Surface changes during turning of grey cast iron

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Abstract: The surface quality and the material near the surface are changed due to stresses induced by the machining process. In this work, surface and subsurface changes caused by turning of grey iron are studied. It was verified the formation of marks caused by the advancing edge of the cutting tool, material override, presence of debris on the surface and micro pores left by the fracture and pullout of graphite flakes. Thus, the surface roughness of the part is the result not only of the marks left by the cutting tool but also from the deformation and micro fractures that this surface undergoes during machining. In the region just below the machined surface it was observed intense plastic deformation of pearlitic matrix, causing thinning and expulsion of graphite through the surface and morphology change of sulphide particles. The implications of these surface features on the performance of the part are discussed.

Keywords: machining; turning; grey iron; surface integrity.

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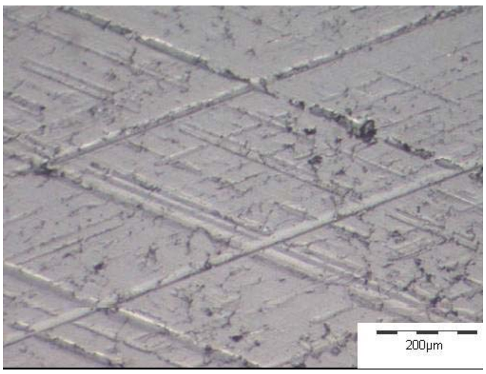
1 Introduction

Machined surfaces will be the working surfaces of automotive components and machine parts, and the properties of these surfaces can significantly affect component performance. Machining operations involve considerable mechanical and thermal stresses, so at the end of machining the work piece surface can have very different properties from its core. This kind of study is called surface integrity, and was review by Bellows et al. (1975) for high strength alloys, looking to prevent fatigue failure. Studies on texture and residuals stresses after machining were conducted by Jawahir et al. (2011) and by Navas et al. (2012).

Figure 1 Honed surface of a cylinder block



Note: Honed grooves and micro pores from the fracture of graphite.

Source: Mocellin (2004)

A classic example in cast iron refers to the honing of cylinder blocks for internal combustion engines. In this case the purpose is to obtain a wear resistant surface containing a net of channels formed by the honing process and a uniform distribution of small pores that act as lubricant retainers, ensuring a constant presence of lubricating oil during the movement of the piston. This distribution of small pores is achieved with the fracture and removal of graphite particles in contact with the surface. In addition, the honing operation is conducted so as to prevent deformation of the surface, which could result in delamination that could covers the pores left by the graphite fractured (Figure 1). From the standpoint of the material, it is a pearlitic grey iron (to provide high wear resistance and hinder the formation of delamination in honing) with graphite particles finely divided (to provide small and well distributed pores).

This is an example where the machining operation is planned to generate the desired surface properties. However, in many cases the resulting surface properties are very different from the objective.

In turning operation, Marwanga et al. (2000) characterised changes in the microstructure of cast irons in machining. In ductile irons, the graphite nodules ahead of and beneath the cutting undergo severe deformation and are preferentially elongated in the shearing direction. Surface graphite nodules are subjected to micro extrusion processes and 'pop out' during machining. The higher the ferrite content in the matrix structure, the more the plastic deformation and elongation of the graphite nodules. In grey iron the machining characteristics are fundamentally different: very little plastic deformation is observed and fracture events are predominant, associated with the lamellar graphite structure.

This study aims to characterise the machined surfaces for grey cast iron in turning operation, using different cutting speeds. The results presented here are part of the master's thesis at UFSC of one of the authors (Souza Pereira, 2012).

2 Experimental procedure

The tests were conducted with a grey iron grade 250 (4.0% carbon equivalent, 0.10% S, CrCuSn alloyed), with pearlitic matrix and A type graphite. In Figure 2, it is shown the graphite particles and MnS inclusions. In Table 1, one can see the size and amount of graphite and MnS particles.

