Tapping Operation at High Cutting Speed

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Abstract. *The main goal of this work is the evaluation of the performance of high-speed steel taps when machining grey cast iron at high cutting speeds. It is used high speed steel with addition of vanadium (HSS-E), uncoated and coated with TiN. It is also analysed the effect of the method of cutting fluid application. The tests were carried out in a machining centre at a constant cutting speed of 75 m/min. It was used dry cutting and also the MQL technique. The tool life criteria was based on the dimensional tolerances of the threads, using a thread plug go not-go gauge, on the tool wear measured according to a previous methodology and also on a catastrophic failure of the tool. Analysis in the scanning electron microscope and optical microscope were done to determine the type and mechanisms of wear. The results show that the cutting fluid has great effect on the performance of the taps. The best performance was achieved when using coated tools and cutting fluid.*

Keywords: *Tapping, MQL, Grey cast iron, Tool wear.*

1. Introduction

Although the studies on high-speed cutting (HSC or HSM) dated back to the end of the twenties with the famous experiments of the German scientist Salomon, the technique of HSC was applied to the production line only in the beginning of 1980. The use of this technique was possible only after the development of the high rotation spindles (Schulz, 1997). This marks also the starting point of the researches on high-speed cutting operations. The first experiences of HSC on conventional cutting operation were on turning and milling due to their importance for the industry. This also may be because these two processes are simpler when compared to the others, in terms of cinematic, process control, chip formation and heat dissipation (Bezerra, 2003).

Besides all the practical difficulties of machining at high cutting speeds, there isn't definition of HSC yet. It is a common practice to define HSC as the cutting speed beyond the current values normally used, which sometimes is a limitation of the machine tool or the cutting tool (Müller, 2000). In general, high speed is twice or five times higher than the standard cutting speeds. For the tapping process, the cutting speeds used in the industry are relatively low values, compared to the conventional cutting operations like turning or milling. It is about 20 m/min, which means that a speed as high as 50 m/min could be considered as high cutting speed (Linss, 2002).

The necessity of a perfect synchronization between the cutting movement and the feed movement, together with the necessity of a fast spindle reversion at the end of the thread justify the low cutting speeds used in the tapping operations. The development of devices that drives the tap automatically in the reverse direction when the thread is completed, in the 1990's, allowed the beginning of researches on high-speed tapping. Therefore modern machine tools with devices for reversion at high speed let the cutting speeds to raise to values around 180 m/min with good thread quality, depending on the tool diameter and the workpiece material (Agapiou, 1994). The improvement of CNC softwares also contributed to the application of high cutting speeds to tapping operation with precise synchronism between cutting and feed movement.

The main advantages of machining at high cutting speed, which can apply also to the tapping process, according to Bezerra et al (2003) are: high material removal rates; reduction of cutting forces (due to the temperature on primary shear zone); better heat dissipation, because the major part of the heat goes to the chip, which means less distortion of the workpiece and the possibility of machining fine sections; reduction of machining and non productive times, and total cost per piece, and reduction of vibration.

However, high cutting speeds mean higher temperatures on the tool, which affects the strength of the tool material. It is necessary therefore a tool material that resists to the high cutting temperature and also the inevitable temperature variations during the operation. According to Muller (2000), this is satisfied in an effective way by the high-speed steel with high content of cobalt, obtained by conventional methods or by powder metallurgy. Another improvement on cutting tools for tapping operation is the coating of high speed steel, to improve the wear resistance. The most used coating materials for tap tools is the titanium nitride (TiN with hardness about 2500 HV). This is not only due to the effect of the coating on the performance of the tool, but also due to economic factors. The TiN coating has relatively low cost compared to the others coatings normally used in cutting tools. Others coatings can have better performance, it will depends on the workpiece material, cutting speed, machine tools, among others.

