

Abrasive Flow Machining using Abrasive Paste with Oiticica Oil

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Abstract — This paper presents the use of Abrasive Flow Machining (AFM) and development of abrasive paste using oiticica oil, a typical plant in the northeast region of Brazil, are presented as a necessity in the face of the problems related to the surface finishing process parts employing existing commercial paste. Proper surface finishing and polishing improves the quality and performance efficiency of the work. With this, the main objective of this work is to use an equipment and an alternative paste for the machining of aluminum 6061-T6 and SAE 1045 steel parts. A prepared formulation of abrasive paste with oiticica oil and solid particles of silicon carbide was proposed and compared with a conventional paste in the machining of the two metals in question. The mass and the internal diameter of the parts were analyzed before and after the machining. It was established the variation of the number of cycles in Abrasive Flow Machining, keeping constant the concentration and size of the metal particles in the paste considered. The paste formulation with oiticica oil showed a new commercial paste option under development that may contribute to a better performance in the micro-machining of metal parts.

Keywords — Abrasive Flow Machining, Oiticica Oil, Aluminum 6061-T6, SAE 1045 Steel.

I. INTRODUCTION

The dimensional precision and alignment, as well as the quality of surface finish, are considered by processes such as machining, polishing, sharpening, that is, traditional methods of surface finishing. These finishing operations represent a critical phase and high cost for global production processes [1, 2].

With this, there is a need to develop a finishing process with broader limits of application areas, better quality performance, increased productivity and the possibility of automating the operation. The Abrasive Flow Machining (AFM) is a process that meets these requirements.

Studies have shown that in the Abrasive Flow Machining,

after a few initial cycles, material removals and improvement in surface roughness of the work part surface [3, 4, 5, 6].

Therefore, it proposes in this work the construction and use of the equipment for the Abrasive Flow Machining and the development of an alternative abrasive paste with oiticica oil.

II. OITICICA OIL

The Licânia rigid Benth, vegetation known regionally as oiticica, it belongs to the Crysobalanaceae family, typical of riparian forests of the caatinga, grows in deep alluvial watersheds of rivers and streams that are in the regions of northeast states of Brazil (Piauí, Ceará, Rio Grande do Norte and Paraíba), mainly in the backwoods [7]. It is from the nut that the highest oil content is extracted, used in large scale by the industries producing automotive paints, printers, varnishes, fine glaze and tarpaulins [8].

The oiticica has its potential underutilized, being often employed only in the soap industry, is a species that presents high yield relative to others in the production of oil. The nut occupies about 70% of the composition of the fruit and 60% to 63% of oil content [9].

III. ABRASIVE FLOW MACHINING

The Abrasive Flow Machining is a non-traditional machining process which removes the material from the surface of the part and produces residual compressive tension, can be worked with various metal materials such as steel, stainless steel, aluminum, zinc, brass, cast iron, titanium and nickel alloys, as well as in thermoplastic materials, which can not be machined by conventional machining processes efficiently and economically [5], [10]. The purpose of this process is to produce a nano-level finish on machined components, time saving, and is considered one of the best methods for finishing complex geometries not accessible by conventional finishing tools. In Abrasive Flow Machining a semi-solid and flexible abrasive compound ("paste") is charged and

forced through, by an extrusion process, on the surface to be machined of one or more parts, removing small amounts of material with each pass. The paste is composed of the semi-solid carrier and the abrasive grains, that is, it functions as a sandpaper and its particles act as cutting tools. The abrasive action during the process depends on the extrusion pressure, volume and flow rate of the paste, determined by machine configuration (equipment) and the paste passage area, considering the type of paste to be used, its formulation includes the viscosity, the type and size of abrasives [11]. However, the influence of three controllable variables (extrusion pressure, concentration and abrasive grain size) are responses to the removal of material and consequently internal diameter increase.

Abrasive Flow Machining can produce surface finishes of up to $0.05 \mu\text{m}$, to thin out small holes with diameters of 0.2 mm , generate curved surfaces with radii ranging from 0.025 mm to 1.5 mm [12].

