ISSN 2176-5480

22nd International Congress of Mechanical Engineering
November 3-7, 2013, Ribeirão Preto, SP, Brazil

IMPORTANCE OF MICROBIOLOGICAL CONTROL IN THE MANAGEMENT OF CUTTING FLUID

Milena Chanes de Souza
Instituto Tecnológico de Aeronáutica – ITA/CCM, Marechal Eduardo Gomes, 50 - Vila das Acácias – São José dos Campos – SP, Brasil
milena@ita.br

Samir Yuji Lutif
Universidade Paulista UNIP, Rod. Presidente Dutra, km 157,5 pista Sul, São José dos Campos - SP, Brasil
samir@ita.br

Janaina Fracaro de Souza Gonçalves
Universidade Tecnológica Federal do Paraná UTFPR, Av. Alberto Carazzai, 1640, Cornélio Procópio – PR, Brasil
janainaf@utfpr.edu.br

Sônia Khouri
Universidade do Vale do Paraíba UNIVAP, Av. Shishima Hifumi, 2911, São José dos Campos – SP, Brasil
soniak@univap.br

Jefferson de Oliveira Gomes
Instituto Tecnológico de Aeronáutica – ITA/CCM, Marechal Eduardo Gomes, 50 - Vila das Acácias – São José dos Campos – SP, Brasil
gomes@ita.br

Anderson Vicente Borille
Instituto Tecnológico de Aeronáutica – ITA/CCM, Marechal Eduardo Gomes, 50 - Vila das Acácias – São José dos Campos – SP, Brasil
borille@ita.br

Abstract. *Cutting fluids used in the metalworking industries have as their main purpose increasing useful life of the cutting tool through the minimization of friction at the tool-chip interface, controlling the temperature during the process and removing particulate material, which is an ideal scenario for proliferation of micro-organisms. The management of metalworking fluids is being increasingly deployed by medium and large enterprises in order to minimize environmental costs due to disposal problems. This study aims to assess the microbiological control of samples of emulsifiable cutting fluid of vegetable, synthetic and mineral bases. The emulsions were sampled at the beginning and end of machining tests on 7050 T7451 aluminum alloy. Microbiological control of samples was studied by quantitative and qualitative methods, using differential and selective culture media for isolation of bacteria and fungi of interest. There was incidence of fungi in samples of vegetable and synthetic bases cutting fluids and better machining performance in the vegetable base emulsion. The presence of these micro-organisms may favor the reduction of the service life of the cutting fluid and premature disposal of the emulsion; provide corrosive environment on machine tools and workpiece, increase formation of sludge and occurrence of diseases among employees, affecting lungs, ears, eyes and skin.*

Keywords: Cutting fluid, microbiological degradation, management of lubricating oils, Environmental Costs.

1. INTRODUCTION

Lubricants are widely used in industry in various functions, such as friction, wear, temperature and corrosion control, insulation, power transmission, shock mitigation, removing contaminants and seal formation. In the machining process they are applied on the interface between cutting tool and workpiece material, in order to facilitate the cutting operation, as well as the chip formation (Sokovic *et al.*, 2001; Schroeter *et al.*, 2002; Stoeterau, 2004; Mang and Dresel, 2007).

Cutting fluids consist of oily bases, and these bases can be of vegetable, synthetic or mineral origin. The addition of additives can represent up to 30% of the composition of an emulsion lubricant oil. The most commonly used additives are: antioxidants; viscosity modifiers; pour-point depressants (PPD); detergents and dispersants; antifoam agents; emulsifiers; dyes; antiwear (AW) and extreme pressure (EP) additives; friction modifiers (FM); and corrosion inhibitors, in order to improve product performance (Mang and Dresel, 2007).

The mineral-based emulsions are widely used in the metalworking industry, due to their good lubricating ability, high thermal conductivity and high stability, ensuring long service life. However they can be aggressive to health and

ISSN 2176-5480

the environment. Vegetable-based cutting fluids are considered more sustainable products, but more susceptible to degradation, behaving as culture medium and easily attacked by microorganisms due to its chemical composition. This may change the quality of the product, making it improper for use and reducing its service life. The microbiological contamination of cutting fluids can also bring occupational risks to their handlers representing major damage to health, loss of productivity and economic damage. Therefore, microbiological management and control become essential in machining processes (Dilger *et al.*, 2005; Mang and Dresel, 2007; Cardoso *et al.*, 2011; Cardoso, 2012; Gonçalves, 2013).

This case study aims to assess the microbiological control of samples of emulsifiable cutting fluids of vegetable, synthetic and mineral bases used on milling tests of 7050 T7451 aluminum alloy, material which is employed in the aviation industry, with varying cutting parameters. By analyzing cutting fluids at the beginning and end of machining tests, potential impacts of degraded fluid on productivity and environmental health were mapped. It was also possible to analyze the cooling and lubrication functions of the emulsifiable cutting fluids when applied to different cutting conditions.

