STUDY ON THE MACHINABILITY OF VP100 MOLD STEEL

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Abstract. *The goal of this study was to evaluate cutting parameters and different types of inserts in machining of standard pocket in VP100 steel used for molds and dies. The tests were conducted in standard pocket in order to bring near a studied model to reality found in the toolmaking industry. The cutting parameters were selected together with tools manufacturer and taking into account also common parameters used by toolmakers. Flank wear of tool and chip formation were evaluated periodically. The power cut consumed was monitored by sensors connected to the machine tool during machining. The geometry of cutting edge was scanned by Coordinate Measure Machine - CMM. The results show the selection of tool and cutting parameters appropriate improve tool life and consequently offer a satisfactory yield of material machined.*

Keywords*: VP100; steel; mold; machinability.*

1. INTRODUCTION

The importance of plastic industry is today notorious, due to the rapid increase in plastic parts production and the enlargement of their application in different market fields. Especially in the injection molding process, steel molds are usually necessary, being machined from steel blocks. And, considering the total mold cost, the machining process is of especial interest, corresponding to one of the major cost factors (Mesquita, 2009). This fact brings the machinability factors to attention of mold makers and steel producers. The term machinability include all materials property that have influence on machining process. The machinability of material must be observed in context of manufacture process, tool material and cutting condition (Schroeter and Weingaertner, 20XX; Trent and Wright, 2000).

The performance of the solid carbide tools is strongly dependent on their composition and microstructure, properties that not only depend on the type and amount of carbides, but also on their size and the amount of binder metal. The alloys consisting of tungsten carbide particles bonded with cobalt (WC-Co) are the most common tools used in metal cutting. In several applications, higher resistance is required at the cutting edge, being necessary the application of sub-micron carbides tools. Grain refinement in these alloys is obtained by small additions of tantalum carbide, niobium silicon, vanadium carbide and chromium carbide. Carbide tools may be subject to abrasive wear when abrasive particles are present in the machined part, either on its surface (like sand on the surface of castings) or within its microstructure, such as hard carbide or alumina inclusions. Tools with low content of binder (cobalt) and / or refined carbide can withstand the abrasive wear (Metals Handbook, 1989).

Coating tool materials are also important in relation to wear in metal cutting. Among all possible coatings, Al_2O_3, TiN and TiC are commonly used due to the high obtained hardness. TiC coatings can be more effective in flank wear, where the temperature rarely exceeds 600 ºC during the machining. At lower speeds, TiC also provides adequate protection to rake face of abrasive wear. On the other hand, Al_2O_3 can provide better resistance to high speed cutting, due to the higher hardness at high temperatures. The compounds TiC and TiB_2 have higher hardness at room temperature and often offer better protection against abrasive wear. With increasing temperature, however, these coatings quickly reduce their hardness, while Al_2O_3 retaining the best hardness in high temperatures (Metals Handbook, 1989). Hard coatings also reduce the friction at the interface chip/tool, which in turn reduces the heat generated in the tool and therefore results in lower temperatures at tool tip. The compound TiN has prominence in lubricant effect. Reports in the literature suggest that TiN is more resistant to crater wear and that TiC is more resistant on flank wear. The alumina coating shows no significant differences in relation to carbides and nitrides coated. The biggest difference in the rate of wear is observed in the notch wear where occurs sliding and rather than seizure. In this position the wear is minimal with alumina coating (Trent and Wright, 2000).

To accordingly respond to market needs, in terms of surface quality, strength and machinability, steel makers are constantly searching for better products, either by process modifications or new alloy compositions. Some interesting examples to machinability improvement are related to product and process modifications, such as: alloying modifications (addition S), process control (ESR – Electro-Slag Remelting) and special melting shop treatments (Ca inclusion modification). In this context, a completely new chemical composition could be very beneficial to increase machinability, but other characteristics are necessary to develop new steel for plastic injection mold, sometimes variable metallurgical parameters are somewhat difficult to connect to this machinability increase (Rech *et al.* 2004; Chandrasekaran and M'Saoubi, 2006; Barretos *et al.* 2000; Baptista and Nascimento, 2005; Luiz *et al.* 2003). To ensure the successful development requires a synergy between cutting tool makers, mold makers and steel makers.

