# DEEP DRILLING IN GG25 GRAY CAST IRON USING TUNGSTEN CARBIDE DRILLS WITH STRAIGHT FLUTES

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***Abstract.*** *The drilling process is one of the most important processes of metal cutting used in the manufacturing industry, responsible for approximately 30% of all the machining operations. Almost 60% of all the drilling applications in the mechanical industry are related to short holes, with a depth up to 2.5 times the tool diameter. However, a great number of operations in the industry require a length-to-diameter ratio greater than 5 times tool diameter. These type of operations, known as deep drilling, normally need the use of special tools and devices. The deep drilling is a process of high complexity due to its special difficulties such as cutting in a closed and limited space, high cutting temperature and the difficulty of chip formation and removal. Such conditions involve the chip formation and the flow difficulty, the tool overhang length, the surface quality and the hole geometric and form tolerances. This work presents an analysis of the performance of four different types of carbide drill geometries in drilling of GG25 gray cast iron. The experiments have been carried out in line of production and laboratory, using tungsten carbide drills with straight flutes and internal cutting fluid. This research verified the influence of geometry modifications on the tool over the quality of deep holes. The variables evaluated were the cylindricity, roundness, surface roughness and diameter. With the results obtained in this work it was possible to acquire a major knowledge on the deep drilling process of gray cast iron, which allow improvements in the production of pieces in industrial scale.*

***Keywords:*** *deep drilling, carbide drills, straight flutes, GG25 gray cast iron.*

## 1. Introduction

The drilling process is nowadays an operation with huge numbers of applications in the industry. Although the most holes are short, in a significant parcel the relation length/diameter is greater than five. This kind of process, named deep drilling, is a complex operation because of the difficult chip formation and flow, the tool overhang length, the surface quality and the demanded hole geometric and form tolerances. Thus the deep drilling needs special conditions to be made, such as the adequate tools and the coolant fluid injection under pressure in the cutting area (Tönshoff, 1994; Stemmer, 2001; Aronson, 2003). In some cases, the deep drilling can also be executed by conventional helical drills, using interruption cycles in the process for chip removal (Aranson, 2003; El-Khabeery *et al.* 1990).

The deep drilling is widely used in the manufacture of mechanical components as crankshafts, conrods, hidraulic cylinders, turbines parts, heat exchangers etc. In a global industry which is necessary care with quality rigid norms, a machining process inside of a production line must conjugate the quality of the machining parts and the tool life, in short time of manufacture.

This study aims to analyze the performance of four different types of carbide drill geometries in drilling of GG25 gray cast iron. Moreover, this research has for objective to generate information about the disturbing factors in the process, which are directly related with the machine-tool, the workpiece part, the tool and the cutting parameters. The variables evaluated were the hole's cylindricity, roundness, surface roughness and diameter.

With the results obtained in this work it was possible to acquire a major knowledge on the deep drilling process of gray cast iron, which allow improvements in the production of pieces in industrial scale.

