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GRINDING CUSTOMIZED CARBIDES FOR THREAD TURNING OF TITANIUM ALLOYS

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Abstract. Several titanium alloys have been used for machining orthopedic and orthodontic devices, like bone screws, because of their interesting behavior in terms of corrosion resistance and biological response. Of course, this behavior is strongly affected by the surface integrity of the manufactured components. The present study aims to manufacture and evaluate customized carbide inserts for thread turning titanium alloys. Clearance angle and chamfering were chosen as input variables regarding the tool geometry. Results showed that grinding cemented carbides with a bigger clearance angle provided lower surface roughness, with a strongly symmetric profile in terms of widths of valleys and peaks and also considerably good repeatability. In terms of cutting edge irregularities, grinding a chamfer may help to reduce them, especially for a bigger clearance angle. These conditions may improve both tool life and the machined surface integrity for titanium screws.

Keywords: Machining, tool geometry, cutting edge, clearance angle, chamfer.

1. INTRODUCTION

Osseointegration is defined as a time-dependent healing process whereby clinically asymptomatic rigid fixation of alloplastic materials is achieved and maintained in the bone during functional load. In this scenario, different methods are used for this purpose, for example, the use of plates and screws that allow the mechanical fixation of these fragments. The use of plates and screws is widespread in the orthopedic environment, this method being used in a variety of fractures and being highly adaptable to the patient's needs (Zarb and Albrektsson, 1991).

Titanium alloys, in particular, show great utility in these applications as they have density and elasticity close to the ideal and do not easily corrode, in addition to being inert to the human body, that is, they do not cause allergic or pathological reactions when implanted in humans (Black and Hastings, 1998). Briefly, titanium and its alloys have extremely interesting properties for medical applications, however, there are cons in their use, especially the price, which is high, and the fact that it suffers corrosion by friction (Barbucci, 2002). Since the end of the 20th century, titanium-molybdenum alloys have been frequently used in the manufacture of prostheses, as they have excellent biocompatibility and mechanical resistance, low modulus of elasticity and good corrosion resistance. However, such alloys turn out to be difficult to use, running in an inefficient and expensive process. From this perspective, recent researches have been looking for cutting conditions that lead to an improvement in the surface integrity of the machined component and a longer tool life, which can also be achieved through a suitable tool, not only in terms of material, but of superficial characteristics (Pivotto, 2020).

Thus, it is necessary to consider the difficulties regarding the machinability of these materials, since titanium alloys have low thermal conductivity, which impairs heat dissipation, and a considerably low elastic modulus, that generates high vibration during cut, impairing the precision of the manufactured parts and accelerating tool damage (Antonialli, Diniz and Pederiva, 2010). Choosing a suitable grade of cemented carbide, as well as tool insert geometry, is a key factor in overcoming all these difficulties.

Comparison of the performance of different grades of cemented tungsten carbides demonstrates very well that wear rate is very dependent on the type of wear process or mechanism involved. Thus wear resistance is not a unique property of a tool material which can be determined by one simple laboratory test or correlated with one simple property such as hardness. Correct diagnosis of the controlling wear mechanism for a particular operation, like the thread turning of titanium alloys can often be the starting point in selecting the optimum tool grade (Trent and Wright, 2000).

The general manufacturing chain of cemented carbides consists of powder mixing, pressing of the green parts, sintering, grinding and coating (if there is). Grinding is one choice for the post-processing of sintered cemented carbides

that is appropriate to small workpieces with high quantity and suitable material removal rate and the better process control. So, it is quite possible to produce tools with a considerably high reproducibility in terms of geometric features (Bergs *et al.*, 2021).

The choice of grinding wheel has a major impact on the tungsten carbide tool topography. Selecting a diamond grinding wheel with grosser grains reduces material adhesion that might occur on the tool during its usage, directly affecting the avoidance of built-up edges and preventing fatal tool failure. Takeyama, Iijima and Yamamoto (1987) concluded that a higher grain size for the grinding wheel may be advantageous because the carbide grains are willing to be crushed to a finer structure, and also the concentration of cobalt could be appreciably reduced on their ground surfaces.

