COMPOSITES MATERIALS MACHINED BY CNC MILLING CONSIDERING THE EFFECTS OF CUTTING PARAMETERS AND PROPERTIES IN RESPONSE SURFACES MRR AND VOLUMETRIC COEFFICIENT OF CHIP

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Abstract. *Composite materials are being tested for commercial production of the inserts and also tests on production of inserts in metal molds for plastic injection at several jobs in UTFPR (Federal Technological University of Paraná). For purposes of machinability in five specimens (Csp) from recent composites processed polymeric material (epoxy) reinforced with non-ferrous metal (aluminum) and hardening agents was proposed its machining cutting parameters adopted (v_c, f_z, a_p) from the simulation CAD/CAM (Computer Aided Design/Computer Aided Manufacturing) CNC milling in Csp. In the initial stage of this project were obtained from the inference from the Shore D hardness scale and the measures taken according to ASTM – 2240 Norm, measured first the circumstance of gross area, as measured also in intermediate stages of milling process after conventional manual (CMP) and the final step after the milling process CNC (CNCMP). Throughout the process steps were evaluated the results of measurements of hardness index, conferred by variable values statistical tests for equal means. However, after the events of the processing of specimens, were also carried out preliminary tests of hardness for comparison with the resins market Ren Shape RS family, however, the mechanical properties of strength and fracture toughness of these are Csp analysis CNC machining composites evaluated in the same university. Therefore startup were machined by chip (waste) and then subjected to various types of tests, among which the rate of material removal (MRR) and volumetric coefficient of chips (ω), whose values corroborate authenticate parameters cut when machined using the cutting tool as an end mill. Through this study are presented which summarized the values of R_a as a function of cutting parameters already realized at an earlier stage of the process of CMP and CNCMP. Consequently MRR was used to obtain an equation in which data are handled on the cutting parameters and tool geometry, and also the area of the reamed canal. Therefore, in determining the volumetric coefficient data were imputed in the classical equation, where the same authors determined this equation the numerical values of volumes of chips, and even prepared a chart to explain the influence of the shape of chips in the machining conditions in which products are Turning tests with cutting parameters defined for metallic material. To analyze the results were obtained with the respective response surface equations for material removal and volumetric coefficient using the program Statistica from mathematical models obtained by multivariate regression, as the delineation of relationships between variables in the machining of composites.*

Keywords: *CNC milling, Mathematical models, Surface response of the MRR and volumetric coefficient.*

1. INTRODUCTION

Since when Yang and Ryu (2001) developed composite material to assist the rapid prototyping, tests were performed on specimens in order to evaluate the mechanical properties and promote their application in the manufacture of prototype mold. The specimens were machined using HSM (High Speed Machining), resulting in a forked mold which was injected a propeller with the same composite. From this study, suggestions were made for corrections of defects in the composite processing. For reciprocal purposes, commercial resins are being tested for the manufacture of inserts, according to research from Lanz *et al*. (2002), and also tests on production of inserts in metal molds for plastic injection in UTFPR (Federal Technological University of Parana - Brazil) in the work of Richter *et al*. (2003), Volpato *et al*. (2003) and Derenievicki (2007). In these works with commercial, resins illustrated by Tab. 1, were tested the application scope and the potential of the machining of materials for inserts, using CNC (Computer Numerical Control) technology and CAD/CAM (Computer Aided Design/Computer Aided Manufacturing) as an alternative to Rapid Tooling RT.

In parallel, the UFTPR has also been researching the development of a composite of epoxy and aluminum powder for machining by Serafim *et al.* (2006) and Veroneze *et al.* (2009). Such composite materials have been subjected to various physical and mechanical tests, such as: density, hardness, superficial roughness, compressive strength, fracture toughness and micrographs; however the main available results are summarized in Table 2.

Table 1. Commercial resins, source and catalog by Maxiepoxi Axson Technologies (2005) and (Oliveira *et al.*, 2010)

Description of Resins	Ren Shape RS 460	Ren Shape RS 5166	(1)Express RS 2000	Lab 1000
Industrial Application	Standard model prototypes and mockups	Jigs and tools for shaping	Moulds for thermoplastic injection and devices	Stamping tools
Colors	Brown	Ivory	Gray	Gray
Density (Kg/m^3)	700 - 750	1700	1800	1670
Hardness Shore D (ASTM D-2240)	60 - 65	85 - 90	90 - 91	88 - 89
Compressive strength (N/mm^2)	20 - 25	90 -100	250 - 260	91
Cutting speed v_c (m/min)	157.0 – 196.3	109.7 -141.4	471.2 -785.4	100 - 400

Note: (1) Express 2000 and no longer marketed in Brazil

Table 2. Physical parameters of composite materials, source: (Veroneze *et al.*, 2009)

Physical Parameters	Specimen Cp-1	Cp-2	Cp-3	Cp-4	Cp-5
	Chemical composition of the specimens				
	10% mAl 3%EAl 5%AcmR	10% mAl 3%EAl 7.5%AcmR	10% mAl 3%EAl 10%AcmR	15% mAl 3%EAl 10%AcmR	20% mAl 3%EAl 10%AcmR
Density ρ (g/cm^3)	1.35	1.35	1.35	1.4	1.5
Compressive strength $\sigma_{máx}$ (Mpa)	46.079	85.368	92.752	83.081	84.492
Fracture toughness K_{IC} (Mpa*m$^{1/2}$)	0.6273	0.6943	0.9191	1.081	1.2449

Abbreviations: mAl-weight aluminum; EAL-aluminum stearate; AcmR-curing agent resin mass

Considering that, the machinability event of these composite materials is a complex interplay of variables of the material properties to be machined versus cutting tool (milling cutter) and environment (dry), as well as the definition of: the parameters of the machine, cutting parameters and process parameters; such as described in the literature for metals according to Ferraresi (1995) and Shaw (2005). Therefore, the analysis of machinability of particulate polymeric composites (epoxy) reinforced with non-ferrous metal (aluminum) and percentage of composition was necessary tests on five specimens (Csp), in order to evaluate the effects of the properties and parameters that allow ensure the use of these composites in industrial applications in the technologies of rapid prototyping (RP) and rapid tooling (RT).