The effects of cutting fluids on cutting operations are well known. They can improve tool life and increase machine surface quality for example. Cutting fluids can reduce tool wear, help to dissipate the heat and therefore decreasing workpiece and tool temperature, and improve the removal of chip and particles from the workpiece and tool (Müller, 2000). The severe cutting conditions imposed by the high cutting speed demand high volumes of cutting fluids due to the high temperatures generated on the cutting zone (Bezerra, 2001). However cutting fluids can represent a high cost for the operation and some alternatives to eliminate or reduce them are welcome by the industry. There is also a pressure to reduce the fluid utilization, due to the pollution and health problems. This had forced the development of the MQL technique (Müller, 2000) and also new coatings materials to allow the dry cutting operation.

The main goal of this work is the evaluation the behaviour of high-speed steel taps, uncoated and coated with TiN, with high vanadium content (HSS-E) when tapping grey cast iron at high cutting speeds. It is also investigated the effect of the cutting fluid when it is applied by the MQL technique.

2. Experimental Procedure

The tap tools used in this work are for M6 threads and the main characteristics of them are presented in Tab. 1. The tool material, according to the tool maker, is a high-speed steel with AISI designation M3, with 3% of vanadium and an average hardness of 879 HV (about 66.4 HRC). It was used uncoated and TiN coated tools, dry cutting and with application of MQL, witch means four cutting condition: high-speed steel coated and uncoated at dry conditions, and the same tools when MQL is applied. These conditions are summarized on Tab. 2. The depth of the previous hole was 16.6 mm and the length of the thread was 11.0 mm. The cutting speed was kept constant at 75 m/min (3980 rpm) for all the tests. The cutting speed usually adopted in the production line is about 10 m/min for grey cast iron and uncoated high-speed steel taps. The value of the cutting speed used in the experiments can therefore be considered high cutting speed for this operation. The cutting fluid was applied using a flow of compressed air and an intermittent spray of vegetal oil at a frequency of 1 pulse per second, resulting in a flow rate of 30 ml/h.

The tests were carried out in a machining centre with maximum spindle rotation of 10000. It was used the mandril of the machine tool, and the automatic cycle of the numeric software available in the machine (cycle 84 of the SIEMENS CNC).

The workpiece material was a grey cast iron classified as GH 190 (according to FIAT standard from 1991) with dimensions of 250 mm X 250 mm X 50 mm. The chemical composition of the material is presented on Tab. 3.

The geometric quality of the thread produced was controlled using a thread plug go-not-go gauge M6 x 1.00 mm (Ferriplax 19264). Tool wear was measured direct in the tool using an optical microscope and a special device designed in the laboratory to help with the positioning of the tap to measure the wear in all the teeth of all the rows. The methodology to measure tool wear was the same described by Reis (2004). This methodology consists of measurements of some dimensions in the tool flank face, and adopting the most critical one. For this case, the wear was measured in the first three teeth of the rows, which are the teeth that perform the cutting. They are in the chamfer region of the tap.

The momentum was measured using a dinamometer Kistler 9272 for all the four cutting conditions when the tool was new and when it approaches the end of the life.

The tools were observed in the scanning electron microscope to identification of the type and mechanisms of wear.

The end of life criterion adopted was the catastrophic failure of the tool or the inspection using the plug. However, some tests were interrupted after 1000 threads produced.

Table 1. Some characteristics of the tap tools used in this work.

Tap ISO 529 M6x1 6H (spiral point tap)	
Nº of flutes	3
Nº of teeth in the chamfer	2
Chamfer angle	20º
Rake angle	12º to 14º
Major diameter	6 mm (M6)
Pitch	1,0 mm
Helix angle	60º
Overall length	66 mm

Table 2. Cutting conditions.

Test number	Coating	Lubrication
1	TiN	Dry
2	TiN	MQF
3	Uncoated (UC)	Dry
4	Uncoated (UC)	MQF

Table 3. Characteristics of the grey cast iron GH-190.