Also the correct choice of grinding parameters for tungsten carbide tools directly influences the residual stress on their surfaces. High residual stresses are linked to the propagation of micro-cracks on the tool surface and in processes involving machining titanium such a factor combined with cutting heat and cutting force can lead to fractures on the tool's cutting edge. Zhao *et al.* (2016) compared two grinding conditions for the production of carbide end mills and observed that lower depth of cut (0.0635 mm versus 0.0762 mm) but higher grinding speed (38.1 m/s versus 17.8 m/s) provided micro-cracks that could be observed even before their usage. It is also reported that it is possible to achieve better finished surfaces for tungsten carbide inserts when they come through a near-ductile regime. Kuppuswamy and Mkhize (2017) used a diamond tool to machine cemented carbide and observed that higher cutting speeds decreased the un-deformed chip thickness which facilitated an increase in ductile fractures, and so provided lower cutting forces and lower surface roughness.

Clearance angle has an obvious relation with tool life, because smaller angles enhance cutting edge strength, but bigger angles may reduce flank wear (Barzegar and Ozlu, 2021). It is also interesting to study chamfer variations because it can reinforce the strength of the cutting edge, especially for some tool grade with low fracture toughness (Ventura, Köhler and Denkena, 2014).

The focus of this work is on the production of customized inserts to be used in thread turning operations on titanium alloys like commercially pure titanium (#4), Ti-6Al-4V ELI and Ti-15Mo, which are widely applied in orthopedic implants. It is expected that the grinding process presents enough repeatability so that no significant difference may be found between the carbide inserts prepared with different geometric features. With this condition approved, it will be possible to evaluate the performance of all those carbide inserts in terms of tool life and surface integrity of different titanium alloys subjected to thread turning using each one of them, which will be the subject for further papers.

2. MATERIALS AND METHODS

Carbide uncoated T-shape inserts (specification TNRW320, HW K10 grade) were ground to obtain customized inserts, with two different clearance angles, 8° and 11°, and two different chamfer configurations: no chamfer and with a 20° chamfer angle. Two replies of each combination were produced in order to infer the reproducibility of the manufacturing process.

The grinding process was performed on a four-axis CNC grinding machine model Agathon DOM Plus (maximum power of 16 kW and maximum rotation of 3400 rpm). For the grinding process, a cup-type diamond grinding wheel with resinoid binder and C100 concentration was chosen. The grinding wheel granulometry, as well as the parameters used, were chosen based on the work carried out by Pivotto (2020), with the grain size chosen for the grinding wheel being 15 µm (D15), the grinding speed of the grinding wheel (v_c) is 20 m/s, the axial feed rate (v_{fa}) is 4 mm/min, the insert rotation speed for the nose radius grinding (v_r) is 50°/min and copious application of oil will be used mineral. For each insert manufactured, the grinding wheel will be dressed using alumina, following a particle size of 220# and constant parameters with a tangential dresser speed (v_{cd}) of 10 m/min and a dresser feed speed (v_{fd}) of 3 µm/s, for 5 seconds. This parameters are aligned to the discussions reported by Takeyama, Iijima and Yamamoto (1987), Zhao *et al.* (2016) and Kuppuswamy and Mkhize (2017)



Figure 1. CNC grinding machine model Agathon DOM Plus

For the process of characterization of the inserts, a microscope for generating three-dimensional images was used, model Alicona Infinite Focus SL; this equipment works with a focus variation system, being then possible to obtain the desired parameters. Images were obtained from the clearance surface, to analyze the roughness parameters Rz, Rsk and Rku; and also the nose radius, to analyze the irregularity parameters in the cutting edge Δr and $W\Delta r$. A magnification of 100X was used, with the use of a 10X magnification objective lens and a 10X eyepiece.



Figure 2. Alicona Infinite Focus SL

After the characterization process, the obtained parameters were compared through an analysis of variance (ANOVA).