In the initial stage of the project was obtained the inference from the Shore D hardness scale in all samples, measured primarily in rough condition of the surface, as well as measured also in the intermediate stage after conventional milling process (CMP) and in the final stage after the process of CNC milling (CNCMP). However, other mechanical properties are often estimated from data obtained from hardness tests explained according Callister (2002), pointing out that the hardness is an important piece of information of the material and also of cutting tools used in the steps of machining in milling. In this way, the samples of composite materials were machined by chip breakaway (waste) and then they were subjected to various types of tests, among which the rate of material removal and the volumetric coefficient of chips, whose results corroborate to authenticate the cutting parameters: cutting speed (v_c), feed per tooth (f_z) and axial cutting depth (a_p); when used a milling cutter in the machining of a composite.

Through this study are presented, in a brief way, the measured values of superficial average roughness (R_a) in function of cutting parameters, where they are already evaluated previously in machining in CMP and completed in CNCMP, according to results in the samples analyzed by Oliveira *et al.* (2010).

To obtain the removal of material *MRR* in cm^3/min was used the Eq. (1), which was managed data of cutting parameters, tool geometry and, axial depths a_p and radial depths a_e were also performed both in mm conjunction with the product of the feed speed f_f of the router table (mm/min).

$$MRR = \frac{a_p . a_e . f_f}{1000} \tag{1}$$

To determine the volumetric coefficient of chips (ω) data were imputed in the Eq. (2) which is used in studies by Wulf, Sagrezki and Efron (1956) *apud* Ferraresi (1995). Where they also determined the numerical values of volumes of chips, and also elaborated a graph to explain the influence of the shape of the chip in machining conditions, attributes of which are products of turning tests with cutting parameters defined for metallic material. And to impute data from the list of variables, the v_e is the volume occupied by the chip in cm^3 and ρ is the specific mass of the composite machined in g/cm^3, and derivation P is the mass of the chip having the unit in kg.

$$\omega = \frac{\rho . v_e}{P.1000} \tag{2}$$

Purpose to trust the analyzes, were obtained response surfaces with the respective equations of both material removal rate and the volumetric coefficient of chips, by using the program Statistica from mathematical models obtained by multivariate regression, as studies with end milling led by Kanenobu *et al*. (2004), using in the technique of multiple regression a tool to delineate the relationships between variables, which can be implemented in order to determine relationships between dependent and independent variables, this area used to analyze data and generate a model according to Jenrich (1995).

2. EXPERIMENTAL PROCEDURE

2.1. Material compositions and specimen

Five Csp were used in the tests of properties and machining, and these samples in the raw state, they are composed of epoxy polymer matrix and aluminum, a non-ferrous metal, having a percentage components (%): mAl- aluminum mass, EAl-aluminum stearate and AcmR - curing agent in resin mass; therefore, in the Csp -1: 10% mAl, 3% EAl, 5% AcmR; Csp-2: 10% mAl, 3% EAl, 7.5% AcmR; Csp-3: 10% mAl, 3% EAl, AcmR 10%; Csp-4: 15% mAl, 3% EAl, 10% AcmR; and Cp-5: 20% mAl, 3% EAl, 10% AcmR; where each Csp presents prismatic geometry. For CNC milling was idealized a virtual model of Csp, which was designed in the application Solid Edge that has dimensions of (45x70x150 mm), which also has channels of varying depths in the range of (8 to 2 mm), and length machined on margin of (50 to 70 mm). The final model of the specimen is shown in Fig. 1 which validates with the rigidity and with less complexity, when milled.

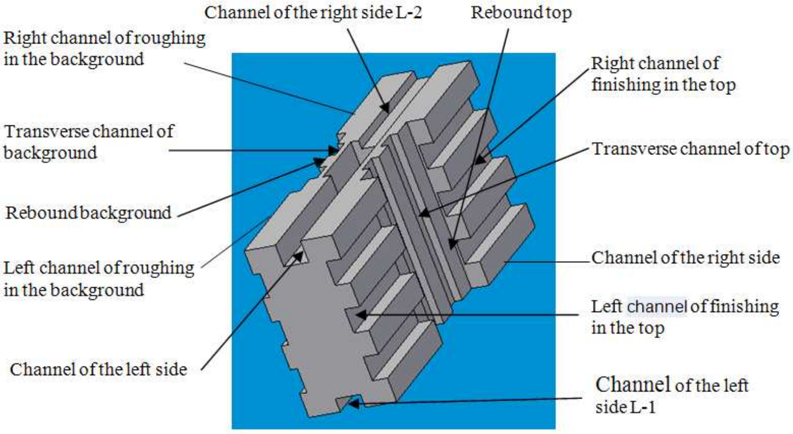


Figure 1. Project of the specimen

2.2. Machine tool accessories and cutting

In CMP was used an end mill made of high speed steel (HSS) multislice, with the diameter of the milling cutter equal to 16 mm, with four cutting teeth (z) and concentric 30° helix angle. In CNCMP was selected a end mill of hard metal with diameter of 10 mm and helix angle of 30° with four cutting teeth (*z*). The testing execution in CNC milling in the specimens was performed in a Vertical Machining Center CNC ROMI Discovery 560, equipped with CNC GE-Fanuc 21i-M, and having information technology of the machine as: power of 11 kW and 7500 RPM spindle speed. The whole process of machining of the channels in the specimens was done by applying the cutting parameters, for such purposes was executed a *pre-set* of the tool balance, and in the operation was also used a base with a height marker with digital readout. In the next step the hard metal end mill is already presented itself mounted in the magazine tool holder ISO-40 modular interchangeable installed on the CNC machine spindle. Moreover, to avoid damaging in the fixing of the sample, it was protected with aluminum shim on the lateral jaw of the hydraulic bench vise, pointing the alignment and centering of the piece, after the *pre-set* of the cutting tool.

