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HARD TURNING OF INDUCTION HARDENED SAE 1045 STEEL WITH PCBN TOOLS UNDER DRY MACHINING AND MINIMUM QUANTITY OF LUBRICATION (MQL)

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Abstract. *MQL is an efficient practice in machining of soft materials. According to relevant literature its application during machining of hard materials has not yet been completely explored in scientific research. This work evaluates flank and crater wear of PCBN tools, and surface roughness in hard turning of induction hardened SAE1045 steel at dry machining and MQL. Experiments were conducted using two ranges of cutting speed and at a constant feed rate and depth of cut (DOC). Results demonstrated that the tool wear modes were: average flank wear, crater wear and notches on the tool corner and at the end of the depth of cut. The latter has an important influence on roughness. Also there is a running in period, where a reduction in the roughness with an increase in the average flank wear was observed. The use of MQL, despite reducing the average flank wear, increased the notch wear and consequently increased the surface roughness. In regards to crater wear, the MQL reduced its occurrence.*

Keywords: Hard Turning, Induction Hardening, PCBN, Tool Wear.

1. INTRODUCTION

The use of high hot hardness and chemically stable cutting tools in the machining of hardened steels as a substitute for the grinding process is already a practice adopted in the mechanical manufacturing industry. The advantages involve the possibility of machining complex surfaces, lower operating costs and reduced environmental impact, as cited by (Tonshoff *et alli*, 2000). The popularization of PCBN and ceramic tools, high rigidity and good accuracy machine tools, also contribute to this success. Special attention must be paid to PCBN tools. They are not the hardest tool offered by the market, diamond tools are. Also the PCBN is not the cheapest high hardness tool offered by tool manufactures, ceramics are. Unfortunately diamond tools have chemical affinity with the iron and carbon, and a deterioration process is activated with the increase of the cutting temperature, (Byrne *et alli*, 2003). Diamond tools are widely used in the machining of non-ferrous and non-metallic compounds. Ceramic tools are not suitable to operate in wet machining since they have low resistance to abrupt temperature variations, leading to thermal cracking if exposed to this condition. CBN, on the other hand, does not suffer from these conditions, because in its pure state it has high thermal conductivity and low coefficient of dilatation. However, the commercial and usual presentation form of CBN tools is polycrystalline. The quantity of ceramic phase and pure CBN phase depends on the application. When more toughness is necessary, the quantity of CBN is also more.

Single crystal CBN tools have high thermal conductivity (400 ~ 800 W/mK). Low content CBN tools have (20 ~50 W/mK), (Stahl and De Vos, 2014). For the single crystal CBN tools the necessary material softening around the cutting zone, which would make the cutting easier, is not allowed. The material with a lower percentage of CBN and high ceramic percentage has lower thermal conductivity, keeping the softening effect on the cutting surface, as described by (Chinchanikar and Choudhury, 2014).

MQL appears as a good option between dry cutting and abundant cutting coolant. The principle of operation of the MQL is to mix a small amount of cutting oil with compressed air and precisely reach the area between the tool and the chip and between the tool and the work piece , (Chinchanikar and Choudhury, 2014). MQL system uses 5 to 50 ml / h of lubricant. A conventional system uses an average of 8 liters per minute for conventional machining, based on a 5% emulsion. Usually a conventional refrigeration-lubrication system has a closed circuit, in order to minimize the waste. In an MQL system, the mist of lubricant is not reused because it evaporates into the environment.

The use of MQL improves the tool life, reducing the rate of flank and face wear, due to lubrication capillary effect. But, on the other hand, the use of MQL increases the notch wear which in turn has a strong influence on the roughness.

2. EXPERIMENTAL PROCEDURE

Machining tests were performed on work pieces made of AISI 1045 steel with an average hardness of 59 HRC, hardened by induction heating. The effective hardness depth was 2 mm, in accordance with ISO3754. Two ranges of cutting speed were selected: 100 m/min and 150 m/min, the cutting feed was kept constant: 0,08 mm/rot. The samples were machined in a dry condition and MQL. A low content PCBN tool was used, made up of 75% fine grain of CBN and 25% TiN ceramic content. The following variables were analyzed: average flank wear (Vbb), crater wear (Kt), notch wear (Vbn), and surface roughness, measured in r_a.

