# CHARACTERIZATION OF BURR FORMED ON ENGINE BLOCKS USING METALOGRAPHIC TECHNIQUES

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***Abstract.*** *This work presents the results of a study on burr formed during face milling of motor engine blocks of grey cast iron using metallographic techniques and an image analyser software. Samples were taken out from the exit face edges of engine blocks after face milling with ceramic and PCBN tools and metalographically analysed. Cutting conditions were varied and the results were compared to those found in a previous work where the dimensions of the burrs were determined using the displacement control of the CNC machine-tool used in the tests.*

***Keywords:*** *Burr formation; Milling process; Image analyzer; Ceramic tools; PCBN tools.*

## 1. Introduction

In manufacturing processes of recent days production of high quality components, and this depends on surface qualities, is of prime importance for competitiveness. To achieve this it is necessary to invest in research in order to have the manufacturing process dominated and under control to guarantee the product manufactured at the least time and lowest cost possible.

In machining processes much time has been dedicated to study tool wear because many details and mechanisms are associated to it and any attempt to minimise the wear will prolong tool lives and therefore reduce manufacturing costs. For quality achievements research has been directed to surface integrity and this comprises sub-surface alterations and surface roughness and its related parameters principally $R_a$ (roughness average), $R_t$ (the vertical height between the highest and lowest points of the profile within the evaluation length) and waviness, $W_t$ (parameter relative to $R_t$).

Burr formation is also a matter of concern because burrs are always present and practically impossible to be eliminated, but they can be minimised, though. The presence of burrs is extremely undesirable in the production line because they may offer risks to the machine operator, hinder parts' assembly besides deteriorate surface integrity and accelerate tool wear. An additional operation is therefore required, namely *deburring*, which is an undesirable operation because it spends time and increases costs.

The search for cost reduction has lead the manufacturing industries to develop advanced technologies such as *High Speed Cutting* – HSC, which uses cutting speeds well above the normally used, requiring rigid and high quality machine tools that provides high spindle speed without vibrating. The new generation of tool materials, including ceramics and ultra-hard materials (CBN, PCBN and PCD) has also contributed to this new technology. However, even though HSC has diminished manufacturing time, it was not able to avoid burr formation.

Particularly at the assembly sector of the head and the motor engine block in the car manufacturing industry the surfaces of the components must be free of burr because a joint goes in between them to guarantee sealing and this follows a manufacturer' standard to achieve the required performance of the engine.

The burr formation process is complex because it involves tri-dimensional plastic deformation with high degree of freedom, that is, highly dependent upon several parameters. Thereby theoretical analysis of burr formation is a complex task (Nakayama & Arai, 1987).

Gillespie and Blotter (1976) identified three basic mechanisms of burr formation: a lateral deformation involving material flux to the free surface of the workpiece; chip bending to the same cut direction as the tool reaches the workpiece end tensile rupture of the material located between the chip and the piece. According to these mechanisms they classified the burrs in four types: *Poisson* bur, *rollover* bur, *tear* burr and rupture or *cut-off* burr.

Another classification was given by Nakayama and Arai (1987) according to the cutting edge involved in the burr formation: main cutting edge and secondary cutting edge. They also classified them according to the direction of their formation relative to the tool: entrance burr, lateral burr, exit burr and inclination burr.

Ko and Dornfeld (1996) identified the sequence of steps for the burr formation: continuous cut, pre-initiation, pivoting and development of a negative shear zone. From this point onwards the identification of the burr will be a function of the work material properties. For ductile materials a burr may form while for brittle material, such as grey cast iron, the rupture of the negative shear plane (Pekelharing, 1978) may occurs leading to a phenomenon known as *break-out*.

Ko and Dornfeld (1996) after exhaustively studying the stress and strain present at the cutting region concluded that they play an important hole in the process of burr formation and also in the process of *break-out* that may scrap the workpiece.

The burr can be characterized by their geometrical dimensions and two parameters are normally used: its thickness "B" and its height "H" as illustrated in Figure 1.

