EVALUATION OF WEAR IN MILLING WITH MINIMUM QUANTITY LUBRICATION

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Abstract. *Great amount of lubricant fluid at a low pressure from the back side of the chip is the most common way of applying coolants at the cutting region for attaining better tool life and surface finish. But for milling the application of cutting fluids does not get a good result, because it can generates thermal shocks in the tools, minimizing their lives. Using minimal quantities of lubricant with adequate air to mechanically break up the oil particle into droplets is a useful technique to solve this problem. This process may be identified as Minimum Quantity Lubrication (MQL). A high proportion of harmful substances present in cooling and lubrication of machining operations, the costs of process, the growing ecological awareness and the rigor of the law relating to the purchase, maintenance and disposal of cutting fluids, contributed to the increasing questions about the use of these resources, increasing the development of techniques, aiming to minimize them. However, to ensure the reliability of the process of dry machining it is necessary to find new approaches compatible with the operation, the user and the environment. Therefore, this work presents a study of milling process of hardened steel AISI P20 with MQL application and two different types of oil. The lower wear rates were obtained with the minor cutting speed and the synthetic oil provided better results at the higher cutting speed.*

Keywords: *machining, MQL, tool wear, cutting speed.*

1. INTRODUCTION

The milling is one of the most used processes in the confection of cavities, while been one of the most complexes machining process, characterized by a great variety of tools, machines and high rate of material removal. Another relevant factor is the possibility of obtaining complex surfaces and the great finishing generated. With the discontinuity of the material removal at each tool rotation, the forms of the first and last contact between tool and workpiece have great influence on wear and chipping of tool. With this, the alternating thermal and mechanical solicitations in the edge can lead to the crack formation and breakage due to fatigue (Silva Filho, 2000).

The wear is defined as the destruction of one or both of the surfaces that composed the tribological system, usually involving progressive lost of material (Hutchings, 1992). The problems with the cutting tool wear have been always a concern, due to the need to process stop to change the tool, meaning additional costs and lost of the productivity (Klocke and Gerschwiler, 1996). A practice commonly used to reduce tool wear is the use of cutting fluids.

In the machining, the cutting fluids show primary functions such as refrigeration, lubrication and chip transport. However, in some apply conditions, the cutting fluids can increase the tool wear and cause damage to the environment and to user (Zeilmann, 2003). Moreover, there is a global tendency for reduction or elimination of the application of cutting fluids. But to change the usual process (with application of abundant cutting fluid) for a process with reduction or elimination of the fluid, there is a change of equilibrium of the input (machine, workpiece, cutting fluid, tool and cutting parameters) and output factors (Hoff, 1986; Grass, 1988; Ruziczka, 1995).

For the industry, the requirement for adopting a machining process without cutting fluid is that the involved operations must at least have the same cutting time, tool life and surface quality of the workpieces made with cutting fluid. Thus, dry machining doesn't consist in simply interrupt the fluid supply, but requires a compatible adaptation of all factors that affect the process (Klocke and Gerschwiler, 1996). According to Zeilmann (2003), it's known that for some process it's not possible fully restrict, but only reduce its quantity, using minimum quantity lubrication technique (MQL). The MQL has proven to be a great alternative for some process where the cutting fluids can't be fully eliminated.

Keeping the environmental concern, is searched the use of MQL oils less aggressive to health and the environment, like the synthetic oils. These fluids are chemical solutions composed by organic and inorganic salts, lubricity additives, biocides and corrosion inhibitors, added to water. They present a longer life than emulsions, since are less attackable by bacteria and reduce the number of changes in the machine. They also form transparent solutions, resulting in a good visibility of the cutting process (Teixeira Filho, 2006). Another relevant factor is the maintenance of its lubricity in higher temperatures, under 400 ºC, when compared to vegetable oils, which can only sustain its lubricity in temperatures less than 200 ºC (Blaser, 2007). The synthetic oils offer a great anticorrosion and cooling protection, and the most complexes, that contain extreme pressure additives (EP), offer good lubricant and cooling properties. EP additives are added to fluids used for machining operations where cutting forces are particularly high or for operations performed with heavy feeds. Chemical or EP additives provide a tougher, more stable form of lubrication at the chip/tool interface. These additives normally include sulphur, chlorine or phosphorus compounds that react at high temperatures in the cutting zone to form metallic sulphates, chlorides and phosphides. In addition to providing extreme pressure lubrication, these additives provide a film on the tool surface with anti-weld properties that minimize the built-up edge (El Baradie, 1996).

