SURFACE QUALITY OF DRILLED HOLES USING CARBIDE TOOLS

Rodrigo P. Zeilmann, rpzeilma@ucs.br
Gerson L. Nicola, glnicola@ucs.br
Tiago Vacaro, tvacaro@ucs.br
Juliano S. Bueno, jsbueno@ucs.br
Grupo de Usinagem, NP Projeto e Fabricação em Engenharia, Centro de Ciências Exatas e Tecnologia, Universidade de Caxias do Sul, Caxias do Sul, Brasil

Cleiton R. Teixeira, cleitonteixeira@furg.br
Universidade Federal do Rio Grande - FURG, Rio Grande, Brasil

Roland Heiler, Roland.Heiler@HTW-Berlin.de
Hochschule für Technik und Wirtschaft - HTW, Berlin, Deutschland

Abstract. *In metal removal process, the interaction of the tool and the workpiece may create a modified material zone and causes various geometrical and metallurgical changes in the surface region like plastic deformations and alteration on the roughness and texture of the surface. The drilling process is an important machining process and is often the last manufacturing operation performed before assembly. Therefore, the surface changes generated by this process often will be present in the final product. When combined with the fact that holes act as stress concentration locations and amplify any in service stresses a significant demand for high surface quality and production process security is created. Therefore, increased attention must be paid to the surface changes because they could have a major impact on the performance of the machined component. In that context, this work presents a study of surface quality of holes made with solid carbide drills in AISI P20 steel, in conditions of machining with minimal quantities of lubricant (MQL) and dry machining.*

Keywords: *machining, drilling, roughness, plastic deformations, MQL, dry.*

1. INTRODUCTION

The surface quality of a machined component is one of the most important quality demands and in most cases a technical requirement for mechanical components. Achieving the desired surface quality is of great importance for the functional behavior of a part. To prevent an unsatisfactory surface finish or even cutter breakage, the most common strategy involves the selection of conservative process parameters, which neither guarantees the achievement of desired surface finish nor attains high metal removal rate (Lu, 2008).

Surface quality influences machined components characteristics such as fatigue strength, wear rate, corrosion resistance, etc., due to the fact that surface layers experience the highest load and are exposed to environmental effects. There are various parameters such as cutting speed, feed rate and the radius on the cutting edge that are known to have a large impact on surface quality (Javidi *et al.*, 2008).

The characterization of the surface quality can be made by surface geometric analysis, as roughness and texture, and physical properties such as residual stress, hardness and microstructure of the surface layers (Schwach and Guo, 2006). As far as the surface metallurgy of the machined component is concerned, the heat generated during cutting is a main source of damage. Possible surface and sub-surface alterations include: plastic deformation, micro-cracking, phase transformations and residual stress effects (Che-Haron and Jawaid, 2005).

Dry machining and minimum quantity lubricant (MQL) machining have caught the attention of researchers and technicians in the field of machining as an alternative to traditional fluids. The drastic reduction or even the complete elimination of this fluid can undoubtedly lead to higher temperatures in the process, causing reduction of the tool life, loss of dimensional and geometrical precision of the workpieces and variations in the machine's thermal behavior. On the other hand, despite persistent attempts to completely eliminate cutting fluids, in many cases cooling is still essential to the economically viable service life of tools and the surface qualities required. This is particularly true when strict tolerance and highly exact dimensions and shapes are required, or when the machining of critical difficult-to-cut materials is involved. Minimum quantity lubricant, in these cases, is an interesting alternative because it combines the functionality of cooling with an extremely low consumption of lubricant, usually less than 50 ml/h (Silva *et al.*, 2007).

This work presents a study of surface quality of holes made with solid carbide drills in AISI P20 steel, in conditions of machining with MQL and dry machining. The analysis included surface roughness and texture, and sub-surface characterization, by plastic deformation and micro-hardness measurements.

2. METHODOLOGY

The workpieces were prepared with AISI P20 steel and were hardened to obtain a final hardness of 360 up to 380 HV. This steel is frequently used in the manufacture of moulds and die cavities. The chemical composition is given in Tab. 1.

Table 1. Chemical composition of AISI P20 steel (% wt, ASTM).

C	Si	Mn	Cr	Mo	Ni
0.35-0.45	0.20-0.40	1.30-1.60	1.80-2.10	0.15-0.25	0.90-1.20

The tools used in the experiments were coated carbide drills, DIN 6537K, with two cutting edges, provided by Walter AG Company. The diameter of the tools is 8.5 mm and they are coated with standard TiAlN for MQL application and polished surface (after coating) for dry condition. Figure 1 shows the tool used in the experiments.