Figure 2 Grey iron grade 250, with pearlitic matrix, graphite particles and MnS inclusions (see online version for colours)

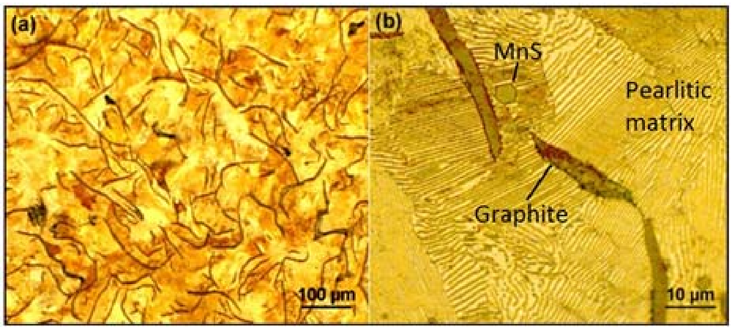
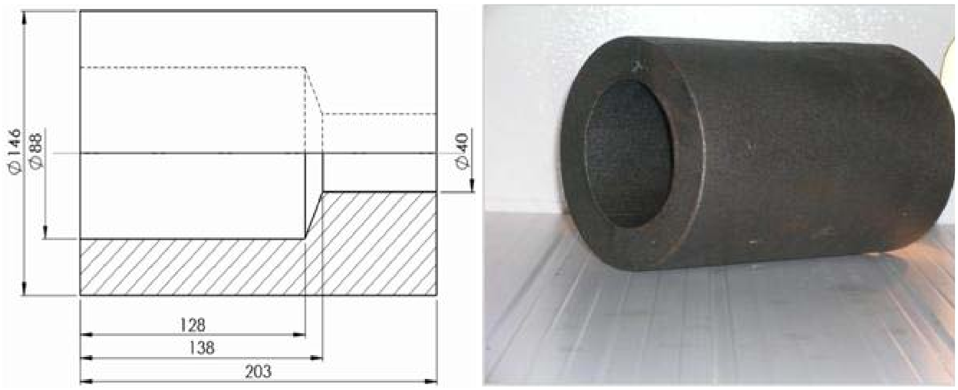


Table 1 Number of particles and size of graphite and manganese sulphide

	Amount	*Size of the particles*
Graphite	134 cells/cm^2	500 µm
MnS	14 particles/mm^2	3 µm

Figure 3 presents the dimensions of the test part, with a section thickness of 29 mm. The machining tests were done on the external surface of the test part. The experiments were performed on a turning centre Heynumat, with nominal power of 75 kW and maximum speed or 4.500 rpm. The tests were performed at four cutting speed (vc = 400 – 700 – 1.200 – 1.400 m/min, feed (f) = 0.2 mm/rev and depth of cut (ap) = 2 mm.

Figure 3 Test part for the turning experiments: machining of the external surface (see online version for colours)



The inserts used were silicon nitride (Si_3N_4), uncoated, grade 6090. It is a negative basic-shape insert (nose radii = 0.8 mm, insert chamfer angle = 20°, insert chamfer width = 0.20 mm, insert thickness = 6.35 mm, insert length = 12 mm). To characterise the texture of machined surface, roughness measurements were performed at 100 mm from the edge of the specimen making up seven measurements, using a portable roughness Mitutoyo SJ 201P model. The parameters Ra, Rz and Ry were characterised.

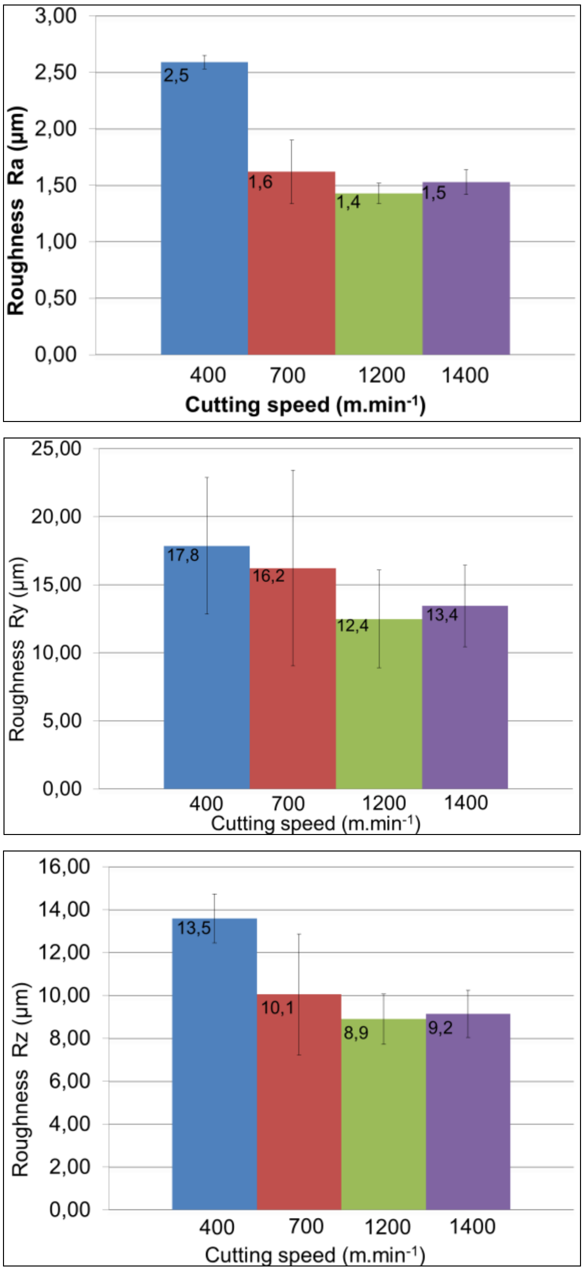
The characterisation of the surface texture was complemented by the use of a scanning electron microscope, trying to verify the presence of micro pores, delamination and adhesions on the surface of the specimen. The evaluation of the integrity of the machined surface was performed by examining the microstructure just under the machined surface.

