



Study of machinability of VP 100 steel with different levels of titanium in end milling operations

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ABSTRACT. During the manufacture of a mould, machining is certainly the most important process. The composition required to provide important properties in the steels used, such as hardness, wear and corrosion resistance, results in a low machinability has resulted in a low volume of material removed by the end of life of the cutting tool, due to the strong wear generate. In this study, we investigated the behavior of steel processing VP 100 is used in manufacturing plastic injection molds. To this end, we used two versions of VP100, one with 270 and another with 350 parts per million (ppm) of titanium. The tests comprise six different cutting conditions in end milling operations. We observed the volume of material removed for each tested condition, considering the evolution of flank wear of tools to a maximum of 0.5 mm. Steel VP 100 with 350 ppm of Ti showed a higher volume of material removed in five of six tests showing that, in this case, a higher content of titanium improved the machinability of the steel under study.

Keywords: machinability, steels for plastic injection mould, volume of material removed, flank wear, VP 100 steel.

Estudo da usinabilidade do aço VP 100 com diferentes teores de titânio em operações de fresamento frontal

RESUMO. Durante a fabricação de um molde de injeção de plástico, a usinagem é parte importante dos processos envolvidos. Entretanto, a composição química necessária para se obter propriedades mecânicas (dureza, resistência ao desgaste e à corrosão - fundamentais nos aços utilizados para esse fim) leva à baixa usinabilidade, tendo como consequência um baixo volume de material removido até o fim de vida da ferramenta de corte, pelo acentuado desgaste gerado. Neste trabalho, é investigado o comportamento em usinagem do aço VP 100 utilizado na fabricação de moldes de injeção de plástico. Para tanto, utilizaram-se duas versões do VP100, sendo uma com 270 e outra com 350 partes por milhão (ppm) de titânio. Os testes realizados compreendem seis condições de usinagem diferentes em operações de fresamento frontal. Foi observado o volume de material removido para cada condição testada, considerando-se a evolução do desgaste de flanco das ferramentas até um valor máximo de 0,5 mm. O aço VP 100 com 350 ppm de Ti apresentou maior volume de material removido em cinco dos seis testes realizados evidenciando que, nesse caso, um maior teor de titânio melhorou a usinabilidade do aço em estudo.

Palavras-chave: usinabilidade, aços para moldes de injeção de plástico, volume removido, desgaste de flanco, aço VP 100.

Introduction

The molding industry plastic injection constitutes a growing sector due to the widespread use of plastic parts in other sectors. These molds are manufactured from castings steel bars and laminated whose cavities are generated by machining operations which represent the greatest part of the time of manufacture and the final cost of the mold. The steel has more influence on the total cost of the mold due to its machinability than through the raw material cost. For this reason, the

optimization of machining conditions is needed to reduce the cost of a mold. (RECH et al., 2004).

The machinability is generally defined in terms of strength, power consumption, volume of removed material, tool wear, surface integrity and finish end. Therefore, a material with good machinability generally features low power consumption during machining, as well as a small wear rate with large volume of material removed and good finishing (KALPAKJIAN, 1985; ABDEL-AAL et al., 2009).

The improvement of response variables such as tool life, cutting forces, surface roughness can result in a significant improvement in machining operations costs through the optimization of cutting parameters such as feed, cutting speed and depth of cut. This optimization can lead to a greater volume of material removed during machining, thereby minimizing manufacturing costs of the mold (AMIN et al., 2007).

Steels for plastic injection moulds

Some plastic parts are produced in series, in very short cycles using molds with many cavities. Others have great size and are made of smaller scales and larger cycles. Regardless of the type of production, a mold to be used in plastic injection need is in perfect condition. To get good results, with good quality molds must be used, since any imperfections will be reproduced in the plastic part. An important decision to obtain a good mold is to select a steel suitable for the application. In the Brazilian industry of molds, steel is the most widely used AISI P20, which is an alloy of chrome-molybdenum steel. This material is classified as a tool steel, used for making plastic injection molds, extrusion dies, blow molds, tools for profiling and other structural components (ABOU-EL-HOSSEIN et al., 2007).

