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THE EFFECTS OF CHAMFERED AND HONED TOOL EDGE GEOMETRY ON DRILLING PROCESS OF SAE 4144M STEEL

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Abstract. *Cutting edge preparation, when properly carried out, increases the strength of the tool's cutting edge and the tool's life. The edge of the twist drill, for instance, can be protected by rounding, chamfering or the combination of both. This paper aims to analyze the influence of edge protection by two different methods, honing and chamfer on a solid carbide twist drill for drilling of SAE 4144M steel used in injection pumps for diesel engines. The diameter of the bores, roughness and roundness revealed significant differences in results. It was observed that the cutting edges of tools without protection undergo great cut pressures that lead to further tool failure, causing significant tool's life instability when compared to those tools whose cutting edges are protected by honing, which showed lower tool wear.*

Keywords: *Drilling, Twist drill, Re-sharpening, Honing, Edge geometry*

1. INTRODUCTION

In order to achieve the product's specifications and production requirements, all processes parameters that influence productivity and quality must be considered. Regarding machining process with defined cutting edges and especially when a cemented carbide tool (WC-Co) is used, it is very important to consider the tool's cutting edge geometry, material, coatings and wear, as well as the cut parameters, process kinematics and row material (KLOKE, 2011; SME, 1999).

There are four linked aspects in the development of high performance cutting tools: Substrate, coating, macro-geometry and cutting edge preparation. As far as the substrate is concerned, it is possible to find a lot of grade with different grain size on the market. In regarding to coating it is possible to choose according to the tool's applications (FRIEMUTH, 2002; PRENGEL1998; TÖNSHOFF, 2004). However, when it comes to macro-geometry different geometries to apply in different kind of materials can be easily found in the literature, but studies about cutting edge preparation are quite rare, especially when applied to twist drills, since most of these studies are related to either turning or milling process (RODRIGUES, 2009).

There are many kinds of cutting edge preparation processes applied in the industry as magnetic abrasive, polishing, abrasive flow machining, abrasive filled nylon filament brushing, abrasive blasting, electro-discharge machining, water jet machining, micro grinding and others (GILLESPIE, 1999; RODRIGUES, 2009).

The geometry of the edge preparation influences the thermomechanical aspects of the cutting process, such as shape of the deformation zone, temperature distribution in the cutting process, machining forces, chip formation and flow, superficial integrity of the work piece and the tool's resistance to wear (DENKENA et al., 2011, HOSSENI, 2012, WOON et al., 2008_1, WOON et al., 2008_2, HEO et al., 2011). Due to its importance in the machining field, cutting edge failures and some benefits related to the protection of the cutting edge achieved in different processes have been the subject of studies from several researchers (BIERMANN et al., 2008, BIERMANN et al., 2012, BOUZAKIS et al., 2000)

Edge preparation has been made to avoid common defects from the sharpening process such as chipping, cracks and breakage in order mainly to improve the tool life by changing the micro-topography of cutting edge and also to adapt the surface of the cutting edge for a subsequent coating process of the tools (CHEUNG, 2008; RECH, 2006). Some authors presented results which showed the influence of edge preparation on the machining surface quality, tool wear, cutting forces and temperatures (FANG, 2005; BOUZAKIS et al, 2003; ÖZEL, 2005; RANGANATH et al., 2007).

This paper presents the influence of the cutting edge geometry (chamfered and honed) on the bores diameter, roughness, roundness and its tool life.

The workpieces that was used in this study were unit pump bodies designed to raise the pressure and inject diesel in the diesel injection system from the diesel engines. These workpieces were made at a multinational company in the same condition as used in their current production line.

2. EXPERIMENTAL DETAILS

The workpieces' raw material is from SAE 4144M forged, quenched end tempered (38HRc) steel, with a 100% martensitic structure. In figure 1 it is possible to see the workpiece's raw material composition and in figure 2 its micro-structure is shown.