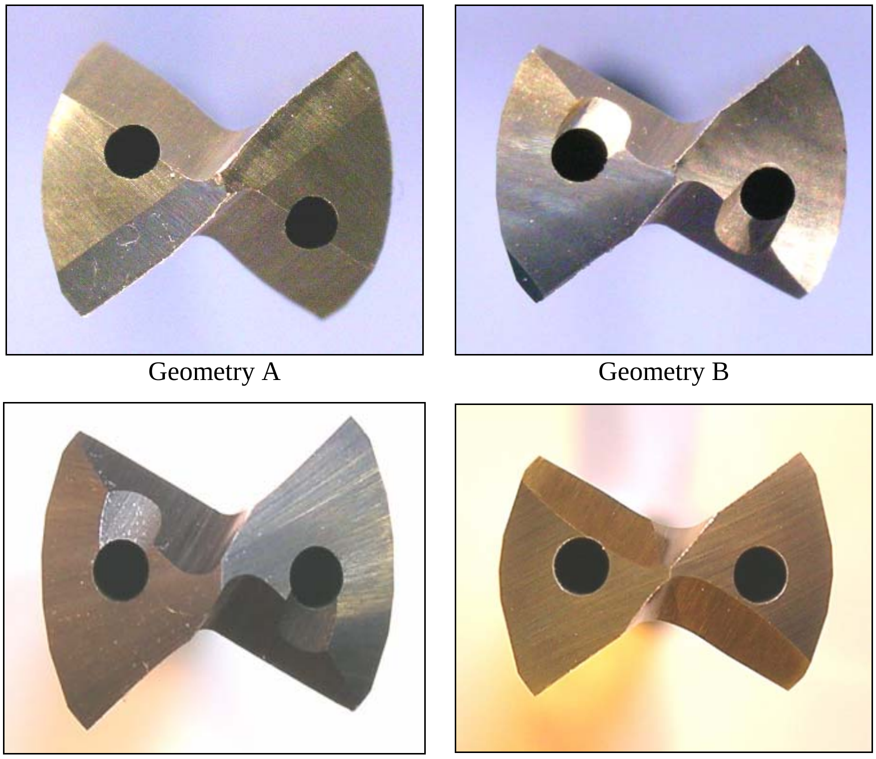
## 2. Experimental Details

The specimens used were turned and faced cylindrical pieces in gray cast iron GG25, with 72 mm length and 16 mm diameter. The specimen hardness value was 260 HB, with a 10 HB standard deviation.

The feed force acquisitions were made in a three axis numerical command milling machine, Romi Polaris F400, installed in the Mechanical Precision Laboratory (LMP) – UFSC. This machine has a vertical arbor with 6.000 rpm highest rotation. In this machine, it was install a high pressure coolant fluid system, and the work pressure was 25 bar.

The wear tests were developed in a drilling horizontal machine commanded by CLP, whose maxim spindle rotation is 5.000 rpm. This machine possesses a rotating tool configuration and the workpiece is submitted to a pneumatic clamping system.

In this work it was used a set of twelve carbide drills, with 9.5 mm diameter and four different sharpening, classified as A, B, C, and D geometries. The Figure. 1 shows the four drills geometries characteristics. This carbide tools are K20 class with straight flutes and internal refrigeration orifices.



Geometry A    Geometry B

Geometry C    Geometry D

Figure 1. Geometries of tools used

The Table 1 describes the main characteristics of the four drill geometries. The tools present different sharpened geometry with variations related to the point angle, clearance angle, chisel edge angle, chisel edge length and width guide. The cutting parameters were based in the normalized numbers R20 series, extracted from the DIN 323 standard. The cutting parameters are shown at Table 2.

Table 1. Tool's specifications

| **Geometry** | **A** | **B** | **C** | **D** |
|---|---|---|---|---|
| Point angle $\sigma$ [°] | 120 | 140 | 140 | 120 |
| Clearance angle $\alpha$ [°] | 12 | 14 | 14 | 20 |
| Chisel edge angle $\psi$ [°] | 68 | 48 | 48 | 55 |
| Chisel edge length [mm] | 0.64 | 0.63 | 0.63 | 0.30 |
| Width guide [mm] | 0.70 | 0.76 | 0.72 | 0.75 |
| Diameter Ø [mm] | 9.55 | 9.55 | 9.55 | 9.55 |

Table 2. Cutting conditions tested

| **Condition** | **$v_c$ [m/min]** | **f [mm]** |
|---|---|---|
| 1 | 112 | 0.08 |
| 2 | 125 | 0.08 |
| 3 | 140 | 0.08 |

The cutting fluid used was a semi-synthetic emulsion oil, with 8% of concentration. The cutting fluid supply was made internally through refrigeration orifices in the tools. The injection pressure was kept constant at 25 bar for all the tests.

The machinig forces experiments have as objective to test parameters related to the efforts generated by the process in diverse cutting conditions. Variables such as: speed, feed, tool geometry, cutting fluid and wear influence the forces directly. The results obtained allow establish relations between the parameters of the testes and the generated forces, the quality and the failure mechanisms tool.

The infrastructure used for measure forces consists in a Kistler AG drilling piezoelectric platform (model 9273), two Kistler amplifiers (model 5011), an acquisition data board (model SCB-68) and a microcomputer with acquisition signals software. The piezoelectric platform was assembled on the machine's table and over this, a three-jaw chuck, where were fixed the specimens. The system was calibrated before the tests have been started. The calibration was made between the measure range of feed force 0 to 5.000 N and torsion moment between 0 to 1.000 N.cm, with errors smaller than 1%. The acquisition time and frequency used were 25 seconds and 0.5 kHz respectively.

