CHARACTERIZATION OF INTEGRITY OF MACHINED PARTS[1]

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Abstract

In manufacturing companies, one of the main factors to be evaluated in the manufacture of moulds and dies is the quality of machined surfaces. But now, another evaluation becomes of great importance in analyzing the behavior of life of special machined components: the surface and sub-surface integrity. The process of machining results in thermal and mechanical stresses, which can change the status of surface and sub-surface of the machined material. Thus, a study of the condition of machined surfaces is proposed for certain conditions of machining. Tests were carried out with high-speed steel mills without and with coating TiN, in the conditions of dry milling and with minimal quantity of lubricant (MQL). Generally, the continuous wear of tools and the condition of application of fluid influenced the formation of part's surface and sub-surface changes due to the process.

Keywords: Milling; Surface integrity; Dry; MQL

CARACTERIZAÇÃO DA INTEGRIDADE DE PEÇAS USINADAS

Abstract

Nas industrias de manufatura, um dos principais fatores a serem avaliados na manufatura de moldes e matrizes é a qualidade das superfícies usinadas. Mas agora, outra avaliação torna-se de grande importância na análise do comportamento da vida de componentes usinados especiais: a superfície e a integridade subsuperfícial. Os processos de usinagem resultam em tensões térmicas e mecânicas, que podem alterar o estado da superfície e subsuperfície do material usinado. Deste modo, um estudo da condição das superfícies usinadas é proposto para certas condições de usinagem. Testes foram realizados com fresas de aço-rápido com e sem revestimento de TiN, nas condições de fresamento a seco e com mínima quantidade de lubrificante (MQL). Generalizadamente, o contínuo desgaste das ferramentas e a condição de aplicação de fluído influenciaram a formação de alterações na superficiais e sub-superficiais na peça.

Palavras-chave: Fresamento; Integridade superficial; Seco; MQL.

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1 INTRODUCTION

The manufacturing of moulds and dies has become more prominent as the world economy advances toward reduced lots, larger diversity of products and more importantly, reduced time for launching new products.(1) And one of the most commonly used materials in the manufacture of moulds and dies is the hardened steel, due to its capability in high strength retention and wear resistant at elevated temperatures. The moulds and dies are applied in processes such as die casting, forging, plastics injection moulding, extrusion etc., that are used in a wide range of industries including automotive, aerospace and electronics.(2) Therefore, the requirements of quality are extremely high.

The quality of machined components is currently of high interest, for the market demands mechanical components of increasingly high performance, not only from the standpoint of functionality but also from that of safety. Components produced through operations involving the removal of material display surface irregularities resulting not only from the action of the tool itself, but also from other factors that contribute to their superficial texture. This texture can exert a decisive influence on the application and performance of the machined component.(3)

Results of the latest research indicate that the life and the reliability of machine components or elements are affected greatly by the technological manufacturing and varieties of surface enhancement technologies applied and also by the sequence and conditions of their application. The field of surface engineering is highly respected and has demonstrated many developments that have improved the operational life of engineering components. A new field ‘engineered surfaces’ would be even more effective and economic route to successful manufacture. Engineers who want to improve the life of a component will eventually have to take into consideration the surface of the component. Virtually all fatigue and corrosion-related failures originate from a surface produced by a manufacturing process.(4)

The surface of a part has two important aspects that must be defined and controlled. The first aspect are geometric irregularities on the surface, and secondly the metallurgical alterations of the surface and the surface layer. This second aspect has been termed surface integrity.(5) The surface integrity of a machined component is a function of its material processing and machining conditions, and includes knowledge about the residual stress, hardness and metallurgical structures especially of surface and sub-surface layer. The mechanical properties and the structural state of the machined surface determine the behaviour of components.(6)