Carbon	Manganese	Phosphorus	Sulfur	Silicon	Copper	Chromium	Nickel	Molybdenum
0,42% a 0,46%	0,90% a 1,00%	0,025% máx	0,01% a 0,02%	0,20% a 0,30%	0,35% máx	1,15% a 1,30%	0,25% máx	0,25% a 0,35%

Figure 1. Workpiece's raw material composition

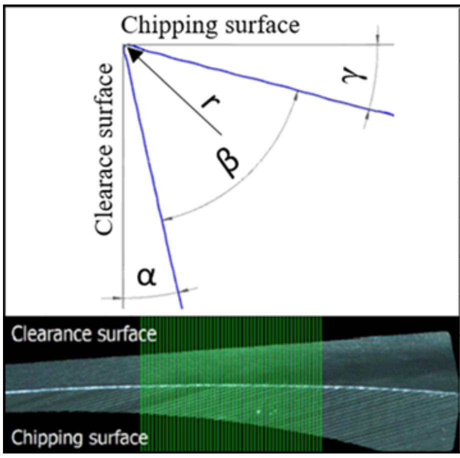
Figure 2. Workpiece's raw material micro-structure (100% martensitic)

The machine used for conducting the machining tests was a CNC vertical lathe, manufactured by EMAG, model VSC-250.

For machining, tungsten cemented carbide twist drills with Ø11mm were used, coated with a 3µm layer AlCrN-Based (Helica® from Oerlinkon Balzers), with three different cutting edge geometries, sharpened, chamfered and honed as illustrated in figures 3, 4 and 5.

The tools' macro geometries (chip angle, clearance angle and drill point angle) were prepared on a CNC grinding machine manufactured by Walter, model Power Production. In order to perform the micro geometry (chamfer and hone) some especial devices were used to make the tool's positioning aided by one optic microscopy. A file was used to produce the chamfer and the diamond brushes assembled in a Kennametal equipment to perform the honing.

The characterization of the micro geometries of the cutting edges, was performed using one optic equipment from the manufacturer Alicona, model Infinity focus Edge Master.

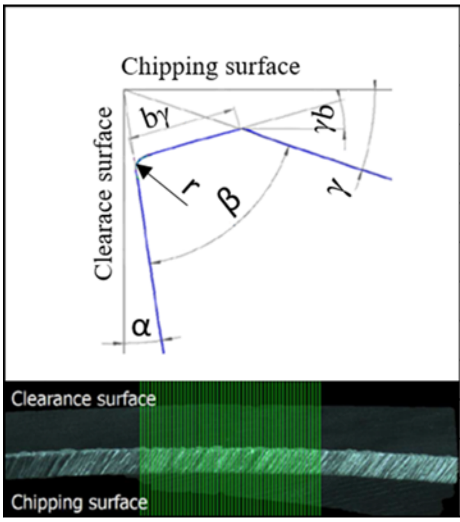


Name	Value	[u]	Description
r	2,7421	µm	Mean radius of mean edge
α	12,5586	°	Clearance angle
β	65,0178	°	Wedge angle
γ	12,4236	°	Chip angle
Sα	5,4315	µm	Disp. apex to end of clearance roundness (former: a)
Sγ	4,6482	µm	Disp. apex to end of chipping roundness (former: b)
K	0,8558		Symmetry of cutting edge
Δr	2,7098	µm	Min. dist. of edge to apex (former S)
Ecq	0,0801	µm	Form deviation of circle (RMS)
Form	Waterfall		Estimated Curvature

Figure 3. Alicona's report of the tool edge characterization for a sharpened tool.

It is important to highlight the radius between clearance and chipping surface is only 2.7µm, as shown in Alicona's report in figure 3. The chip angle, the radius and the clearance angle define the contact zone between the tool's edge and the workpiece's surface.

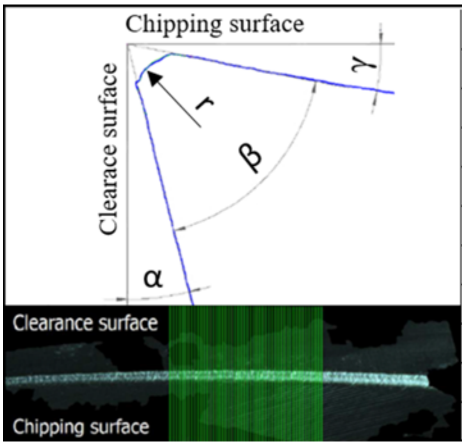
The contact zone on the chamfered tool is completely different compared with sharpened and honed tools presented in figures 4 and 5. The chamfered length (by) and its angle (Yb) resulted in a negative contact zone between the tool's edge and the workpiece's surface. The figure 4 illustrated a combination between chamfered and hone (Yb=15.5°; by=120.8µm and r=15.5µm) in the cutting edge.