2.3. Cutting parameters

The parameters shown in Table 3 were set to random values dispersed in the range of arithmetic means. However, for purposes of assigning the numbers of machining variables in the specimen channels, the values of cutting parameters (v_c, f_z, a_p) served as reference to write calculation of variables in the subsequent stages. Moreover, the machining in the conditions of: drafting conditions, finish and varied cuts in events; the range of *values was* indicated by the catalogs of commercial resins and still based on the work of Yang and Ryu (2001), Lanz *et al*. (2002), Volpato *et al*. (2003) and Derenievicki (2007). Thus, the definition phase of the machining was implemented already considering the reliable machining parameters for the generation of CNC program and using *MASTERCAM* application of CAM/CNC technology.

Table 3. Cutting parameters in CNC milling of composites

Machined Component	Acronyms	Operations	Cutting Parameters		
			Cutting speed v_c (m/min)	Feed per tooth f_z (mm/dente)	Depth of cut a_p (mm)
Rebound top	RT	Event 1 Ledge	120	0.042	6.5
Rebound background	RF		120	0.042	3.0
Roughing top channel 1	DTC1	Event 2 Roughing	90	0.010	5.0
Roughing top channel 2	DTC2		90	0.070	5.0
Roughing top channel 3	DTC3		90	0.130	5.0
Roughing top channel 4	DTC4		90	0.190	5.0
Roughing top channel 5	DTC5		90	0.250	5.0
Roughing top channel 6	DTC6		90	0.280	5.0
Finishing background channel 1	AFC1	Event 3 Finishing	150	0.010	2.5
Finishing background channel 2	AFC2		150	0.070	2.5
Finishing background channel 3	AFC3		150	0.130	2.5
Finishing background channel 4	AFC4		150	0.190	2.5
Finishing background channel 5	AFC5		150	0.250	2.5
Finishing background channel 6	AFC6		150	0.280	2.5
channel transverse 1 Top	CT1-T	Event 4 Variable a_p	175	0.155	2.0
channel transverse 2 Top	CT2-T		175	0.155	4.0
Channel transverse 1 background	CT1-F		175	0.155	6.0
Channel transverse 2 background	CT2-F		175	0.155	8.0
Side-1 channel 1	L-1 C-1	Event 5 Variable f_z	175	0.020	8.0
Side -1 channel 2	L-1 C-2		175	0.040	8.0
Side -2 channel 1	L-2 C-1		175	0.080	8.0
Side -2 channel 2	L-2 C-2		175	0.160	8.0

2.4. Mean superficial roughness (R_a)

Milled channels were observed in measures of average surface roughness Ra (μm), using perfilometer style-type Mitutoyo SJ 201P value of having the Cut-Off 0.8 mm x 5. However, the measures were based on the application of cutting parameters in milling shown in Table 3, the measures conferred after CMP in six locations and five locations of the milled surface of the specimens after CNCMP, according to ISO 4287. Therefore, the values of roughness Ra in the five most significant specimens were machined in step CNCMP intervals of average roughness 0.57μm < R_a < 2.00 μm, with cutting speed 90 < v_c < 150 m/min, with the Feed per tooth of 0.01 < f_z < 0.07 mm/tooth and also the depth of cut 2.5 mm < a_p < 5.0 mm as the graphs are plotted in Figure 2 and Figure 3.

2.5. Hardness Shore D

The hardness measurements shown in Table 4 were performed using a portable duromer for rubber and epoxies with Shore D scale of the brand *INSTRUTHERM* and model DP - 400. At first, the measured values of hardness index were obtained in 12 points in the composite material to surfaces even in the raw state; the measurements were taken according to ASTM – 2240 Standard. The next step, after the CMP measures were adopted the totaling of 42 points, in all Cp facets; and the final step, after CNCMP were chose on 30 points.

Table 4. Values of hardness measurement in machining steps of the specimens

Test of hardness	Qualities	Cp-1	Cp-2	Cp-3	Cp-4	Cp-5	Scale
Raw state	Average	57.358	64.725	64.908	61.833	70.875	Shore D
	SD	9.919	12.005	9.321	9.292	7.470	
	CV%	17.294	18.548	14.361	15.028	10.540	
	Median	57.700	68.200	65.250	59.950	70.600	
	Variance	98.397	144.130	86.886	86.342	55.802	
After CMP	Average	80.231^{a}	82.819^{b}	82.067^{ab}	79.176^{a}	82.740^{b}	
	SD	5.893	3.861	6.421	4.920	2.499	
	CV%	7.346	4.662	7.824	6.214	3.021	
	Median	82.250	82.700	84.250	79.200	82.650	
	Variance	35.585	15.275	42.243	24.800	6.400	
After CNCMP	Average	84.073^{a}	84.403^{b}	85.416^{c}	83.123^{ab}	83.753^{ab}	
	SD	3.193	3.253	3.710	2.983	2.581	
	CV%	3.798	3.855	4.344	3.589	3.082	
	Median	84.950	84.200	86.700	83.550	84.000	
	Variance	10.197	10.587	13.771	8.903	6.663	