In fact, a completely new grade has been designed by Villares Metals company, with commercial name of VP100. This new steel is supplied in the pre-hardened condition, to 32 HRC and ~ 1000 MPa strength, employing high contents of alloying elements, such as Cr, Ni and Mn. These elements are related to a steel the property named "hardenability", meaning that it is able to be hardened in large sections, through the heat treatment. The VP100 steel is designed to be hardened by slower cooling than the traditional process of quenching. This occurs because the effect of micro alloys elements as Ti and V, which promote the formation of a microstructure of lower bainite. By this chemical balance, the mechanical properties very homogeneous, uniform hardness. Another important modification in this grade is the reduction of carbon content, leading to improved weldability and reducing the brittle characteristic of Electrical Discharge Machined surfaces (Mesquita, 2009).

Therefore, due to the importance of machinability in mould production, the present paper evaluates this property in this new VP100 steel. Steel microstructure and machining process is considered together, in order to give a better understanding of the machining process. Distinct cutting conditions, different tool materials and coatings are evaluated, developing important data to the machining of VP100 steel.

2. STATEMENT OF EXPERIMENT

The cutting parameters and grades of inserts were compared by evaluating the following criteria:

- Tool life;
- Chip shape and color;
- Power consumption;
- Geometry of the edge.

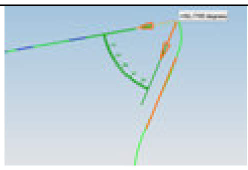
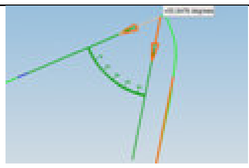
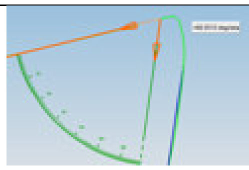
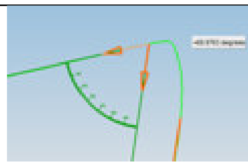
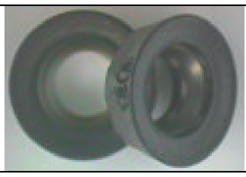
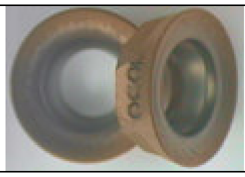
2.1. Materials

The tests were performed in a machining center model Hermle C600U, with maximum rotation equal to 16,000 rpm and power of 15kW.

The cutting tool used was a round insert milling cutter R300-25T12-10M type threaded coupling, by Sandvik. It has toroidal top, 25 mm diameter and 3 teeth. It was used four different inserts, all of hard metal and with radius 5 mm.

Table 1 shows the characteristics of coatings and geometries of inserts. The geometrical characteristics were obtained by scanning of insert on the CMM (Coordinate Measuring Machine). The angle measurement was the angle between flank face and rake face with restrict contact.

Table 1. Characteristics of inserts tested.

Insert	R300-1032E-PL	R300-1032E-PL	R300-1032M-PH	R300-1032M-PH
Grade	1010	1030	4220	4230
Coating	TiAlN	TiAlN	Ti (C, N) - Al_2O_3 - TiN	Ti (C, N) - Al_2O_3 - TiN
Coating methods	PVD (Physical Vapour Deposition)	PVD (Physical Vapour Deposition)	MT-CVD (Medium Temperature-Chemical Vapour Deposition)	MT-CVD (Medium Temperature-Chemical Vapour Deposition)
Angle measurement (°)	56,8	55,8	68,1	69,0
Angle measurement				
Cutting edge radius (mm)	0,022	0,033	0,050	0,060
Insert				

Tests of tool life had been carried out in blocks with dimensions 180x180x180 mm (Figure 1). Before starting the experiment, the samples were faced, to leave the area to be machined flat and parallel to the plane determined by X and Y axes of machine. The pocket has opening 170x170 mm, with radius of 25 mm in corners, 15° inclination of side walls and maximum depth of 50 mm.