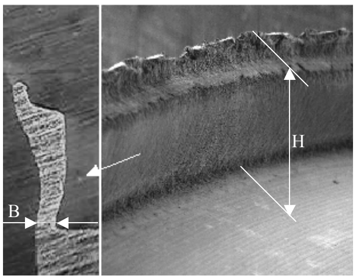


Figura 1. Main parameters used to characterize a burr: its thickness "B" and its height "H" (Kaminise et al., 2001)

Articles about burr are not abundant in the literature and the few available normally shows great interest in the mechanism of burr formation and in the behavior of the burr dimensions with the main cutting parameters.

Studies on burr formation and burr behavior comprise one active research area at the Machining Research and Teaching Laboratory (LEPU) of the Mechanical Engineering Faculty (FEMEC) of Federal University of Uberlândia (UFU). The first work was presented by Kaminise et al. (2001) and by Machado et. al. (2003) after studying burr formation processes in turning of ABNT 1045 carbon steel. This was followed by the work developed by Da Silva (2004) when the burr formed during milling of engine blocks was studied.

Da Silva' (2003) studies were motivated by the work developed by Souz Jr. (2001), when investigating the tool lives of ceramic and PCBN tools in face milling engine block of grey cast iron he came across with the undesirable presence of the burr. Immediately a work was proposed with the objective of investigating the burr behavior under these circumstances. Both Souza Jr (2001) and Da Silva (2004) observed that burr with higher dimensions were located at the centre of the exit face edge, denoted as the *critical point*. They also pointed out that the burrs formed at the exit face edges (where the tool leaves the engine block) were far bigger than those formed at the entrance face edge (where the tool enters into the engine block).

Da Silva (2004) used a methodology proposed by LEPU's research team to measure the burr height "H". An electronic device was design to detect contact of a stylus with the workpiece. A sound and a light alert the person developing the measure, indicating contact. The burr dimensions could then be measured placing the stylus at the two positions illustrated in Figure 2 and using the displacement control of the machine-tool.

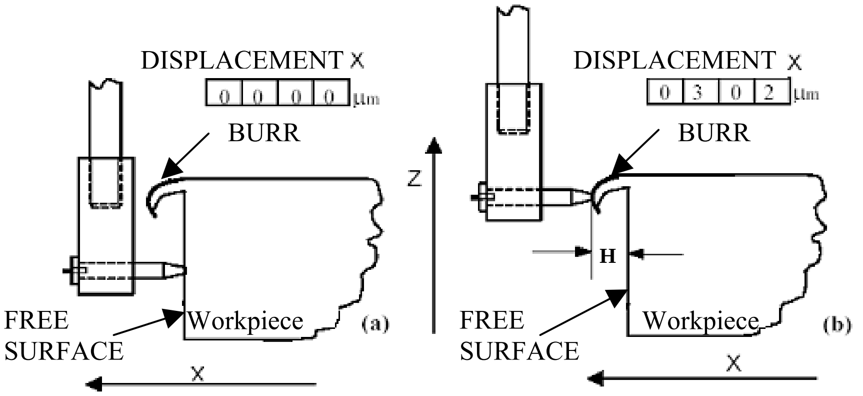


Figure 2 – System used by Da Silva (2004) to measure the burr

The purpose of the present work is to repeat the machining tests carried out by Da Silva (2004) and, using metallographic technique, to measure the dimensions of the burrs formed at the exit face edges of the engine blocks with the aid of an image analyzer and to compare the results obtained from the two measuring techniques. The metallographic technique, besides the dimensions, will also provide details of the burr morphology.

## 2. Experimental Procedure

Face milling tests were carried out in engine blocks (FIRE motors of Fiat Powertrain Tchnology) of GH190 grey cast iron, with an average hardness between 190 to 240 HB and Yong modulus of 117700N/mm$^2$, using ceramic and PCBN tools. A CNC machine-tool center Interact IV, manufactured by ROMI, with 7.5 CV of motor power was used. Figure 3 shows the top view of the engine block, identifying the exit face edge where the burrs were controlled.