Further details of the experimental procedures can be seen in Souza Pereira (2012) and Souza Pereira et al. (2012).

3 Results and discussions

The results of surface roughness of the machined samples may be observed in Figure 4, referring to the parameters Ra, Ry and Rz for the various cutting speeds tested.

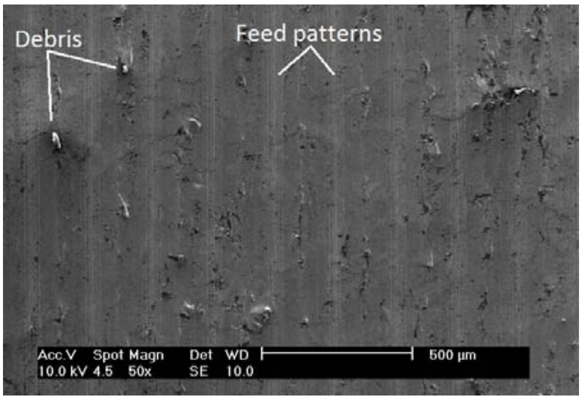
Figure 4 Surface roughness results, Ra, Ry, Rz (see online version for colours)



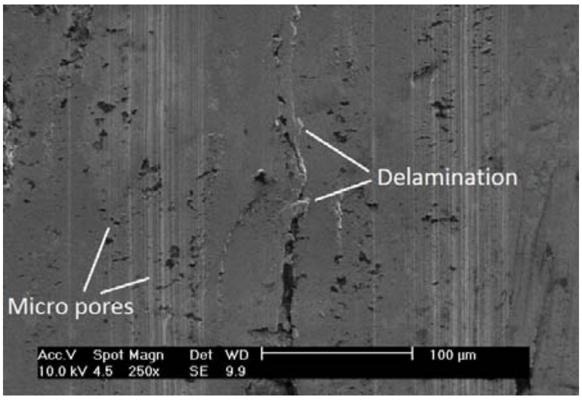
The results show that the roughness obtained at v_c = 400 m/min is higher than those obtained at higher cutting speeds. This observation needs further confirmation, since the dispersions on the roughness value are very high. This behaviour agrees with previous studies in the literature (Boehs, 1979; Machado and Silva, 2004; Diniz et al., 2003). At the speed of 1,400 m/min it was found a small increase of roughness, which was attributed to vibration of the test piece at this speed, caused by lack of rigidity of the specimen holding device.

Figures 5–7 show the machined surfaces observed in scanning electron microscopy (SEM).

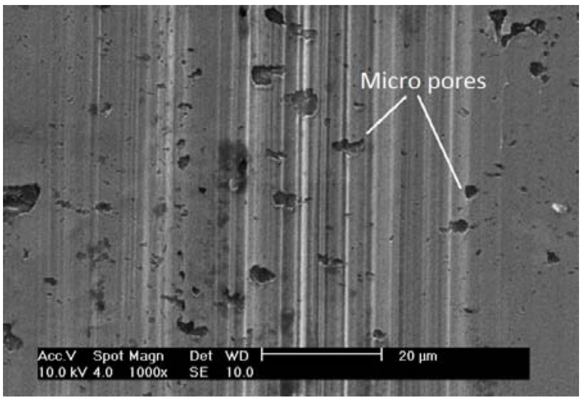
Figure 5 SEM of the test pice machined at $v_c = 400$ m.min^{-1}, showing (a) deposited particles and feed patterns, (b) delamination and (c) pores and feed patterns (50 – 250 – 1.000 x)