2. MATERIALS AND METHODS

The machining tests were performed in the laboratory of the Competence Center in Manufacturing – CCM at Aeronautics Institute of Technology – ITA, and microbiological studies were done in partnership with the University of Vale do Paraíba – UNIVAP, using the following methodology, Figure 1.

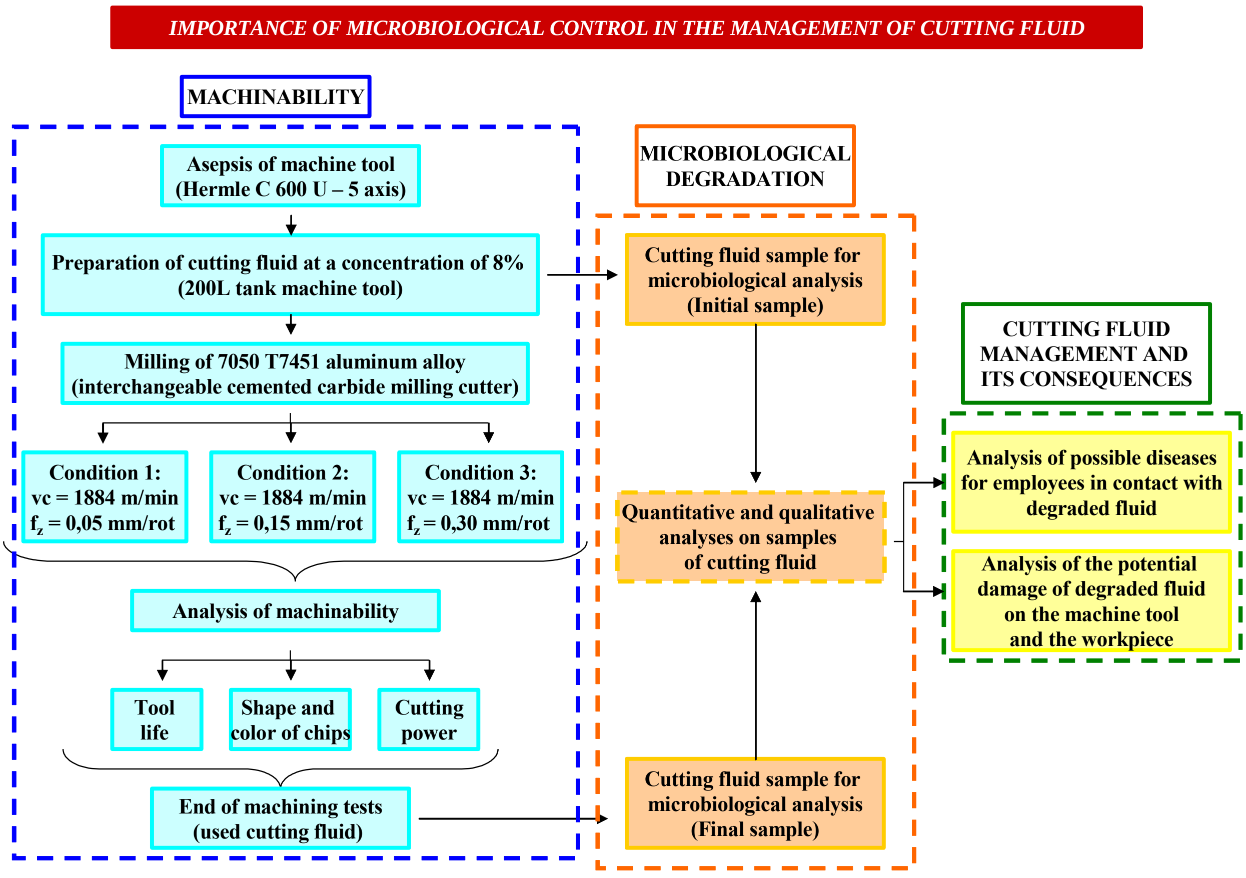


Figure 1. Methodology for testing machinability and microbiological degradation.

2.1. Machinability experiments

A Hermle C 600 U – 5-axis machining center was used for the milling tests and performance evaluation of commercial cutting fluids of three distinct origins: vegetable, synthetic and mineral bases at a concentration of 8%, Figure 2. The milling tests were performed in blocks of 7050 T7451 aluminum alloy (6.2 Zn – 2.3 Cu – 2.2 Mg – 0.12 Zr) with standard dimensions (300x103x143) mm, and interchangeable carbide inserts (square end, 50 mm in diameter and 4 teeth), from ISCAR manufacturer, code LNAR 1106 PN-N-P IC07. To monitor the wear of the cutting tool during the milling experiments, an optical stereoscope Wild M3C was used, Figure 3. During trials chips and cutting power data were collected.