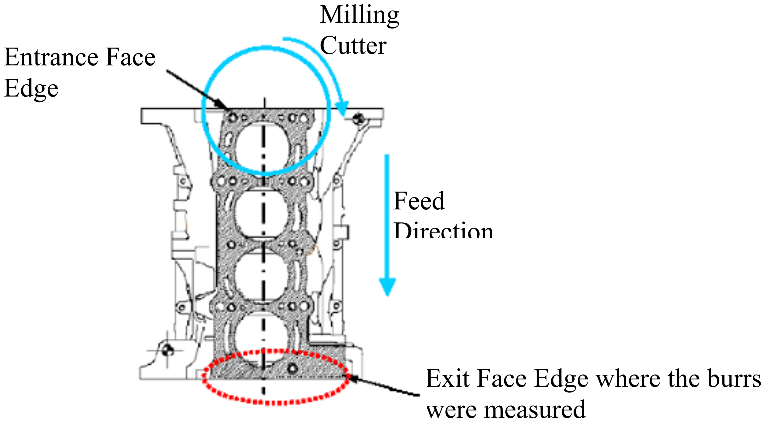


Figure 3. Top view of the engine block illustrating the edge where the burrs were controlled (Souza Jr, 2001)

The milling cutter has a diameter of 160 mm manufactured by Walter do Brasil with the flowing specification: F-2146.0.40.063.160. This cutter is able to have twenty two octo inserts clamped on it. Eighteen of them are roughing inserts and four wipers (or finishing) inserts. The wiper inserts can be axially adjusted to guarantee planarity among them and a good surface finishing. Figure 4 shows details of this system. The ISO geometries of the inserts are OPHN0504ZZN for the roughing and OPHX0504ZZR for the wiper inserts. Both $Si_3N_4$ and PCBN inserts were manufactured by Walter do Brasil. The latter are a thin layer of PCBN brazed on cemented carbide tips. Figure 5 shows the two types of inserts used.


(a) (b)

Figure 4. (a) The milling cutter used in the tests; (b) Detail of the screw that allow axial adjustment of the wiper inserts

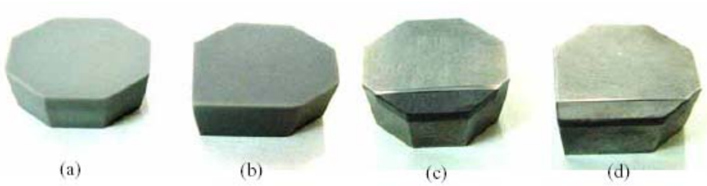


Figure 5. Tool tips used in the tests. Ceramic inserts (a) - roughing (b) - wiper. PCBN inserts (c) - roughing, (d) - wiper

Cutting speed *($V_c$)*, feed per tooth *($f_z$)* and depth of cut *($a_p$)* were varied. The tests were divided in two parts, the first using ceramic inserts and the second using PCBN inserts, according to the diagram of Figure 6 and Table 1. The number of tests were defined by the application of an experimental full factorial planning, resulting in eight [$2^3$] tests with the ceramics and eight with the PCBN tools.

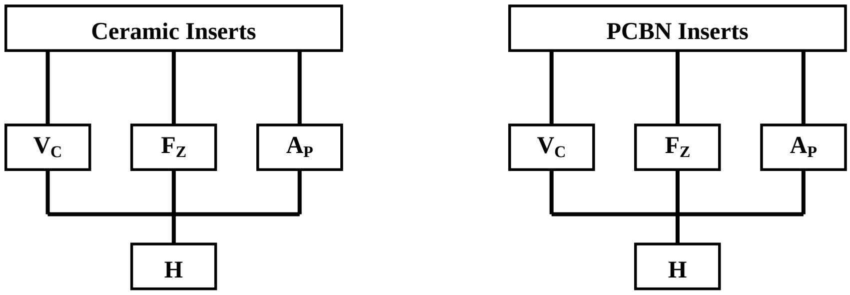


Figure 6. Diagram showing the machining tests for each tool material

Table 1. Cutting parameters used in the tests

| Tools | Cutting speed m/min | Feed per tooth mm/tooth | Depth of cut mm |
|---|---|---|---|
| Ceramic | 1000 | 0,04 | 0,2 |
| | 1500 | 0,08 | 0,5 |
| PCBN | 1000 | 0,04 | 0,2 |
| | 1500 | 0,08 | 0,5 |