Chemical composition (%)					Structural characteristics			Hardness (HV)
C	Si	Cr	S	P	Matrix	Graphite	Cementite and carbon	200
3.2-3.5	2.0-2.5	≤ 0.2	≤ 0.15	≤ 0.10	Lamellar pearlite max. 5% ferrite	Types B and D	Max. 1%	

3. Results

The results of number of threads produced by each one of the four cutting conditions according to Tab. 1 are presented on Fig. 1. It is observed that only with TiN coated HSS-E tools and MQF lubrication it was possible to machine 1000 threads. For the other cutting conditions the tests were interrupted due to the dimensional quality of the threads, verified by the thread plug go-not go gauge. There was no catastrophic failure of any tap.

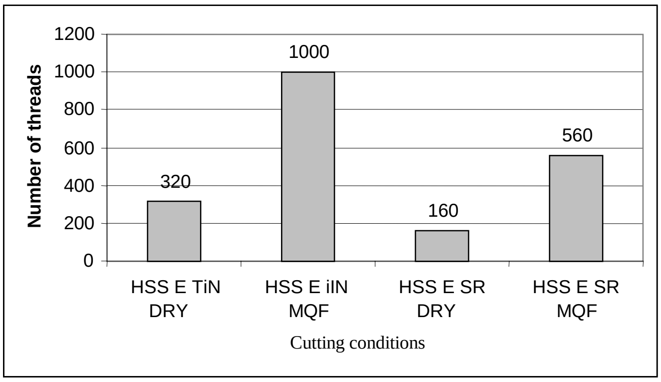
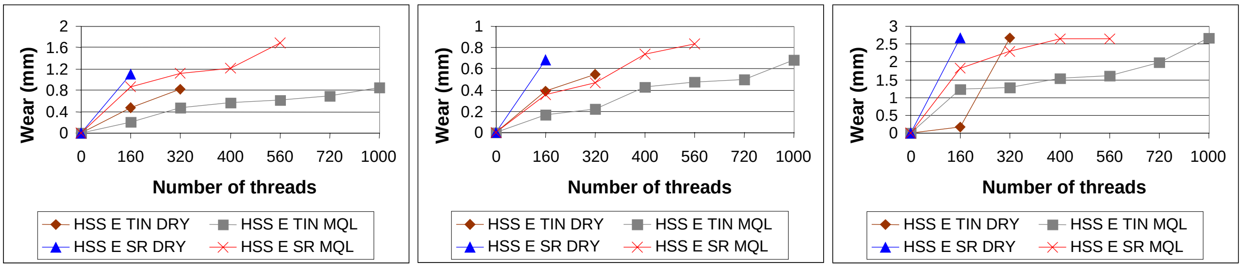


Figure 1. Number of threads machined by each cutting conditions (Vc = 75m/min).

It is also observed the great effect of the lubrication. For both cutting tools, coated and uncoated, the number of threads produced increases considered when MQF is applied. The coated tap in dry condition machined nearly 68% less compared with MQF condition. For the uncoated tap, the dry condition machined about 72% less compared to the MQF conditions. These results clearly show the efficiency of the MQF to lubricate, cooling and to protect the tool surfaces against the wear mechanisms. Another important observation is that the MQF is more effective than coating concerning the performance of the tools. While the coating increased the number of threads from 160 to 320, compared to the HSS-E for dry conditions, the application of MQF increased the number of threads to 560.