The abrasive paste is the main component of the Abrasive Flow Machining process. The paste consists of a viscoelastic polymer reinforced with the abrasive particles. This viscoelastic polymer acts as a carrier medium and the abrasive particles act as a cutting tool that removes the material from the work part. The polymer pastes used are Polybiosiloxane and Silicone Rubber, the commonly used abrasives are silicon carbides, aluminum oxide, boron carbide and polycrystalline Diamond [13].

In this work it is proposed the use of an abrasive paste using oiticica oil.

IV. MATERIALS AND METHODS

The tests were carried out using a hydraulic press and a Abrasive Flow Machining device also developed, as shown in Figure 1.

The hydraulic press was used to perform the compression movement, where the piston compresses the abrasive paste downwards inside the cylinder, forcing it to pass through the internal diameter of the parts fixed in the working support. As a result, the abrasive paste abrades the tested parts. After the initial linear movement of 25 mm , the cylinders are manually inverted.



Fig. 1: Abrasive Flow Machining Equipment

In the opposite direction, the 25 mm stroke is again completed and the work part wears. This combination of movements in both opposing directions compose a cycle in the Abrasive Flow Machining process [14].

The applied pressure was 50 bar (725.189 Psi). The tested aluminum and steel parts are machined for a number of pre-determined cycles. For the aluminum and steel parts for both the conventional pastes, commercial use and the developed paste, 720 compression cycles were carried out.

After the Abrasive Flow Machining procedure, the parts were removed from the equipment and underwent a cleaning process, to start the measurements of mass and diameter of the machined parts.

To measure the masses of the work parts a balance of the mark Bel Engineering Mark was used, model M214A, with resolution of 0.0001 g , under the room temperature of 33°C and ambient air relative humidity of 44% . The amount of material removed from each part was estimated by the difference between its masses, respectively before and after each machining operation.

The machining tests were performed with two types of working materials 6061-T6 aluminum and $\text{SAE } 1045$ steel, this is because aluminum has a greater lightness in transportation and higher resistance to corrosion and steel is currently the most used metal alloy, being used intensively in numerous applications such as machines, tools and construction.

After that, the parts were prepared and transformed in the formats established, as shown in Figures 2 and 3, so as to be fixed by threading in the holes of the working support.



Fig. 2: Aluminum parts 6061-T6

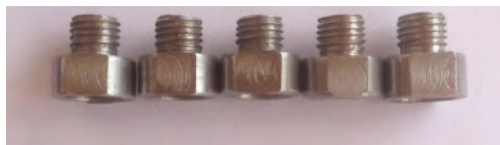


Fig. 3: Steel parts SAE1045

The paste developed for the tests is a mixture of plaster powder (2.400 grams), abrasive particles of silicon carbide (500 grams), oiticica oil (600 grams) and linseed oil (5 grams).

The plaster powder, oiticica oil and linseed oil were mixed with the abrasive particles in a defined ratio (0.685: 0.171: 0.001: 0.143) respectively, under the conditions of room temperature of 27°C and humidity of 79% to achieve the desired percentage concentration of particles by weight [weight of abrasive particles x 100 / (weight of developed paste)]. However, the common definition of the percentage of abrasive particle concentration is given by: weight of the abrasive particles x 100 / (weight of the abrasive paste). The homogenization of the abrasive paste was performed manually. Before starting the actual tests, a preliminary one was performed with 2 machining cycles for every 5 work parts, in order to obtaining a homogeneous mixture inside the equipment cylinders [14].

V. EXPERIMENTAL RESULTS

The results obtained after the accomplishment of the machining tests related to the removal of material and variation of the internal diameters of the machined parts will be presented.

During the tests, the influence of the number of cycles and the type of abrasive paste employed on the amount of material removed and on the variation of the internal diameter was evaluated, while the concentration, the size of the abrasives and the paste speed remained constant. The results obtained with the developed abrasive paste were compared with those obtained in the tests carried out with a conventional (commercial) one. The dimensional analysis of the machined parts were analyzed by means of images obtained by scanning electron microscopy (SEM). The first result presents the values of material removal in grams, according to the variation of the number of cycles, which were 20, 60 and 100 cycles for the aluminum and steel parts, according to Figures 2 and 3. The use of the conventional paste was compared to the paste developed

in this work for Abrasive Flow Machining. Each experiment was realized in a set of 5 parts for each cycle. Table 1 shows the material removal for aluminum and Table 2 shows the removal for steel, both for 20 cycles and for the conventional and developed pastes. The same procedure was repeated for 60 and 100 cycles.