ISSN 2176-5480

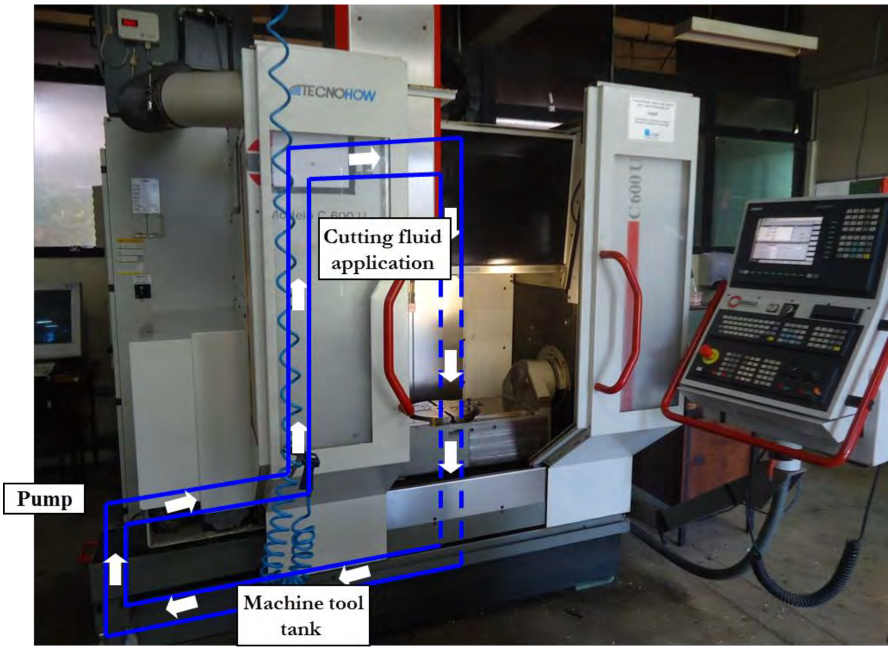


Figure 2. Diagram of cutting fluid flow in the Hermle C 600 U – 5-axis machine tool.

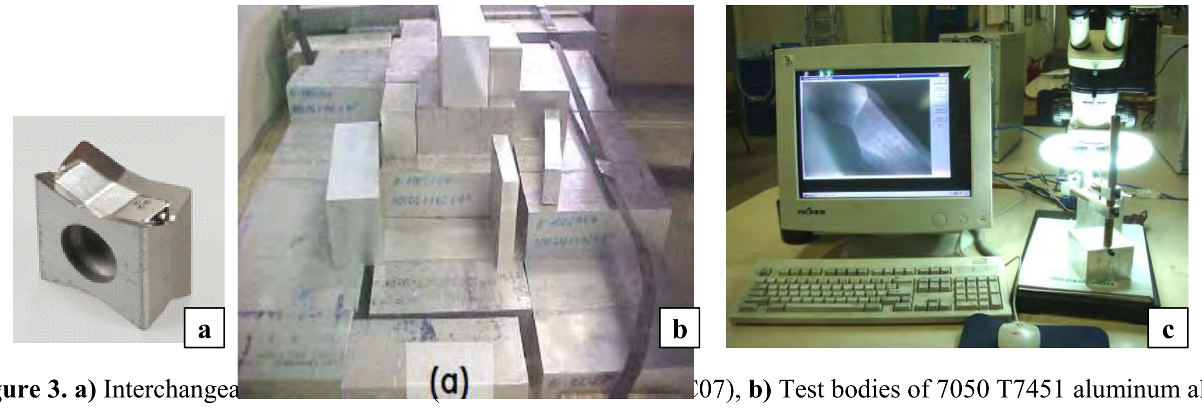


Figure 3. a) Interchangea 07), **b)** Test bodies of 7050 T7451 aluminum alloy and **c)** Optical stereoscope Wild M3C.

The milling tests were performed in three conditions of cutting parameters, Table 1.

Table 1. Cutting parameters.

Cutting parameters	Cutting speed (m/min)	Depth of cut (mm)	Feed rate (mm/rot)
Condition 1	1884	2.88	0.05
Condition 2	1884	2.88	0.15
Condition 3	1884	2.88	0.30

The end of tool life was determined by the following criteria:

- Maximum flank wear of 0.2 mm ($VB_{máx}$);
- Formation of chipping at the cutting edge;
- Occurrence of intense noise.

2.2. Microbiological degradation of emulsion cutting fluids

Before the preparation of each cutting fluid, asepsis of the machine tool was performed with concentrated bactericide and fungicide to ensure no contamination of emulsions and not influence the microbiological analyses of cutting fluids, using the methodology described by Lutif *et al.* (2011). The microbiological control of the emulsions was done with samples collected at the beginning and end of milling tests. Analyses for quantification and qualification of fungi and bacteria followed the methodology below, Figure 4.