(a)

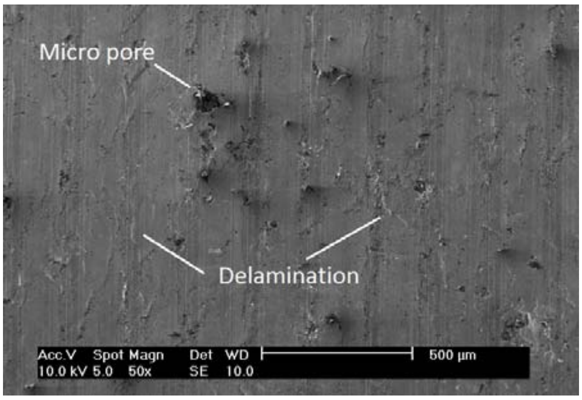


(b)

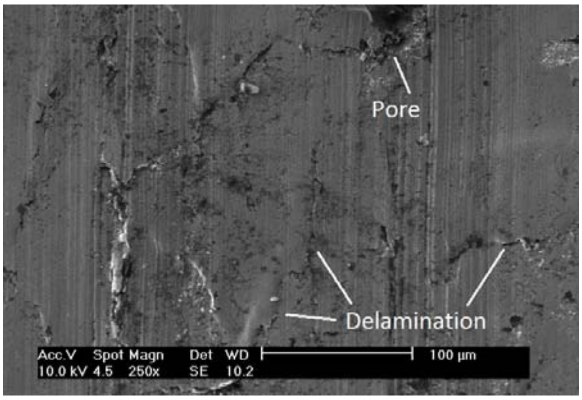


(c)

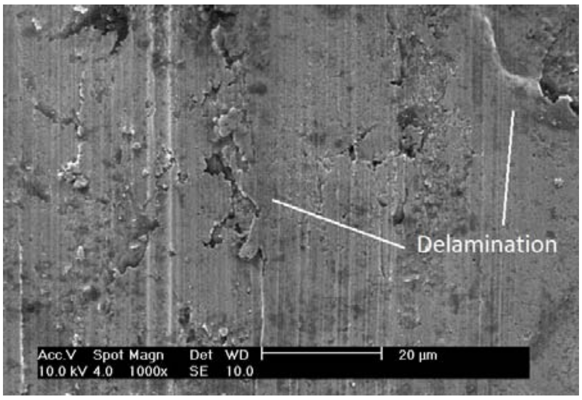
Figure 6 SEM of the test pice machined at v_c = 1.200 m.min_1, showing (a) deposited particles and pores, (b) overlay material and pores and (c) feed pattern and overlay material (50 – 250 – 1.000 x)



(a)

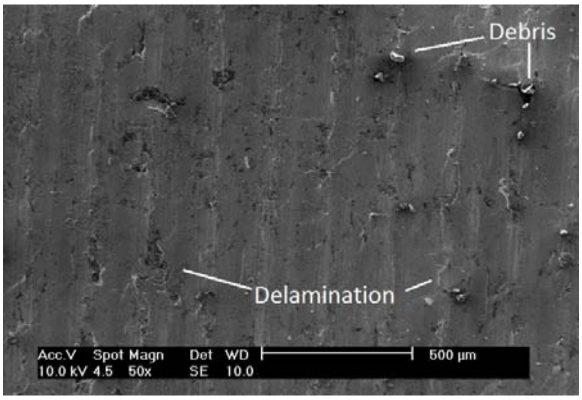


(b)

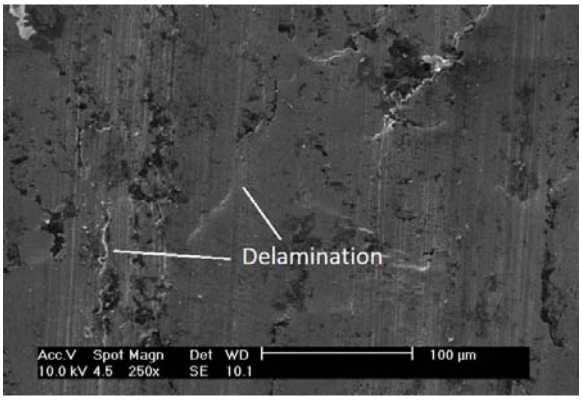


(c)