In the recent years a lot has been done to avoid the cutting fluids from the production. Dry cutting and semi-dry cutting such as minimum quantity lubrication (MQL) have been favored by the industry.(7) Negative impacts on the environment and waste disposal problems of cutting fluid have already been stated. Because of its toxicity, there may be health problems such as dermatitis, problems in the respiratory and digestive systems, and even cancer to operators who are exposed to cutting fluid. Improper disposal of cutting fluids may cause serious environmental problems such as water and soil pollution.(8) Still, in operations characterized by intermittent cutting such as milling, the large fluctuation of cutting temperature could cause thermal cracks on the cutting edge and subsequently leads to failure of the cutting tool due to edge fracture.(9)

However, it should be noted that the absent cutting fluid also involves the absence of its positive functions during metal cutting process. The functions of cutting fluids are lubrication (reduction of friction), coolant (dissipation of heat) and assistance in chip flow (flushing). Therefore, the consequences of fluid abandonment are high mechanical and thermal loads on cutting tool and machined surface which increased tool wear and surface integrity alteration effects.(10)

The application of layers of a coating to the tool is frequently used as an effort to shield the tool material from the destructive influences during machining. Typically, coatings are materials that possess superior mechano-chemical properties (e.g. hardness, hot hardness, oxidation resistance, chemical stability, etc.).(11) By selecting proper coating methods and coating materials, we may prolong the service life of the substrate material and increase the commercial value of the products.(12)

This work presents a study of the condition of machined surfaces in the milling of hardened steel with high-speed steel (HSS) mills without and with coating. Tests were carried out in dry and with minimal quantity of lubricant (MQL) conditions.

2 MATERIAL AND METHOD

The milling process was carried out in a Dyna Myte Machining Centre, model DM 4500, with maximum rotation on the spindle of 6000 rpm and power of 7.5 kW.

The tools applied in tests were DIN 844 high-speed steel mills, uncoated and coated with titanium nitride (TiN), with diameter of 6 mm and four cutting edges. Figure 1 shows the tool and the detail of secundary cutting edge.

Figure 1. Tool DIN 844 used in the tests.

The parameters used in the tests are shown in Table 1.

Table 1. Cutting parameters used in the tests.

	Cutting speed v_c [m/min]	Radial depth of cut a_e [mm]	Axial depth of cut a_p [mm]	Feed per tooth f_z [mm]
Uncoated mills	20, 40	2	0.4	0.1
Coated mills	60, 90			

The tests were carried out in the conditions of dry and with minimal quantity of lubricant (MQL). The MQL condition was applied with 4 bar of pressure and flow of 50 ml/h. The oil used in the MQL condition was the VASCOMILL MMS SE 1, provided by Blaser Swisslube of Brazil Ltda. The workpiece material used was AISI P20 steel, with hardness between 31 to 33 HRc. This material is quite used in manufacturing of dies and moulds. The chemical composition, according to ASTM, is shown in Table 2.

Table 2. AISI P20 chemical composition, in %.

C	Mn	Si	Cr	Mo
0.28 – 0.40	0.60 – 1.00	0.20 – 0.80	1.40 – 2.00	0.30 – 0.55

To evaluate the surface integrity was used a second workpiece, which took one pass at the beginning and one at the end of the tool life, as seen in Figure 2.

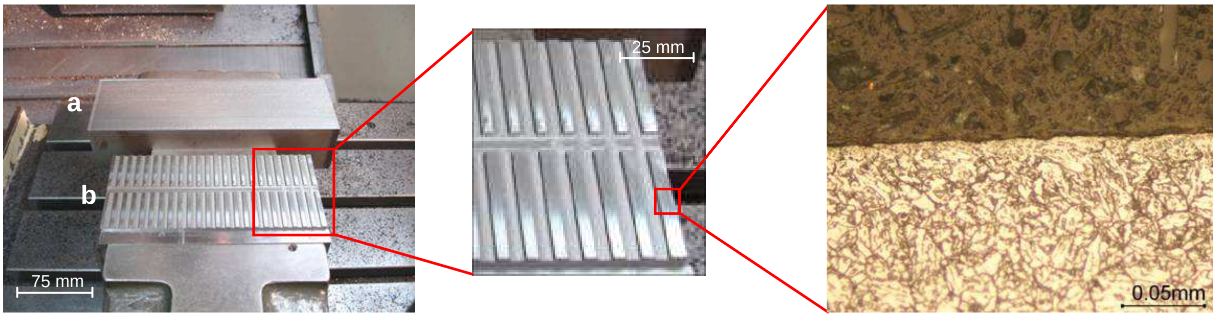


Figure 2. Workpieces used in the tests – (a) cutting, (b) – integrity evaluation for beginning and end of tool life.