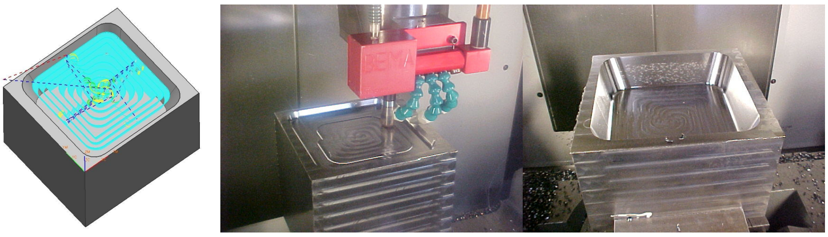


Figure 1. Simulation in CAM (left); sample during the machining (center); finish sample (right).

2.2 Methods

The goal of this study is approach a model of study of reality found in the manufacturing of molds. The cutting parameters were selected in conjunction with the manufacturer of tools and also taking into account common cutting conditions used in tool manufacturing (Table 2).

Table 2. Cutting parameters applied in life tool tests.

	Cutting speed, v_c [m/min]	Feed per tooth, f_z [mm/tooth]
Condition 1	200	0,23
Condition 2	200	0,40
Condition 3	300	0,23
Condition 4	300	0,40

The evaluation of tool life is achieved on monitoring periodically, through the following criterion:

- flank wear, for an end of life (VB max = 0.3 mm);
- due to intense noise (due to friction caused by excessive wear and rounding of edge) and
- formation of edge chipping.

To measure the flank wear was used a microscope Wild M3C of Switzerland Herrbrugg type S, with a capacity increase of 6.4 X, 16X, 25X and 40X, with software Leica Qwin Pro.

The tools were placed under the lens of a microscope and, through a video cam attached to it and switched to computer; photos were taken of the region of edge of tool. The height of flank wear was measurements in these photos.

It was determined the value of axial depth cut (a_p) as 0.5 mm and the radial depth cut of work (a_e), 10 mm, these values are also used to roughing operations with tools of diameter used (D = 25 mm). The three inserts were mounted in the tool. The strategy used was spiral-cut, with ramp angles of entry into the 5^o and relief of corners with radius of 13 mm.

The chips were analyzed for their shape and color in all intervals of measurement of wear. As reported here, only on three occasions at the beginning of experiment, when the wear reached VB half life, and at the end of tool life of each condition.

The electrical power consumed was real time monitored through the measurement of the electrical current of the main motor of the machine tool. Each time a pocket increased 2 mm flank wear was measured. Each experiment was carried out once time and all the experiments were made without cutting fluid.

3. RESULTS AND DISCUSSION

Figure 2 illustrates the volume of material removed in machining in the end of tool life according to the insert and cutting conditions used.

Observe that cutting condition which has the largest amount of volume of chip, was the condition with cutting speed of 200 m/min and feed of 0.4 mm/tooth, where a medium cutting speed combined with a high feed avoided the early wear by abrasion. This cutting condition was undoubtedly the best for all classes of inserts used with reference to the insert R300-1032M-PH 4230 with the best performance.

The worst condition tested was cutting speed of 300 m/min and feed of 0.2 mm/tooth, in this case the tool stayed friction more time against titanium nitride carbides characteristic of this steel, leading to premature wear of edge by abrasion.

On the same cutting condition all grades obtained similar results in spite of coatings and geometries differences.