The hardness of the material is an important property to be taken into account in selecting a steel. Steels with a hardness in the range 38-42 HRC are given for moldings which require more strength. Hardness imply a greater improvement in polishability steel. Good levels of polishability allow obtaining molds for plastic parts that need to be translucent. This is the case lens headlights and taillights of cars, which should have a transparency as high as that obtained with glass (ABOU-EL-HOSSEIN et al., 2007; MESQUITA et al., 2009).

The VP100 is a steel developed with microalloying elements such as titanium and vanadium, which can be hardened at different cooling conditions of traditional tempering presenting homogeneous hardness from the surface to the core of the block with dimensions of up to section 400 x 1200 mm². The lower use of alloying elements on the VP100, for example, the low chromium content, contributes to reducing the costs of manufacturing the same, increasing their competitiveness. Its design does not employ high cooling rates, leading to a considerable reduction of the residual stresses. Besides these features, the fact that this steel having carbon content less than traditional steels, causes, after application of solder, provide adjustment for machining facilitated due to the lower hardness generated. For plant it is

recommended lower cutting speeds and higher advances, and their behavior in the processes of texturing and polishing, similar to that of traditional steels like, for example, the VP 20 ISO (MESQUITA et al., 2009; SUN et al., 2009).

The comparison of properties is important when selecting the mold material. The choice is made according to the degree of abrasion of the plastic to be injected, the appearance of the number requested and the desired strength of the tool (RAHMAN et al., 2006).

This study aims to compare the machinability of steels VP 100 with 270 and 350 ppm of titanium used in the manufacture of plastic injection molds. The machinability in this case is expressed by analyzing the volume of material removed and the flank wear of the cutting tools in end milling operations.

Material and methods

The tests used machining milling operations where there was flank wear of the tool due to the volume of material removed using VP100 two blocks, one with 350 ppm of titanium and another with 270 ppm of titanium whose dimensions are 203 x 203 x 184 mm as shown in Figure (1), which has its mounting on the table of the machining center.



Figure 1. Block VP 100 used in the tests milling mounted on the table of the machining center.

Tools used

The experiments milling inserts used carbide from Kennametal KC725M coated with a triple layer of tin TiCN TiN, deposited by the PVD method, mounted in a Weldon shank end mill with three pellets 32A03F039B32SSP10G, also from Kennametal, as shown in Figure 2. The machine tool used was a Machining Center Discovery 760 CNC SIEMENS 810D, with rotation range between 7 and 7000 rpm and 15 CV of power.

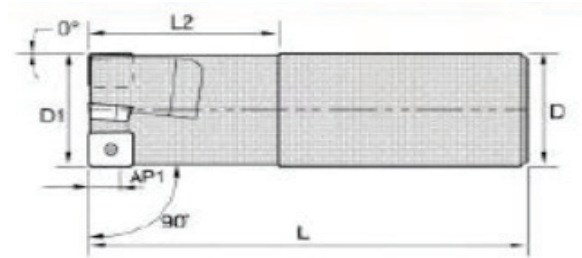


Figure 2. End mill used in milling tests with $D1 = 32$ mm and $L = 100$ mm.

Process monitoring

In tests of milling, the evolution of tool wear was monitored using an optical microscope with digital camera model SZ61, Olympus manufacturer, and a Pentium III 900 MHz with 1024 MB of RAM, equipped with a acquisition plate signals with 16-bit resolution and sampling rate up to 1.25 MS s^{-1} . and software LabVIEW 7. Figure 3 shows a photo montage with such equipment.

