21	2,52	10,7
AVERAGE	1,31	7,21	1,61	8,32	1,87	8,81

TABLE 6 - TURNING - 1020 STEEL - GLICERIN "A"

	Ap (0,5 mm)		Ap (1,0 mm)		Ap (1,5 mm)	
	Ra [µm]	Rz [µm]	Ra [µm]	Rz [µm]	Ra [µm]	Rz [µm]
GLICERIN "A" (V)	1,18	6,54	1,69	8,84	1,37	7
	1,32	6,92	1,33	6,99	1,49	7,18
	1,27	7	1,17	6,65	2,01	9,07
AVERAGE	1,26	6,82	1,40	7,49	1,62	7,75

TABLE 7 - TURNING - 1020 STEEL - GICERIN "B"

	Ap (0,5 mm)		Ap (1,0 mm)		Ap (1,5 mm)	
	Ra [µm]	Rz [µm]	Ra [µm]	Rz [µm]	Ra [µm]	Rz [µm]
GLICERIN "B" (VI)	1,44	7,14	2,05	10,2	1,7	8,54
	1,58	8,06	1,55	8,18	1,86	9,16
	1,44	7,32	1,53	7,79	2,34	11,3
AVERAGE	1,49	7,51	1,71	8,72	1,97	9,67

In relation to roughness R_a , Fig.3 shows the results obtained from Tab. 2 to 7 for the roughness values in 1020 steel turning.

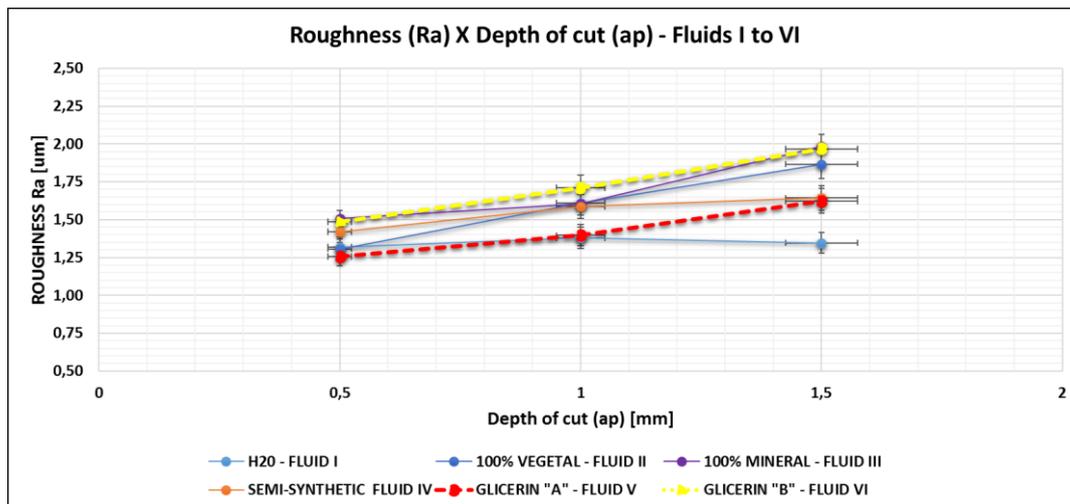


Figure 3. Relation between Roughness (R_a) x Depth of cut (a_p)

The results obtained, in ascending order, of R_a values, for the fluids from I to VI according to each depth of cut:

- a) **Depth of cut ($a_p=0,5\text{mm}$):** Glycerin “A” ($R_a=1,26\mu\text{m}$); 100% Vegetal ($R_a=1,31\mu\text{m}$); H₂O ($R_a=1,31\mu\text{m}$); semi-synthetic($R_a=1,42\mu\text{m}$); Glycerin “B” ($R_a=1,49\mu\text{m}$); 100% Mineral ($R_a=1,51\mu\text{m}$).
- b) **Depth of cut ($a_p=1,0\text{mm}$):** H₂O ($R_a=1,38\mu\text{m}$); Glycerin “A” ($R_a=1,40\mu\text{m}$); semi-synthetic ($R_a=1,59\mu\text{m}$); 100% Mineral ($R_a=1,60\mu\text{m}$); 100% Vegetal ($R_a=1,61\mu\text{m}$); Glycerin “B” ($R_a=1,71\mu\text{m}$).
- c) **Depth of cut ($a_p=1,5\text{mm}$):** H₂O ($R_a=1,35\mu\text{m}$); Glycerin “A” ($R_a=1,62\mu\text{m}$); semisynthetic ($R_a=1,64\mu\text{m}$); 100% Vegetal ($R_a=1,87\mu\text{m}$); Glycerin “B” ($R_a=1,97\mu\text{m}$), 100% Mineral ($R_a=1,98\mu\text{m}$)

Results obtained for the fluid based on Glycerin "A" (V fluid) presented good roughness values of R_a in relation to the other fluids, having similar performance to the 100% vegetable based fluid. The V fluid had the lowest values of R_a with cut depths of 0.5 and 1.0 mm. It is noteworthy that H₂O presented an anomalous behavior for an $a_p = 1.5$ mm, most probably it results from errors inherent to the process, since it was the only one to present a decrease in the value of R_a with increasing depth, which contrasts as what theory says. If it were not for this deviation, most likely Glycerin "A" would have the best results in all trials.

On the other hand, the glycerin based fluid "B" presented the poorest performance compared to the other fluids in all the circumstances analyzed. It is noteworthy that this fluid becomes biphasic almost instantaneously after shaking, which can make a negative effect over the tool chip interface, since the effects of lubricity may not have acted properly.