The systematic used in the forces measurement was always the same all along the work. In general way, three repetitions had been carried in all testes and the acquisition occurred always during the machining process, since the beginning of the drilling to the exit of the hole. The feed force and the torsion moment were measured only two times: one on the beginning, with sharpen tools and another time on the end of tool-life. For this test, the hole quality was chosen like tool life criterion (for example marks on the hole's wall, burrs, hole edge breaking).

The holes quality was evaluated through the analysis of different parameters, like the roundness, the cylindricity, the diameter, the roughness and visual quality at the hole exit region. That evaluation aims registering the wear tool influence over hole quality. The methodology was based on the analysis of the specimens collected in defined intervals. The tool life criterion was the number of pieces machined. The test end was determined by the visual inspection of the pieces machined. In this way at moment that the hole had presented the first defect, which the subsequent operation could not eliminate (e.g. reaming operation), the test was over.

For the roughness evaluation it was chosen the Ra parameter because this parameter is normally used in the quality control in machining surfaces destined to the automotive industry. It was taken by roughness limit Ra= 5 µm. The Ra parameter represents the arithmetic mean of the variations absolute values of the real profile in relation to the mean line. To ensure a correct measurement roughness, three repetitions in three different places on the hole wall (entrance and exit hole) were carried out and the average and the dispersion was calculated. To avoid errors on the valuations, all the measurements were made to approximately 3 mm from the hole edge. Those measurements were carried out using a Mitutoyo Surftest model SJ 301.

For the diameter hole valuation, the same criterion was used: three measurements on the entrance and three on the hole exit and the average and dispersion were calculated. In the same way for the roughness evaluation, all diameter measurements were made approximately 3 mm from the hole edge. For these measurements, a three points internal micrometer was used.

The roundness and the cylindricity were analyzed using a Mitutoyo roundness tester model RA – 400. The specimens were fixed and aligned on the equipment table. Afterwards, using a feeler, three measurements on different sections were made all along the hole (entrance, middle and exit). Thus, three roundness values and another value of cylindricity were obtained.

For the qualitative evaluation of the different tested drill geometries performance, at each end of tool-life it was collected and photographed the last machined piece. Afterwards, a comparison between each tested conditions and each drill geometry was made. The analysis was made on hole exit side, because it is where occurs the most number of quality problems.

## 3. RESULTS AND DISCUSSIONS

Next the drill geometries performance results are presented in relation to the machining forces, roughness, geometric and form tolerances and hole quality at the exit side.

### 3.1 Feed force analysis

All geometries showed a similar behavior for the feed force in the three cutting speeds, whith sharpen tool. This fact agrees with a many authors that proved the low influence of the cutting speed over the machining forces (Stemmer, 2001; König, 1997; Ferraresi, 1977).

For the end of tool-life condition, the result tendencies differ significantly for the different geometries of all the conditions. This performance can occurs because of the difficulty to finish each test exactly at the same wear level for all the conditions tested. The criterion for finish each test was the hole quality. So, it is possible that the forces can vary because the own wear level in each tool. The Figure 2 shows the feed force values for new tools and on their end of tool-life, for the third cutting condition.

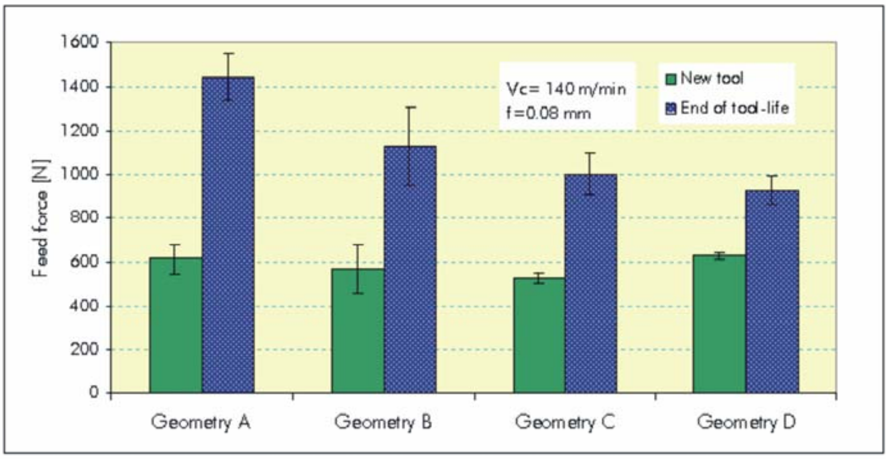



Figure 2. Feed forces – condition 3

For each one of the three machining conditions, three holes were made to valuate the feed force. The results showed on the Figure 3 represent the average of the three repetitions of the effective feed force and its dispersion for each condition tested.