Figure 1. Drill used in the experiments.

An Okuma Ace Center MB – 46 VAE Vertical Machining Centre, with maximum rotation of 15.000 rpm and power of 18.5 kW, was employed to perform the machining tests. To qualify the texture of the machined surfaces was used a Universal Stereoscope. Surface roughness R_a was measured using a Taylor Hobbson 3+ Surface Roughness Tester. To analyze the microstructures and to measure the depth of the plastic deformations it was used a Nikon Optical Microscope Epiphot 200, with a CCD camera. Micro-hardness tests were carried out with a Shimadzu HMV-2 Micro-Hardness Tester to prove if there was some metallurgical alteration into the sub-surface of the machined material.

The analysis made in the holes was carried out in the initial and final regions along the hole. The roughness measurements were made in three equidistant points for each depth (initial and final regions). Figure 2 shows the analyzed depths and illustrates the roughness measurement positions.

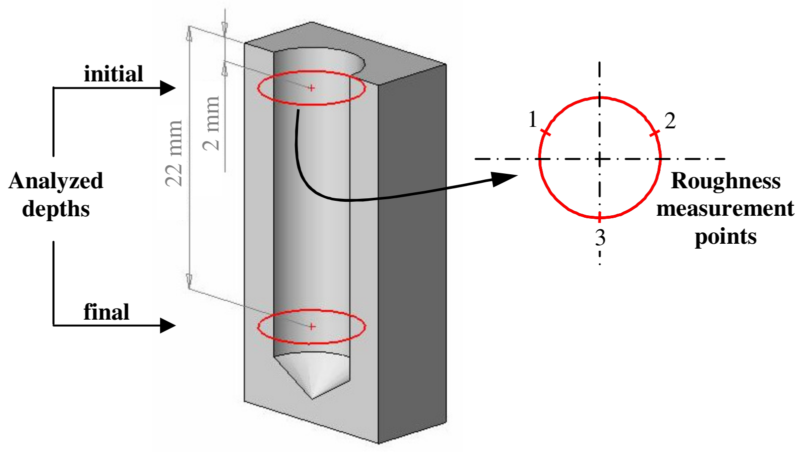

Figure 2. Analyzed depths and roughness measurement positions.

The cutting parameters used in the tests were cutting speed of 50 m/min and feed of 0.1 mm/rot. The hole depth was three times the diameter of the tool (25.5 mm). The tests were carried out with external application of MQL and completely dry cutting conditions. The MQL oil used was the VASCOMILL MMS SE 1, provided by Blaser Swisslube do Brasil Ltda. Figure 3 shows the MQL device, by Fuji BC Engineering Company, EcoBooster Model EB-3, coupled to Machining Centre and also details the nozzle position regarding the tool.

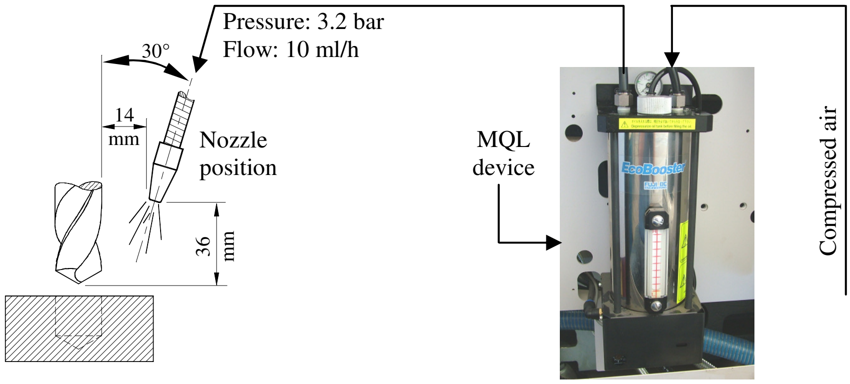

Figure 3. MQL device and external nozzle position.

For the experiment were made three repetitions for each condition of application of fluid in order to achieve a satisfactory result. As end tool life criteria, it were adopted the maximum flank wear of 0.2 mm or the occurrence of chipping. But due to cost and time limitations, the tests were interrupted after the carrying out of 1200 holes, even if the tool didn't achieve the end tool life criteria. As machining strategy it was adopted the pecking cycle, with increase of 1.5 mm and retreat to out of the hole. This cycle was used to facilitate the expulsion of the chip from the hole.