The choice of the value and range of cutting speed was based on tool manual data, shop floor experience and prior studies from researchers (Diniz *et alli*, 2003), (Diniz and Oliveira, 2008), (Poulachon *et alli*, 2004) and (Bouacha *et alli*, 2014). According to (Bouacha *et alli*, 2014) the optimal cutting speed—which produces the lowest specific cutting energy—for machining 100Cr6 bearing steel treated at 54HRC was around 120 m/min. The same author stated that an increase in the cutting speed was done in order to reduce the time spent on experiments.

3. RESULTS AND DISCUSSION

The objective of this work was to evaluate the pattern of the tool wear during the machining of hardened steel and the influence of use of a lubrication and cooling media, specifically Minimum quantity of lubricant technique. Figure 01and Figure 02 shows that the abrasive wear was predominant. Regular grooves on the flank wear surface also demonstrated that heating on this area is not sufficient to avoid it. The heating makes the cutting process easier due to annealing, but there are still traces of hard particles on the interface. The abrasion may be due to the loose CBN particles since they are easily released as free fragments, (Bouacha *et alli*, 2014). Furthermore free cementite particles are also easily generated in hard turning along the tool rake face and flank face. These hard particles are forced against the tool surfaces, causing three-body abrasive wear. Three-body abrasive wear is considered the dominant abrasive wear mechanism in hard turning, (Huang and Dawson, 2005).

Figure 01 illustrates how the behavior was of PCBN tool on machining of SAE1045, at 100m/min of the cutting speed. A reduction was observed on average flank wear (Vbb) when using MQL media. Otherwise, the primary and secondary notch wear were greater than dry conditions. As will be explained further, notch wear has an important influence on roughness. Figure 02 shows the flank and crater wear at 150m/min. The application of MQL provoked a relevant reduction of flank and crater wear, but kept the same pattern regarding the notch wear. This result is associated with the correct position of the nozzles, oil quantity and pressure of the Venturi system, and meaningfully due to the capillarity effect on the cut interface. The grooves on the surface of the tool flank make this effect possible – see figure 1 (b). The use of MQL reduced the flank wear rate. The abrasive grooves on the flank and face areas allow micro drops of oil to reach the interface between work piece and tool, and chip and tool. The capillarity effect helps to reduce the machining forces after the run in period. The evaluation of crater wear has a great influence on the chip formation mechanism.

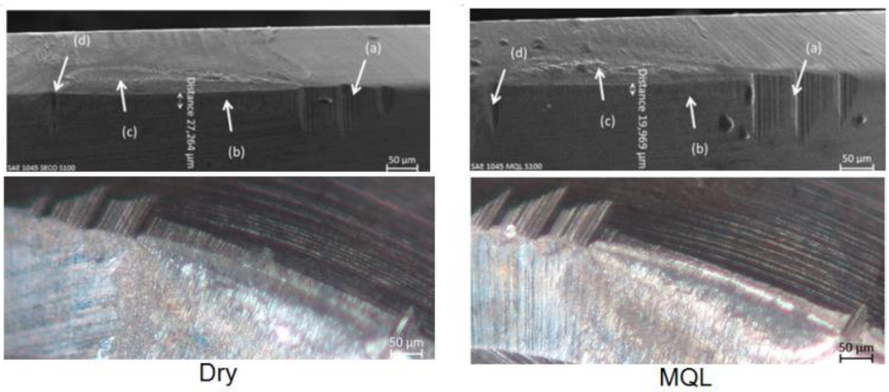


Figure 01 – SAE 1045, flank and crater wear, S=150m/min. (a) Secondary notch wear, (b) flank wear, (c) crater wear and (d) primary notch wear.