Thus, this experiment presents an initial study of the behavior of mechanisms and types of wear with coated HSS AISI M2 mills in the machining of hardened steel AISI P20 with MQL technique. The main goal was to evaluate the influence on tool wear by using vegetable and synthetic based oil.

2. EXPERIMENTAL PROCEDURE

This work had as methodology the realization of end milling operation. The Fig. 1 shows the milling process with MQL. The tests were conducted in a Dyna Myte Machining Centre, model DM 4500, with maximum rotation of the spindle of 6000 rpm and power of 7.5 kW. Were conducted operations of end milling, with a single direction climb and linear cutting, and the application of MQL, with the pressure of 5 bar and flow of 50 ml/h, using two types of oils: a vegetable based oil, Vascomill MKS 42, and a synthetic ester based oil, Vascomill MMS SE 1, both integral oils provided by Blaser Swisslube do Brasil Ltda. The MQL equipment was provided by Tapmatic do Brasil Indústria e Comércio Ltda.

Figure 1. Picture of the milling tests with MQL application.

The material used was the AISI P20 steel with hardness between 31 and 33 HRc, fixed at zero degree (0º) on the machining table. The dimensions of the workpiece were 80 x 60 x 240 mm. The tools used in the experiments were HSS mills AISI M2, according to DIN 844, with four cutting edges, diameter of 10 mm and coated with titanium nitrite (TiN), provided by Irwin Industrial Tool Ferramentas do Brasil Ltda. Figure 2 shows a picture of the tool used during the tests.

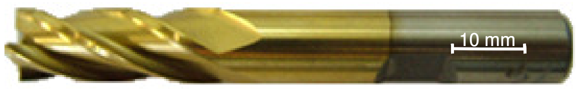

Figure 2. Picture of the tool used in the tests.

The cutting parameters used in tests are shown in Tab.1. For each test condition, three repetitions were made in order to improve the results reliability.

Table 1. Cutting parameters employed in tests.

Cutting speed v_c [m/min]	Axial depth a_p [mm]	Radial depth a_e [mm]	Feed per tooth f_z [mm]
30 and 50	0.8	3.33 (1/3.d)	0.1

Based on the results of tool wear and machining time obtained in the tests, machined volume calculations were performed. For wear behavior analysis, was conducted the evaluation of the mills according to previously defined end tool life criteria. The assumed end tool life criteria were maximum flank wear (VB_{max}) of 0.60 mm or cracks, being used what first occur. For the wear analysis was used a Trinocular Stereoscope of Universal Measure, model TNE-10B, brand Entex.

3. RESULTS AND DISCUSSIONS

For the condition with v_c = 30 m/min, the tools obtained a higher machined volume and cutting time, when compared to v_c = 50 m/min. For the lower v_c of 30 m/min, the cutting time and consequent machined volume results were statistically equal for synthetic and vegetable oils. But for v_c = 50 m/min, the synthetic oil provided a bigger tool life time than vegetable oil, as seen in Fig. 3.