In relation to R_z roughness, Fig. 4 shows the results obtained from Tab. 2 to 7 for the roughness values in the 1020 steel turning.

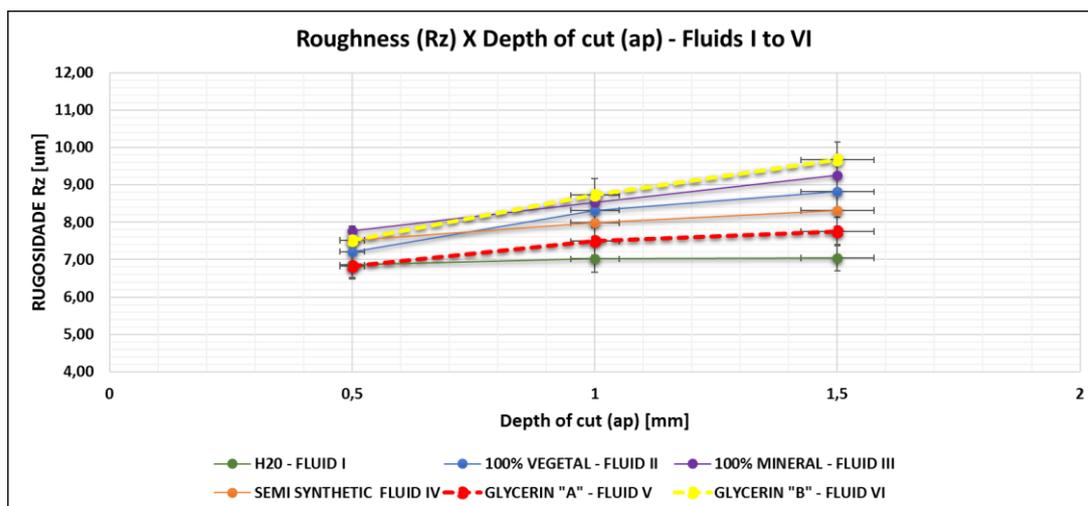


Figure 4. Relation between Roughness (R_z) x depth of cut (a_p)

The results obtained, in ascending order, of R_z values, for the fluids from I to VI, according to each depth of cut:

- a) **Depth of cut ($a_p=0,5\text{mm}$):** Glycerin “A” ($R_z=6,82\text{ um}$); H₂O ($R_z=6,86\text{ um}$); 100% Vegetal ($R_z=7,21\text{ um}$); Glycerin “B” ($R_z=7,51\text{ um}$); Semisynthetic ($R_z=7,52\text{ um}$); 100% Mineral ($R_z=7,78\text{ um}$).
- b) **Depth of cut ($a_p=1,0\text{mm}$):** H₂O ($R_z=7,02\text{ um}$); Glycerin “A” ($R_z=7,49\text{ um}$); Semisynthetic ($R_z=7,98\text{ um}$); 100% Vegetal ($R_z=8,32\text{ um}$); 100% Mineral ($R_z=8,53\text{ um}$); Glycerin “B” ($R_z=8,72\text{ um}$);
- c) **Depth of cut ($a_p=1,5\text{mm}$):** H₂O ($R_z=7,05\text{ um}$); Glycerin “A” ($R_z=7,75\text{ um}$); Semisynthetic ($R_z=8,31\text{ um}$); 100% Vegetal ($R_z=8,81\text{ um}$); 100% Mineral ($R_z=9,25\text{ um}$); Glycerin “B” ($R_z=9,67\text{ um}$);

Values presented in R_z basically had the same behavior as in R_a values. Once again glycerin “A” (fluid V) had good results for all the circumstances and the Glycerin “B” had the poorest results. It was expected that water, as it did not have relevant lubricity effects in relation to the other fluids, presented the highest values of roughness, which in fact did not occur. In machining processes with relatively high cutting speed the thermal effect can be emphasized especially in the regions close to the cutting edge because of the considerable temperature elevation. An increase in temperature in a material has the effect of increasing its elastic capacity, causing the chip to become less brittle and having a greater grip to the part and to the tool. This may compromise the surface finish, causing roughness to increase. Most probably, the

water, having higher thermal conductivity (k) coefficient, compared to oils, acted in the cutting process as refrigerants predominantly, guaranteeing lower temperature, a factor that contributes to better roughness results. However, obviously, water does not play other vital functions to a cutting fluid, especially protection against oxidation, and that is the main motive why it can't be used as cutting fluid in general.

4. CONCLUSIONS

Based on the roughness results obtained from the machining tests there is an evidence, albeit preliminarily, that cutting fluids developed from inputs such as glycerin have potential to be used in general machining processes. The bars machined with V fluid, glycerin "A", presented interesting roughness values, having even higher performance than other commercial fluids already widely used by market. The fluid VI, glycerin "B", in turn, did not obtained good results, presenting the worst values of roughness. It becomes biphasic almost instantaneously after shaking, which could have made a negative effect over the tool chip interface, since the effects of lubricity may not have acted properly.

From the results of this work, the *Grupo de Tecnologias Ambientais – GRUTAM* of the *Departamento de Química da UFMG*, in partnership with other institutions and related companies, will continue the development of a cutting fluid using chemically modified glycerin. The idea in a first step is to develop a useful base for a cutting fluid from pure glycerin. After exhaustive mechanical e chemical works in MWF made of glycerin the next step will be to pass to the use of the so-called crude glycerin, which can be obtained as a reject from the biodiesel production process, and then to elaborate a new cutting fluid. Further testing and analysis, both mechanical and chemical, of this new product will be carried out in a timely manner to guarantee the quality of the product.

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