The measurements results were submitted to variance analysis, with 95% significance level, to verify the existence of significant differences. The statistics analysis made for the three cutting speeds for the sharpened tools has confirmed that the differences between the results are significant. Although, it was difficult to conclude which geometry presented resulted better in relation to the machining forces. It can be perceived that, for the D geometry tool the forces had been always bigger in relation to the other geometries, even this is similar to A geometry tool in relation to the point angle of 120°. An hypothesis for the explanation of this phenomenon is the influence of the sharpening finishing on the tool faces and the flanks over the machining forces (Stemmer, 2001; Ferraresi, 1977; Micheletti, 1980). The attrition coefficient on the tool geometry is directly related to the wear mechanisms like adhesion and abrasion, which have a negative influence in relation to the tool life and the machining forces (El-khabeery *et al*., 1990; Coldwell *et al*., 2004). Because the D geometry tool be the only one sharpened in a conventional sharpening machine among all carried out (the surfaces quality in this drill was worse in relation to the sharpening geometries machined in a sharpening CNC 5 axis machine), it is possible that this difference has been determinative on the worse performance of the D geometry tool in relation to the machining forces, although this geometry have the biggest clearance angle among all tested geometries.

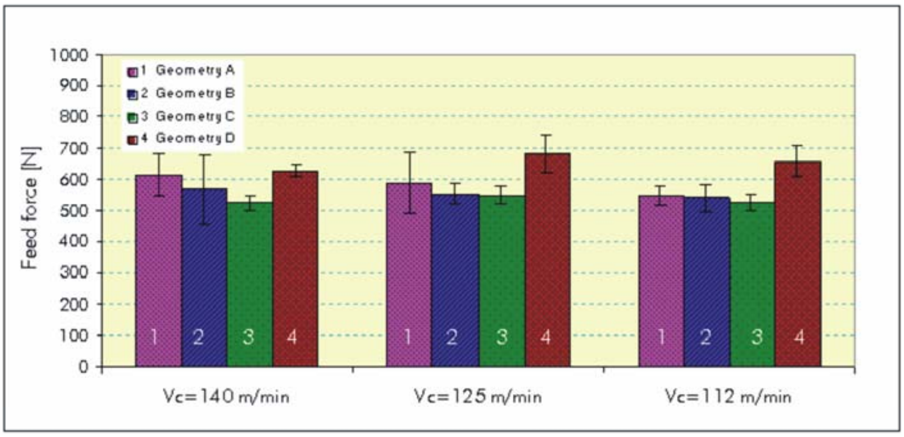



Figure 3. Feed forces for sharpened tools

### 3.2 Torsion moment analysis

The result tendencies of torsion moment maintained the same tendency showed by the feed forces. It was observed a significant increase on the torsion moment results between sharpened tools and end of tool-life drills. This behavior may be justified by the tendency to the increase of machining forces due to the tool wear level, after the tests ended (Stemmer, 2001; Aronson, 2003; El-khabeery *et al*., 1990; Ferraresi, 1977).

The end of tool-life result tendencies was clearly different. The result tendencies differ significantly for the different geometries of all the conditions. This performance can occurs because of the difficulty to finish each test exactly at the same wear level for all the conditions tested.

The obtained results for the sharpened tools, at the conditions of 112 and 125 m/min were similar. A better performance for B geometry tool was observed, with lower torsion moment. The worst performance was shown by D geometry tool. On the other hand, for the 140 m/min's cutting speed (Fig. 4), C geometry tool showed the lowest torsion moment value and D geometry tool maintained the highest value.