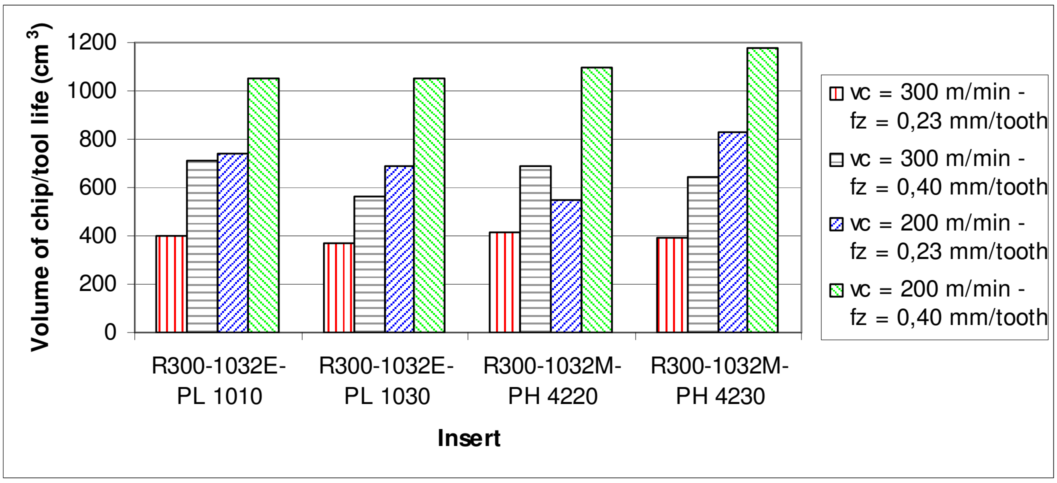


Figure 2. Volume of chip removed per insert and cutting condition tested.

Figure 3 shows the evolution of flank wear of tool as function of volume removed for each class of insert used and cutting condition. For all grades tested, there is the development of premature flank wear on condition v_c = 300 m/min and f_z = 0.23 mm/tooth, color red. The green curve, condition v_c = 200 m/min and f_z = 0.4 mm/tooth presents the best cutting condition in which the edge of tool resist more time the abrasive action of titanium nitride carbides. The curves in blue and gray show intermediate conditions, with random behavior between other grades of inserts.

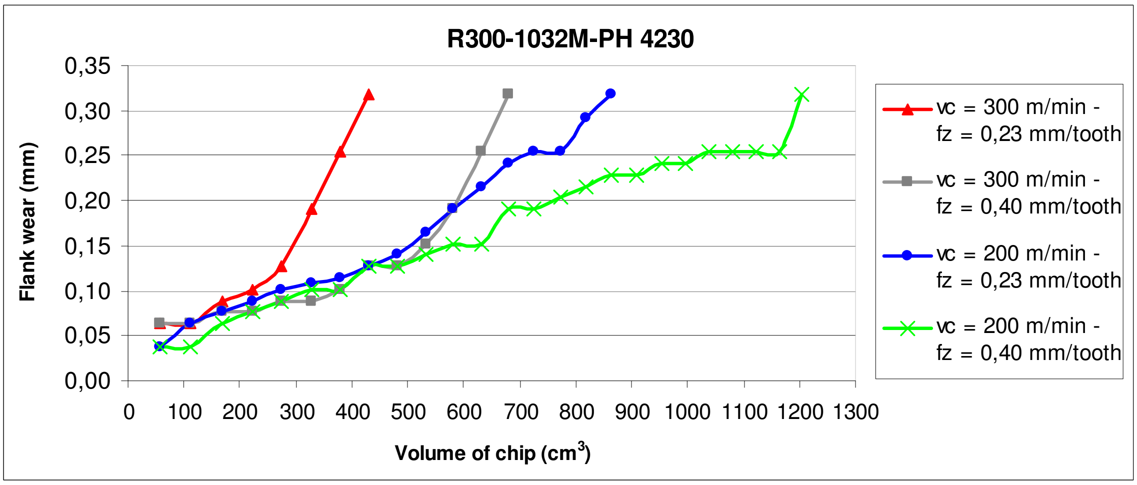


Figure 3. Tool flank wear R300-1032M-PH 4230 as function volume of chip.

In the analysis of chip formation, observe in low feed conditions (f_z = 0.23 mm), a color more blue from beginning to end of life of insert, showing a greater generation of heat during cutting (Figure 4).

The shape of chips in all grades studied was very similar; with increase of flank wear is observed a malformation of chips in relation a new edge, because of change of edge shape with flank wear.

The cutting forces in milling operations are constantly changing their value during the operation. This makes some comments are necessary, because this variation is an aim cause of end of cutting tool life.