Name	Value	[u]	Description
r	15,5499	µm	Mean radius of mean edge
bγ	120,8929	µm	True negative bevel lenth (former: Nt)
γb	15,5660	µm	Angle of negative bevel (former: α negative)
α	8,6621	°	Clearance angle
β	62,9441	°	Wedge angle
γ	18,3938	°	Chip angle
Sα	12,3617	µm	Disp. apex to end of clearance roundness (former: a)
Sγ	16,8719	µm	Disp. apex to end of chipping roundness (former: b)
K	1,3648		Symmetry of cutting edge
Δr	5,3854	µm	Min. dist. of edge to apex (former S)
Ecq	0,0487	µm	Form deviation of circle (RMS)
Form	Trumpet		Estimated Curvature

Figure 4. Alicona's report of the tool edge characterization for a chamfered tool.

The honed tool presented in figure 5 revealed a radius of 46µm (r) between the clearance and chipping surface. As far as the contact zone is concerned, there are certain similarities when compared with the sharpened tool, but with a great difference in value for variable radius, which is not perfect in shape and present the variable K larger than 1, meaning that the estimated curve has the shape of a trumpet reveled in Alicona's report.



Name	Value	[u]	Description
r	46,0183	µm	Mean radius of mean edge
α	14,0489	°	Clearance angle
β	65,2674	°	Wedge angle
γ	10,6837	°	Chip angle
Sα	62,0830	µm	Disp. apex to end of clearance roundness (former: a)
Sγ	82,0890	µm	Disp. apex to end of chipping roundness (former: b)
K	1,3222		Symmetry of cutting edge
Δr	38,9835	µm	Min. dist. of edge to apex (former S)
Ecq	1,6410	µm	Form deviation of circle (RMS)
Form	Trumpet		Estimated Curvature

Figure 5. Alicona's report of the tool edge characterization for a honed tool.

In order to assess the superficial integrity of the obtained bores, a Zeiss three-dimensional machine, the Contura model, and a Taylor Hobson roughness meter (Form TalySurf Series 2 120i) were used.

The quality of the bores obtained was verified after performing 1/25 diameter frequency measurements of the machined parts (depths of 5mm and 43mm from the entrance of the hole), roundness and roughness (Ra and Rz analyzed with 5.6mm in length and a cut off of 0.8mm). For each workpiece, two bores Ø11 x 48mm in length machined.

The process parameters used for drilling blind bores without tool retraction at a depth of 48 mm were kept the same during all tests, whereas the rotation was at 2,350rpm, feed rate of 0.3mm/rev (700mm/min), cutting speed of 81m/min, and internal cooling by emulsion with 40bar of pressure were used.

The criteria established to interrupt the tests were: flank wear of 0.3mm, chipping of 0.3mm or the tool breakage.

In order to improve the accuracy from obtained results, three tools for each tool's edge geometry were prepared.

3. RESULTS AND DISCUSSION

In figure 6 it is possible to observe the amount of bores machined for each kind of edge geometry. The sum of machined bores was 6,250 as shown in figure 6, using three tools for each edge micro-geometry (3,125 workpieces, where each one has two bores), from which the honed tool performs more than both sharpened and chamfered tools perform toghether, totaling 3,500 bores.

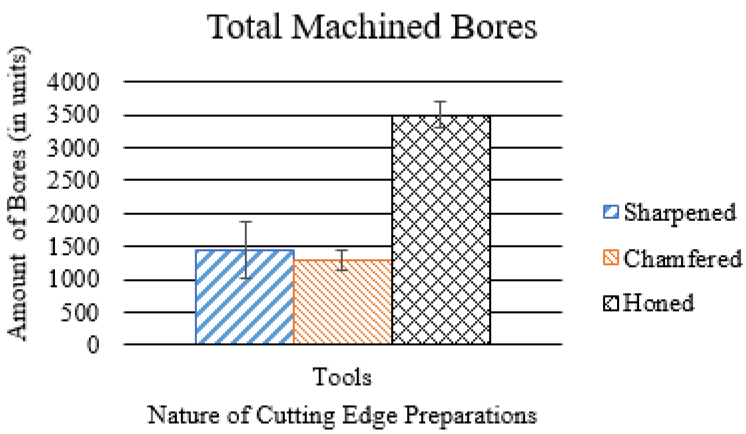


Figure 6. Total machined bores

The tool's life for each edge micro-geometry with three test rounds for each kind of tool are shown in figure 7. Firstly, the sharpened tools achieved results completely different in each test round, reveling that this geometry is not reliable. Secondly, all chamfered tools reach more than 14 meters in tool life performance and, for such length of tool's life, the chamfer is considered reliable. Finally, honed tools present the best result regarding tool's life, achieving results around 50 meters.