Table.1: Comparison of material removal for aluminum in 20 cycles

Aluminum	Conventional Paste		Developed Paste	
	Parts Numbers	Mass before AFM (g)	Mass after AFM (g)	Mass before AFM (g)
1	1.6833	1.6820	1.6848	1.6838
2	1.7086	1.6970	1.6920	1.6892
3	1.6995	1.6924	1.6948	1.6942
4	1.6935	1.6916	1.7075	1.7046
5	1.6922	1.6920	1.6934	1.6908

Table 2 - Comparison of material removal for steel in 20 cycles

Steel	Conventional Paste		Developed Paste	
	Parts Numbers	Mass before AFM (g)	Mass after AFM (g)	Mass before AFM (g)
1	5.1641	5.1605	5.3942	5.3892
2	5.6866	5.6798	5.6877	5.6757
3	5.2633	5.2546	5.4449	5.4389
4	4.8252	4.8214	5.3759	5.3691
5	5.7983	5.7934	5.3327	5.3234

Removal of material occurred in the 6 conditions tested, resulting from the combination of 3 cycle numbers and 2 types of materials and are shown in Tables 3 and 4. Where **D** represents the developed paste, **C** is the conventional paste and **n** is the number of cycles.

Table 3 - Average removal of material: Aluminum (g)

D(n100)	C(n100)	C(n20)	C(n60)	D(n20)	D(n60)
0.0331>	0.0241>	0.0221>	0.0157>	0.0153>	0.0139

Table 4 - Average removal of material: Steel (g)

D(n20)	D(n100)	D(n60)	C(n20)	C(n60)	C(n100)
0.0391>	0.0353>	0.0352>	0.0278>	0.0253>	0.0223

Removal of material from steel parts resulted higher than aluminum, although this material offers greater resistance to abrasion in relation to aluminum, due to the fact that in the primary machining the surface finish of the steel parts was inferior compared to that of the aluminum parts.

The second result presents the effect of the parameters of Abrasive Flow Machining on the variation of the internal diameter of the parts and the difference between the initial and final values for the aluminum and steel parts. Table 5 shows the comparison of the diameter before and after the AFM process for the aluminum parts tested in 20 cycles and Table 6 compares the steel parts under the same conditions, for both abrasive pastes.

Table 5 - Comparison of the internal diameters for the aluminum parts in 20 cycles

Aluminum	Conventional Paste		Developed Paste	
	Diameter before AFM (mm)	Diameter after AFM (mm)	Diameter before AFM (mm)	Diameter after AFM (mm)
Parts Numbers				
1	7.631	7.780	7.682	7.747
2	7.872	7.874	7.689	7.800
3	7.746	8.000	7.706	7.885
4	7.998	8.101	7.710	7.928
5	8.325	8.342	7.758	7.873

Table 6 - Comparison of the internal diameters for steel parts in 20 cycles

Steel	Conventional Paste		Developed Paste	
	Diameter before AFM (mm)	Diameter after AFM (mm)	Diameter before AFM (mm)	Diameter after AFM (mm)
Parts Numbers				
1	8.208	8.295	7.585	8.071
2	7.683	8.330	7.288	8.102
3	7.564	8.443	7.288	7.550
4	7.689	8.253	7.552	8.117
5	7.334	8.232	7.766	8.181

The Tables 7 and 8 present the results of increasing diameters for all the cycles tested, comparing the conventional paste with the developed one for the aluminum and steel parts.

Table 7 - Average diameter of parts: Aluminum (mm)

D(n100)	C(n60)	C(n100)	D(n60)	D(n20)	C(n20)
0.649>	0.437>	0.422>	0.272>	0.138>	0.105

Table 8 - Average diameter of parts: Steel (mm)

D(n100)	D(n60)	C(n20)	C(n60)	D(n20)	C(n100)
0.672>	0.628>	0.615>	0.524>	0.508>	0.382

The highest average diameter variation occurred for both aluminum and steel with 100 cycles with the developed paste D. However, in all cycles and both materials occurred the increase of the diameter of all the parts. In order to verify the dimensions of the diameters and the

effect of the number of cycles, it was used Scanning Electron Microscopy in all the parts tested.