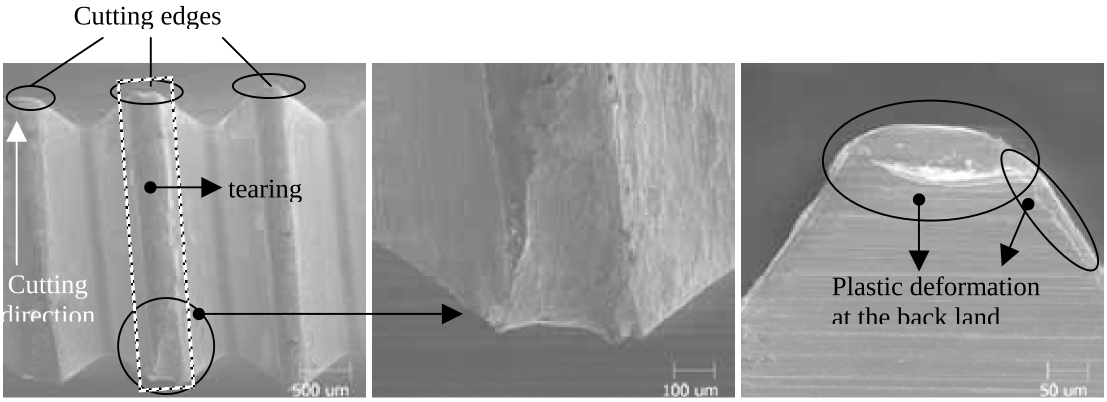
The graphs on Fig. 2 show the behaviour of tool flank wear during the tools life for each of the four cutting conditions used in this work. The values of wear are the maximum wear length measured on the first three teeth for the tree rows of the taps. It is observed that the uncoated tool at dry condition presented a high flank wear for the first 160 threads machined. For this tool the wear on the third tooth (witch is the first tooth in the cylindrical region of the tap) extended for all the length of the tooth, in the flank face. This is a typical failure for tap tools, described in the literature as tearing (OSG, 1999; Reis, 2004).

Tearing is a plastic deformation of the tool material in the flank face. This kind of failure is shown in Fig. 3. This figure shows some photos taken into the scanning electron microscope (SEM) for the uncoated tool after machining 160 threads in dry condition. Figure 3a shows the 3rd, 4th and 5th teeth of one of the rows for the uncoated tool used on dry condition. It is observed tearing on the 4th teeth along all the length, resulting in a lost of material at the end of the crest (back land), highlighted on Fig. 3b. This kind of failure is a result of the intense plastic deformation of the material in the crest, which starts on the cutting edge and extends until the back land, causing the elimination of the relief angle (or changer relief) of the tooth. Figure 3c shows a detail of plastic deformation of the back land. The plastic deformed material will eventually be detached from the crest and the result is a cavity, shown in Fig. 3b. For this particular tool, this failure occurred until the eighth tooth.



(a) (b) (c)

Figure 2. Tool flank wear for the four cutting conditions tested as a function of the number of machined threads (Vc=75m/min): a) first tooth; b) second tooth; c) third tooth.



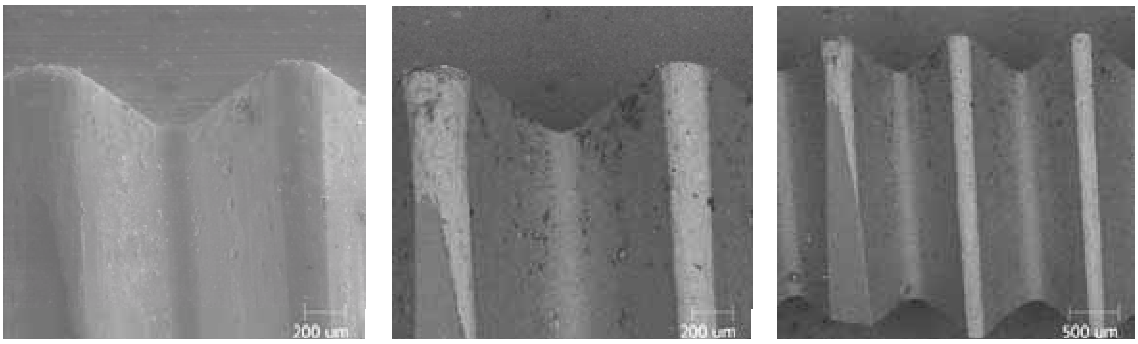
(a) (b) (c)

Figure 3. SEM views of the wear on the crest for uncoated tool used under dry condition..

It is observed, in Fig. 2, that the uncoated tool when machining under MQF condition machined 560 threads, however it presented a high level of wear after 320 threads, including tearing for some teeth. While the TiN coated tools in dry condition was rejected by the plug test after only 320 threads.