2.6. Material removal rate (*MRR*)

The variable *MRR* has a strong influence on the degree of surface finish on the workpiece, according to Dormer (2009), moreover the MRR favor the production too. Therefore, measurable diagnosis was provided for the volume in unit of time in the *MRR* (cm^3/min), and these values are obtained when applied in machining the parameters adopted in the CNC milling (see Tab. 3), where such were also performed using Eq. (1). However, the removal rate *MRR*, observed in five specimens of composite materials, for such purposes was considered the equality between the samples (Cp-1 = 2 = 3 = 4 = Cp-5). The event values of the volume measuring in cm^3 and milling time in seconds s of the 22 machining channels were formatted with acronyms/values (see Tab. 3), being the first the milling of rebounds (RT 42.19995 and RF 19.4769 measured with manufacturing time of 24 s); in the event of roughing (DTC1 5.728 DTC2 40.096 DTC3 74.464 DTC4 108.832 DTC5 143.200 D6MWT 160.384 and time equal to 254 s); in finish machining (AFC1 4.774 AFC2 33.418 AFC3 62.062 AFC4 90.706 AFC5 119.35 AFC6 133.672 manufactured in 226 s); the event in the transverse channels was (CT1-T 69.068 CT2-T 138.136 CT1-F 207.204 CT2-F 276.272 manufactured in 33 s), and even the side channels as (L-1 C-1 35.648, L-1 C-2 71.296, L-2 C-1 142.592, L-2 C-2 285.184 machined 23 s). Therefore, the sum of the volume totaled the value ($\sum = 2263.760$ cm^3) with total time on CNC milling (560 s). However, the *MRR* in cm^3/min was done with the manufacturing time equal 560 min ... = 9.33 s, consequently for a unit of the composite the material removal rate is equal to 242.550 (cm^3/min), therefore this *MRR* inference is important as machinability index for productivity in manufacturing.

2.7. Volumetric coefficient of chips (ω)

In each of the two milling stages were individually collected the chips, which are cutting products, and after they were stored up, then the ship were separated by the sample and process (one of CMP and the other CNCMP). After these processes, the product has already collected (waste) was prepared for weighing and measuring, and the next step the volume of chips was measured, for this purpose was used a precise digital balance (Quimis® brand) with scale in tenths of a gram. However, the volume measurement was used glass containers and Becker Laborglas Boro 3.3-600 ml cup. The whole scheme of measured values of volumetric coefficient (ω) was performed by Eq. 2 and the information's of Tab. 2 are summarized in the values shown by Tab. 5, and these preliminary observations of the measurements of the coefficient during the machining.

Table 5. Volumetric coefficient of chips observed after machining CMP and CNCMP

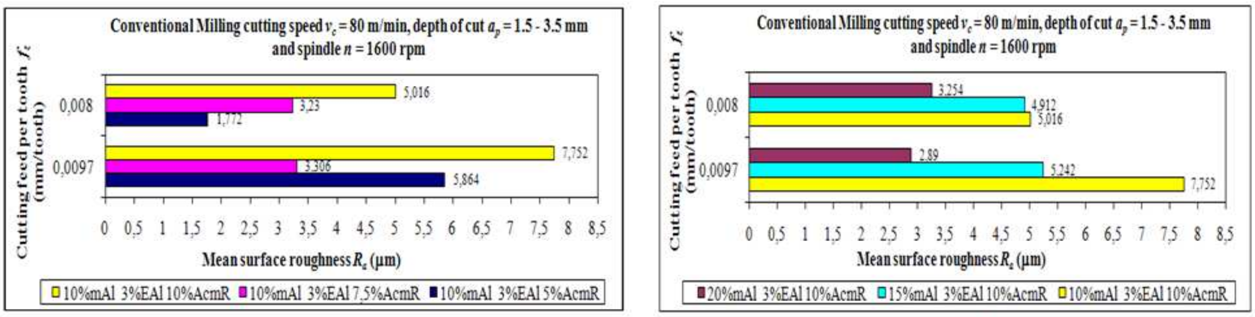
Specimens color/Compositions		Mass of the chip (g)		Volume chip (mL)		Volumetric coefficient of chip (ω)		Density ρ (g/cm^3)
		CMP	CNCMP	CMP	CNCMP	CMP	CNCMP	
Cp - 1	10%mAl3%EAl 5%AcmR	55.00	75.40	390	940	9.57	16.83	1.35
Cp - 2	10%mAl 3%EAl 7,5%AcmR	23.70	97.90	140	1060	7.97	14.61	1.35
Cp - 3	10%mAl 3%EAl 10%AcmR	25.95	97.65	150	1040	7.80	14.37	1.35
Cp- 4	15%mAl 3%EAl 10%AcmR	26.05	134.55	165	1170	8.86	12.17	1.40
Cp - 5	20%mAl 3%EAl 10%AcmR	28.65	111.00	195	1100	10.02	14.86	1.50

2.8. Response surface and statistical analysis

From the values of the parameters in the process, the response surfaces of the dependent variables of removal rate (*MRR*) and the volumetric coefficient of chips (ω) were plotted, and for these purposes in the tests a mathematical model was used using the Statistica software, the values of the coded variables in the regression are in the interval +1, 0, –1, which was made from the model equations. These variables form the product of the coefficient data and intersection for structuring of the general equation, with parameters estimated by degree of importance, and those are encoded in the table, they were presented in Pareto diagrams, where these are obtained by multivariate non-linear regression of response surface using the program Statistica. However, analysis was performed for a significance level of 5%, in other words, for a confidence level of 95%, it is acceptable for a determination coefficient $R^2 \geq 70\%$, and this range is considered adequate when assigned in the equation.