3. RESULTS AND DISCUSSION

Surface quality is one of the important factors for evaluating workpiece quality of the machined components because it influences the functional characteristics of the workpiece such as compatibility, fatigue resistance and surface friction. It is also one of the criteria in assessing the machinability of materials. Hence, the surface quality can become a significant performance measure (Reddy *et al.*, 2008).

For the surface quality analysis developed in this study, to facilitate the comparisons, it was selected one tool tested for each condition of fluid application that made 1200 holes without achieve the end of life criteria, because in dry tests any of the tools reached the end of life. Figure 4 shows the values of roughness R_a measured in the initial and final regions of the holes.

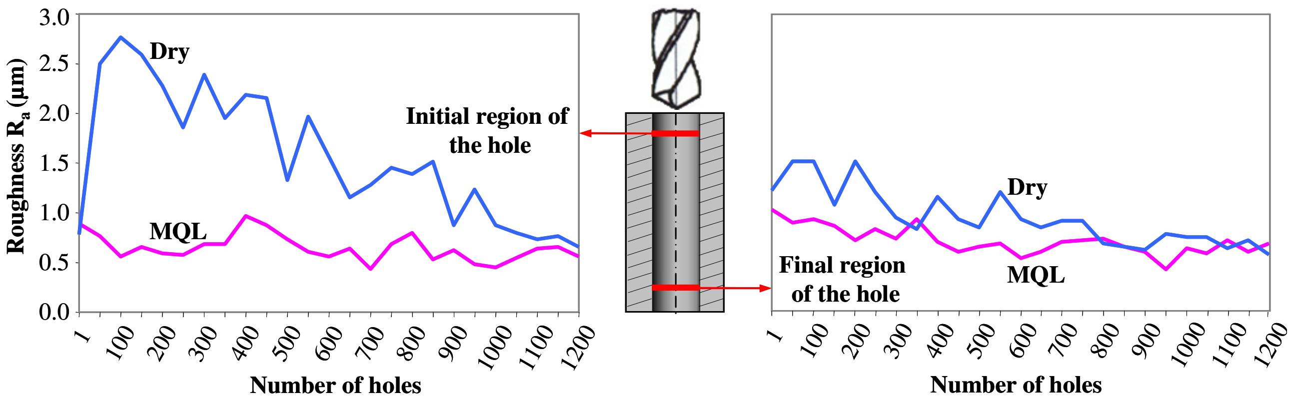

Figure 4. Graphs of roughness R_a values measured in the initial and final regions of the holes.

In the analysis made in the initial region of the holes, the dry tests resulted in the highest roughness values. The elimination of cutting fluid tends to worsen the quality of the surface due to the larger friction forces and increased detachment of material particles adhesions that release from the tool (Teixeira, 2001). The micro-lubrication provided by MQL condition reduces the friction, resulting in minor roughness values (Zeilmann, 2003). With the employment of the strategy of pecking cycle, the edge receives a micro-lubrication after each retreat, which reduces the attrition and provides minor roughness results. However, after the completion of approximately 900 holes, dry and MQL results present a tendency to achieve similar values. The friction caused by dry condition is reduced along the carrying out of the holes due to the adjusting of the cutting edge, decreasing the roughness in the machined surface.

The measured values in the final region of the holes presented a small tendency to bigger results for dry condition, but after the completion of approximately 800 holes, the same tendency to similar values for dry and MQL condition is observed, like was for initial region analysis. Texture and micro-hardness analysis in the final region of the holes showed, especially for dry condition, the occurrence of micro-welding of the chip on the surface, caused by elevated temperatures during machining, which are resulting from the worn cutting edge.

The worn cutting edge has its geometry changed, what reduces its cutting properties, hindering the shear of the material. With that, due to friction and the high temperatures generated in the process, parts of the removed material are welded on the surface, providing a smooth aspect, which reduces the values of roughness (Zeilmann *et al.*, 2008). Figure 5 illustrates the surface texture in the final region of the 1200° hole for MQL and dry conditions.

As it mentioned previously, any of the analyzed tools for surface quality achieved the end of life criteria, and the tests were interrupted after 1200 machined holes by each tool. However, wear analysis resulted in maximum flank wear of 0.08 mm for the tool applied in dry condition and 0.06 mm for the tool used in MQL condition. Considering that the tool has a cutting edge radius of 50 µm, it can be stated that these wear values are significant to influence the surface changes.