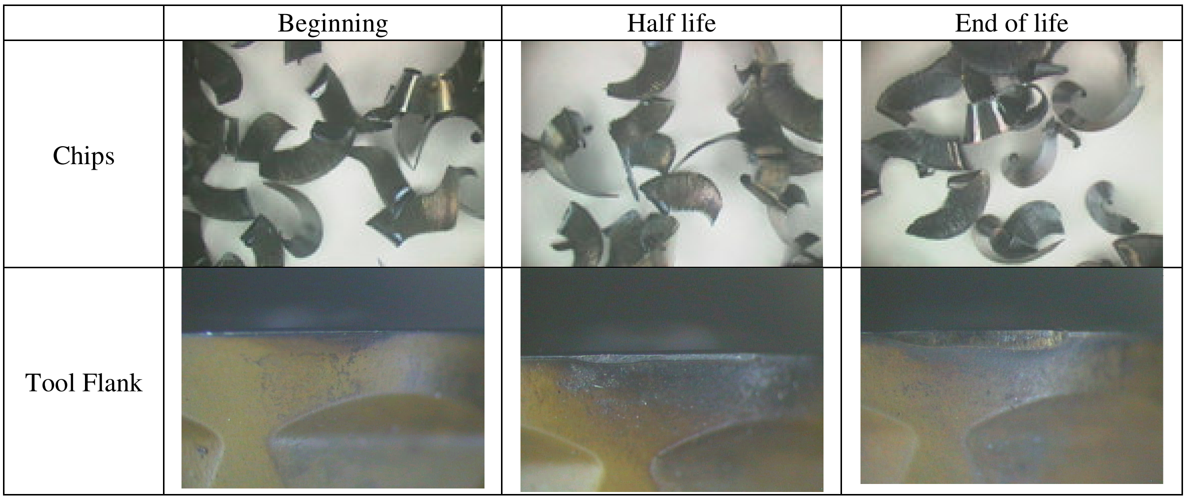


Figure 4. Flank wear evolution of cutting tool and shape of chips in the beginning, half life and end of life to v_c = 200 m/min and f_z = 0.4 mm/tooth with insert R300-1032M-PH 4230.

Figure 5 illustrates the power consumption as function of volume of chip for each different combinations of cutting parameters evaluated. The curves show a increase of power consumed during cutting with the increase of flank wear. As power consumption is a function of product between cutting speed and feed, the power consumption was proportional conditions evaluated, the higher power consumption on condition v_c = 300 m/min and f_z = 0.4 mm/tooth. It was observed that the power consumption was up to 10% lower in grades 1010 and 1030 due a geometrical characteristics of tool with restricted contacts and smaller radius tip in relation of grades 4220 and 4230 (Table 1)

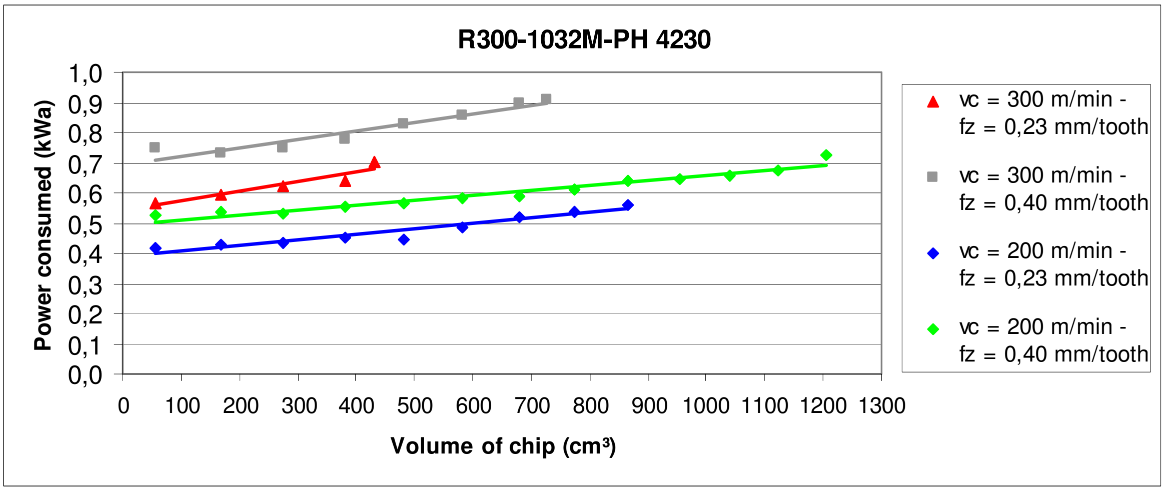
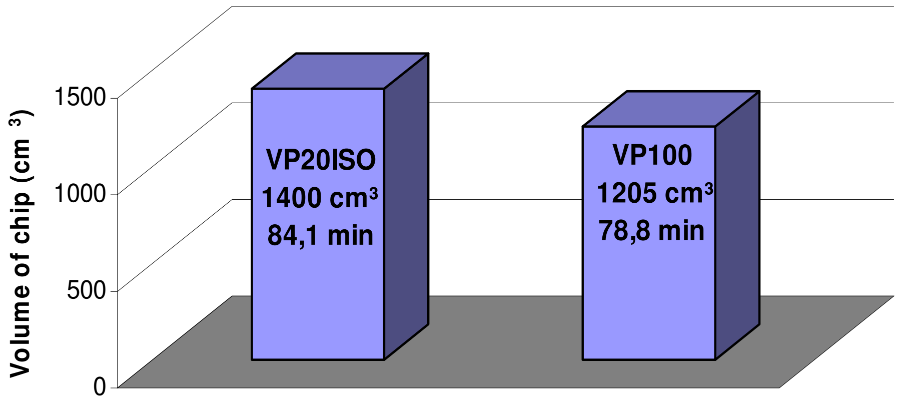