The heights of the burrs were measured using an image analyzer software (IP PLUS) after samples from the exit face edges were taken out and metallographic prepared and observed in an optical microscope. Three points of the exit face edge of the engine blocks were considered for sampling after they have been considered of major importance by Da Silva (2004). From each of these points a sample was sawed, sandpapered, polished and etched with Nital 4% reagent. They were identified by $A_S$, $I_S$ and $E_S$, respectively, according to the segment showed in Figure 7. The value of each burr height (H) considered was an average of three measurements taken on each sample (each segment), distancing approximately 1 mm from each other (determined by sandpaper grinding and polishing). The angles between the exit face edge and the cutting direction are defined by tool exit angle (θ) and tool entry angle (Ψ) to distinguish the part where the teeth of the cutter exit and entry the block face edge, respectively.

Table 2 present the test sequence of the milling tests with the three main cutter parameters being varied.

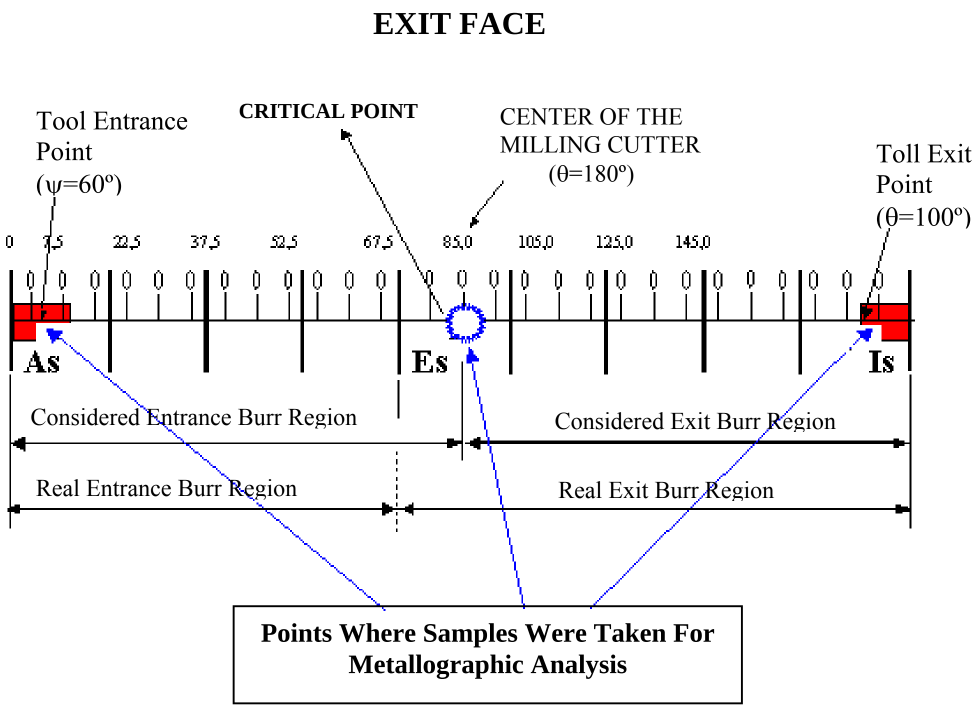


Figure 7. Identification of the three positions at he exit face edge of the engine block after machining where the samples were taken out for measuring the burr dimensions

Table 2. Test sequence and the cutting parameters used

| TESTS | | | | |
|---|---|---|---|---|
| Test number | $V_C$ (m/min) | $F_Z$ (mm/z) | $a_P$ (mm) | Tool |
| 1 | 1500 | 0,04 | 0,5 | CERAMIC |
| 2 | 1500 | 0,08 | 0,5 | CERAMIC |
| 3 | 1500 | 0,04 | 0,5 | PCBN |
| 4 | 1500 | 0,08 | 0,5 | PCBN |
| 5 | 1500 | 0,08 | 0,2 | CERAMIC |
| 6 | 1000 | 0,08 | 0,2 | CERAMIC |
| 7 | 1500 | 0,08 | 0,2 | PCBN |
| 8 | 1000 | 0,08 | 0,2 | PCBN |
| 9 | 1000 | 0,04 | 0,2 | CERAMIC |
| 10 | 1500 | 0,04 | 0,2 | CERAMIC |
| 11 | 1000 | 0,04 | 0,2 | PCBN |
| 12 | 1500 | 0,04 | 0,2 | PCBN |
| 13 | 1000 | 0,08 | 0,5 | CERAMIC |
| 14 | 1000 | 0,04 | 0,5 | CERAMIC |
| 15 | 1000 | 0,08 | 0,5 | PCBN |
| 16 | 1000 | 0,04 | 0,5 | PCBN |