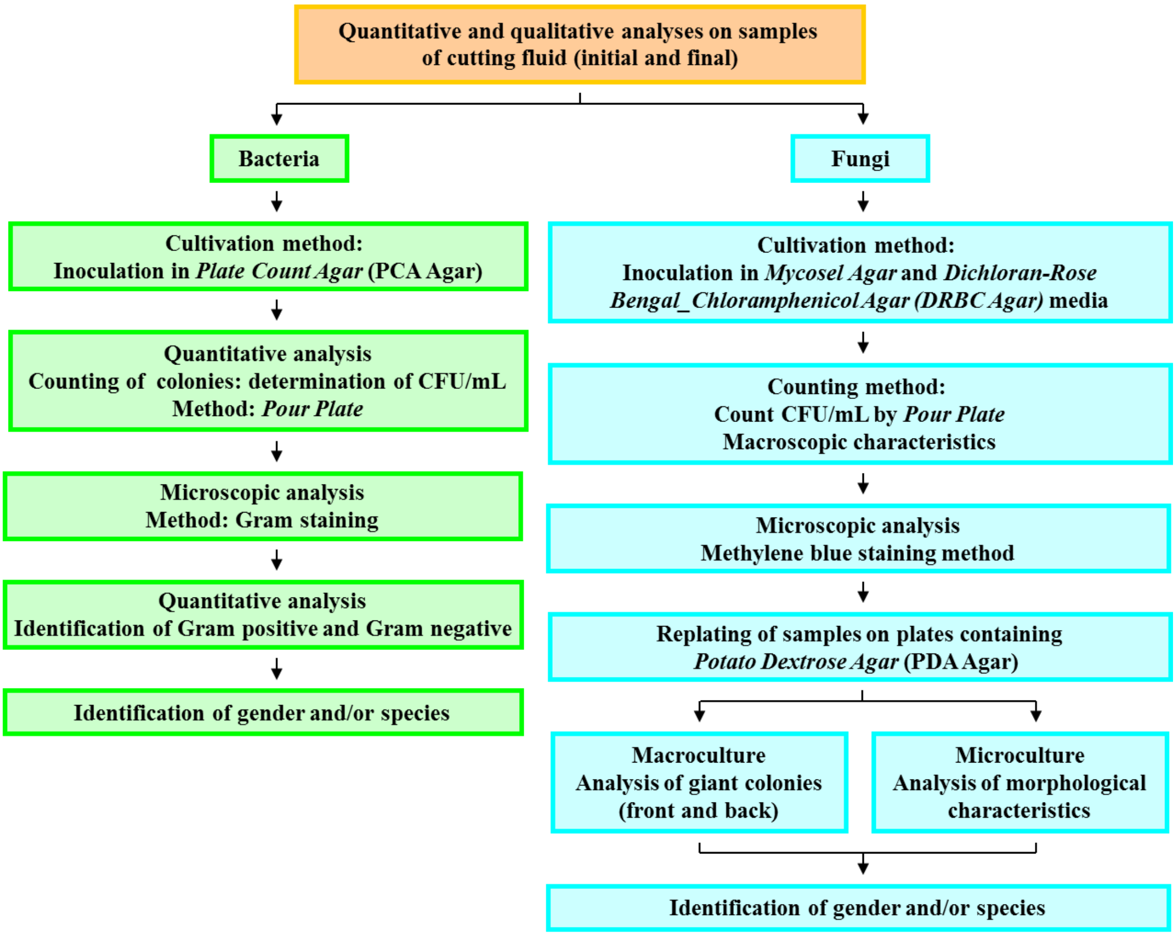


Figure 4. Microbiological methods for emulsion cutting fluids.

3. RESULTS AND DISCUSSIONS

3.1. Machinability experiments for 7050 T7451 aluminum alloy

In order to better compare the machining performance, the cutting conditions were assessed separately, making it necessary to create three graphs of lubrication and cooling performance of the cutting fluids of vegetable, synthetic and mineral bases, Figure 5.

So as to evaluate the lubrication and cooling performance of cutting fluids, the tests were conducted with constant cutting speeds and depths of cut (vc = 1884 m/min e a_p = 2.88 mm). For the condition 1 with the lowest feed rate, the contact time of the cutting tool with the workpiece is greater, especially to assess the cooling performance of cutting fluids. In condition 3 with highest feed rate, the contact time of the cutting tool with the workpiece is lower and the rate of material removal is greater, and may mainly evaluate the lubrication performance, according to Table 1.

Figure 6 contains three comparative graphs of cutting power at the beginning of the trial and the last milling pass. In Figure 7, the images of the chips formed at the beginning of the test are shown.