An analysis of the wear progression showed a wear on the margin of the drill for the tool tested in dry condition after the completion of 800 holes, what can be linked with the tendency to micro-welding formation and consequently roughness reduction observed in the final region after 800 machined holes.

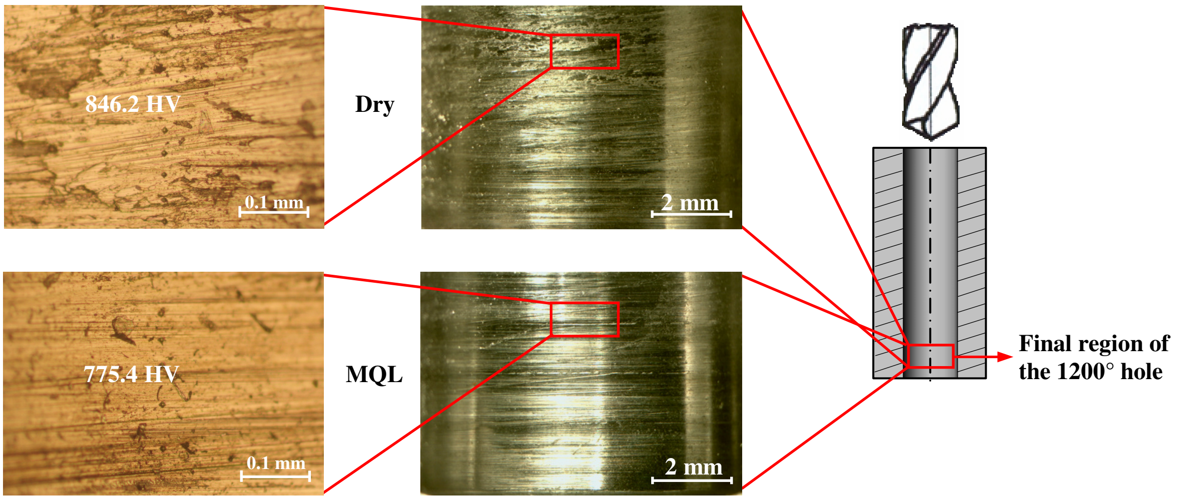

Figure 5. Surface texture at the end of the last holes.

The figure above also shows the medium value of micro-hardness measured on the surface of the hole. The measured values are approximately twice bigger than the micro-hardness value of the base material, 390 HV on average. These results corroborate the hypothesis of micro-welding occurrence, since the welded chip is submitted at high thermal and mechanical loads, what causes the micro-hardening of the chip.

Beyond the surface region of the holes, the metallurgical alterations in the surface integrity also were studied. This analysis has great importance for surface quality characterization, due to its direct relation with the performance of the machined component. These metallurgical alterations are observed in the sub-surface of the machined component.

The changes in workpiece microstructure during material removal are inevitable but it's an important consequence of any finishing process. This change occurs because of intense, localized and rapid thermal mechanical working in metallurgical transformation and, perhaps, chemical interactions when cutting tool get into contact with the workpiece at the high elevated temperature (Kamely and Noordin, 2007). Figure 6 presents the medium values of plastic deformations measured in the initial and final regions of the holes.

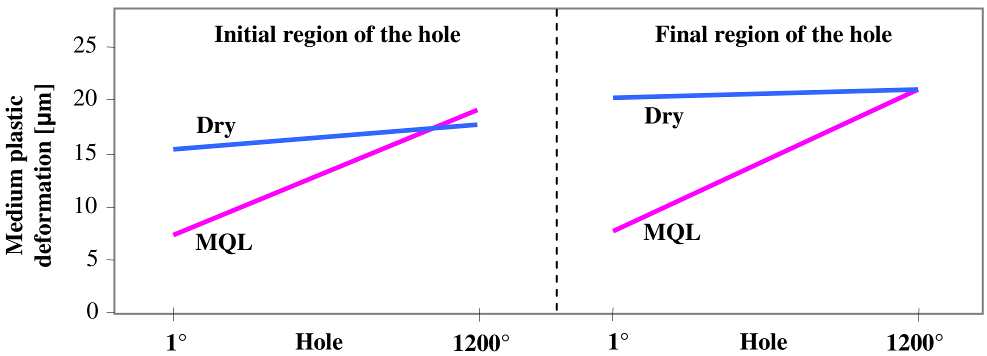

Figure 6. Medium plastic deformation in the initial and final regions of the holes.