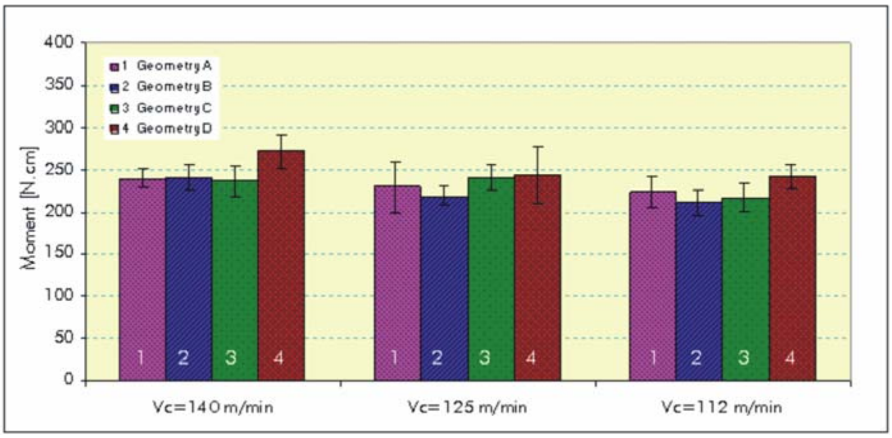



Figure 4. Moment for sharpened tools condition

### 3.3 Surface quality

The roughness dispersions resulted in the three speed conditions had kept in low levels. This means that did not have great differences between the measurements carried through for each body of test (enter and exit hole).

In this assessment, in the speed conditions tested, a speed influence over the roughness $R_a$ on the holes machined was not observed. The result trends had practically been constant with few variations all along the tool-life.

The Fig. 5 shows the roughness values in function of the machined holes number for all the tool geometries, at the condition 1. It is perceived that all the geometries resulted in similar values for the $R_a$ roughness parameter. Those values varied between 1.3 and 2.3 µm.

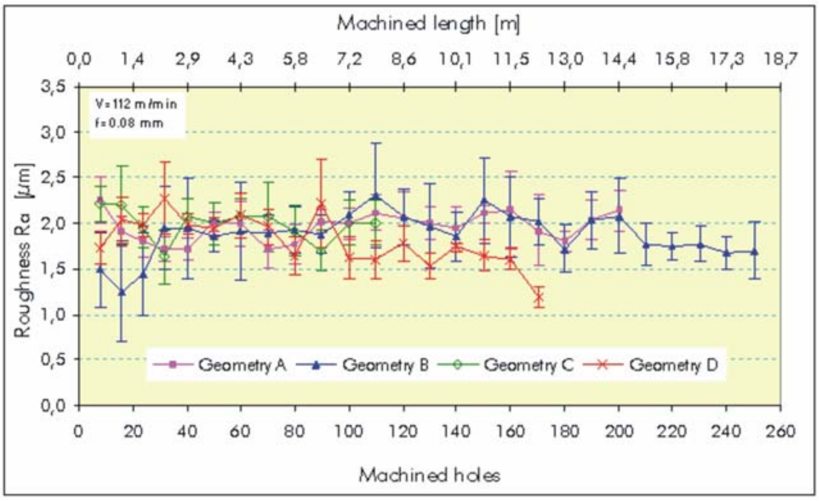



Figure 5. Roughness $R_a$ – condition 1

For the other conditions, it was obtained a similar tendency, with roughness values varying in a range of 1.0 to 2.5 µm and also it was not possible to determine which geometry obtained the best performance for the quality on the wall hole surface roughness.

### 3.4 Roundness error

At the machining conditions 1 and 2, it was perceived that the roundness results were uniform during all the tool-life, for all the geometries.

Observing the Fig. 6, for the condition 3, it is perceived that, with exception of the initial holes, the A, C and D geometries showed some instability, wich is not verified for B geometry tool. A hypothesis for this fact is that the chamfered noses of B geometry tool may have positively influenced the roundness, since the corners with radius or chamfers contribute for the reduction of problems on the hole exit.

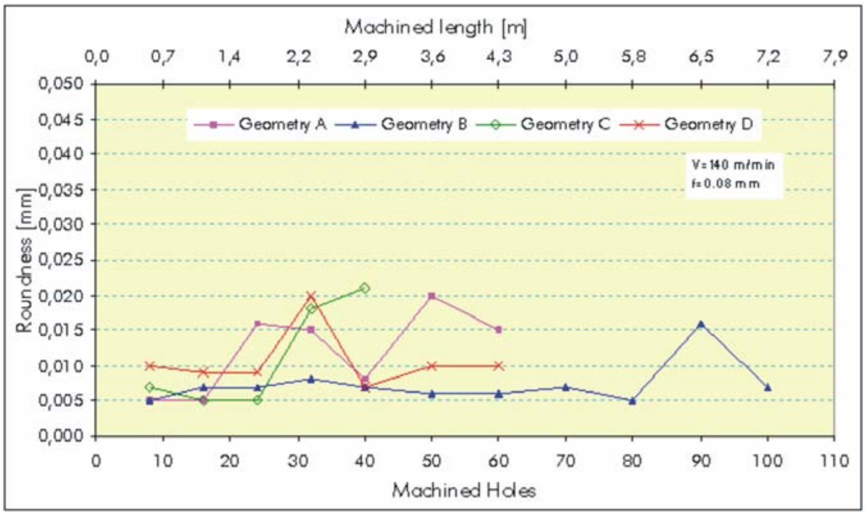



Figure 6. Roundness – condition 3

### 3.5 Cylindricity error

In all conditions, it was observed some variation of the cylindricity results for all the geometries. On the other hand, the B geometry showed the greater stability.