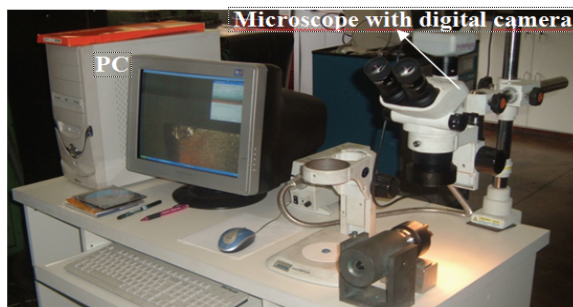


Figure 3. Arrangement drawing system for acquiring images of the evolution of tool wear.

The volume of material removed during milling experiments were calculated by considering the area of the machined surface of the block multiplied by the respective depths of cut for each condition tested until it reach the end of tool life. Each full cycle of the milling tool flank wear was measured to enable the construction of curves of evolution of the wear on the volume of material removed to a $VB_{\max} = 0.5$ mm. It is understood by milling cycle completes one pass of the cutter on the surface of the block of material in machining, where the cutter moves of advance exerted in both directions, concordant and discordant, always working with a penetration equal to 24 mm and without losing contact with the play until the end of the cycle. Figure 4 illustrates the trajectory of the cutter from start to finish of a milling cycle.

Were performed also hardness tests with both steels, whose results are shown in Table 1, where it can be seen that the hardness of steel 100 with VP 270 ppm of Ti is less than the average hardness of steel 100 with VP 350 ppm Ti.

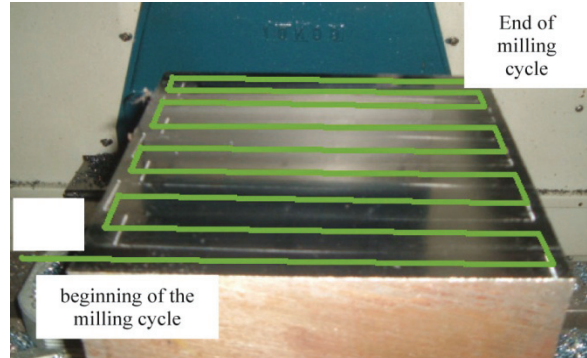


Figure 4. The trajectory of the cutting tool from start to finish of a milling cycle.

Table 1. Average hardness of steels VP100.

Test Hardness Rockwell C		
Universal Hardness Testers Wolpert - Load: 150 kg		
Steel	Average hardness HRC	Standard Deviation
VP100 270 ppm Ti	30	1,6
VP100 350 ppm Ti	33	1,5

Milling Tests

From the testing of milling was possible to observe the evolution of tool wear due to the volume of material removed for steels VP100 with 270 and 350 ppm titanium, using six different machining conditions for each complete cycle of milling (Figure 4). The machining parameters used in each of the six conditions tested are shown in Table 2. In all cases it was used a penetration working $a_e = 24$ mm recommended by tool manufacturer.

Table 2. Parameters used in the machining conditions tested.

Machining Conditions						Unidade
1	2	3	4	5	6	
$V_c = 100$	$V_c = 200$	$V_c = 100$	$V_c = 200$	$V_c = 100$	$V_c = 100$	m min^{-1}
$f = 0,1$	$f = 0,1$	$f = 0,2$	$f = 0,1$	$f = 0,1$	$f = 0,2$	mm rev^{-1}
$a_p = 1$	$a_p = 1$	$a_p = 1$	$a_p = 2$	$a_p = 2$	$a_p = 2$	mm

The results for the evolution of the wear of the tools used in milling tests, adopted a maximum flank wear $VB_{\max} = 0.5$ mm recommended by ISO 8688-2/1989, and the analysis of wear was made for each complete cycle of milling depending on the volume of material removed from the workpiece.

The behavior of wear of the milling tools used in VP100 with 350 ppm of titanium, showed that were required 13 passes to complete the condition 1 is reached the end of tool life, the volume of material removed was approximately 473.9 cm^3 . As for condition 4, onlthree passes are complete enough that the tool reached the end of life, and volume of material removed approximately 247.25 cm^3 .

The pictures relating to the behavior of wear of the milling tools used in VP100 with 350 ppm of titanium are shown in Figures 5 and 6.