ISSN 2176-5480
Proceedings of the 22nd International Congress of Mechanical Engineering – COBEM 2013
November 3-7, 2013, Ribeirão Preto, SP, Brazil

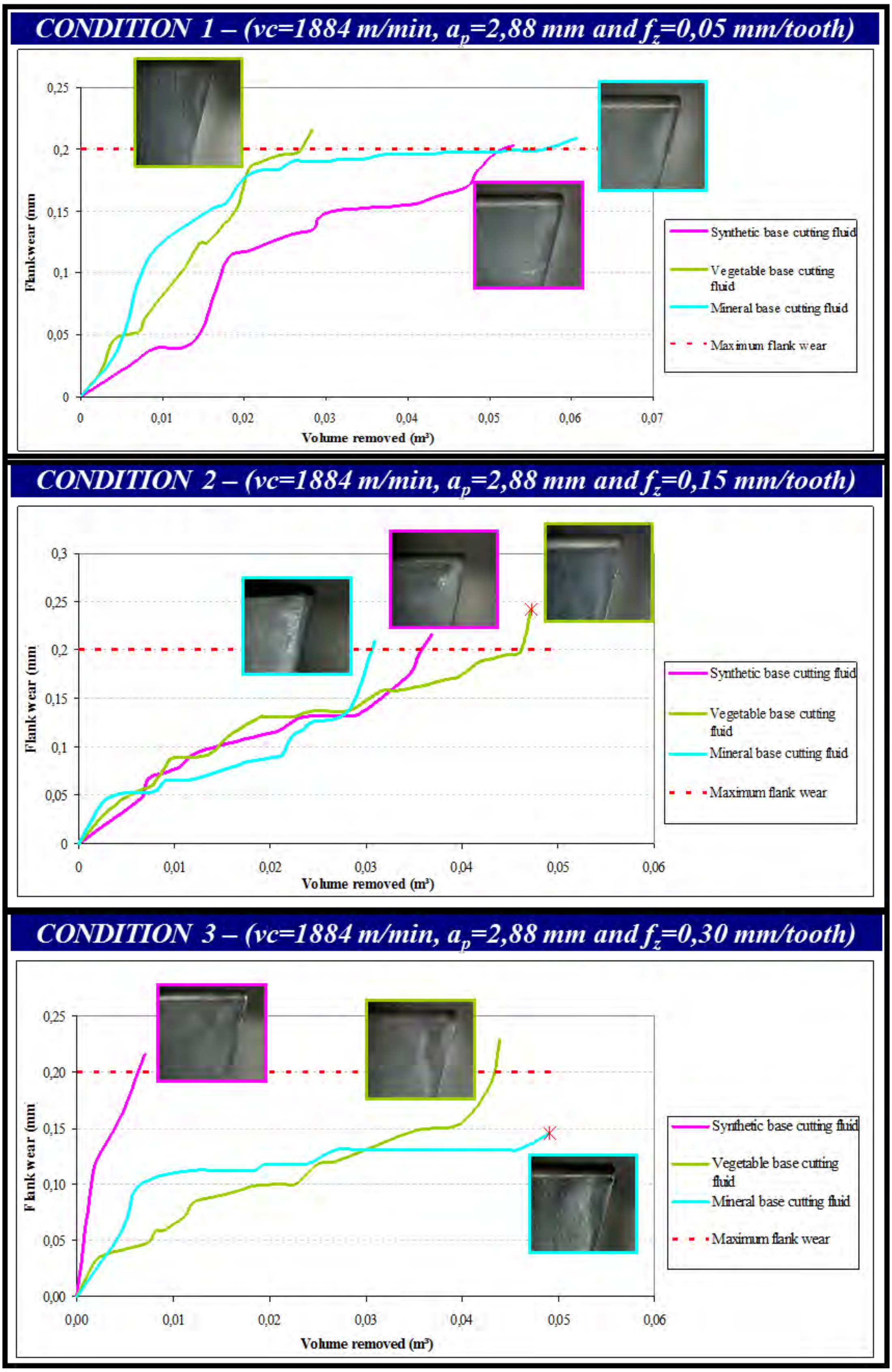


Figure 5. Cooling and lubrication performance of the vegetable-, synthetic- and mineral-based cutting fluids in the process of milling of 7050 T7451 aluminum alloy, using cutting conditions 1, 2 and 3.