Surface roughness was measured using a Taylor Hobson 3+ surface roughness meter. A universal stereoscope was used to qualify the texture of the machined surfaces. To analysis the microstructures and to measure the depth of the plastic deformations it was used a optical microscope Nikon Epiphot 200, with a CCD camera coupled. 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 was done with the tools in new state and at end of life. It were adopted as end of life criteria the maximum flank wear of 0.6 mm and the occurrence of chipping.

3 RESULTS

The superficial texture characterization (roughness, waviness and feed slots of the cutting tool) is important to evaluate the quality of the surface obtained. Hence, the type and the quality of the texture depend on many factors, among them the cutting tool geometry, the material to be machined and the machining process.

The Figures 3 and 4 show the measured values of surface roughness Ra and Rz, for two speeds and two conditions of cutting fluid application for the coated and uncoated tools. The measurements were done with new and end tool life (VBmáx = 0.6 mm) conditions.

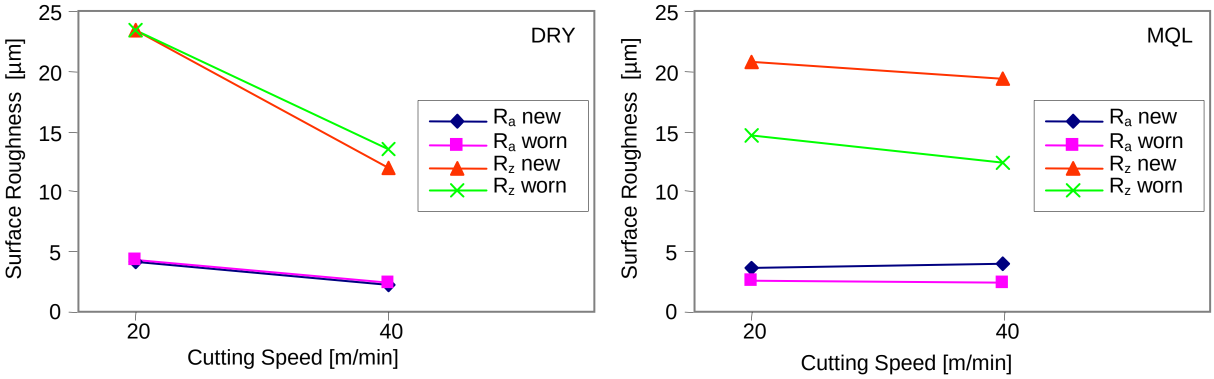


Figure 3. Curves of surface roughness for the uncoated tools.