## 3. Results and Discussions

Table 3 shows the average height H of the burrs at each segment $A_S$, $E_S$ and $I_S$ identified in Figure 7. Actually two measures are presented in this table, one using the metallographic and image analyzer software (hereby denoted by MET) and the other using the electronic device used by Da Silva (2004) (hereby denoted by ELECT).

Table 3. Burr height obtained using metallographic (MET) and electronic (ELECT) technique

| BURR HEIGHT "H" [µm] | | | | | | | |
|---|---|---|---|---|---|---|---|
| TEST NUMBER | $A_S$ ($\psi = 60^O$) | | $E_S$ ($\theta = 180^O$) | | $I_S$ ($\theta = 100^O$) | | TOOL |
| | MET | ELECT | MET | ELECT | MET | ELECT | |
| 1 | 55,18 | 10,00 | 129,84 | 91,42 | 34,60 | 22,50 | CERAMIC |
| 2 | 17,19 | 20,92 | 69,43 | 84,59 | 44,69 | 45,92 | CERAMIC |
| 3 | 20,63 | 81,17 | 67,04 | 116,08 | 38,96 | 106,83 | PCBN |
| 4 | 75,34 | 65,33 | 102,5 | 106,34 | 95,89 | 102,17 | PCBN |
| 5 | 13,12 | 22,25 | 38,91 | 68,25 | 58,43 | 48,83 | CERAMIC |
| 6 | 29,79 | 23,25 | 71,06 | 76,92 | 69,91 | 34,25 | CERAMIC |
| 7 | 30,09 | 63,42 | 82,54 | 92,08 | 98,14 | 88,17 | PCBN |
| 8 | 26,36 | 58,33 | 37,17 | 86,08 | 33,23 | 85,33 | PCBN |
| 9 | 69,91 | 15,42 | 110,44 | 96,08 | 95,13 | 42,75 | CERAMIC |
| 10 | 38,96 | 30,42 | 22,92 | 94,00 | 63,03 | 42,17 | CERAMIC |
| 11 | 24,64 | 48,09 | 68,76 | 96,17 | 47,56 | 107,17 | PCBN |
| 12 | 14,89 | 45,34 | 31,00 | 110,17 | 48,137 | 120,08 | PCBN |
| 13 | 34,38 | 33,92 | 74,49 | 76,75 | 44,69 | 58,92 | CERAMIC |
| 14 | 60,74 | 19,25 | 84,03 | 87,67 | 85,96 | 34,25 | CERAMIC |
| 15 | 31,58 | 55,33 | 46,99 | 80,25 | 49,67 | 54,59 | PCBN |
| 16 | 40,15 | 90,25 | 73,20 | 134,25 | 56,52 | 119,08 | PCBN |

Analysis of Table 3 confirms that generally, the segment $E_s$ with the tool exit angle = 180° shows the highest value of the burr height regardless the technique used to measure it. Furthermore, the burrs formed where the teeth of tool enter the workpiece (segment $A_s$), generally showed the lowest values. Using MET technique test nº 1, $E_s$ segment ($\theta = 180^o$) showed the highest burr value (H = 129,84 µm) and test nº 12, $A_S$ segment ($\Psi=60^o$) the lowest (H = 14,89 µm).