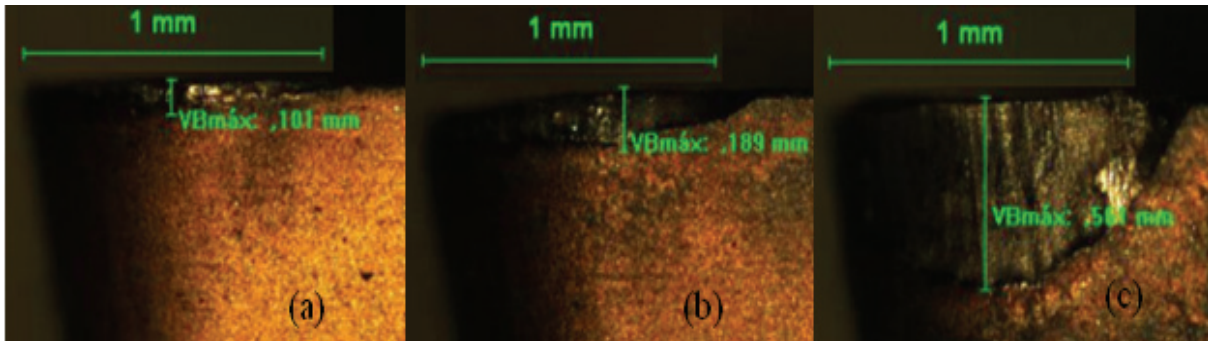


Figure 5. Evolution of tool wear in milling trials with the VP100 350 ppm Titanium using $V_c = 100 \text{ m} \cdot \text{min}^{-1}$, $a_p = 1 \text{ mm}$, $f_z = 0.1 \text{ mm} / \text{tooth}$ and $a_e = 24 \text{ mm}$ a) 1^a last b) 6^a c) last 13^a and last pass.

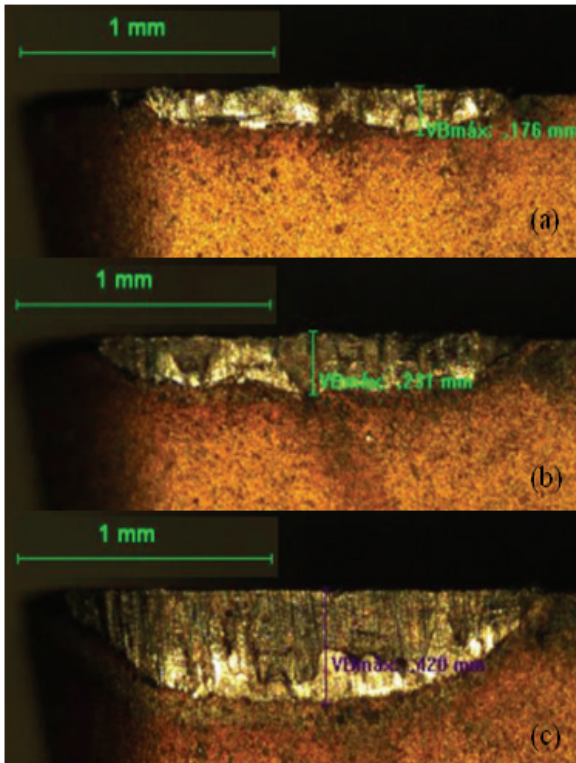


Figure 6. Evolution of tool wear tests used in milling the VP100 with 350 ppm Titanium using $V_c = 200 \text{ m} \cdot \text{min}^{-1}$, $a_p = 2 \text{ mm}$, $f_z = 0.1 \text{ mm} / \text{tooth}$ and $a_e = 24 \text{ mm}$, a) 1^a last, b) 2nd last c) 3rd and last pass.

Results and discussion

The results are shown in Figures 7, 8 and 9 where it is possible to observe a difference between the values for the volume of material removed for each material tested under the conditions specified.