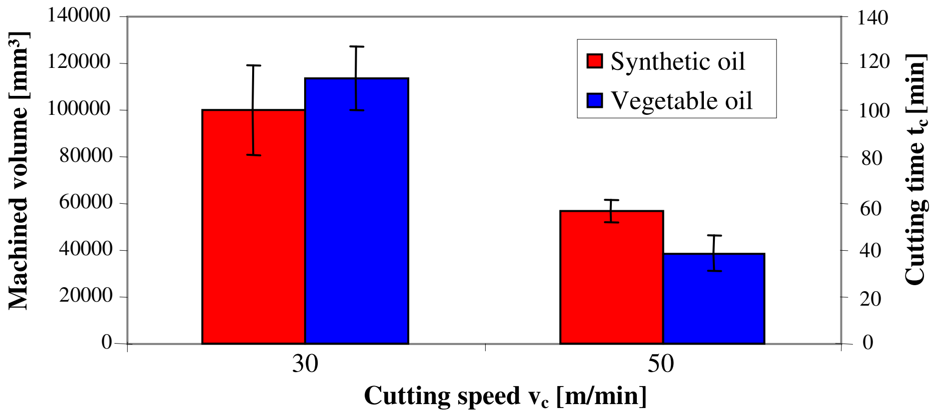

Figure 3. Comparison between oil types and cutting speed variation.

With the increase of the cutting speed, there is an increase in process temperatures, what causes a higher tool wear, leading to a shorter life time. For 30 m/min there are no significant differences between the oils. But for 50 m/min, the better tool life results provided by synthetic oil are related to the presence of extreme pressure (EP) additives in this type of oil. With the higher thermal requests that occur when is applied the higher cutting speed, the temperature range of utilization of the vegetable oil is exceeded, reducing its lubricity properties, which reduces the tool life. For the synthetic oil, the temperature range of utilization is higher, due the presence of the additives, that keeps the oil lubricity properties even at higher temperatures resulted from severe machining conditions. Thus, for 50 m/min, the process severity reduces the vegetable oil efficiency, what doesn't happen with the synthetic oil, due the presence of the EP additives.

The Fig. 4 shows the comparison of the maximum flank wear behavior, along the cutting time, for experiments with the two types of MQL oils, for v_c = 30 m/min.

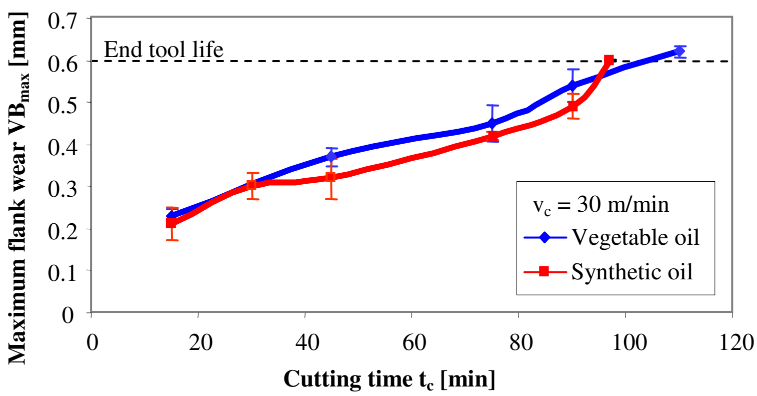

Figure 4. Wear behavior for vegetable and synthetic oils (v_c = 30 m/min).

The analysis of the wear progression shows a very similar behavior of the tools tested with synthetic and vegetable oil, especially in the region between 15 and 90 min. In this region, the integrity of the cutting edge geometry is maintained, and a progressive wear is observed. The difference is detected after 90 min, when the tool tested with vegetable oil keeps a progressive wear, and the tool tested with synthetic oil presents an accelerated wear increase. The tool with application of the vegetable oil lasted in average 110 min before reach the end of life criterion (VB_{max} = 0.60 mm), while the tool with the synthetic oil reached the criterion after 100 min of machining, on average.

With the support of a microscope, it was possible to evaluate the mechanisms and types of tools wear, allowing to conclude about the presence of adhesion and abrasion wear mechanisms, along with flank wear and micro-cracks. Figure 5 shows pictures with details of the main flank and the respective face, with v_c = 30 m/min, and the wear typically presented after machining.