The TiN coated tools with MQF presented the lower wear levels compared to the other conditions and reach the maximum number of threads, 1000, when the tests were stopped. However, after 1000 threads, the taps presented a high level of wear, and tearing in some teeth, which means that the tools end of life was close. Figure 4 shows some SEM views of the flank face of this tool using the secondary electron analysis (Fig. 4a) and scatter electron analysis (Fig. 4b and 4c). These figures show that the coatings had been plucking away revelling the tool substrate. It is clear the high tool wear in one of the teeth and tearing in the other two.

It is worth also to mention that two other wear mechanisms were observed in the SEM analysis: abrasion and adhesion (also called attrition in the literature). The plastic deformation seems to occur after the tool had been highly worn by these two wear mechanisms. Plastic deformation is the result of the high temperature in the contact between tool and workpiece, decreasing the mechanical strength of the workpiece material.



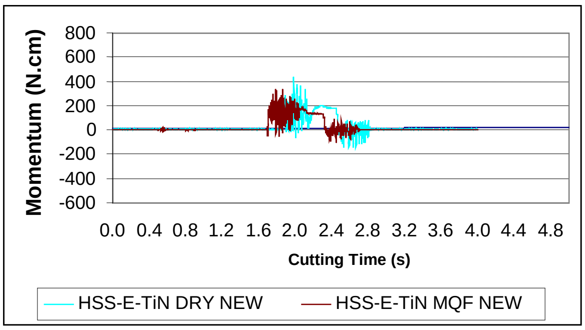
(a) (b) (c)

Figure 4. SEM views showing the wear fot the TiN coated tool used under MQF condition: a) secondary electrons technique; b) and c) scatter electrons technique.

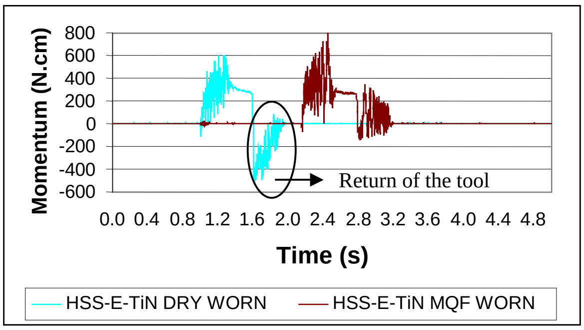
The results of the momentum measured during the tapping operations for the different tools used are presented on Fig. 5. It was measured the momentum for new tools and also for worn tools at different levels. It is clearly observed that the momentum is higher for the worn cutting tools. Figure 5a shows the result for a new HSS-E coated with TiN. The results for dry and lubricated conditions are similar. On the other hand, when comparing the same result for the worn tools, it is observed that the momentum rises when the MQL is applied, Fig. 5b. This same figure also shows that the momentum when the tool is returning is different, the highlighted part of the graph. This behaviour can be related to the chips clogging in the flutes and between the teeth in the tool (Cao *et al.*,2002).

For the uncoated tools the MQL increases tool life and this could be attributed to the lubrication effect, but it should be confirmed when measuring the momentum. However, the application of MQL resulted in a higher level of momentum. At first this situation is opposite to the literature and also to the results of the number of threads produced. For this particular situation, high-speed steel cutting grey cast iron, the lubricant can act to protect the tool from abrasive wear. However the cutting fluid cause the chips to be clogged in the tap flutes, as shown in Fig. 6, which can result in an increase of cutting forces. This did not happen for new coated tools. The TiN coating can act to reduce the adherence and friction between chip and tools surfaces, reducing the chip clogging. When the tool looses the coating after a certain machining time, the effect of the chip clogging increases the forces again when applying MQF.