From the results obtained it is possible to realize the VP100 with 350 ppm of titanium showed a greater volume of material removed as the VP100 with 250 ppm of titanium in almost all conditions tested, exception to this tendency only condition 5.

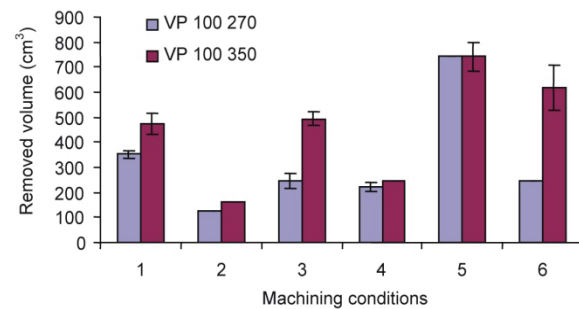


Figure 7. Volume of material removed in the six test milling machining conditions used (Table 2) for steels VP100 with 270 and 350 ppm titanium. $VB_{max} = 0,5 \text{ mm}$

A more detailed analysis of some of these results can be seen in the graphs of Figures 8 and 9 where the volume is shown removed from milling tests for each stage of evolution of the wear of the tool until the end of life.

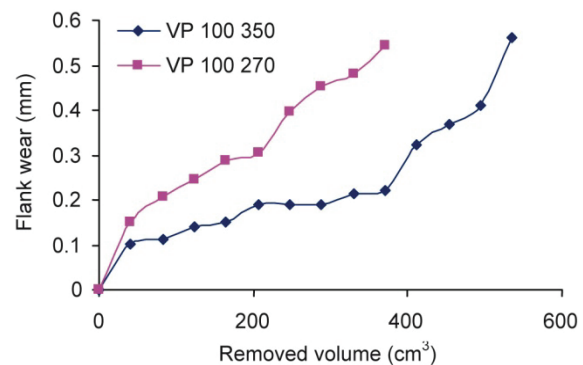


Figure 8. Flank wear as a function of the volume of material removed obtained in milling tests performed in condition 1 (Table 2) steels VP100 with 350 and 270 ppm titanium - Volume removed to $100 \text{ m} \cdot \text{min}^{-1}$.

The graphs show the trend behavior of steels studied indicating better machinability of VP100 with 350 ppm titanium. In this case, a greater percentage of titanium and a high-hardness steel made in this respect to VP100 with 270 ppm of

titanium, did not result in a worsening of their machinability.

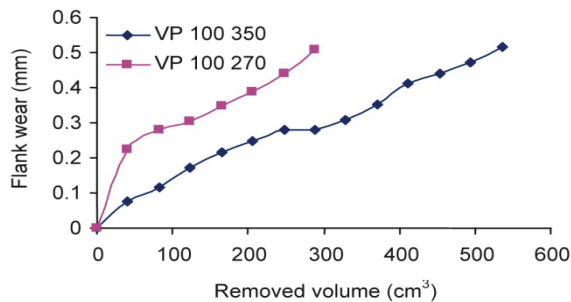


Figure 9. Flank wear depending on the volume of material removed milling obtained in the tests performed in condition 3 (Tabela. 2) VP100 steels, with 350 and 270 ppm of titanium. Volume removed to 100 m min⁻¹.

However, a lower hardness and consequently higher ductility of the VP100 with 270 ppm Ti requires greater plastic deformation, which can generate a greater hardening of the workpiece material. By hypothesis, this may have been one of the factors that led to such results.

Conclusion

Increase in the percentage of titanium and increased hardness VP100 with 350 ppm of titanium not become worse its machinability compared to VP100 with 270 ppm of titanium;

VP100 with 350 ppm of titanium showed better machinability than the VP100 with 270 ppm of titanium in almost all conditions tested; If Makes necessary a careful characterization of both steels in order to diagnose the possible causes for the phenomena described above; A Greater ductility and consequent greater plastic deformation and hardening of the VP 100 with 270 ppm of Ti, hypothetically, may have contributed to these results.

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