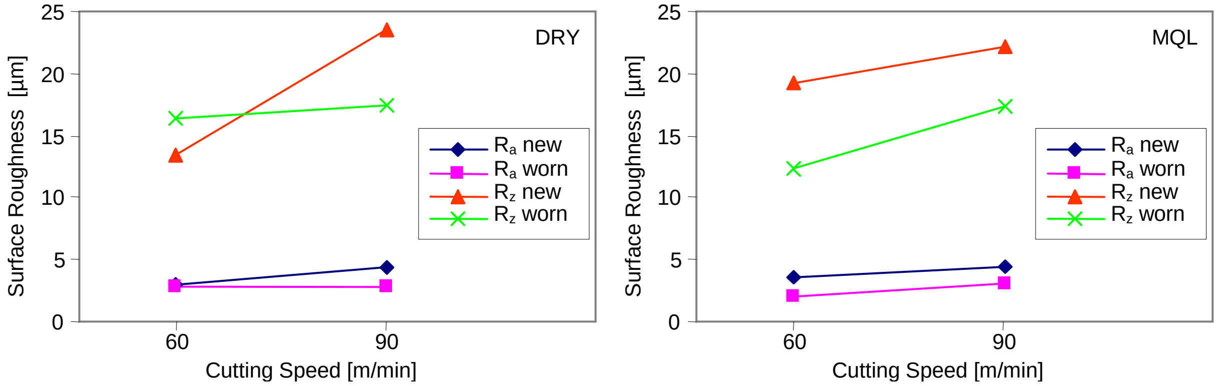
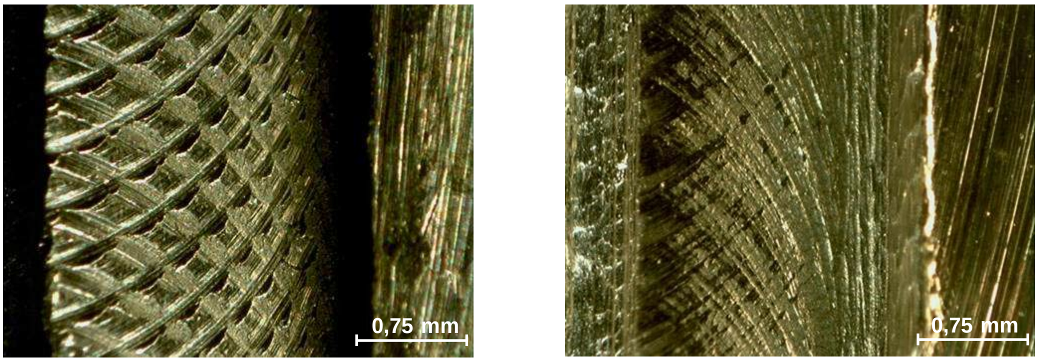


Figure 4. Curves of surface roughness for the coated tools.

Typically, the roughness tends to decrease with increasing of cutting speed.(13) In general, the uncoated tools followed this behavior, but for coated tools was observed an opposite situation. To coated tools was observed an increase in roughness to an increasing the cutting speed, which may be associated with the high cutting speed of 90 m/min, considered severe for this condition.

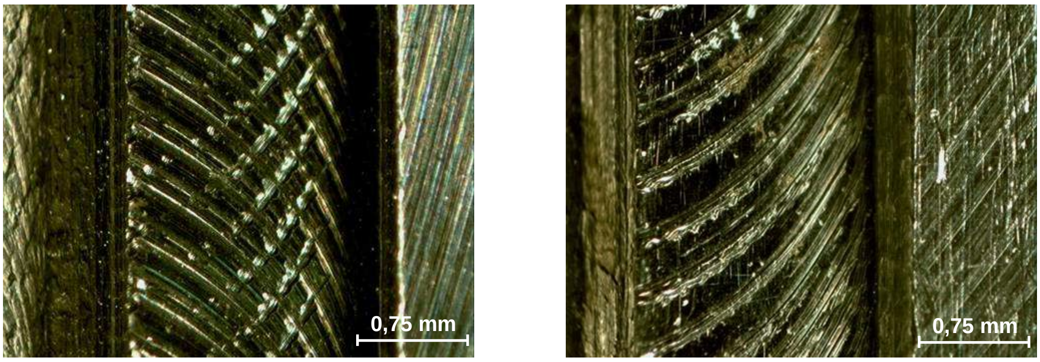
For coated and uncoated tools, the measured values of roughness, in MQL conditions, were higher for new tools than in state of end of tool life. That's because with MQL application the cutting contact is better and the tool geometry marks the edge passage and yours picks.

In Figures 5 and 6 are presented texture images of surfaces machined with uncoated and coated tools, respectively.



(a) (b)

Figure 5. Surface texture of the material machined with uncoated tools: (a) dry milling, vc = 20 m/min, with new tool; (b) machining with MQL, vc = 40 m/min, with end of tool life.