Figures 4 and 5 shows the internal diameter variation of an aluminum part, respectively before and after 20 cycles with the conventional paste.

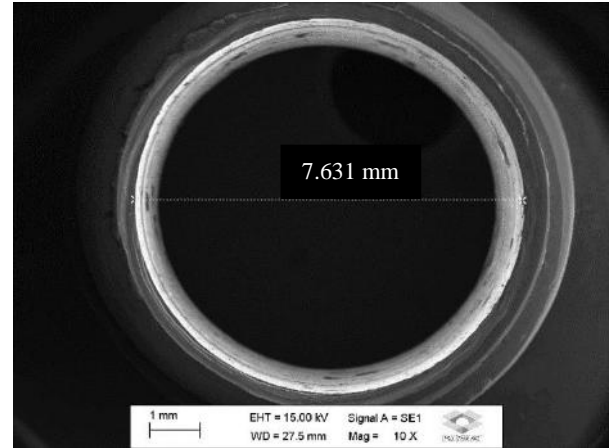


Fig. 4: Aluminum part before the AFM for 20 cycles with the conventional paste

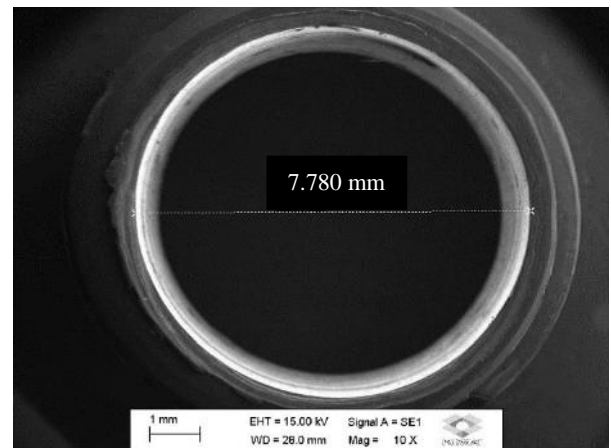


Fig. 5: Aluminum part after the AFM for 20 cycles with the conventional paste

The Figure 6 shows the aluminum part to be tested with the developed paste and the Figure 7 shows the variation of the internal diameter after 20 cycles of the Abrasive Flow Machining process with the developed paste.