After observing figure 7, it is possible to conclude that honed tools endure three times more than chamfered tools. However, it is not possible to make any comparison with sharpened tools due to the huge differences in tool life between the test rounds.

The tool's life was also a subject of study for Cheung et al., 2008, where they compared sharpened tools (Ø6 HSS twist drill) with honed tools with two different radii values (24µm and 42µm), in drilling DIN 40CrMnNiMo8-6-4 of plastic mold steel. According to their study, the honed tool with a 24µm radius was proved to have the longest tool's life among the ones analyzed.

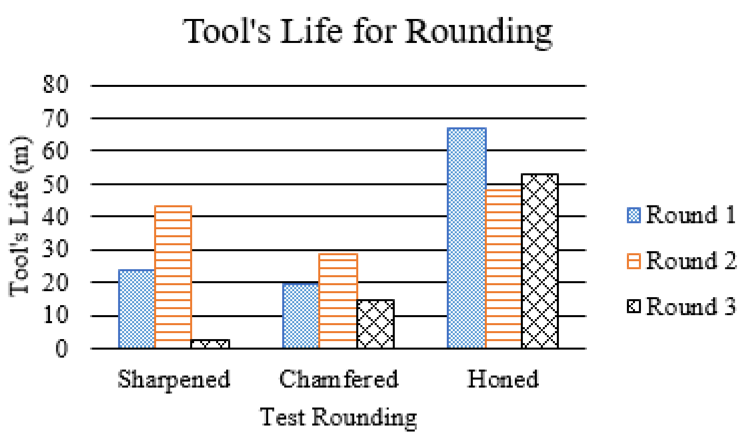


Figure 7. Tool life for sharpened, chamfered and honed tools geometries

According to Denkena et al., 2014, the heat dissipation during this process is greater when using tools with rounded edges due to their larger contact surface area. Rounded cutting edges present high stability on the cutting edge due to a reduction of the mechanical loads and the mechanical stress at the tool's cutting edge. Moreover, it has been proved that the stress gradient along the tool's cutting edge is smoother for rounded cutting edges when compared to sharpened cutting edges. The results obtained on this paper are in agreement with Wang et. al., 2013, who stated that tools with rounded cutting edges, when compared to tools with chamfered cutting edges, presented the best results for the tool's useful life.

Firstly, in figure 8 the sharpened tools wear was presented in pictures which are meant to be analyzed after all of them reached the tool's life limit.

When the tool number one reached 500 machined bores it broke leading to the end of test. Consequently, the tool's tip was completely lost and it was not possible to make any significant observation of the tool apart from taking a picture from the shaft's side because the tool's tip was completely lost. Although the wear smaller than the previously established limits, it broke unpredictably. One hypothesis to that could be an external factor that occurred, but was not monitored, causing the tool's breakage.

The tool number two presented a great wear on the transversal cutting edge with dimensions above the limits established for the end of the tool's life after 900 bores were machined, which lead to the end of test. Moreover, it also presented flank wear (VB) but under established limits. The abrasion between the sharpened cutting edge and the raw material produced a small radius on the cutting edge increasing its wear resistance after a few machined parts. That can be considered one hypothesis to justify the excellent performance from tool number two.

After just 50 machined bores, the tool number three presented a small breakage greater than 0.3mm on the out of corner, leading to the end of the tool's life earlier than the others two sharpened tools. One hypothesis that can't be disregarded to justify the tool's bad performance in the high pressure on the cutting edge, which was great than the edge's resistance to machine raw material.