Figure 5. Power consumed during machining as function of volume of chip with inserts R300-1032M-PH 4230.

Figure 6 shows a comparison between the pocket machining in steel VP20ISO and VP100. With an optimization of cutting parameters and the selection of another grades of inserts for machining steel VP100 is possible to achieve 86% of volume of material machined in steel VP20ISO.

The time calculated by the CAM (Computer Aided Manufacturing) for pocket machining is very close in both conditions. This reflects that with the optimization of cutting parameters and employment of new tool geometries and coatings is possible to reduce costs in the construction of molds and dies, as the new steel VP100 has a lower cost on VP20ISO and meets all applications where the VP20ISO is employed.



Cutting tool: R300-25T12-10M
Cutter Diameter = 25 mm
Number of teeth = 3
Insert: R300-1032E-PM 1025
Carbide coated with TiN by PVD
Round insert: radius = 5 mm
Cutting Conditions: **Down milling**
Cutting speed, v_c = 200 m/min
Feed/tooth, f_z = 0,25 mm/tooth
Axial depth of cut, a_p = 0,75 mm
Radial depth of cut, a_e = 10 mm

Cutting tool: R300-25T12-10M
Cutter Diameter = 25 mm
Number of teeth = 3
Insert: R300-1032M-PH 4230
Carbide coated with TiN by MT-CVD
Round insert: radius = 5 mm
Cutting Conditions: **Down milling**
Cutting speed, v_c = 200 m/min
Feed/tooth, f_z = 0,40 mm/tooth
Axial depth of cut, a_p = 0,5 mm
Radial depth of cut, a_e = 10 mm

Figure 6. Comparison of volume of chip removed and time estimated by CAM to pocket machining between the VP20ISO and VP100 steel.

4. CONCLUSION

Based on the results obtained in this work, the following conclusions can be taken:

1. The most favorable cutting condition for machining VP100 steel was v_c = 200 m/min and f_z = 0.4 mm/tooth, among those studied for all grades inserts, especially for inserts grade R300-1032M-PH 4230.
2. The predominant mechanism of wear of inserts was abrasive, characterized by hard particles (titanium nitride carbides) within the VP100 steel microstructure.
3. The power consumption is proportional to flank wear and also the product of cutting speed and feed used.
4. The power consumption was lower in inserts grades 1010 and 1030, where the tool has restricted contact on rake face and edge radius are smaller.
5. The selection of a new inserts grade and cutting parameters resulted in a volume of chip removed in VP100 steel only 14% lower for the same geometry machined in VP20ISO steel.

5. ACKNOWLEDGEMENTS

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