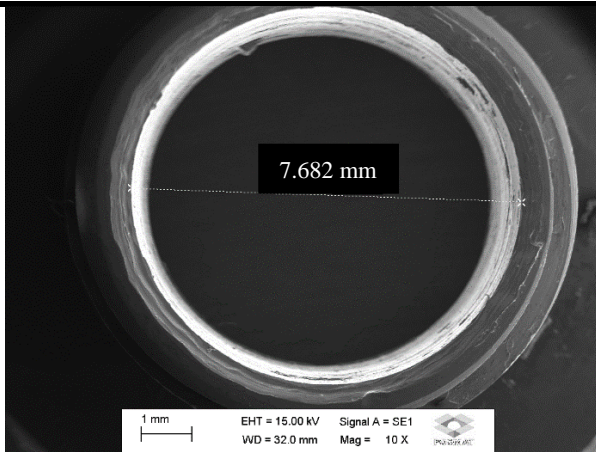


Fig. 6: Aluminum part before AFM for 20 cycles with developed paste

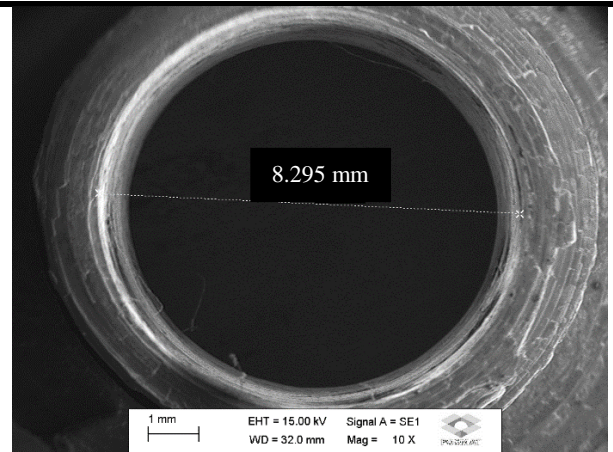


Fig. 9: Steel part after the AFM for 20 cycles with the conventional paste

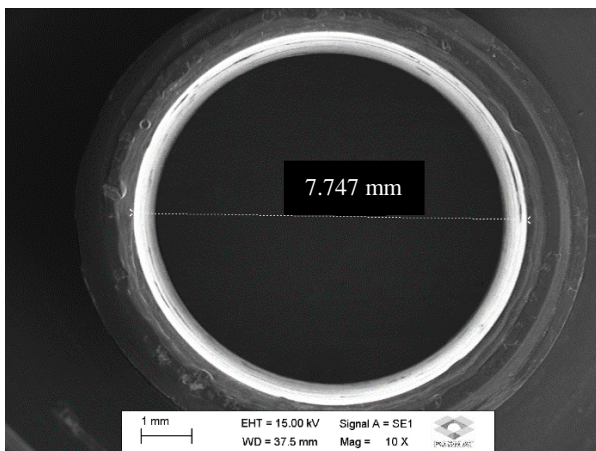


Fig. 7: Aluminum part after the AFM for 20 cycles with the developed paste

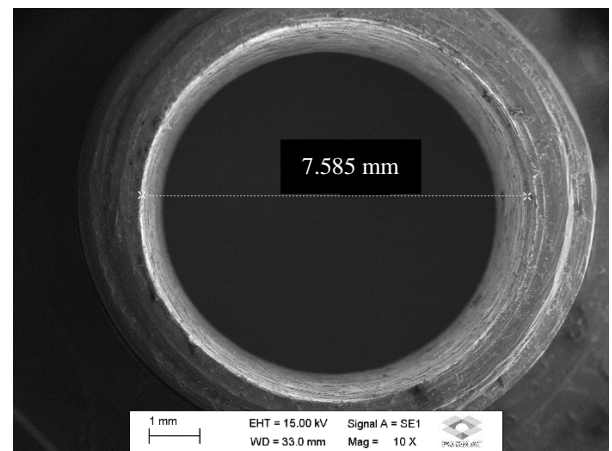


Fig. 10: Steel part before the AFM for 20 cycles with the developed paste

The same procedures was performed with the steel parts. The Figure 8 shows the steel part before the Abrasive Flow Machining procedure; the Figure 9 shows the variation in internal diameter for 20 cycles with the conventional paste.

The Figure 10 shows the steel part before the Abrasive Flow Machining procedure; the Figure 11 shows the variation of the internal diameter for 20 cycles with the paste developed.