The values of the burr's height given by the MET technique are generally smaller than using ELECT technique. The main reason for this result may be the fact that the burr is very irregular in size along the face edges of the engine blocks. SEM photo shown at the end of this document (Figure 12) illustrates this. The MET technique measures it in one point, while the ELECT technique measures it in a region of the size of the stylus point angle, which in this case was 2 mm. Besides of that, the considered value is an average of three measurements for both technique, however, the distance of them for the MET technique is a few millimeters (approximately 1 mm, given by sandpaper grinding and polishing) and for the ELECT technique this distance is approximately 7 mm (Figure 7). Therefore, the MET technique provides an average value more realistic in the direction of the burr height but less realistic in the direction along the face edges of the engine blocks.

Figure 8 shows the burr height as a function of the depth of cut for both ceramic and PCBN tools and for the two measuring techniques used, for the segment $E_S$ ($\theta$ = 180º). The ELECT technique showed only a small influence of the depth of cut on the burr size, while the MET technique clearly showed an increase in the burr height with increasing depth of cut. This last result is more coherent with the literature (Kishimoto et al., 1981) when using small values of depth of cut such as those used here (maximum 0.5 mm).

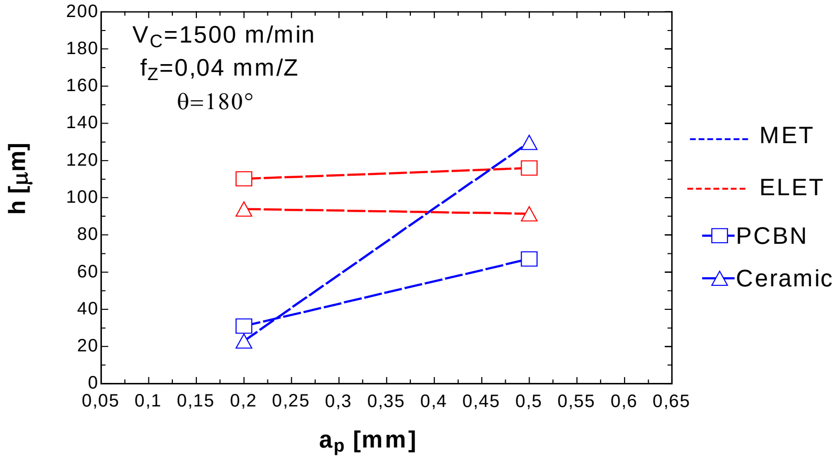


Figure 8. Burr height against the depth of cut for ceramic and PCBN tools, using the cutting conditions shown

Figure 9 shows the burr height as a function of the cutting speed for both ceramic and PCBN tools and for the two measuring techniques used, for the segment $E_S$ ($\theta$ = 180º). The ELECT technique showed a slight tendency of the burr height to increase or to maintain practically constant with increasing cutting speed, while the MET technique presented a more decisive behavior, with the burr height decreasing with increasing cutting speed for both cutting tools used.

Increasing the cutting speed the chip-tool contact length tends to reduce with a corresponding increase on the primary shear angle and, therefore, a proportional increase on the chip thickness ratio (Machado and Da Silva, 2003). These are facts that indicate that the work material has suffered less strain at the primary shear zone and consequently a smaller burr will form. On the other hand, the higher the cutting speed the higher the heat generation and the cutting temperature at the shear zones which tends to leave the material more ductile and this benefits the burr formation process. It seams that the fist argument is overlapping the second.

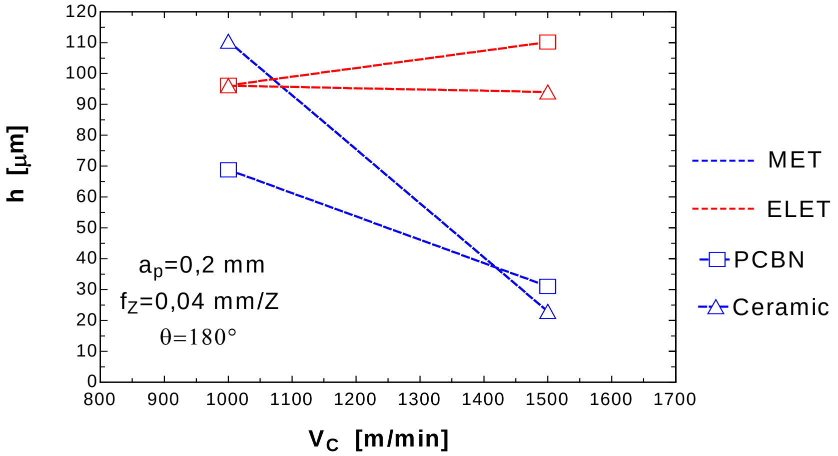


Figure 9. Burr height against the cutting speed for ceramic and PCBN tools, using the cutting conditions shown