At condition 3, Fig. 7, a great instability for D geometry tool is perceived and a reasonable variation of the results for A and C geometry tools, with exception of the initial holes, while the B geometry tool showed a defined tendency all along the tool-life. A possible explanation for the D geometry tool results is that, according to Coldwell *et al*. (2004), on drilling the high machining efforts are related with high roundness values, showing problems chips evacuation. This phenomenon may occur at condition 3, because of its higher cutting speed produces a greater chips volume in a smaller time interval, making it difficult for the chip flow.

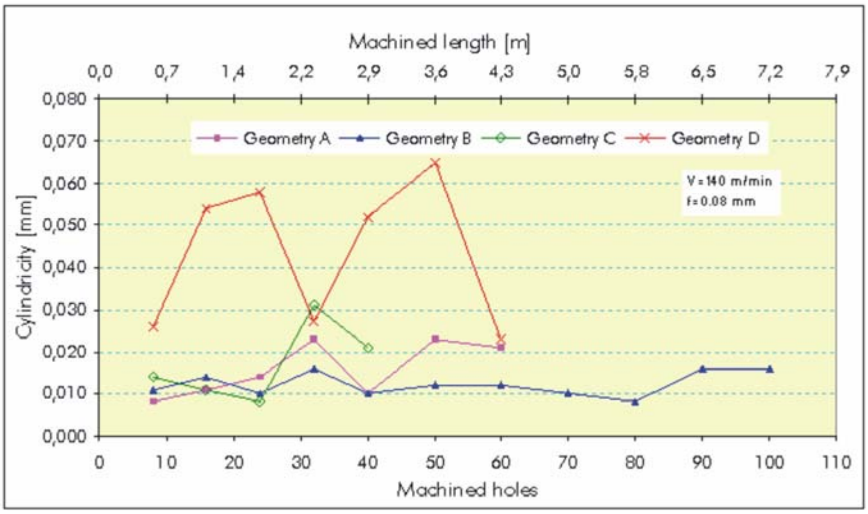



Figure 7. Cilindricity – condition 3

### 3.6 Hole Diameters

The better hole quality obtained with the tools tested in all the machining conditions correspond to IT9 class. This quality was obtained by B geometry tool, in the conditions 1 and 3, and by C geometry tool in the condition 2 (Fig. 8). According to König (1997), on cast iron deep hole drilling process, it is possible to obtain IT9 hole quality. The same result was verified by Santos (1999) for integral carbide drills with straight flutes.

A low tendency of diameter holes reduction was observed all along the tool-life. This fact is attributed to the gradual tool's wear, this tendency was observed for all the geometries, with bigger dispersion in the D geometry tool.