3. RESULTS AND DISCUSSION

In machining of Csp, the average effects of the variable R_a in µm were measured at five points in each of the five specimens after CNCMP milling, and on six points after CMP, so results were assessed in accordance with previous studies by the authors Oliveira et al. (2010), from these results was estimated to specimens the probable indicatives of use, depending on machinability performance has large range of R_a values entered into the scope of production, as referenced by the milling process with common interval being: $0.67\ \mu m < R_a < 6.37\ \mu m$, in other words, these values are often accepted in the metal machining, according to Ferraresi (1995). However, the significances are plotted with roughness comparative vs. cutting parameters, as the graphs shown in Fig.2 observed through the effects of f_z versus R_a in CMP. For each situation in CNCMP the effects of R_a vs. cutting parameters (a_p, f_z) are outlined in Figure 3.



(a) (b)

Figure 2. Comparative effect of superficial roughness R_a versus f_z between the specimens machined in CMP, a) Cp-1 x Cp-2 x Cp-3, b) Cp-3 x Cp-4 x Cp-5

The hardness measurements in the raw-state specimens were taken as expected for this stage, they presented discrepancy data, with standard deviations greater than five in this first inference, probably because of the variability of measurements (see Tab. 4). Therefore, these measures were executed after the step of processing of the material, when the surfaces of the rough composite were not in accordance for the execution of hardness tests, due to its irregular surface, (see measures of Tab. 4), so the probable hardness performance order of the statistical inference presented hypothesis in this way: Cp-5>3>2>4>Cp-1.

The hardness average after CMP (see Tab. 4) were measured with value in the range of the interval from 79 to 83 Shore D, these measures are accepted according to the method, so measurements in hardness order of this phase were: Cp-2 ≥ 5 ≥ 1 ≥ 3 Cp-4, however the specimens are at a hardness level close to the hardness of the similar material commercially available, the material Ren Shape RS 5166 and Lab 1000 (see Tab. 1), which has hardness equal to 90

Shore D and are still suitable for the manufacture of tools for forming, according to information from the manufacturer himself, while other applications have been investigated in these resins in RT technology for Volpato *et al*. (2003).

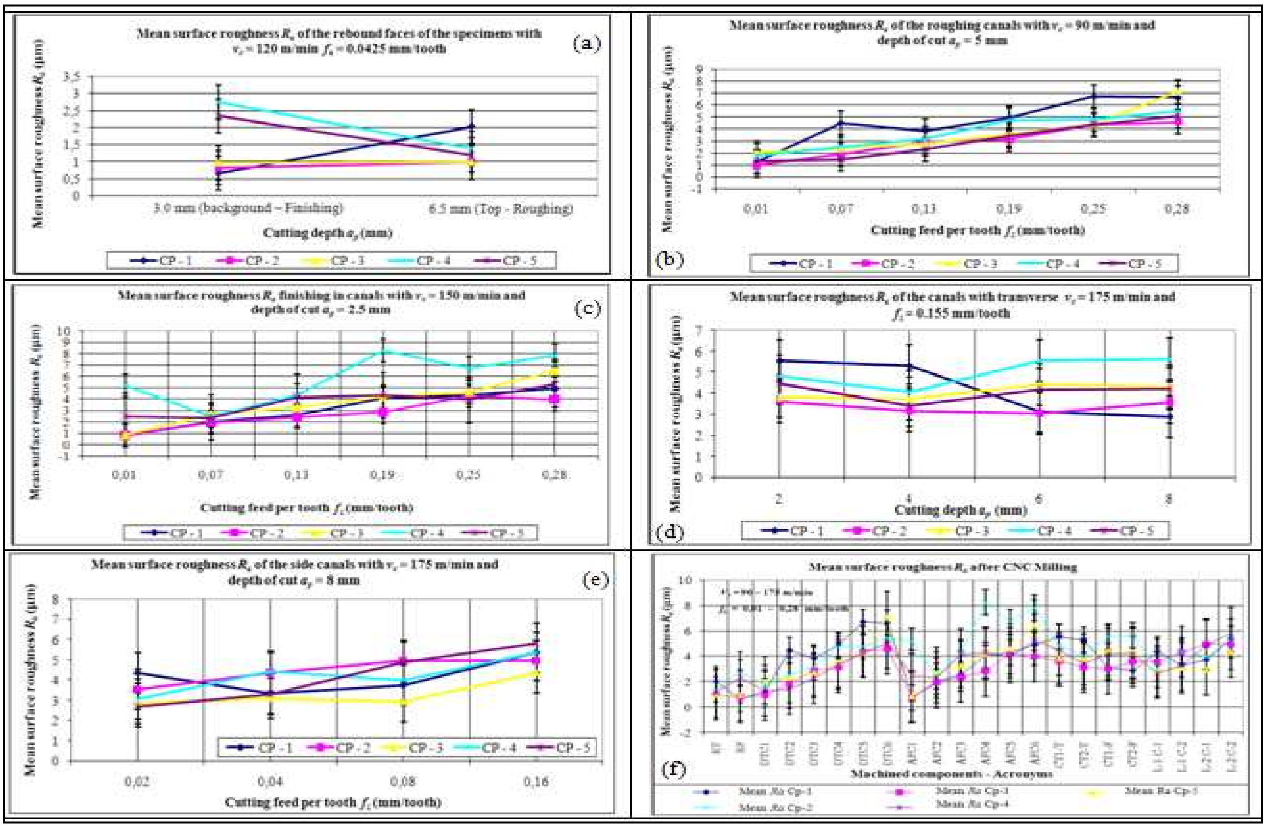


Figure 3. Comparative effect of superficial roughness R_a between the specimens machined CNCMP; a) R_a versus the a_p Rebounds, b) R_a versus f_z Roughing, c) R_a versus f_z the Finishing, d) R_a versus a_p the cross, e) R_a versus f_z the side, f) R_a Milling CNC machined components versus each of the five specimens

The hardness measurements, which were obtained after CNCMP (see Tab. 4), included better representation of the hypotheses, which are noticed being: Cp-3≥2≥1 ≥5≥Cp-4, the order infer the probable homogeneity in the composites. The Fig. 4 presents the performance of *Shore D* hardness, which is grouped by process stages, where the effects were observed in all three tests reported in the five Csp, and which has been summarized in the systematic of the reviews.

