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Surface Finishing and Damage in Metal Matrix Composite Machining

E.S. Jesus Filho and J.L. Rossi

Instituto de Pesquisas Energéticas e Nucleares - IPEN, Powder Processing Centre - CCP,
P. O. Box 11.049, CEP 05422-970, S. Paulo, SP, Brazil

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Abstract This work aims an experimental evaluation of damage and surface finishing caused by machining tools in metal matrix composites. The material was produced by hot extrusion of a powder's mixture. The matrix was an aluminium AA 1100 reinforced with 15% volume fraction of NbC. The machining was performed with hard metal, ceramic and polycrystalline diamond tools. The machining damage and surface finishing effects on mechanical properties are discussed. Attention is given, to the applicability of standard roughness measurement procedures or mathematical roughness modelling that are normally used for conventional materials.

INTRODUCTION

Metal matrix composites (MMCs) have been playing an important role in the materials science field. The search for better components with improved specific mechanical properties can be achieved by joining dissimilar materials. It is obvious that for advanced materials several considerations must be addressed. Among these are the manufacture methodologies for finished products. Machining, for example, is a final operation that may influence mechanical properties. Therefore, possible influences induced in the materials' microstructure by machining must undergo a detailed evaluation. The fabrication of components with good mechanical properties does not imply in optimal machining conditions. In other words, the mechanical properties of a finished product do not have necessarily a direct relation to the best machining condition.

The idea that, more wear resistant tools mean better finishing and less structural damage in metal matrix composites, can be misleading. The literature has shown that tools less hardwearing than polycrystalline diamond (PCD) provide better surface finishing [1, 2]. However, there is no consensus about the best roughness measuring method to evaluate metal matrix composite's surface finishing. Usually, PCD tools show better wear resistance and life usefulness when compared to hard metal tools (coated or not), ceramics or even high speed steels. Besides that, the surface damage caused by machining can substantially reduce some mechanical properties of MMCs. A best compromise between surface finishing and less damage can be achieved in a system where both material and tool are flexible to wear. Even so, residual stresses caused by tool wear during machining, may occur. Therefore, it is desirable to consider the costs involved in each particular case, depending on the production route and final application. It should be also considered, alternative production routes that minimize machining such as near net shape technologies.

EXPERIMENTAL PROCEDURE

The experiment consisted of machining three similar specimens by using three different tools and keeping constant the following parameters: cutting feed (f), cutting speed (V_C) and cutting depth (A_C).

The composite material

The MMC tested was taken from a hot extruded bar produced by powder metallurgy (reduction rate 45:1). The matrix consisted of a commercial aluminium AA 1100 reinforced with 15 % volume fraction of NbC. The aluminium and NbC powders used showed a particle median size of 22 μm and 1.6 μm, respectively. The literature quotes a hardness of 2470 kg/mm^2 for niobium carbide [3]. The production of the MMC by powder metallurgy technique was described elsewhere [4].

Machining

The machining was carried out in a conventional lathe. Initially, the specimens were faced and the centre bore was drilled to ensure uniformity in the tool face entry, avoiding tool cracking or chipping right in the test start and, to make the system stiff by using the lathe chuck and the dead centre [5]. Subsequently, the aluminium alloy layer corresponding to the canning necessary to produce the MMCs by powder metallurgy was machined away from the specimens. At this point, all specimens had a starting diameter of 16.5 mm.

Each specimen was machined with a different tool, hard metal, ceramic or PCD, see Table 1. The machining was done in one single pass with a cutting depth of 1.25 mm (A_C) and a cutting feed (f) of 0.1 mm/rot. over a 70-mm specimen length, see Fig. 1. The cutting depth (A_C) used in the testing was slightly inferior to that recommended by the standard [6] (twice the tool radius). This was done to avoid specimen bending due to excessive cutting stresses that arise from machining reduced size specimens. However, this fact is minimized here, since it is the aim of this work to evaluate the damage caused in the material and not in the machining tool, which is the standard scope.

The cutting speed (V_C) used in the testing was the maximum allowed by the lathe (129.6 m/min corresponding to 2,500 rpm for a specimen starting diameter of 16.5 mm). No cutting fluid or cooling of any kind was used.