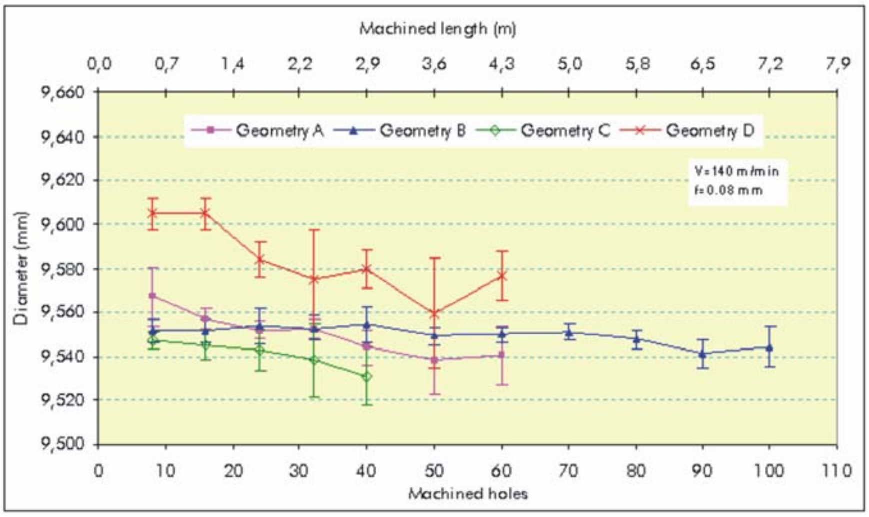



Figure 8. Evolution of the hole diameter – condition 3

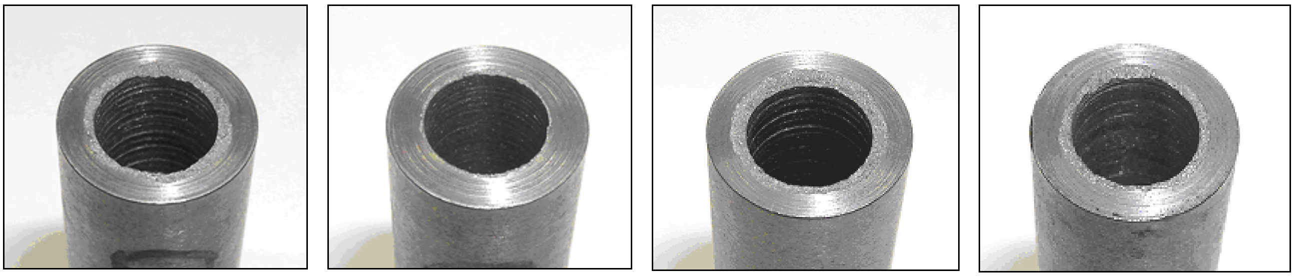
### 3.7 Qualitative analysis of the machined holes

Through this analysis it was possible to establish that the feed is a determinative factor in the hole quality in gray cast iron machining. A higher feed, added to a wear tool, can generate defects of breakings in the hole exit side edge (Stemmer, 2001; Soares, 1995).

In machining holes with the A geometry tool for condition 1 and 2, the results obtained was satisfactory, with small breakings in the hole edge and few marks in the machining surface.

The B geometry tool presented a good finishing for the three machining conditions. The holes did not show marks at the surface, with small breakings in the edge and a good roughness values ($R_a$ close to 2 µm). From this point of view, geometry with chamfered noses can bring benefits for minimizing the breakings in the hole edge, keeping a satisfactory roughness (Aronson, 2003; Soares, 1995).

Figure 9 shows the hole qualitative analysis results in the condition 3, where the defects in the hole edge are evident except for the tool with B geometry tool, which presented a good performance in all the tested conditions.



Geometry A Geometry B Geometry C Geometry D

Figure 9. Hole qualitative analysis – condition 3

In the testes carried through with C geometry tool in relation to the hole edge, the results obtained in the conditions 1 and 2 was acceptable (it means that piece is suitable for a subsequent operation without quality problems, in this case reaming operation for example). With this geometry a surface without marks was obtained, with the condition 3 exception, which presented spiral marks. In relation to D geometry tool, this presented deficient result in relation to the hole edge quality, in the three conditions had been observed.

## 4. Conclusions

This paper established a comparison between four different geometries of tools, where a force increase higher than 30% between the new and the end of tool-life condition was found. This increase shows the effects of a deficient cut carried through by tools that normally present a significant wear in its end of tool-life.

The D geometry tool showed the highest force values in all conditions carried out. This geometry tool had low sharpened surface quality due to conventional grinding process. This leads to confirm the influence of surface quality tool (face, flank, guides etc.) over the machining forces.

The machined surface obtained by all geometry tools tested was considered satisfactory, below the limit of $R_a$ = 5 μm used in this work. The $R_a$ roughness values in all machining conditions tested was inside the range of 1.0 and 3.0 μm.

All geometries tested showed a good stability on roundness and cylindricity parameters in the machining condition 1 and 2. In the condition 3, using cutting speed of 140 m/min, it was observed that the B geometry tool showed the best performance. The best hole quality was IT9 class, which was obtained with the B and C geometry.

The qualitative comparison showed that the best results were obtained by the geometry B. The holes machined with this tool had no surface marks, breakings on the edge and showed a good machining surface roughness. This geometry tool which has chamfered noses showed the best performance and stability of results in the machining of gray cast iron GG25 with the feed and speed tested. Chamfered noses contribute for a good finishing and prevent breakings in the edge of the holes.

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