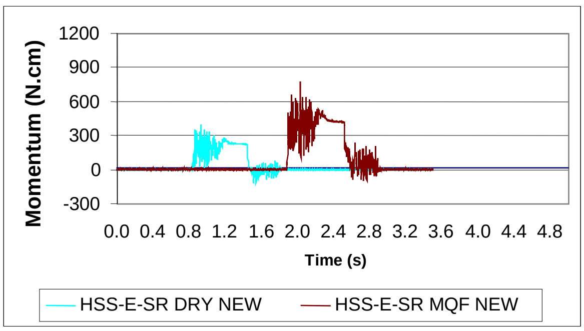
(a)



(b)



(c)



(d)

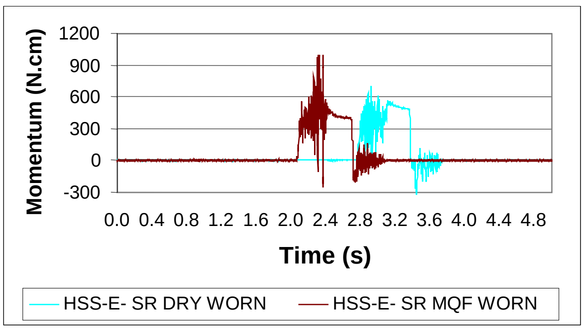


Figure 5. Momentum for the cutting conditions used in this work.

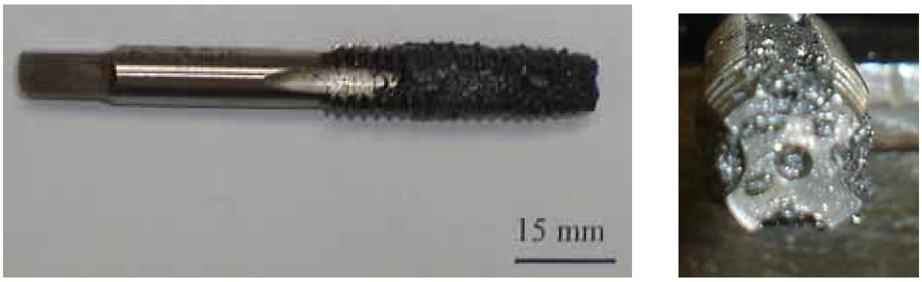


Figure 6. Illustrative photos of a tap tool after machine grey cast iron under lubricated conditions (MQF).

4. Conclusions

The results obtained in this work, with the cutting conditions adopted, allow the following conclusions to be withdrawn:

- The higher tool life was obtained when using the TiN coated tool under MQF conditions;
- The MQF increases tool life compared to dry condition;
- The effect of MQF on tool life is higher the effect of coating;
- The main wear mechanisms were: adhesion, abrasion and plastic deformation;
- The cutting force increases for worn tools compared to new tools;
- The application of MQF increases the cutting force, for both tool, coated and uncoated.

5. Acknowledgments

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6. References

Agapiou, J.S., 1994, “Evaluation of the effect of high speed machining on tapping”, Journal of Engineering for Industry – Transactions of the ASME, Vol. 116, n.4, Nov, pp.457-462.

Bezerra, A. A., 2003, “Estudo do Desgaste no Roscamento com Alta Velocidade em Ferro Fundido”, Tese de Doutorado apresentada a Escola de Engenharia de São Carlos, Universidade de São Paulo, São Carlos, 2003.

Cao, T., Sutherland, J. W., 2002, “Investigation of Thread Tapping Load Characteristics through Mechanistics Modeling and Experimentation”, Journal of Machine Tools & Manufacture 42, pp 1527-1538.

Linss, M., 2002, “ Processo de Rosqueamento de Alto Desempenho”, Máquinas e Metais, dezembro, pp. 24-33.

Müller, P., 2000, “Ferramentas para furar e rosquear com HSC e sem refrigeração”, O Mundo da Usinagem – 1/2000, pp. 13 – 17.

OSG, 1999, “Manual Técnico - Machos”, OSG ferramentas de precisão ltda. V.1, São Paulo, pp. 1-58.

Reis, A.M., 2004, “Investigation of Performance of Different Tool Materials in Tapping Process when Machining Grey Cast Iron by Means of Monitoring of Wear”, PhD Thesis, Federal University of Uberlandia, 192 p.

Schulz, H., 1997, “A alta velocidade corta tempos e custos e aumenta a qualidade das indústrias ”, Máquinas e Metais, fevereiro, pp. 71-76.