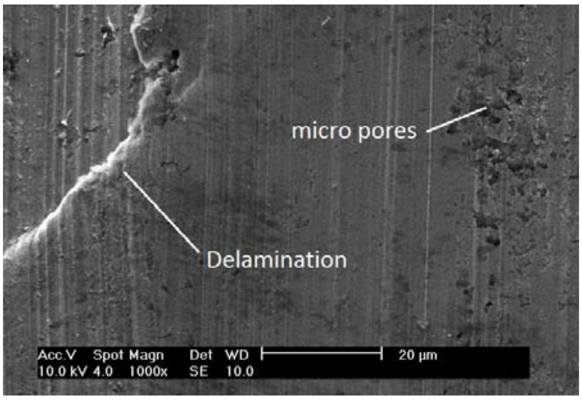
Figure 7 SEM of the test pice machined at v_c = 1.400 m.min^{-1}, showing (a) deposited particles, (b) pores and (c) feed pattern and overlay material (50 – 250 – 1.000 x)



(a)



(b)

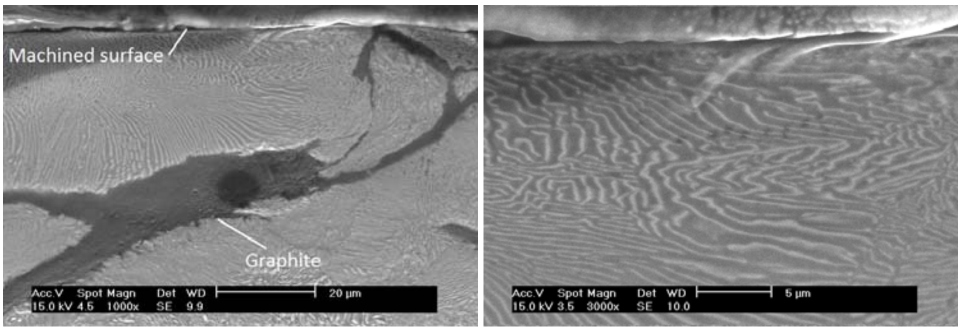


(c)

Some important aspects must be stressed:

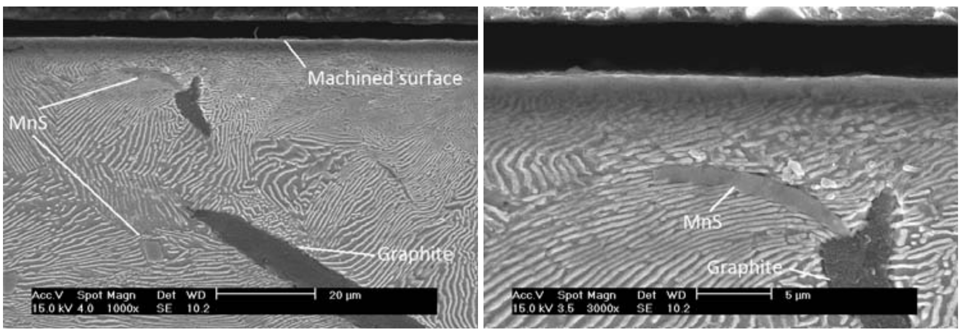
- Tool feed patterns on the work piece surface caused by the cutting tool edge. These patterns have unidirectional orientation, perpendicular to the view plane, characteristic of turning process. They can be minimised by finishing operations.
- Material overlay (delamination). It is associated with intense plastic deformation, tearing and micro welding on the surface. Delamination increases as the cutting speed increases.
- Deposited particles.
- Pores left by the fracture and pullout of graphite flakes and the adjacent matrix. This is also called 'open grain'. It appears as small cavities evenly distributed on the machined surface, affecting the surface quality. The size of graphite flakes and the selected cutting depth affect the size of these cavities (Souto et al., 2002, 2003). Increasing the cutting speed increases the size of these fractured areas associated with graphite (compare Figures 5 and 6).