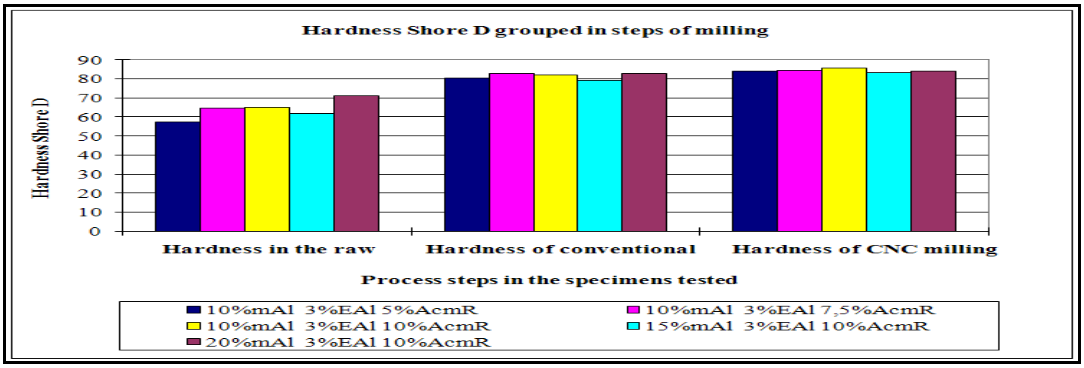


Figure 4. *Shore D* hardness of class on the steps of machining of composites

The *MRR* measured at the five composites is shown by Fig. 5, which was related to the breaking and the cutting parameters, with emphasis on: speed v_c (m/min), speed per cutting tooth f_z (mm/tooth) and the depths a_p and a_e (mm). The feed speed of the milling machine table f_f (mm/min) is in function of f_z, quantities of the mill teeth z and rotation n in (rpm), which are adjustable in the process, and for each different application of cutting parameters had a different *MRR*, that increased with the mill area a_p, and the interactions of v_c, f_z, that acted on the specimen in the end milling, what occur in the metal machining according to Diniz *et al*. (2001).

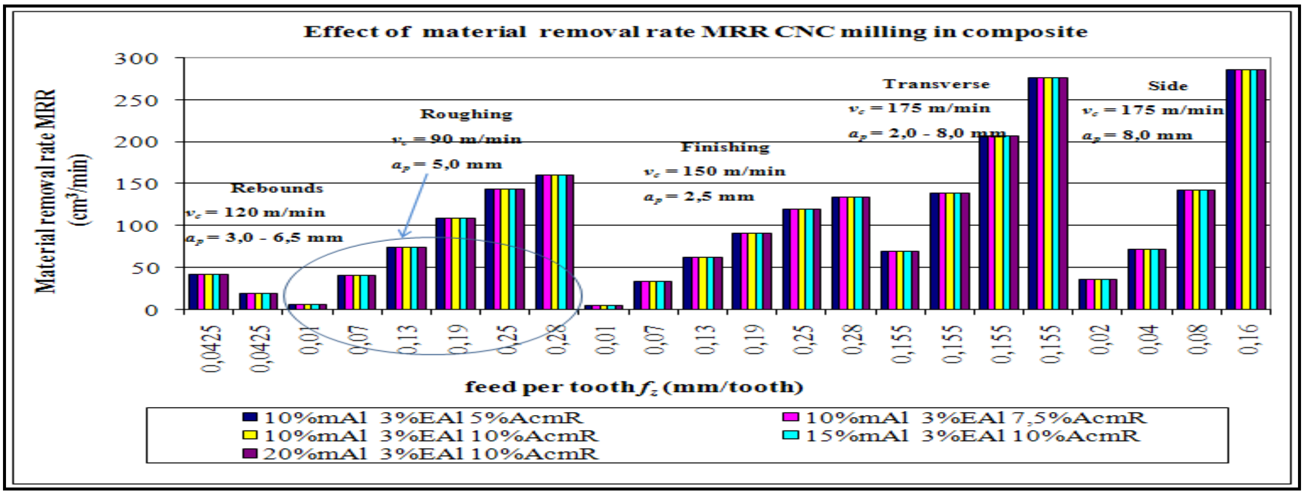


Figure 5. Material removal rate *MRR* (cm^3/min) in the composites

The Figure 6 presents the same graph the individual plotting of *ω* in the CMP and CNCMP proceed from the machining with the parameters, machines and different hardness tools, in other words, it is acceptable to make comparisons with the results, that were measured in metals, on the other hand the similarities in the edge of the tool versus mill, as described by Stemmer (1995). Thus, the referendum was crucial in the approach to determine the geometry of the chip format, which is likely to splinters and breaking by stress, the systematic calculation of ω, which was measured the value and assigned to the variables of Eq. 2, was declinable in the cut in CMP ($7<\omega<11$) and increased in CNCMP ($12<\omega< 20$). Moreover, the ship model was implemented as a photographic record after the machining.