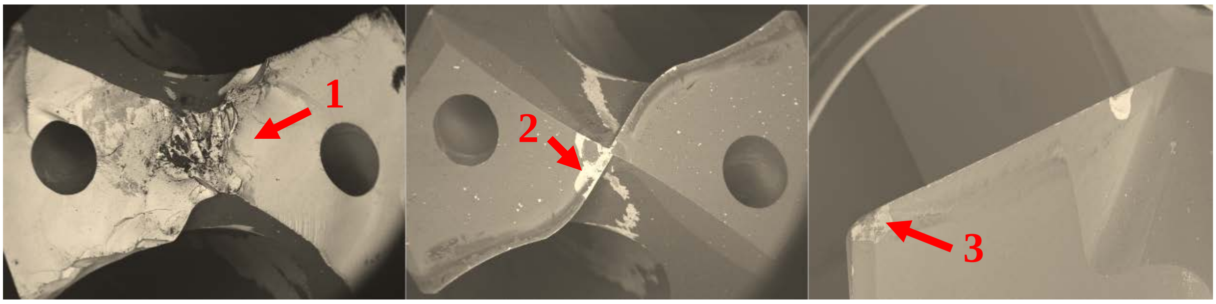


Figure 8. Sharpened tools: 1-Machined 500 bores; 2-Machined 900 bores; 3-Machined 50 bores

Secondly, in figure 9 the wear in the chamfered tools was presented in pictures which are meant to be analyzed after all of them reached the previously established tool's life limit.

The tool number one was removed from the machine when it presented a wear larger than the defined wear test limits on its transition area from the main cutting edge to the transversal cutting edge. The main wear was observed at a critical point in concordance to Bierman et al., 2008 in whose study the same position is presented as the point where the maximum pressure in a drilling process with this kind of tool tip macro geometry occurs.

The tool number two, according to figure 9 showed the main wear in the out corner. Although this tool has the cutting edge protected by a chamfer, its contact region is basically the area from a small radius betweeen the obtuse angle from the chamfer or bevel surface and the clearance surface. In other words, it means that, for this kind of micro geometry, there is still an elevated pressure at the tool's cantact point. Morover, Fang et al., present in their paper the cutting force for a chamfered tool which is greater than that for a honed tool. Furthermore Cheung et al., present in their paper that honed tools have greater cutting force than sharpened tools.

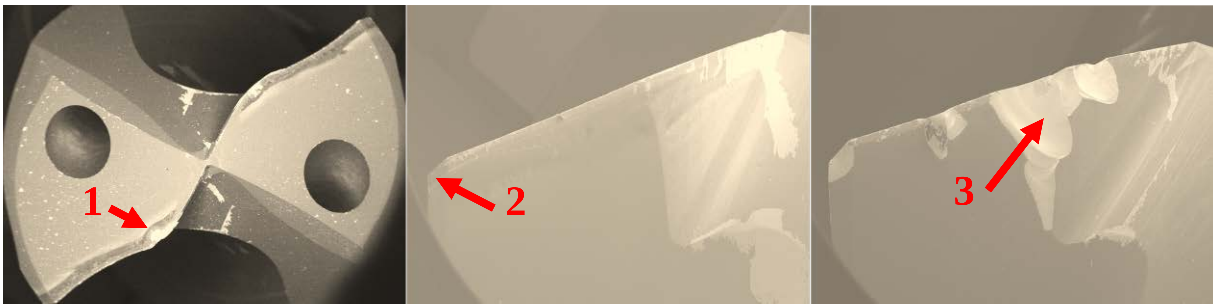


Figure 9. Chamfered tools: 1-Machined 400 bores; 2-Machined 600 bores; 3-Machined 300 bores

The tool number three presented breakage betweeen its main cutting edge and its trasnversal cutting edge, which is considered a rather critical point because it is where the maximun cutting pressure during the drilling process occurs according to Bierman et al., 2008. One hypothesis to be considered is the fast wear propagation, which resulted in the tool's breakage before the defined set point for the cutting edge frequency analisis (1/25) was reached.

Finally, the honed tool presented wear later when compared with the others tools studied in this paper. In figure 10 the wear in honed tools was presented in pictures to be analyzed after all of them reached the previously established tool's life limit.

The wear was notice in the out corner of tool number 1 after 1,400 bores were machined. One hypothesis for such phenomenon could be the abrasion and high temperature due to the friction from the machining process and, apart from that, there is the maximum cutting speed in the out corner. Tool number three presented the same kind of wear as for the tool number one, but was a greater in size.