To MQL condition the results were very similar in the initial and final regions of the holes, with the first holes presenting medium plastic deformations in order of 7.5 µm and the last holes presenting higher plastic deformations, in order of 20 µm. In the first holes, the tool edge is sharp and consequently there is a better chip formation. Then, lower heat is generated and smaller plastic deformations are formed. Also, in these holes, the wear analysis showed the occurrence of material adhesion on the tools.

The plastic deformations in dry condition also presented similar behavior in the initial and final regions of the holes, with the last holes presenting bigger deformations than first holes. However, differently of the MQL condition, the difference between plastic deformations generated in first and last holes was no significant. In the initial region of the first holes were measured plastic deformations in order of 15.3 µm and in the last holes in order of 17.6 µm. In the final region of the holes, the difference was even smaller, with values of 20.3 and 21.0 µm. In dry condition, the absence of coolant and lubricant functions causes higher temperatures, favoring the formation of plastic deformations, even in the first holes. Figure 7 shows pictures of typical regions plastically deformed of the 1200° hole machined in each condition.

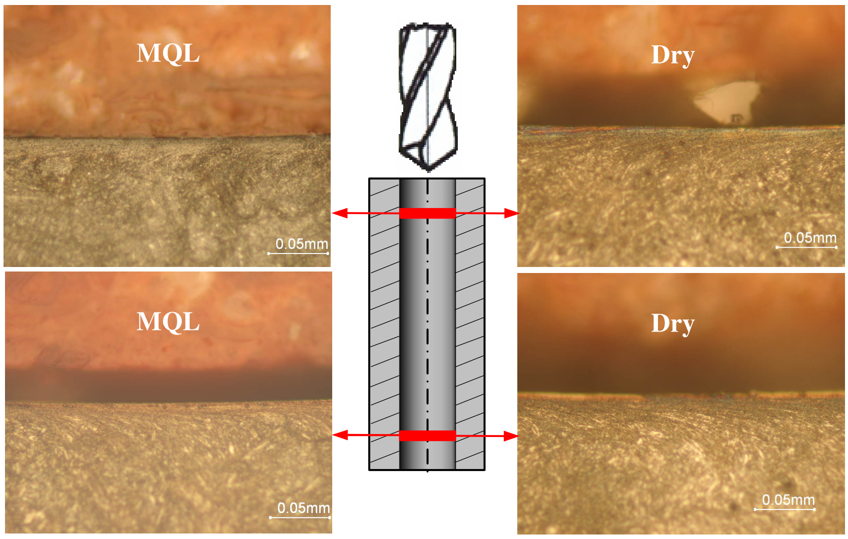

Figure 7. Typical region of plastic deformations in the initial and final regions of the 1200° hole.

To prove if the metallurgical alterations generated in the machined samples really affected them integrity, micro-hardness measurements were made in sub-surface region. Measurements were made in the larger plastic deformations found for each condition and the analysis was carried out according with NBR NM-188-1. But due to equipment limitations, the first point for micro-hardness measurement was 20 µm below the surface. And the metallographic analysis resulted plastic deformation values no bigger than 27 µm. Hence, the measured region for micro-hardness was submitted to lower metallurgical changes. Therefore, the micro-hardness values measured in this region presented a normal dispersion from the average micro-hardness of the material, as seen in Fig. 8.

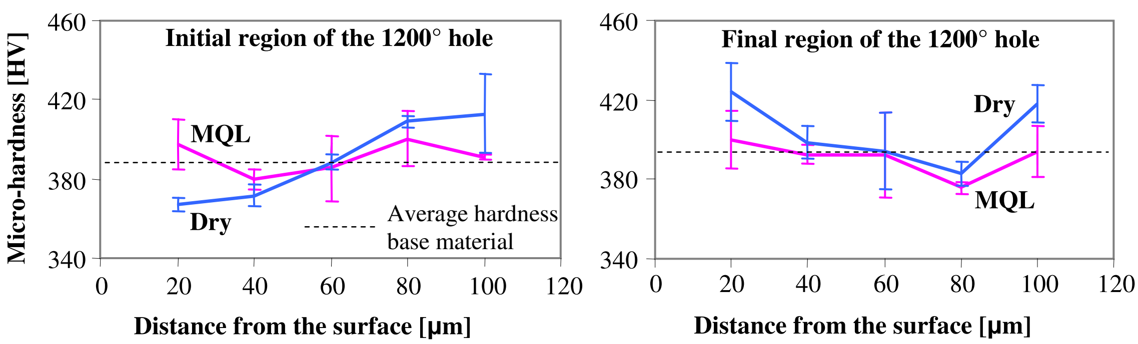

Figure 8. Graphs of the surface micro-hardness versus the distance from machined surface.