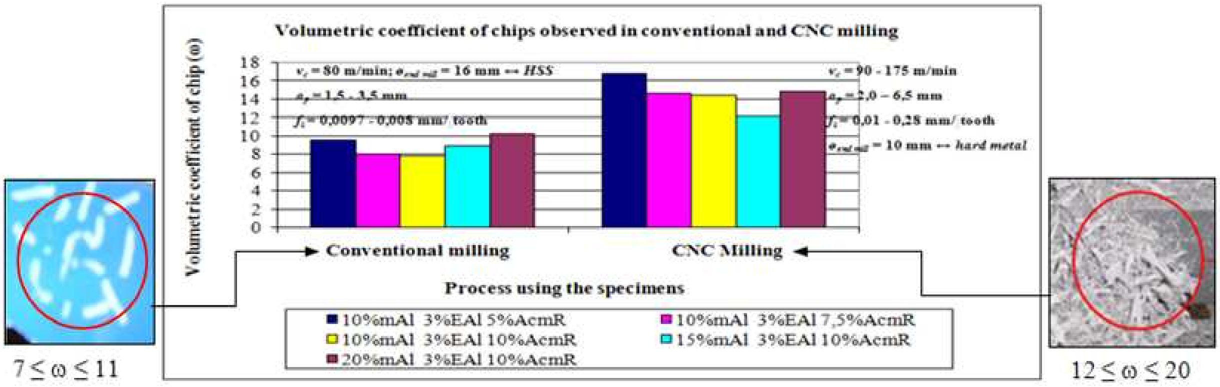


Figure 6. Volumetric coefficient of five chips in the machining of composite

The analysis of the parameters is in accordance with the contribution of each variable on each machined channel. The removal rate *MRR* have a strong influence on superficial roughness R_a in the machined specimen, however *MRR* is correlated in function of cutting parameters, pointing to the largest individual contribution of the cutting speed v_c, feed per tooth f_z and also the cutting depth a_p, and a lower portion in the interaction of f_z with v_c; however, the highest values of v_c, f_z, a_p, in order, decline *MRR*, so it is preferable to machine the specimen by adjusting the major v_c, and minor a_p in the event of the responses of *MRR*, since the parameter f_z implies the cutting feed speed f_f, which is function in the rotation relation *n*, number of teeth *z* end mill, where the observed results have strong correlation with the machined surface. The statistical analysis of values was performed for a significance level of 5%, in other words, for a confidence level of 95% and with the coefficient of determination R^2 equal to 0.544366 (54.4%), therefore they are not estimated in the equations. It is illustrated in Fig. 7 the systematization (a) The Pareto of major importance variables in the event *MRR*, (b) it shows the response surface of *MRR*, which is plotted in the axes f_z versus v_c (c) response surface of *MRR* plotted v_c x a_p; (d) response surface of *MRR* plotted axes f_z x a_p.

The coefficient *ω* superimpose the correlation with linear and quadratic interaction of the mechanical properties of resistance to compression $\sigma_{máx}$ and fracture toughness K_{IC} of composites, which was gage to a significance level of 5%, in other words, for a confidence level of 95%. Therefore, the determination coefficient R^2 is equal to 0.968403 (96.8%), and so the equation is estimated. The Fig. 8 of the model in (a) it shows the Pareto diagram of the variables with greatest importance of the parameter contribution, (b) the response surface significant for the coefficient *ω*.