ISSN 2176-5480

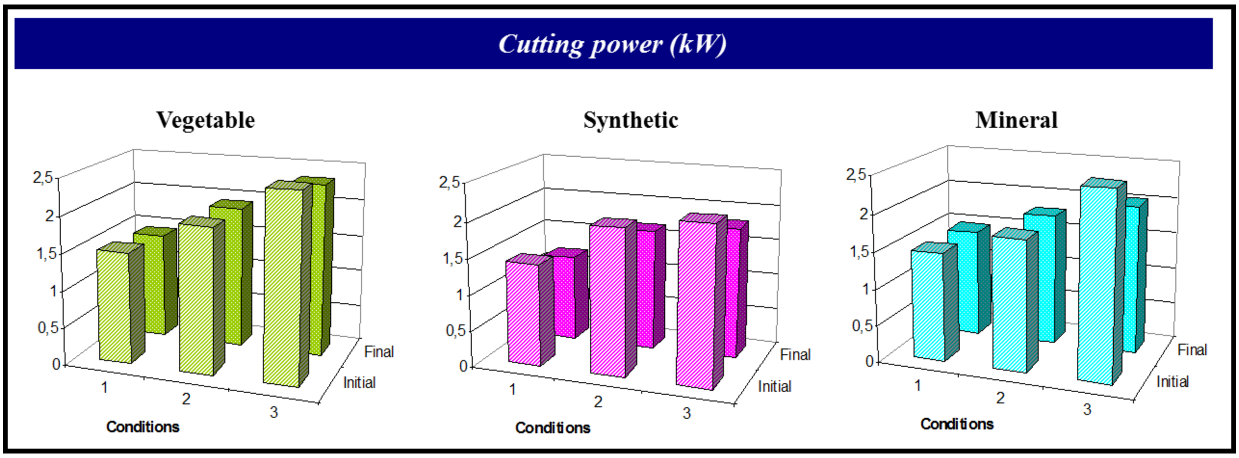


Figure 6. Cutting power (kW) obtained at the beginning and end of each test.

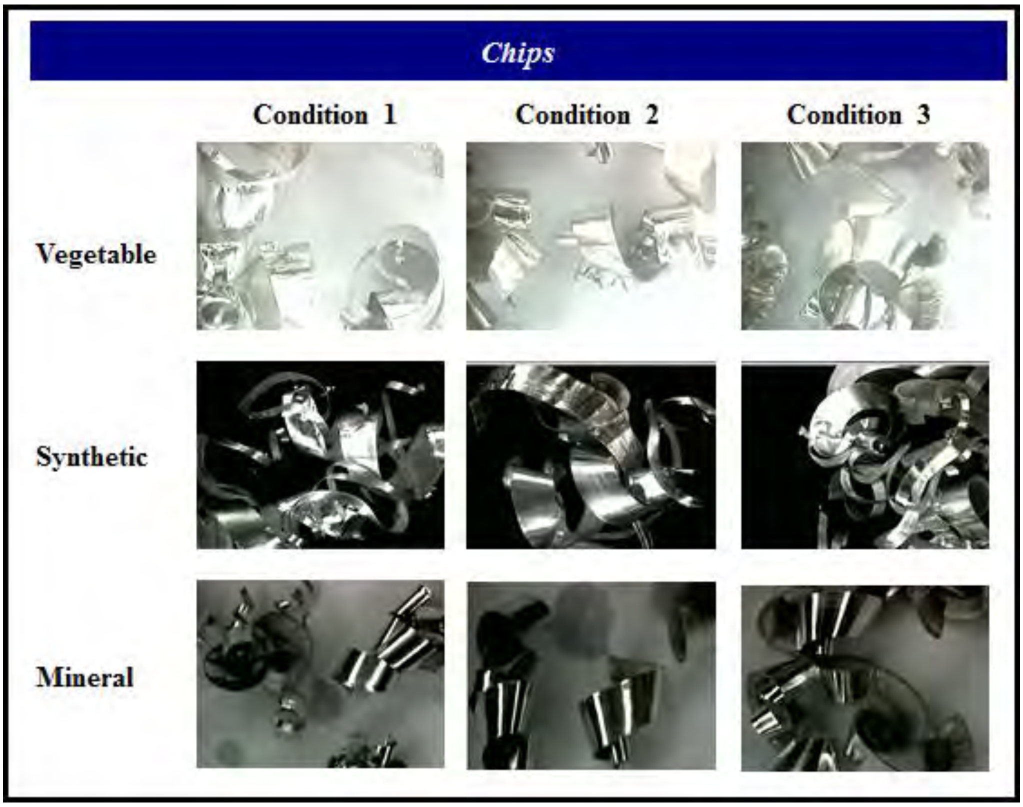


Figure 7. Images of the chips formed during milling.

In condition 1, it can be seen that the contact time of the cutting tool with the workpiece is larger, causing increased heat at the interface tool-workpiece, which is due to the small feed rate ($f_z = 0.05$ mm/tooth). With the increased heat, the need for the cooling function the emulsion is raised. Its efficiency can prevent premature wear of the cutting tool. It was noted that the cooling performance of the vegetable cutting fluid was lower compared to the other two bases (mineral and synthetic). At the beginning of the tests the synthetic base fluid performed better, however near the end of tool life (0.052 mm flank wear), the mineral base fluid stood out.

In trials of condition 2, all emulsions showed similar performance up to 0.150 mm flank wear, after that the vegetable-based emulsion excelled with lubrication and cooling performance by removing about 0.046 mm^3.

The lubrication function can be observed mainly in condition 3. The synthetic base fluid reached the end of tool life by flank wear criterion with smaller removed volume, showing a deficiency in lubricity. The mineral and vegetable based fluids showed similarities until 0.030 m^3 of material removed, when the cutting tool used in the experiment with mineral emulsion chipped, attesting end of tool life. The vegetable-based emulsion obtained the best performance, about 0.043 m^3 of material removed with flank wear of 0.2 mm.