Figure 10 shows the burr height as a function of the feed per tooth for both ceramic and PCBN tools and for the two measuring technique used, for the segment $E_S$ ($\theta$ = 180º). It is noticed that increasing the feed per tooth cause reduction on to the burr height regardless the measuring technique and the tool material used.

In milling operations the chip thickness is variable along the cutter diameter, being zero at the exit angle $\theta = 90^o$, and a maximum for $\theta = 180^o$ (such as for the segment $E_s$). With $\theta = 90^o$ (chip thickness equal to zero) the cut will not happen, beginning only after a certain chip thickness is available, when the exit angle is greater than 90°. Before starting to cut the tool will only cause friction on to the work material, generating heat and also deforming it plastically. It may also workhard. This plastic deformation process, in such circumstances, promotes material displacement what Olvera and Barrow (1995) called *ploughing*. As the tooth of the tool travels into the work material the chip thickness augments and the cutting wedge provides sufficient tension for material rupture and thus, the chip starts to form. A similar phenomenon is occurring when the cutter is approaching the exit face of the engine block, prior to emerge it at the centre of the cutter ($\theta = 180^o$). When the feed per tooth is small *ploughing* effect will cause high plastic deformation instead of cutting, which will produce bigger burrs at that point. Increasing the feed per tooth cut will prevail, reducing the *ploughing* effect and plastic deformation, reducing the burr dimension.

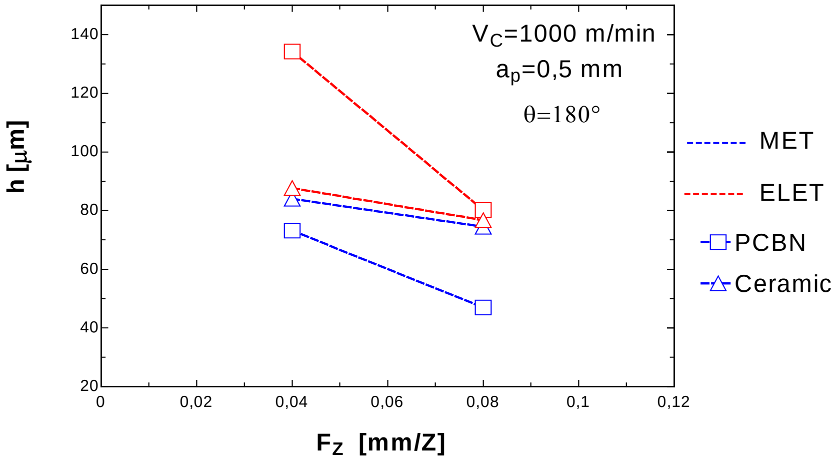


Figure 10. Burr height against the feed per tooth for ceramic and PCBN tools, using the cutting conditions shown

Figures 8 to 10 showed that considering the ELECT burr measuring technique the ceramic tools presented smaller burrs than the PCBN tools. The MET technique showed contrary results, that is, PCBN tools showed smaller burr than ceramic tools. The variation of the burr dimensions along the exit face edge of the engine blocks together with the different distances for measuring the burrs within each segment ($A_S$, $I_S$ and $E_S$) to give the average values for each measuring technique may be responsible for the divergent results.

When using worn tools in similar experiments Da Silva et. al. (2005) showed that ceramic tools always produced higher burrs than PCBN tools. The authors have used ELECT technique to measure the burr height. These results are contrary to those found here with virgin tools (zero wear) and the same measuring technique. This clearly indicates that the wear has a great influence onto the burr formation process (Da Silva, 2004).