The specimen machined surface roughness was measured in a roughness meter and the measurements were expressed in Ra units (average roughness). A qualitative surface observation was carried out by optical microscopy in stereo mode and scanning electron microscopy -- SEM.

TABLE 1. Machining tools and tool holders used in the testing [7].

tool	tool code	tool holder code
hard metal	TCGX16T308AL	STGCR2020K16
ceramic	TPGN110308T01020	CTGPR2525M11ID
PCD	TCMW16T308F	STGCR2020K16

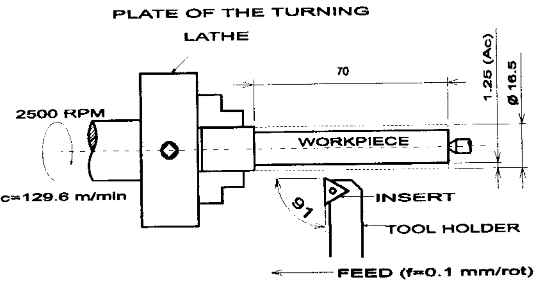

Figure 1. Schematic drawing showing the testing conditions.

RESULTS AND DISCUSSION

Surface finishing

Quantitative analysis

The results of surface roughness are shown in Table 2 and the position where they were measured is illustrated in Fig. 2. A comparison was made with the theoretical roughness obtained with the Eq. 1 that has been used in several works [2, 8, 9].

$$Ra = \frac{32.1 \times f^2}{r} [\mu m], \qquad \text{Eq. 1}$$

where, **f** is the cutting speed in mm/rot. and **r** is the tool-cutting radius in mm.

By using Eq. 1, the calculated roughness was Ra = 0.4 μm, for f = 0.1 mm/rot. and r = 0.8 mm.

All the experimental roughness values were above the calculated. This poses a skepticism about the validity of Eq. 1 and the experimental methodology for metal matrix composite's roughness measuring after machining. Besides that, there is a great dispersion in the experimental data , see Table 2 and Fig. 3. Furthermore, a simple arithmetic average may be not meaningful to indicate composite's roughness with precision and exactness.

Chambers [1] showed some difficulties in measuring roughness and evaluating the surface quality of machined metal matrix composites. Contrasting data were found when results obtained in a roughness meter and by the qualitative analysis performed in a scanning electron microscope – SEM were compared.

The work performed by Sandoz, Tribillon, Gharbi and Devillers [10] using a confocal microscope is very interesting and may represent an alternative for the machined metal matrix composites roughness evaluation. This method allows three-dimensional topographic surface mapping, which could be more significant to metal matrix composites.

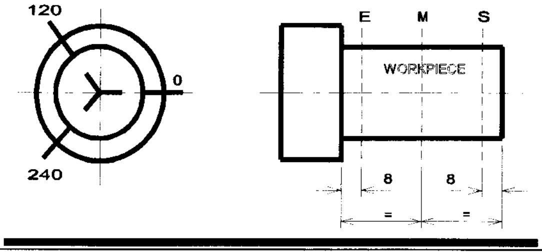

Figure 2. Schematic drawings showing the positions where the roughness measurements were taken on the specimen.

TABLE 2. Roughness measurement data taken at angles φ on the specimens

Roughness Ra (μm)									
	Tools								
Angle	Hard Metal			Ceramic			PCD		
φ	S	M	E	S	M	E	S	M	E
0°	1.16	1.49	0.98	1.62	1.30	1.40	1.19	1.03	1.04
120°	1.50	0.76	0.90	1.79	0.66	1.45	1.41	0.95	0.78
240°	1.87	1.01	0.95	1.02	1.30	1.17	1.35	0.88	1.17

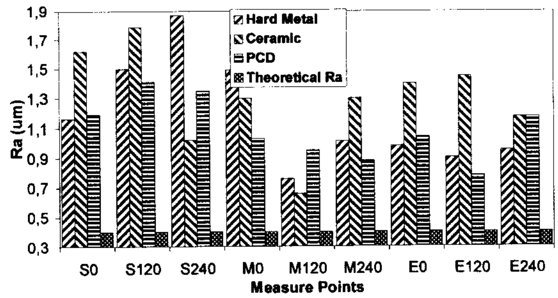

Figure 3. Measured roughness dispersion data

Qualitative analysis

Qualitative analysis by SEM was performed in the middle section (M) of the specimens, see Fig. 2. This analysis showed profiles that were taken with the microscope focused on the specimen curvature in such way that a background relief image was observed, see Figs. 4a, 4b and 4c. The specimen machined with PCD showed a more uniform surface (less relief) in comparison to the specimens machined with hard metal and ceramic tools.