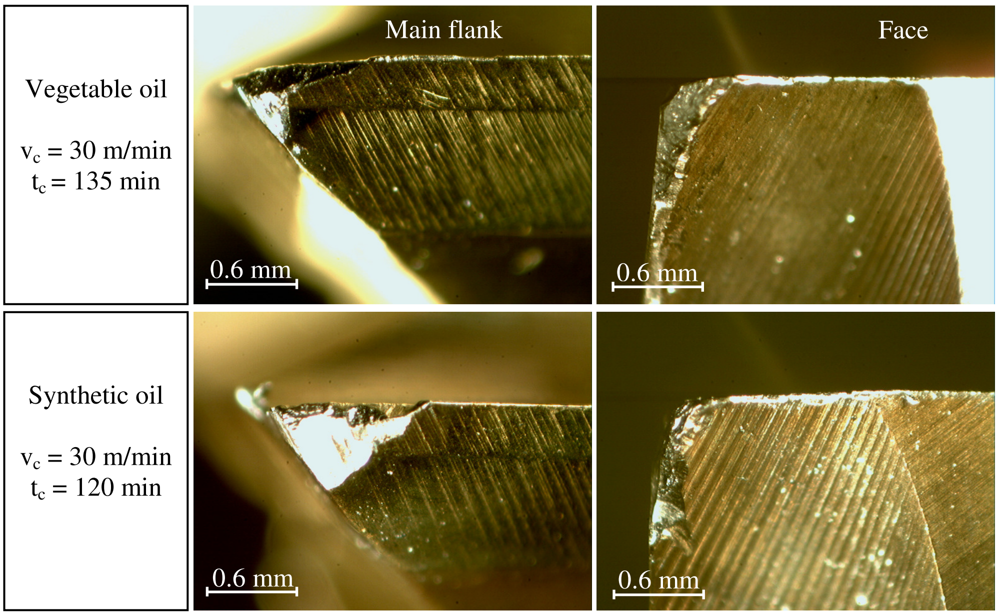

Figure 5. Pictures with detail of the main flank and face for v_c = 30 m/min.

The corner is the point where exists the higher solicitations, due to a greater tangential speed and thermal severity. In the pictures is possible to see the wear condition in the corner. Relating the Fig. 5 with the wear behavior observed in Fig. 4, it can be noted that the tool tested with vegetable oil presented a progressive wear caused mainly by abrasion mechanism. The tool tested with synthetic oil presented a progressive wear too, until 90 min, and then an abrupt removal of material from the cutting edge, leading quickly to end tool life, Fig. 4.

For v_c = 50 m/min, the typically wear behavior, along the cutting time, is showed in the Fig. 6, comparing the two types of MQL oils.

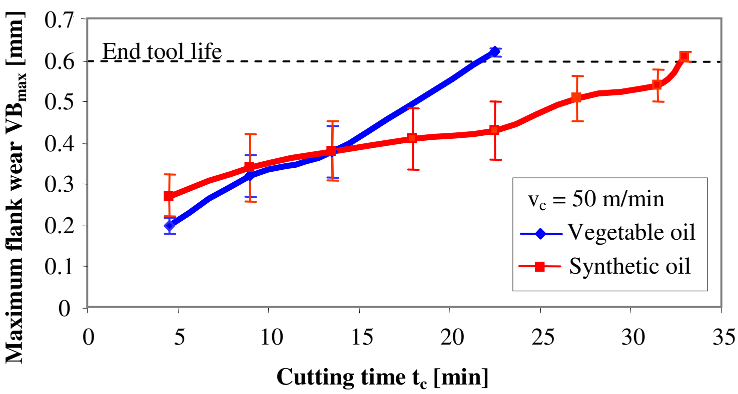

Figure 6. Wear behavior for vegetable and synthetic oils (v_c = 50 m/min).

The machining with synthetic oil lasted in average 33 min before attain the end of the tool life, but the tests with vegetable oil attained in 22 min, on average, its end of life state, showing that the synthetic condition provided a life 50% higher. However, for the first 5 min, the VB_{max} measured for the vegetable oil was 0.20 mm and for synthetic oil was 0.27 mm. But despite the initial bigger wear, the tool tested with synthetic oil showed a more stable and progressive wear, with a region with approximately constant wear rate between around 5 and 31 min. The tool tested with vegetable oil presented a minor initial wear but showed a higher wear increase, especially after around 14 min, attaining its end of life state earlier than the synthetic. This increase of the wear rate can be related with the lost of the coating by the tool.