Figure 11 presents the micrographs of two samples illustrating the morphology of the burr formed at different positions in the exit edge and under different cutting conditions. In figure 11(a) a characteristic burr form is shown while in Figure 11 (b) the burr resumes only into a plastic deformed material.

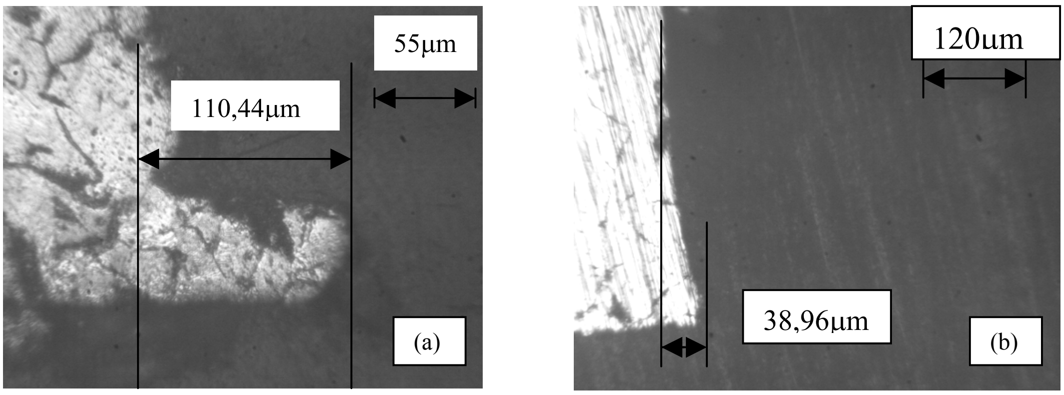


Figure 11. Micrographs of the burrs formed at the exit face edges (a) test nº 9 - $E_S$ segment; and (b) test nº 3 - $I_S$ segment, metallographic technique

Figure 12 presents SEM photos of a *tear* type burr according to the classification given by Gillespie and Blotter (1976), produced after test number 5 of Table 2. It is evident that the burr geometry varies tremendously along the exit border of engine block. Furthermore, the work material is pretty brittle what causes the burr to have a fragmented and irregular characteristic.

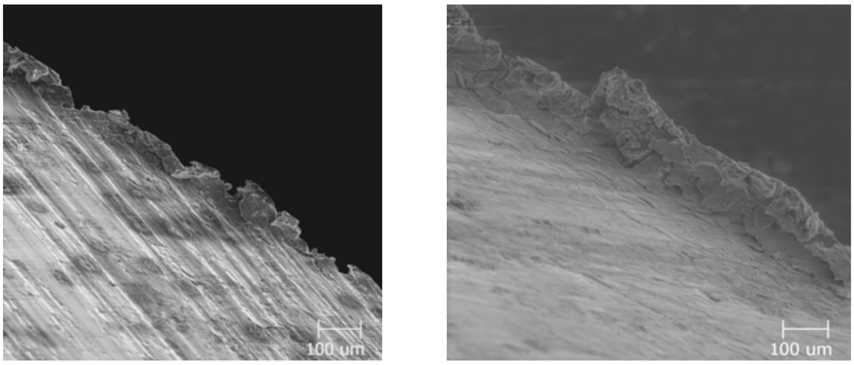


Figure 12. MEV view of segment $E_s$ of test nº 5, metallographic technique

## 4. Conclusions

For the conditions tested the results presented allows the following conclusions to be drawn:

- The metalographic (MET) technique used to measure the burr generally presented burr height values smaller than the electronic (ELECT) technique. These divergences can be attributed to the conspicuous variation of the burr dimensions along the exit border of engine block and the different size of the segment considered for analysis, as well as the influence of the stylus radius of the ELECT technique.
- In general at the cutting conditions investigated the burr sizes decreased with increasing cutting speed.
- The burr size also reduced as the feed per tooth was increased.
- Increasing the depth of cut in the small interval (0.25 to 0.5 mm) the burr size also increased.
- The burr formed by the ceramic tools (new tools), measured with the ELECT technique, are generally smaller than those formed by the PCBN tools. With the MET technique this results are inverted in many situations.

## 5. Acknowledgements

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