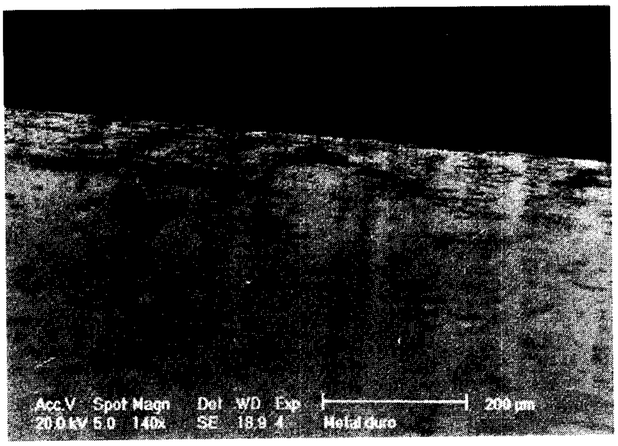

Figure 4a. Profile aspect of the specimen machined with hard metal.

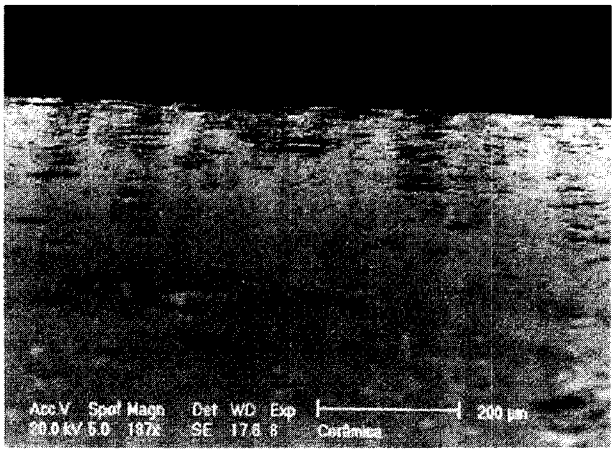

Figure 4b. Profile aspect of the specimen machined with ceramic.

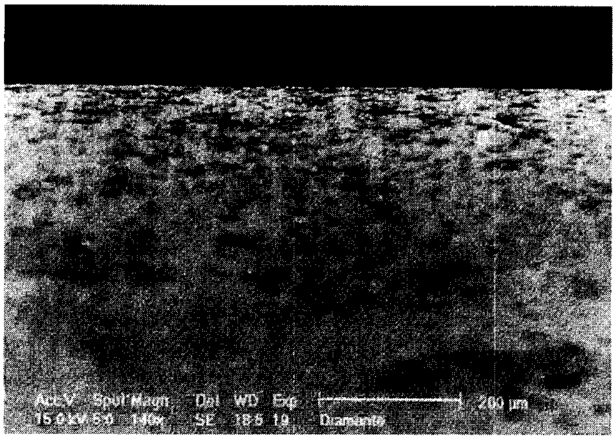

Figure 4c. Profile aspect of the specimen machined with PCD.

The above observations coincide with those made by Chambers [1]. It is quoted that the specimen machined with PCD showed a clean profile. However, Figs. 5a, 5b and 5c which show the specimen surface after machining, contradict the former observation by showing that the surface after machining with PCD tool, see Fig. 5c, shows a more damaged and torn out surface.

A tendency for built-up edge formation was also observed during machining. This was found for the three types of tools, due to the low cutting speed used and the absence of cooling fluid.