Figure 7 shows pictures with details of the main flank and the respective face, with v_c = 50 m/min.

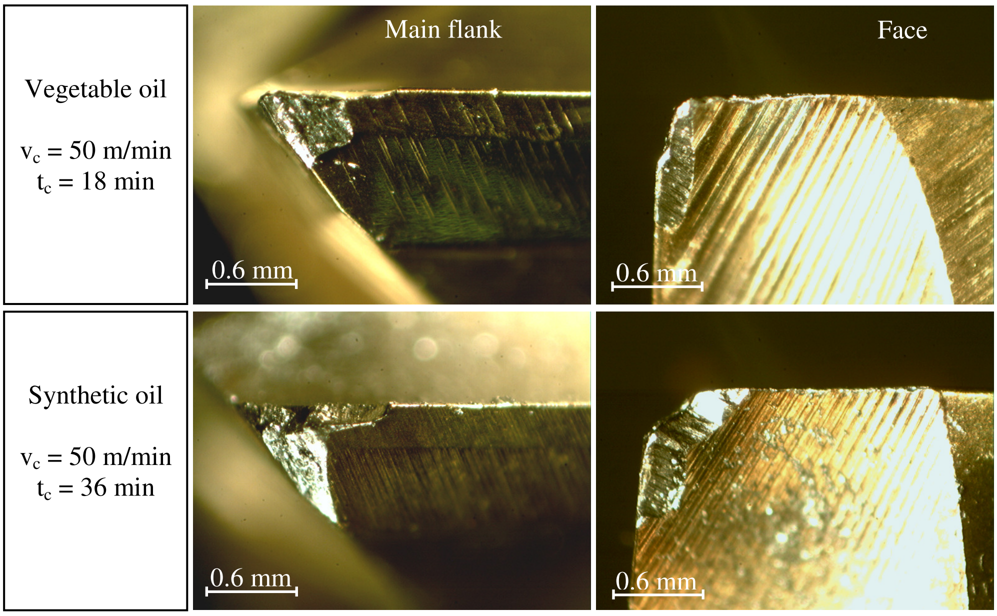

Figure 7. Picture with detail of the main flank and face for v_c = 50 m/min.

To condition with v_c = 50 m/min, the severity in the tools edge for the synthetic oil is apparent, but this condition was reached only at end of tool life, in a time 50% bigger than the vegetable. This time difference is explained by the decrease of the lubricity efficiency of the vegetable oil due to the increase of temperature, above of the fluid temperature range of utilization. Establishing a relation between the images of Fig. 7 with the wear behavior observed in Fig. 6, it's possible to observe that the tool tested with synthetic oil supported a longer time, but after on average 30 min an abrupt removal of material from the cutting edge occurred, leading quickly to end tool life. The image of the tool face shows significant wear on the face, which reduces the corner structural strength, explaining the abrupt removal.

The cutting parameters have a significant effect in the tool life. Generally, as higher is the cutting speed, lower is the tool life for this condition. But more importantly is the type of lubricant fluid applied, that have a direct effect in the machining, the environment and the operator health (König and Klocke, 1997; Weinert, 1999). This experiment showed significant influence of the increase of cutting speed on tool life and, for v_c = 50 m/min, the type of oil used also presented direct effect on tool wear results.

4. CONCLUSION

For all tests, the registered criterion of end tool life was the maximum flank wear, caused by the great attrition between the tool corner and the workpiece surface. The flank wear was predominant in the tests, being caused mainly by the abrasion mechanism.

The increase of cutting speed leaded to an increase of thermal severity, resulting in decrease of tools life. For the condition with v_c = 50 m/min, the thermal request increase had a negative effect on the vegetable oil lubricity, leading to a decrease of the tools life. However, the synthetic oil behavior remained stable, due its temperature range of utilization.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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