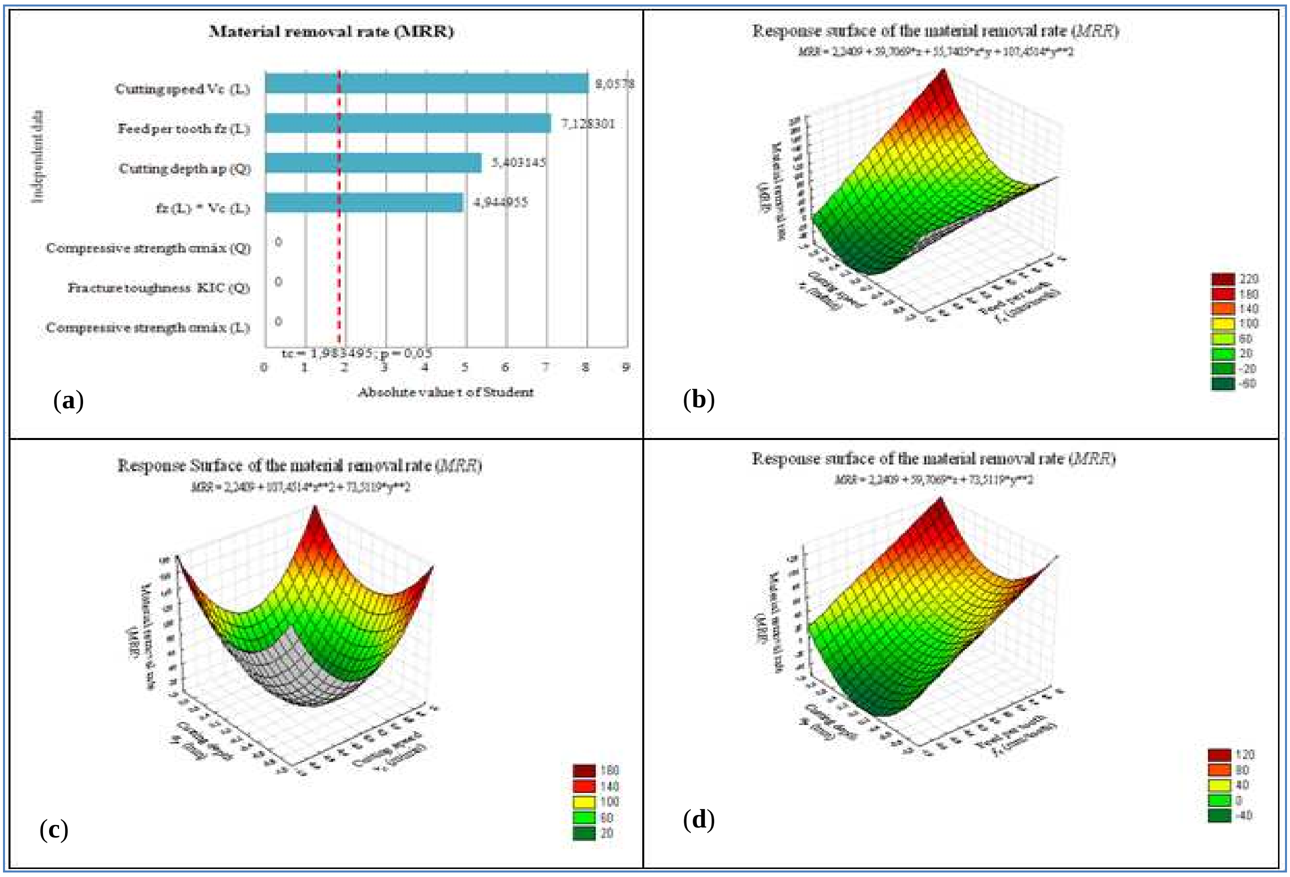


Figure 7. Systematization of the model, a) the relative importance of Pareto parameters of the event contribution *MRR*, b) Response surface effects of *MRR* versus f_z plotted on the axes v_c, c) Response surface of *MR*R effects plotted on the axes v_c x a_p, d) response surface of *MRR* effects plotted on the axes f_z x a_p

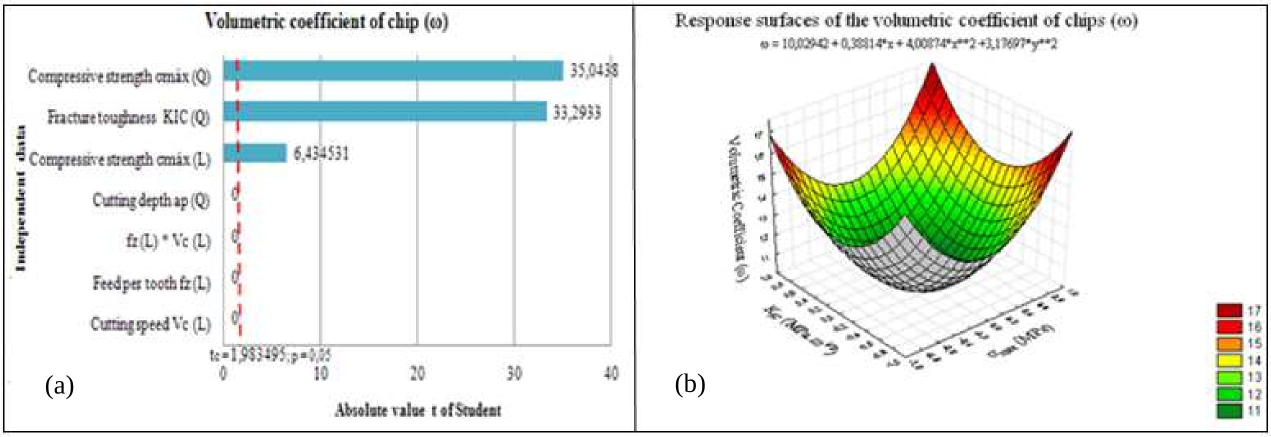


Figure 8. Mathematical model; a) the importance of the Pareto, b) Response surface of parameters (ω)

4. CONCLUSIONS

In the steps of two milling cycles (one in a CMP and another in CNCMP), after each event R_a in Csp, were measured the values of hardness index, that showed uniform effect which does not change the machinability, it performed a function of the composition percentage of EAl, mAl and AcmR in the specimen. The hardness was statistically checked with an interval in the range 79 < Hardness *Shore D* < 87, that are comparable to commercial resin RS 4166 and LAB 1000.

After CNCMP, in Csp were measured the lower values of R_a on the machined surface of the top and bottom rebounds (RT and RF) from both faces and also the R_a values from the first three channels (DTC and AFC) with lower values of f_z on both faces of the composites. For comparative purposes, the magnitude of roughness measurements on the surface of Csp is equivalent to lower average R_a of machining on the commercial aluminum, when they are turned with v_c around 120 m/min, as described for Ferraresi (1995). Moreover, the results of R_a are considered good, according to the scope of the surface application, which are illustrate for Mitutoyo (2005), who mark the value of (R_a = 2 μm), where this value is indicated for the general machined surfaces, which is typical of machine elements.

The material removal rate *MRR* is a machinability index in high demand by manufacturing, and it is correlated with the cutting parameters, highlighting the parameters of: velocity v_c, depth a_p and feed f_z; all in event of the cutting alimentation responses in milling, and these data are reported in the CNC program. The *MRR* obtained the measured result equal to 242.55 cm^3/min, where this result was arranged from the combinations of the parameters in machining, especially the effect of a_p in many situations the results of the *MRR*, although the response not be estimated at the event. It may be noted positively that the depths a_p were much greater ($a_{p(\max)}$ =8 mm>3 mm) in this study, and the greater rotation was almost twice smaller than the rotation used in the HSM with similar materials reviewed by Yang and Ryu (2001), where they obtained the *MRR* value of 226.1 cm^3/min when they applied their cutting variables, highlighting the parameters of: maximum cutting depth a_p in range of 3 mm and rotation n equals 8000 rpm; for comparison purposes the *MRR* measured values of machining were almost 8 times higher than the steel MRR, and 4 times higher than the aluminum MRR, these hypotheses authenticate the milling parameters of the studied composites.

In test group was estimated by volumetric coefficient of chips ω to have total dependence on the mechanical properties ($\sigma_{máx}$ and K_{IC}) of the material through the data observed in the machined chips CMP and CNCMP.

For all, the composites are also promising to HSM machining, and the studied composites probably gets the expected success in applying these materials in the fabric manufacturing of molds for injection and/or prototypes of composites.

3. ACKNOWLEDGEMENTS

For Institutions CAPES-CNPq in the feasibility of Minter-Manaus, UTFPR being the director, FAPEAM for keep the aid, SUFRAMA in financial partnership, SENAI-AM in manufacturing support and also the host institution IFAM.

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