In general, the mineral-based cutting fluid performed better for cutting condition which requires more cooling and vegetable-based showed superior performance when the need is lubrication. It was also noted that with the increase of feed rate in the conditions studied, an increase in the coefficient of friction between tool and chip was generated, and consequently cutting strength and power, requiring a greater lubricity effect of the cutting fluid.

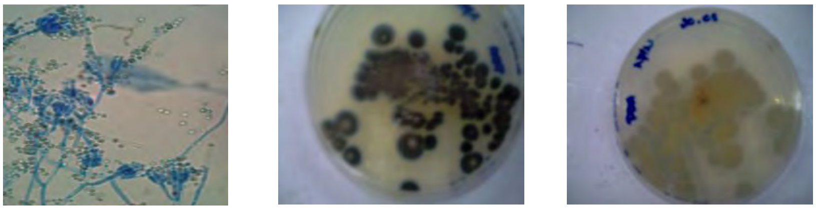
With the images of the chips formed (according to ISO 3658), it can be noted that conical spiral-shaped chip was predominant for the cutting conditions 1, 2 and 3 for the vegetable- and mineral-based cutting fluids. As for the synthetic-based, the chips shape was short conical helical, both considered "good" by Schroeter *et al*. (2002).

3.2. Microbiological degradation

Table 2 contains the results obtained in the analyses of microbiological control using selective culture media. Figure 8 shows macro and microscopic images of fungal colony of *Penicillium sp.* found in the final samples of synthetic- and vegetable-based cutting fluids.

Table 2. Quantitative and qualitative results of the microbiological analyses.

Cutting fluids bases	Days on the machine tool	Sample	Microorganisms identified	Quantitative Results CFU/mL	Qualitative Results
Vegetable	51	Initial	Fungus	0	---
			Bacterium	0	---
		Final	Fungus	20	*Penicillium sp.*
			Bacterium	0	---
Synthetic	108	Initial	Fungus	0	---
			Bacterium	0	---
		Final	Fungus	30	*Penicillium sp.*
			Bacterium	0	---
Mineral	21	Initial	Fungus	0	---
			Bacterium	0	---
		Final	Fungus	0	---
			Bacterium	0	---



a b c

Figura 8. Fungal colony of *Penicillium sp.* **a)** Microscopic figure, **b)** Macroscopic figure (front) and **c)** Macroscopic figure (back).

In the microbiological testing, it can be seen that the sample with shorter usage time in milling trials, the mineral-based fluid, showed no evidence of bacteria and fungi. This result is assigned to the efficacy of fungicides and biocides additives made by manufacturers during product development. The vegetable- and synthetic-based lubricants, that remained around 50 and 100 days respectively, presented Colony Forming Units (CFU) of the fungus *Penicillium sp.* The synthetic-based fluid remained active for a longer time and had 50% more CFU/mL of opportunistic fungi than the vegetable-based.

As stated by Lacaz *et al.* (2002), several species of fungi release mycotoxins that inhibit the growth of bacteria, substances which are used in medicine as active principles of antibiotics. Nevertheless, only a few fungi are able to produce secondary metabolites, at certain stages and under specific conditions of temperature. Having a more complete analysis of identification and quantification of mycotoxins would require a more detailed study using other techniques such as High Performance Liquid Chromatography (HPLC).

According to Mang and Dresel (2007) and Dilger *et al.* (2005), the vegetable-based cutting fluid has high rates of organic matter in his composition, favoring the development of microorganisms and consequently decreasing its service life. The degraded cutting fluid, with acid pH (less than 7), favors the oxidation of the machine tool and workpiece, a critical factor for the aviation industry.

3.3. Cutting fluid management and its consequences

The study was conducted in a machining center with 200 L cutting fluid tank, but the reality of a company is to manage larger volumes. Typically the degradation of lubricant solution is only detected when presenting odor or featuring acid pH, causing a visual oxidation effect of machine tool and workpiece. Once identified, the first step commonly taken by industries is to use high doses of fungicides and bactericides additives, measures that usually are sufficient to control microbiological growth, however can make them more resistant, what consequently generates a more aggressive environment, making employees susceptible to contamination by super-resistant microorganisms. That may cause infections and more complex medical treatment (Trabulci and Alterthum, 2005).

Since it is an expensive procedure, the contaminated cutting fluid exchange is the last option adopted by some companies, because the volume to be properly disposed of is large and presents high costs, as well as the acquisition of new emulsion oil. Being the last action taken, not to allocate properly the cutting fluids with super-resistant microorganisms can boost environmental contamination.