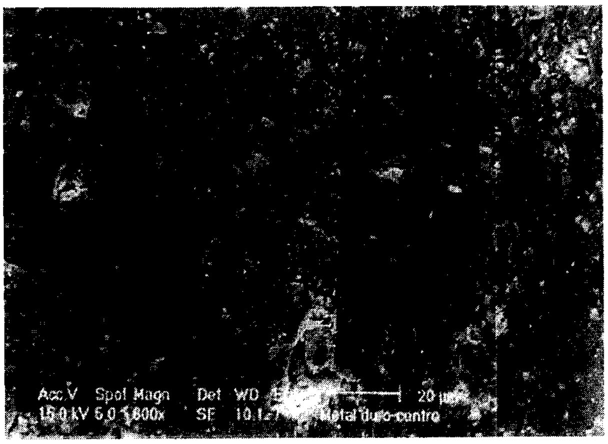

Figure 5a. Surface aspect of the specimen machined with hard metal.

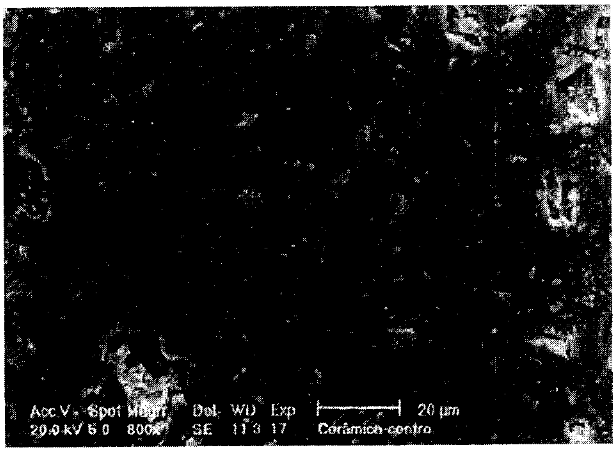

Figure 5b. Surface aspect of the specimen machined with ceramic.

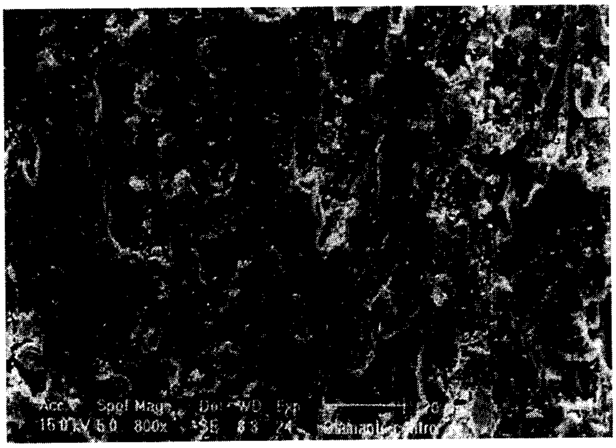

Figure 5c. Surface aspect of the specimen machined with PCD.

The influence of the composite nature on the surface roughness

It is expected that after machining the surface quality will be different from the matrix machined alone, due to the anisotropic nature of the metal matrix composite materials. During machining, the hardest reinforcement particles are pulled out from the matrix leaving craters behind (from the microscopic point of view) in the material surface. This affects the surface quality of the machined material [11]. The more ductile phase (the matrix) is easily sheared during machining. However, it increases the tendency for built-up edge on the tool surface, affecting roughness.

The built-up edge can be reduced by using cooling fluid suitable for high cutting speeds [12]. Therefore, the matrix effect on the final MMC surface quality can be minimized.

Taking into account the reinforcement size, it is expected that the larger the particle size is, the larger the craters or scratches will remain on the surface. So, the surface finishing will be worse. This effect is more pronounced as the reinforcement volume fraction increases.

Regarding the obtainment of MMCs by powder metallurgy, the dimensional context can have other nuances. The relation matrix and reinforcement particle size can be very significant by producing reinforcement agglomeration in the matrix interstices. There, the damage that can be caused by the shock between agglomerates and the machining tool can be increased, depending on consistence and rigidity.

The above observations can explain why Cronjager and Biermann [12] could not find significant differences between the surface quality of the MMC and the aluminium alloy without reinforcement. Also, it explains why the roughness values measured in this work are so different from the theoretical values and so disperse, see Fig. 3.