(a) (b)

Figure 6. Surface texture of the material machined with coated tools: (a) milling with MQL, vc = 60 m/min, with new tool; (b) dry machining, vc = 90 m/min, with end of tool life.

The machining with uncoated tool with vc = 40 m/min is a severe condition, what can be verified by the smoothed surface obtained in this machining condition, as seen in Figure 5 (b). This texture is characterized by micro-welding of the chip on the surface, caused by elevated temperatures during machining, which are resulting of the worn cutting edge. That's result a very stark abrasion conditions between surface and edge. The coated tool with vc = 90 m/min, which is also a severe condition, provided a better result with a more defined texture, as seen in Figure 6 (b). This result evidences the efficiency of the coating, protecting the tool material, reducing the tool wear and providing a better surface quality.

The analysis of the machined sub-surface of a material is very important to the industry of molds and dies, because they are exposed to great effort, which may present problems later, for example cavity with more wears, generating high costs for companies. Therefore it is important to know the integrity of the workpiece, because the cutting processes produces plastic deformations in the sub-surface of the material that may result in micro-cracks, chipping, and therefore, the wear of the cavity. One way to assess the integrity of the material change is through the analysis of micro-structure after machining.

The surface integrity is described as a measure of the quality of the machined surface, bound to sub-surface changes and the finishing of the piece that is dimensioned by the roughness, dimensional tolerance, among others.(14)

During machining, the surface generated undergoes thermal and mechanical effects of the process. The changes caused by machining which occurs under the surface also has a fundamental weight on the performance of machined components. Almost all the mechanical work in machining is converted into heat. Therefore, changes in the surface characteristics are the sum of the mechanical and thermal effects of the machining.(15)

In this test was measure the maximum plastic deformation (MPD), to characterize the integrity of the material. Figure 7 shows the plastic deformations resulting of the machining with uncoated tools. As seen in the graphs, the presence of cutting fluid has influence on the generation of plastic deformations.

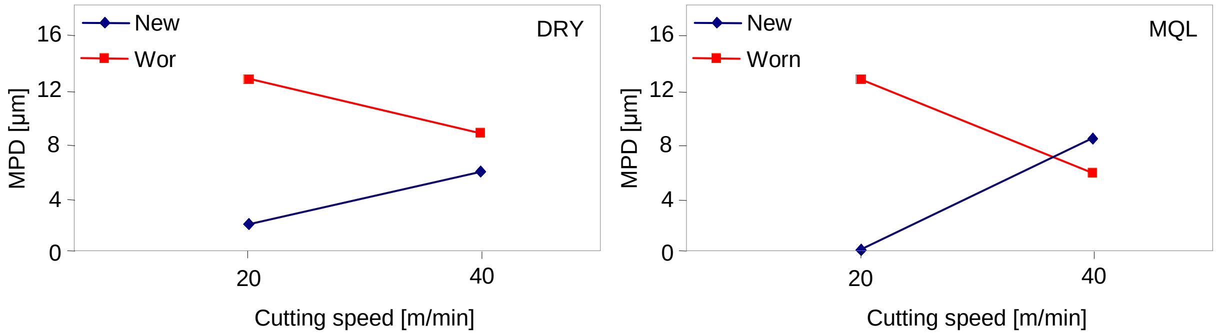


Figure 7. Curves of plastic deformation for dry and MQL conditions, with uncoated tools.

The behavior of plastic deformation followed the same trend for the two machining conditions. The increase of the cutting speed from 20 to 40 m/min, in the dry and with MQL conditions, resulted in an increase of maximum plastic deformations for new tools. However, for tools in end of life, increasing the speed resulted in a decrease in the maximum plastic deformation.

Figure 8 shows the maximum plastic deformations resulting of the machining with coated tools.