Regarding tool number two, the wear was shown at the transversal cutting edge, close to the center of the drill, where the cutting speed tends to zero. In this case, the hypothesis to be are the unfavorable cutting conditions in that region of the tool.

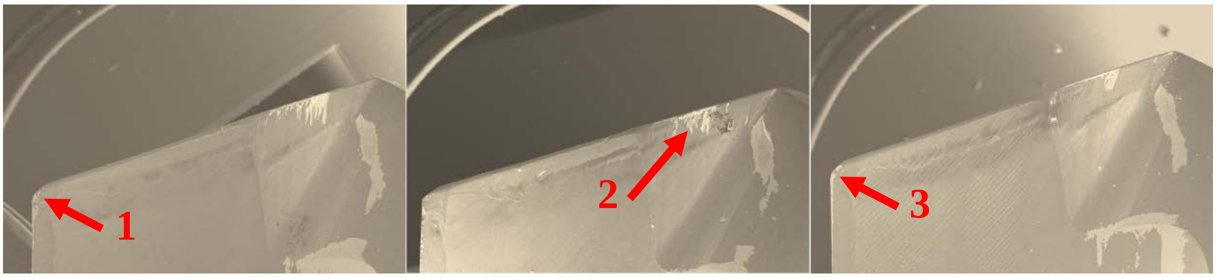


Figure 10. Honed tools: 1-Machined 1,400 bores; 2-Machined 1,000 bores; 3-Machined 1,100 bores

The diameters obtained from sharpened, chamfered and honed tools were observed and the results achieved are ploted in figure 11. All kinds of tool micro-geometries present greater diameters at the entrance than those evalueted at 43mm depth, such difference can nevertheless be disconsidered because the greatest disparity in diameter is of 7µm only. One hipothesys for this phenomenon is the abrasion caused by the friction betweeen the chip and the bore surface which increases the diameter's value at the entrance of the bores. For instance, large edge radiused drills are prone to produce undersized holes according to Cheung et al., 2008. However, such event is not observed in figure 11 when using honed tools with 46µm honing radius.

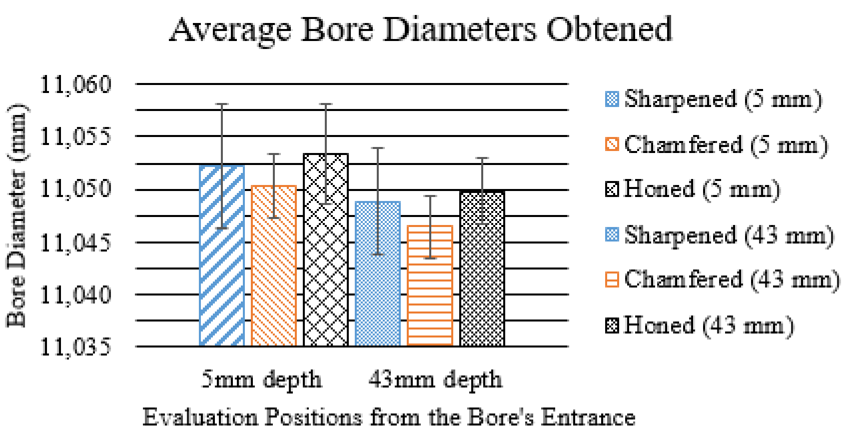


Figure 11. Average diameters obtained from sharpened, chamfered and honed tools

The surface roughness was evaluated and presented in figure 12. The chamfered tool presented the best results for the roughness parameters Ra and Rz, which are the half in value compared to the other ones, whereas the sharpened and the honed tools presented similar results for both evaluated parameters.

After studying cutting edge micro geometry modifications in drilling AISI 1045, Biermann et al., 2008, concluded that large honed tools (60µm) achieved the best results for surface quality according to the Rz roughness parameter.

Apart from that, when Bordin and Zeilmann, 2014, studied the dry drilling process machining AISI P20 steel, the sharpened tools also presented the worst results. They compared edge micro geometry modification of different processes, polishing with abrasive brushes and drag finishing. The surface quality results achieved were influenced by the cutting edge preparation process, for which the honed tool presented the best result when prepared by the drag finishing process. Although dry drilling is not a subject of study in this paper, Bordin and Zielmann, 2014, also achieved a great difference in results between sharpened and honed tools. Although dry drilling is not a subject of study in this paper. One hypothesis is that despite the similarity between these studies there are great differences in machining process parameter as well as in the technology to prepare the cutting edges of the tools and the raw material used. Moreover, according to Cheung et al., 2008, the surface roughness increases when the feed rate is elevated.