4. CONCLUSIONS

With milling trials of 7050 T7451 aluminum alloy and microbiological analyses, the following conclusions about the performance of the studied samples of vegetable-, synthetic- and mineral-based cutting fluid are possible:

- In condition 1, the mineral base fluid analyzed showed best performance on volume removed regarding cooling property, since the feed rate is lower (f_z = 0,05 mm/tooth), followed by synthetic with 87.3% and vegetable with 46.5% of removed volume;
- In condition 2, the vegetable base fluid showed the best performance when analyzed both cooling and lubrication, followed by synthetic with 78.0% and mineral with 65.4% of machined volume;
- In condition 3, where the lubrication is more relevant, vegetable base cutting fluid performed better with higher volume removed, followed by synthetic with 16.2% volume removed. The mineral base demonstrated good performance, but the tool chipped before reaching the maximum flank wear of 0.2 mm;
- The best machining performance by the conditions studied was achieved by mineral emulsion in condition 1 with 0.061 m^3 removed, a condition that requires more cooling, and the worst result was obtained by synthetic-based cutting fluid in condition 3 with 0.007 m^3 of removed material;
- The vegetable-based showed improved performance in conditions 2 and 3, since a greater feed rate requires more lubrication effect;
- The chips formed using vegetable and mineral bases cutting fluids are conical spiral-shaped and the synthetic base resulted short conical helical chips, both considered as “good”;
- It was noted that with the increase of feed rate in the conditions studied, an increase in the coefficient of friction between tool and chip was generated and consequently cutting strength and power, requiring higher lubricity effect of emulsion oils;
- With the microbiological analyses it was possible to detect Colony Forming Units of *Penicillium sp.* fungi in the final samples of vegetable- and synthetic-based fluids, fungi considered as opportunistic;
- The vegetable-based cutting fluids are more favorable to the development of microorganisms, due to the high content of organic matter, a food source for microorganisms. The proliferation of fungi and bacteria promotes the reduction of solution’s service life;
- The degraded cutting fluid, with acid pH (less than 7), may favor the oxidation of the machine tool and workpiece, a critical factor for the aviation industry.
- The absence of ongoing management in cutting fluid reservoirs may cause economic and productivity losses, as well as damage to environmental health. Improper disposal can boost contamination and harm to the environment.

5. ACKNOWLEDGEMENTS

To CNPq for financial support, and to the Competence Center in Manufacturing in Aeronautics Institute of Technology (CCM / ITA) and University of Vale do Paraíba (UNIVAP) for the structure and technical contribution that enabled the study.

6. REFERENCES

Cardoso, K. P. Óleo de Pinhão-manso e fluido de corte emulsionável: estabilidade oxidativa e propriedades lubrificantes. Dissertation in Materials and Manufacturing Processes – Aeronautics Institute of Technology, São José dos Campos, São Paulo, Brazil. 2012. 108f.

ISSN 2176-5480

Cardoso, K. P., et al. Caracterização do óleo de pinhão manso como base para fluidos lubrificantes. II Congresso Brasileiro de Pesquisas de Pinhão-Manso. Brasília, Brazil. 2011.

Dilger, S.; FluriI, A.; Sonntag, H. Bacterial contamination of preserved and non preserved metal working fluids. International Journal of Hygiene and Environmental Health, V. 208, p. 467-476. 2005.

Gonçalves, J. F. S. Análise de requisitos e restrições para avaliação de emulsões de base vegetal na usinagem de ferro fundido cinzento e liga de alumínio. PhD thesis in Materials and Manufacturing Processes – Aeronautics Institute of Technology, São José dos Campos, São Paulo, Brazil. 2012. 346f.

International Organization for Standardization – ISO 3685: Tool-life testing with single-point turning tools, v.2, Genève, p.48, 1993.

Lacaz, C.S.; Porto, E.; Martins, J.E.C.; Heins-Vaccari, E.M.; Melo, N. T. Tratado de Micologia médica. 9. ed. São Paulo, Sarvier, 2002. 1104p.

Lutif, S. Y. S.; Souza, J. F.; Gomes, J. O. Técnicas de assepsia para aumentar a vida útil dos fluidos de corte. XVIII Congresso Nacional de Estudantes de Engenharia Mecânica – CREEM, Erechim, Brazil, 2011.

Mang, T.; Dresel, W. "Lubricants and lubrication". Wiley-VCH Verlag Gmbh, 2nd Ed., Weinheim, Germany, 2007, 850 p.

Schroeter, R. B.; Lindolfo, W. Tecnologia da usinagem com ferramentas de corte de geometria definida – Parte 1. Translation and adaptation of the book "Fertigungsverfahren – Drehen, Bahren, Fräsen", Florianópolis, Santa Catarina, Brazil, 2002.

Sokovic, M.; Mijanovic, K. Ecological aspects of cutting fluids and its influence on quantifiable parameters of cutting processes. Journal of Materials Processing Technology, Slovenia, n109, 2001. p. 181-189

Stoeterau, R. L.; Leal, L. C. "Apostila de Tribologia". Departamento de Engenharia Mecânica, Universidade Federal de Santa Catarina, Florianópolis, Brazil. 2004.

Trabulsi, L. R.; Alterthum, F. Microbiologia. 4. ed. São Paulo, Atheneu, 2005. 718p.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.