In the first case, besides the fact that the used reinforcement volume fraction is quite high (10, 20 and 25%), the surface finishing was influenced by the reduced reinforcement particle size (12 - 13 μm) and by the mixture homogeneity. In this work, it is probable that the difference between the aluminium and the reinforcement particle size (22 μm / 1.6 μm) could have caused agglomeration. These agglomerations would behave differently as machined by the several tools, producing roughness values superior to the theoretical ones and very disperse.

From the above consideration, it is reasonable to conclude that **Eq. 1** is more applicable to conventional materials and its applicability to metal matrix composites increases as the size of the harder phase or its volume fraction decreases. So, the reinforcement particle size and volume fraction are important variables and should be taken into account in future works aiming the mathematical modelling of composite surface roughness.

The surface finishing affecting mechanical properties.

It is known that the MMC's fracture behavior is affected by surface defects [8]. Hence, it is important to study and better understand the machining effect on the surface integrity of the MMCs.

Rasul and Meguid [13] concluded that a component obtained with a fine surface finishing is generally less prone to plastic deformation and, consequently, the induced residual tensile stresses will be less intense. They proposed that the surface roughness given in Ra is not enough to define the surface integrity of a material. They also quote that other aspects that can induce mechanical hardening on the material surface, such as different material removal rate, should also be taken into account.

From the above considerations and results obtained from this work, it is possible to admit that the tool material can interfere and influence the surface integrity of a metal matrix composite, since it has a strong effect on the damage of the composite surface.

Examining Fig. 5c, many scratches caused by the PCD tool are clearly noticed. These scratches, caused by the drag of the harder phase (reinforcement) upon the softer phase (matrix), causes hardening and localized cross section variations. This fact makes the material more susceptible to loading, specially dynamic loads. The regions, which have undergone machining damage, are more prone to crack nucleation that may take the material to an early failure.

CONCLUSIONS

The PCD tool causes more damage to the composite surface, though it leads to a more uniform machined profile.

Eq. 1 is not adequate to represent the composite material roughness variation, since it does not consider the reinforcement particle size and volume fraction, that are important variables in this case.

The average roughness (Ra) was not efficient to characterize the surface roughness of a machined metal matrix composite.

REFERENCES

[1] A. R. Chambers, Composites 27A, 2 (1996) p. 143-7.
[2] O. Quigley, J. Monaghan, P. O'Reilly,. J. Mat. Proc. Tech.43 (1994) p. 21-36.
[3] E. Storms, The Refractory Carbides. Academic, New York and London, 1967. p. 61-81.
[4] A. Mourisco, F. Ambrozio F. J. L. Rossi, Processing and properties of Al/SiC composites produced by powder metallurgy. Powder Metallurgy World Congress, PM' 94, Vol. III, Paris, France, 1994. p. 1959-62.
[5] D. Ferraresi; Metals machining basis. Vol. 1, Edgard Blücher, S. Paulo, 1970. p. 609. (In Portuguese)
[6] ISO/DIS 3685 - Tool-life testing with single point turning tools. International Organization for Standardization, 1975. p. 1-51.
[7] Turning tools. Products for metal machining catalogue 93/94. Sandvik Coromant - C-1000:4-SPA. p. 54. (In Spanish).
[8] J. T Lin, D. Bhattacharyya, C. Lane, Wear, 181-183 (1995) p. 883-8.
[9] D. Brazil, J. Monaghan, Proc. 12th Conf. Irish Manuf. Comm., IMC12, Competitive Manufacturing, 1995. p. 177-84.
[10] P. Sandoz, G. Tribillon, T. Gharbi, R. Devillers, Wear, 201 (1996) p. 186-92.
[11] N. Tomac, K. Tonessen, Machinability of particulate aluminium matrix composites. Annals of the CIRP, Vol. 41/1/1992. p. 55-8
[12] L. Cronjäger, D. Biermann, Turning of metal matrix composites. In: T.W. Clyne, P. J. Withers, eds. Proc. of the 2nd Eur. Conf. Adv. Mat. Proc, EUROMAT 91, Cambridge, Vol. 2, 1991. p. 73-80.
[13] T. Rasul, S.A. Meguid, Mat. Sci. and Tech.12 (1996) p. 445-9.

esjfilho@net.ipen.br, jelrossi@net.ipen.br

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