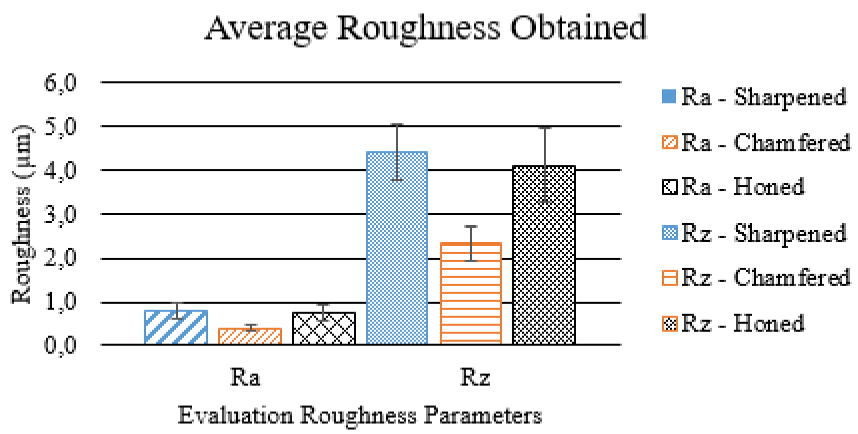


Figure 12. Average roughness from sharpened, chamfered and honed tools geometries

The average roundness is presented in figure 13, where it is possible to observe that the roundness at the bore's entrance is larger than the one observed at 43mm depth for any studied tool. One hypothesis to justify worse results in value at the entrance compared to the end of the bore could be the abrasion caused by the friction between the chip and the bore's surface during the drilling process. The worst results at the bore's entrance occurred with the chamfered tools whereas the honed tools achieved the smallest results in value. The roundness results achieved at the bore's end, on the other hand, have shown small differences compared to one another, from which the honed tool achieved the smallest results in value.

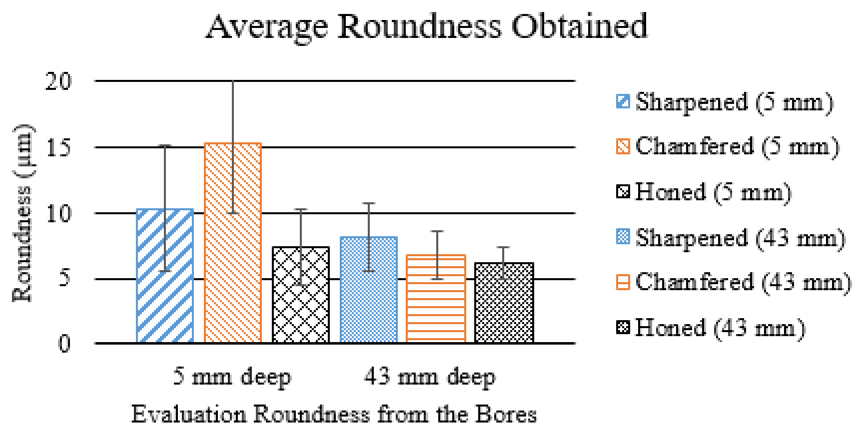


Figure 13. Average roundness from sharpened, chamfered and honed tools geometries

4. CONCLUSIONS

In light of the results presented in this paper, it can be assured that the tool's cutting edge protected by a hone is the best considering the tool's life when compared to chamfered and sharpened tools, whereas the sharpened tools results proved this kind of cutting edge to be unreliable as far as the tool's life is concerned. Moreover, the honed tools also presented the best roundness results. However, the diameter of the bores proved to have no considerable influence whatsoever from the tool's cutting edge preparation. Furthermore, the bore's taper can be disregarded as well. Although chamfered tools presented the best roughness parameters, performing the half of both Ra and Rz parameters in value when compared to sharpened or honed tools, honed tools still proved to be more efficient regarding the tool's life in the drilling process of SAE 4144M steel.

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