These results showed that the process didn't cause significant metallurgical alterations in depths below surface bigger than 20 µm, in agreement with the plastic deformation values found in the tests. However, despite the fact the results didn't present significant variation from the average value, it can be noted that the MQL results presented a more regular behavior than dry results, what can be related with the higher severity and consequently lower mechanical and thermal stability in the dry process.

4. CONCLUSIONS

The dry condition generated bigger values of roughness on the machined surface, especially in the initial region of the holes, due to the higher friction on the interface tool/chip/workpiece. The micro-lubrication provided by MQL condition reduces the friction, resulting in minor roughness values.

Along the carrying out of the holes, the tools generated minor values of roughness on the machined surface, due the lost of its cutting properties that generates elevated temperatures during machining. This condition favors the occurrence of micro-welding of the chip on the machined surface, forming a smooth aspect, which reduces the values of roughness. Micro-hardness measurements on the surface of the holes resulted in values approximately twice bigger than the micro-hardness value of the base material, what corroborates the hypothesis of micro-welding occurrence.

The behavior of plastic deformations was very similar in the initial and final regions of the holes, considering the same application of fluid condition. The bigger plastic deformation were found for dry condition, and measured values for this condition presented little difference between first and last holes, due to the process severity caused by the absence of coolant and lubricant functions. The MQL results showed difference between first and last holes.

The micro-hardness results of measurements made in sub-surface region didn’t present significant variation from the average value, but MQL results presented a more regular behavior than dry results, what can be explained by the higher severity of the dry process.

5. ACKNOWLEDGEMENTS

The authors acknowledge the University of Caxias do Sul (UCS) for the collaboration gave to the *Usimold II* project of the Machining Group (GUS) and the companies collaborating in the project, Walter AG Germany and Blaser Swisslube do Brasil Ltda.

6. REFERENCES

Che-Haron, C.H. and Jawaid, A., 2005, “The effect of machining on surface integrity of titanium alloy Ti–6% Al–4% V”, Journal of Materials Processing Technology, No. 166, pp. 188-192.

Javidi, A., Rieger, U. and Eichlseder, W., 2008, “The effect of machining on the surface integrity and fatigue life”, International Journal of Fatigue, No. 30, pp. 2050-2055.

Kamely, M.A. and Noordin, M.Y., 2007, “The effect of multiple pass cutting on surface integrity when hard turning of AISI D2 cold work tool steel”, International Journal of Precision Technology, Vol. 1, No. 1, pp. 97-105.

Lu, C., 2008, “Study on prediction of surface quality in machining process”, Journal of Materials Processing Technology, No. 205, pp. 439-450.

Reddy, N.S.K., Kwang-Sup, S. and Yang, M., 2008, “Experimental study of surface integrity during end milling of Al/SiC particulate metal–matrix composites”, Journal of Materials Processing Technology, No. 201, pp. 574-579.

Schwach, D.W. and Guo, Y.B., 2006, “A fundamental study on the impact of surface integrity by hard turning on rolling contact fatigue”, International Journal of Fatigue, No. 28, pp. 1838-1844.

Silva, L.R. da, Bianchi, E.C., Fusse, R.Y., Catai, R.E., França, T.V. and Aguiar, P.R., 2007, “Analysis of surface integrity for minimum quantity lubricant - MQL in grinding”, International Journal of Machine Tools & Manufacture, No. 47, pp. 412-418.

Teixeira, C.R., 2001, “Benefícios ecológicos da redução e eliminação de fluidos de corte nos processos de usinagem com ferramentas de geometria definida”, Tese de Doutorado, Universidade Federal de Santa Catarina, Florianópolis.

Zeilmann, R.P., 2003, “Furação da liga de titânio Ti6Al4V com mínimas quantidades de fluido de corte”, Tese de Doutorado, Universidade Federal de Santa Catarina, Florianópolis.

Zeilmann, R.P., Tomé, A., Antonioli, A., Calza, D. and Braghini, M.V.R., 2008, “Analysis of the Surface Integrity in Milling of AISI P20 Steel”, SAE Technical Papers, Vol. 2008, pp. 1-6.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.