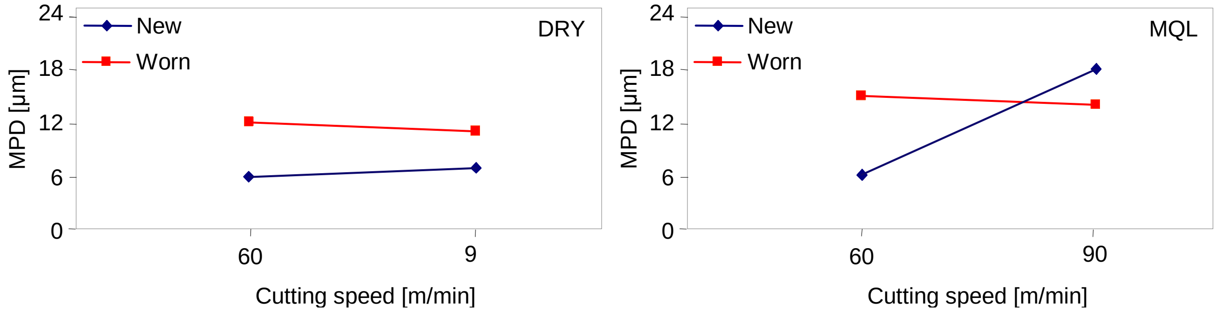


Figure 8. Curves of maximum plastic deformation (MPD) for dry and MQL conditions with coated tools.

The results found for coated tools present similar behavior of the uncoated tools. Also for both conditions of fluid application, increasing the speed of 60 m/min to 90 m/min resulted, for the new tools, an increase of the maximum plastic deformations. However, for the end tools life, the maximum plastic deformation was found for the condition with vc = 60 m/min, and a decrease for the vc = 90 m/min.

For new tools, with vc = 60 m/min, was measured a same value of maximum plastic deformation for dry and MQL condition. Therefore, for speed of 90 m/min, there was a significant difference in deformation, occurring the maximum deformation in the condition with MQL.

Machining with cutting speed of 60 m/min, the surface quality of workpiece was better, because the cutting speed affects the generation of the temperatures in the process and consequently the surface caracteristics. When analyzed for the vc = 90 m/min, for both application of fluid conditions, the machining with new tools as well with tools in state of end of tool life, showed no plastic deformation greater than 18 µm. This is because how greater is the cutting speed, greater portion of the heat is dissipated by the chip. While for lower cutting speeds, lower portion of heat is dissipated by the chip, keeping it in the workpiece, that directly influences the formation of plastic deformations. Figure 9 illustrates the plastic deformations found for machined surfaces with vc = 90 m/min.

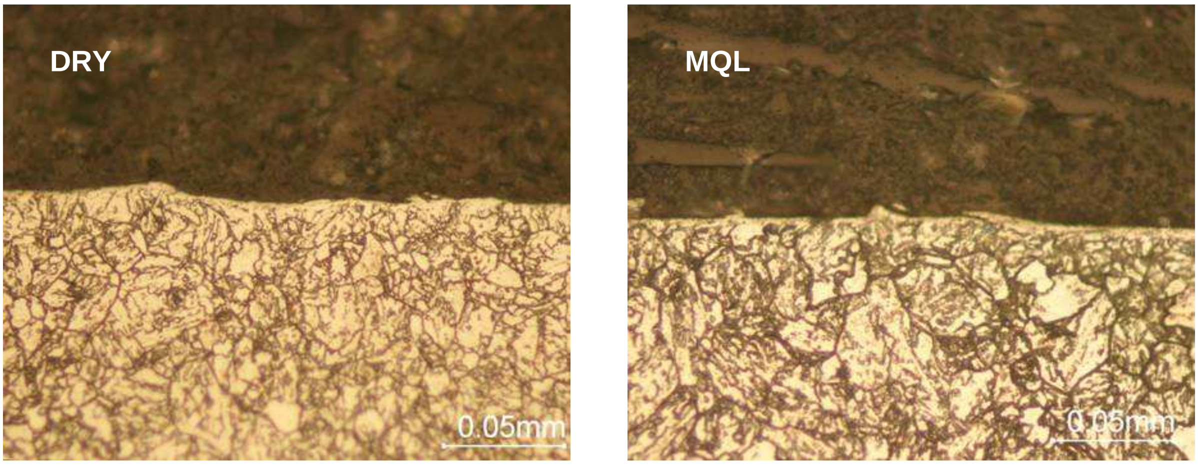


Figure 9. Photo of plastic deformations found for vc = 90 m/min, in dry condition and with MQL respectively, using coated tool.