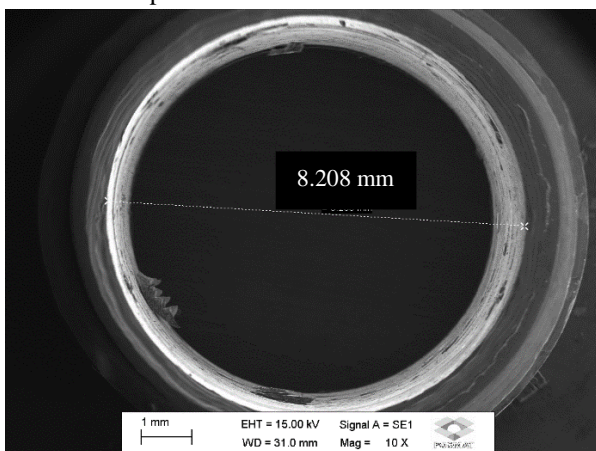


Fig. 8: Steel part before the AFM for 20 cycles with conventional paste

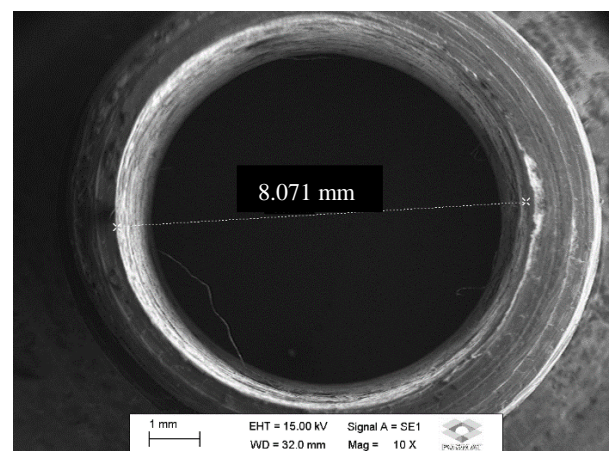


Fig. 11: Steel part after the AFM for 20 cycles with the developed paste

The Figures 4 to 11 represent the Scanning Electron Microscopy with the values of the diameters of both the aluminum and steel parts, before and after the Abrasive Flow Machining, referring to first line, parts numbers of Tables 5 and 6. However, the same procedures was performed for the other pieces tested for 60 and 100 cycles.

VI. CONCLUSION

The paste used experimentally in this work presented good results for the removal of material and for the average variation of the internal diameters of the parts, both for aluminum and steel materials. It has been observed that the removal of material is influenced by the hardness and surface finish of the parts. The highest average variation of diameters occurred in both aluminum and steel with the developed paste for the largest number of cycles D(n100). Therefore, the abrasive paste composed of oiticica oil may serve as an option for the thinning of metal parts by the process of Abrasive Flow Machining.

ACKNOWLEDGEMENTS

This work was supported by FAESO (Faculdade Estácio de Sá de Ourinhos).

REFERENCES

- [1] Muller, M.; Lebedev, A.; Svobodova, J.; Naprstkova, N.; Lebedev, P. (2014). Abrasive-free ultrasonic finishing of metals. *Manufacturing Technology*. vol. 14, pp. 366-370.
- [2] Novak, M. (2012). Surfaces with high precision of roughness after grinding. In: *Manufacturing technology*, vol. 12, pp. 66 -70.
- [3] McCarty, R. W. (1970). U S Patent 3,521,412.
- [4] Shan, H. S.; Dubey, A. K. (1997). Micro machining by flow of abrasives. *Proceedings 17th AIMTDR Conference*, Warangal, India, pp 269–275.
- [5] Jain, V. K.; Adsul, S. G. (1999). Experimental investigations into abrasive flow machining (AFM). *Machine tools & manufacture*.
- [6] Singh, S.; Shan, H. S. (2002). Development of magneto abrasive flow machining process. *Int Journal of Machine Tools and Manufacture*; 42: 953–959.
- [7] Silva, F. J. P.; Silva, R. A.; Silva, M. J. S. (2010). Potencial apícola para apismellifera 1. em área de caatinga no período da floração da oiticica (*Licaniarigida Benth*). *Revista Verde de Agroecologia e Desenvolvimento Sustentável*, v.5, n.1.
- [8] Bayma, C. (1957). Oiticica. Ministério da Agricultura - SAI. Rio de Janeiro. (Produtos Rurais 1), 53p.
- [9] Pinto, G. P. (1963) Características físico-químicas e outras informações sobre as principais oleaginosas do Brasil. Recife: Instituto de Pesquisa e Experimentação Agropecuárias do Nordeste. P. 47-49 (Boletim Técnico, 18).
- [10] Rajesha, S.; Venkatesh, G.; Sharma, A. K.; Kumar, P. (2010). Performance study of a natural polymer based media for abrasive flow machining, *Indian Journal of Engineering & materials Sciences*, 407-413.
- [11] Mali, H. S.; Manna, A. (2012). Simulation of surface generation during abrasive flow finishing Al/SiCp-MMC using neural networks. *International Journal of Advanced Manufacturing Technology* (61): 1263-1268.
- [12] Jain, V. K. (2002). *Advanced Machining Processes*, Allied Publishers, Mumbai (in press).
- [13] Shackelford, J. F. (2004). *Introduction to materials science for engineers*. Prentice Hall, 6 ed.
- [14] Munhoz, M. R. (2017). Case study of an abrasive paste using oiticica oil in an abrasive flow machining equipment. 156f. Master in Mechanical Engineering. Federal Technological University of Paraná. Cornélio Procopio.