Figure 8 SEM of longitudinal section of the specimen showing the integrity of the layer below the machined surface



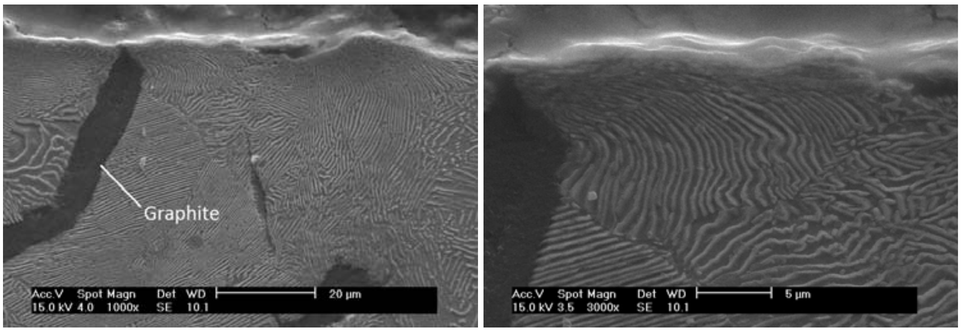
Notes: v_c = 400 m/min. Modifications on the pearlitic matrix and extrusion of graphite particles.

Figure 9 SEM of longitudinal section of the specimen showing the integrity of the layer below the machined surface



Notes: v_c = 1.200 m/ min. Modifications on the pearlitic matrix and on graphite and MnS particles.

Figure 10 SEM of longitudinal section of the specimen showing the integrity of the layer below the machined surface

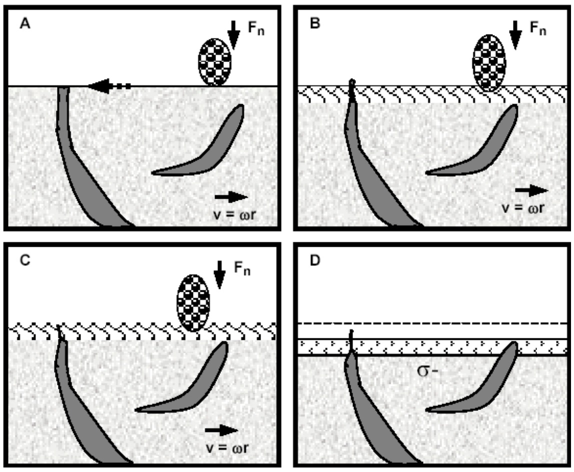


Notes: v_c = 1.400 m/min. Modifications on the pearlitic matrix and on graphite and MnS particles.

It thus appears that the roughness data presented above are the result not only of the marks left by the cutting tool, but also the deformation and micro fractures the surface suffers during the machining process.

Figures 8 to 10 show the microstructure of samples in regions below the machined surface.

Figure 11 Scheme of graphite pullout during wear of a brake disc



Notes: A – action of the normal force and graphite compression; B – surface runoff with graphite extrusion; C – volume collapse occupied by graphite; D – sealing by compressive residual stresses and wear.

Source: Serbino (2005)

It was observed:

- Severe plastic deformation of pearlitic matrix, with fracture of the lamellar cementite of pearlite. Figures 8(b), 9(b) and 10(b) show the deformation of pearlitic matrix just under the machined surface. Figure 9(b) shows the intense fragmentation of cementite lamellae, accompanying the intense plastic deformation of ferrite.

- Plastic deformation of the matrix involving the graphite particles, with thinning of the shafts and expulsion of graphite across the surface. Figure 8(a) shows the thinning of the graphite and its expulsion through the surface. This mechanism has been observed in wear analysis, and presents the sequence of events shown in Figure 11 (Serbino, 2005).
- Plastic deformation of the manganese sulphide particles as shown in Figures 9(a) and 9(b). The particles of polyhedral morphology originally present are elongated, showing the intense local plastic deformation. This had already been registered in machining chip studies by Pereira (2005), but here it is shown that this change in morphology of sulphides occurred before the formation of the chip, then staying in the machined surface.

4 Conclusions

The observations made on machined surfaces and on the matrix below the surface have highlighted the intense plastic deformation involving the turning of grey cast iron, resulting in fracture of the lamellar cementite of pearlite, deformation of the particles of manganese sulfide, thinning of the graphite particles and their expulsion from the surface. In the machined surface it was shown the presence of micro pores resulting from the fracture of graphite flakes and the surrounding matrix, which are partially blocked by the plastic deformation of the pearlitic matrix. Severe plastic deformation still results in delamination, with material adhesions on machined surface.

These surface features remain in the work piece, and can influence their performance in service, so that the decision on the need for finishing machining operations must be taken into account not only according to the desired surface finish but also on the microstructure near and at the surface.

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