In machining without the application of fluid, higher temperatures are generated. Therefore, a reduction in the strength of the material is evident, which facilitates the cutting of the workpiece. However, the work hardening of deformed material in this area is also greater, because one of the main influential factors on changes in the sub-surface is the thermal requests.

For the machining with application of MQL, the micro-lubrication reduces the friction between the tool and the piece, which indirectly reduces the temperature in the region of cutting. With the lower temperature, the strength of the material tends to be bigger, making more difficult the shear of the material, which will increase the wear of the tool. However, the lower thermal influence results in minor plastic deformations.

For both conditions of cutting fluids application, with coating tools, increasing the cutting speed caused an atypical behavior for tools at the end of tool life, showing a reduction of plastic deformations in the machined material. It would be expected that the worn tools cause higher deformations than the new, due to the loss of the tool geometry, specially the cutting edge geometry, and the elevated temperatures resulting from that. But the results pointed in an opposite direction. One hypothesis for this behavior is the relation of the strength versus temperature, showed in Figure 10.

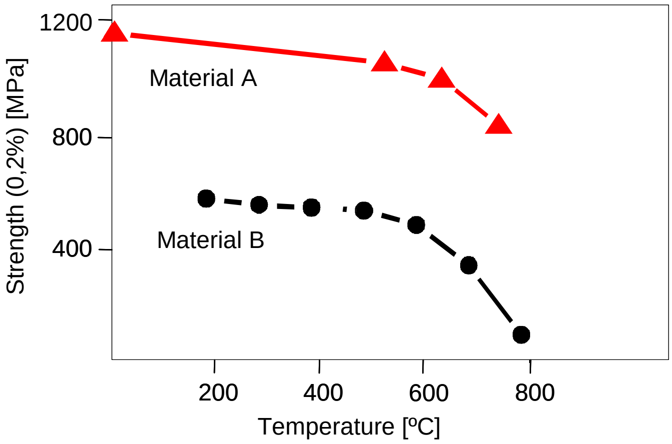


Figure 10. Curve of the strength versus temperature for two diferent materials.(16)

It is observed that the resistance remains constant in a range of temperature. But in a given time, with the continuous increase in temperature, there is a considerable drop in strength. One hypothesis for the data found in the test is that the loss of the tool geometry and the severe cutting speeds may have caused the generation of a great quantity of heat, making the material reach the region that change the behavior of resistance. With the reduction of resistance, the mechanical stresses were lower, thereby generating lower values of deformation. Complementary experiments were developed with micro-hardness tests to prove if there was some metallurgical alteration into the sub-surface of the machined material. It was observed that in the regions where it was found lower deformations, no significamt changes of the material hardness were found. However, for higher deformation cases, it was found significant changes of the material hardness.

5 CONCLUSION

The measured values of roughness in machined surfaces with uncoated tools show a decrease with the increase of the cutting speed. However, for coated tools, the opposite behavior was observed. And in the MQL conditions, the roughness obtained with new tools were higher than those obtained with tools in state of end of tool life.

The greatest depths of plastic deformations were measured for the cutting speed of 90 m/min, with the use of coated tools in new state and application of MQL. Especially for coated tools, the dry results presented lower plastic deformations than those obtained in MQL conditions.

The deformations decreased with increasing speed for the tools in end of tool life state, but increased for the new tools. The plastic deformations lower than 10 µm were considered small because there was not found changes of hardness in these regions. However, for higher deformations, significant changes in the material hardness were found.

An atypical behavior was observed, because the end of tool life presented lower maximum plastic deformations in higher cutting speeds. This behavior can be related to the reduction of the material strength with the increasing of the temperature.

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