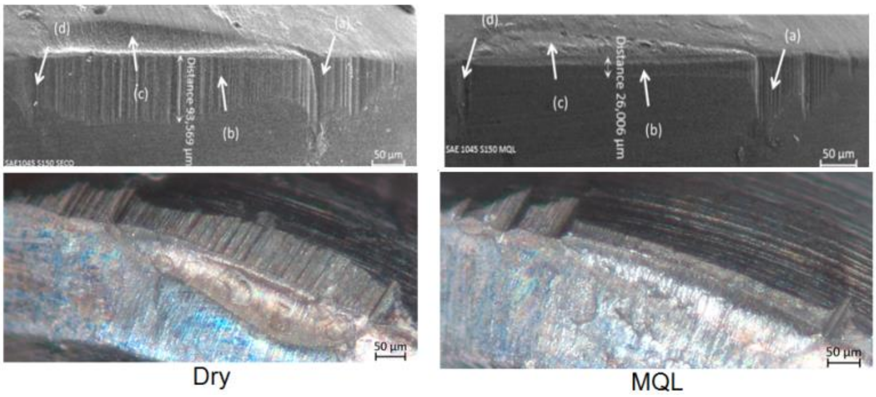
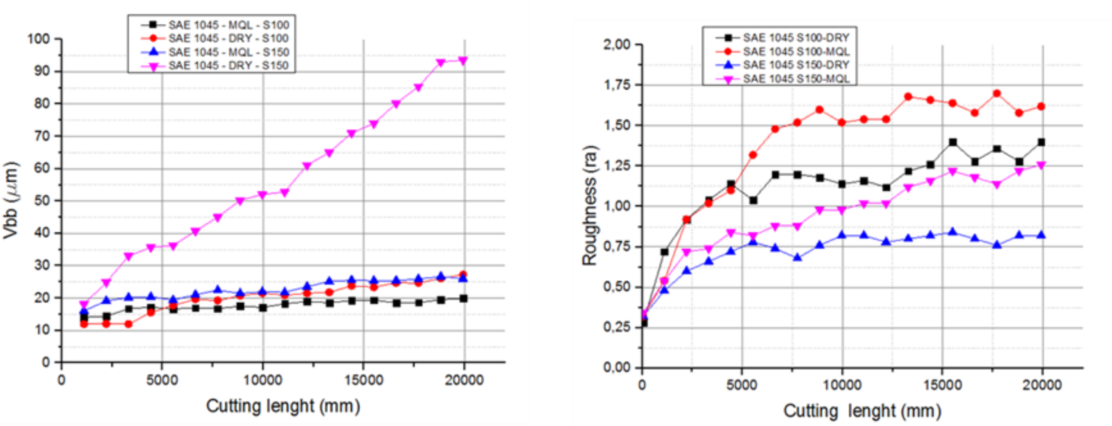


Figure 02 – SAE 1045, flank and crater wear: (A) S=150m/min, dry, (B) S=150m/min, MQL. (a) secondary notch wear, (b) flank wear, (c) crater wear and (d) primary notch wear.

Figure 03 shows the gradual development of the flank wear and roughness. The increase of cutting speed – from 100m/min to 150m/min – resulted in a significant reduction on wear rate of the tool flank during MQL conditions, otherwise the roughness with MQL environment was larger. The surface roughness, in turn, doesn´t exclusively depend on flank wear. The biggest influence of this variable is the notch wear, especially the one that appears after the flank surface area (secondary notch wear). This result is a function of the minimum chip thickness phenomenon, and it is associated with plastic deformation on the fresh cutting area.



(a) (b)

Figure 03 – SAE 1045 (a) Flank wear (Vbb), (b) Roughness (r_a). S=100m/min and 150 m/min, dry and MQL.

4. CONCLUSIONS

Hardened SAE 1045 steel (hardness of 58 – 60 HRC) was machined under dry and MQL technique using PCBN tool at two different cutting speeds: 100 m/min and 150m/min. The feed and depth of cut was kept the same (0,08mm/rot and 0,1mm). The following conclusions can be drawn:

It was observed that the wear on the tool is predominantly by abrasion, by the CBN particles released from PCBN tool and Fe3C released from the work piece.

- The secondary notch wear has a great influence on the surface roughness. The MQL led to greater secondary notch wear, which represents a higher surface roughness.
- The use of MQL caused an important reduction in flank wear at 150m/min cutting speed.
- The capillarity effect and correct position of MQL nozzles led to good results in lubrication.

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