3. RESULTS AND DISCUSSION

Figure 3 presents the principal effects diagram for Rz roughness parameter measured on the clearance face of the ground inserts. For all combinations, Rz was kept around 6 μm , but the ANOVA approach showed that the clearance angle provides a slightly effect over this parameter (p-value = 0.051), whilst chamfering was less influent (p-value = 0.276), as well as the interaction between these variables (p-value = 0.645). Considering a 95% confidence level, none of them is statistically significant, but clearance angle obviously deserves some attention.

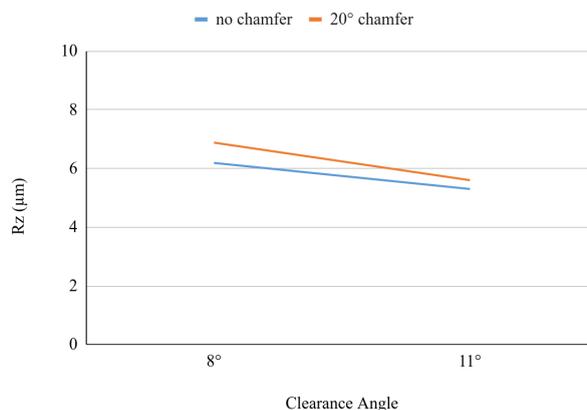


Figure 3. Rz roughness parameter

Results shown in Figure 3 indicate a trend that grinding bigger clearance angles ($11^\circ > 8^\circ$) may provide a slightly smoother surface than grinding smaller clearance angles. Anyway, the analysis of other parameters is essential, as follows.

Figure 4 presents the principal effects diagram for Rsk and Rku roughness parameters measured on the clearance face of the ground inserts.

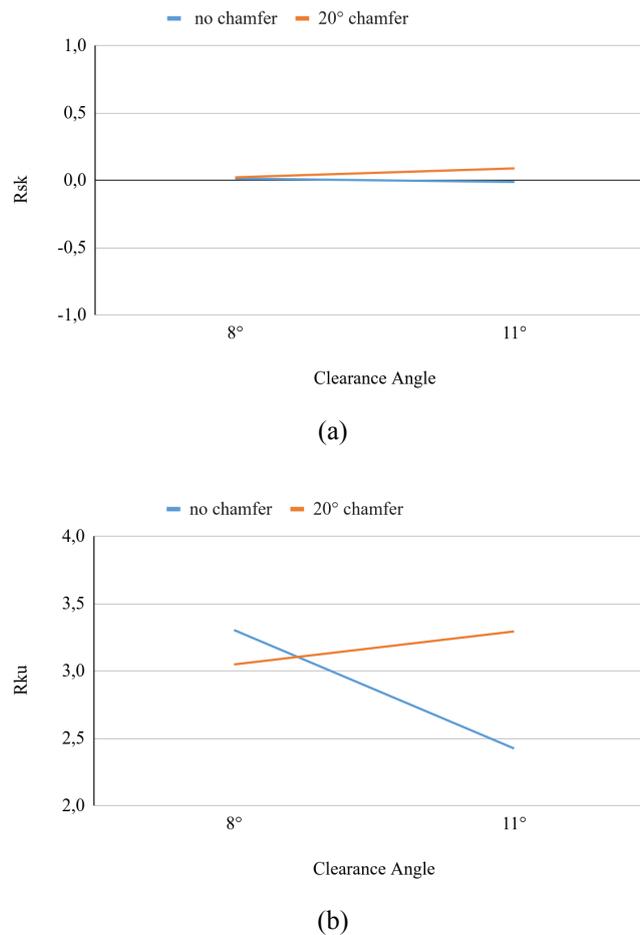


Figure 4. Roughness parameters (a) Rsk and (b) Rku

For Rsk (Figure 4(a)), results show that the clearance surfaces ground were practically perfectly symmetric ($R_{sk} = 0$), which means valleys and peaks present almost the same width along the profile; and none of the input variables, clearance angle (p -value = 0.869), chamfering (p -value = 0.663) or their interaction (p -value = 0.717) may be considered significant.

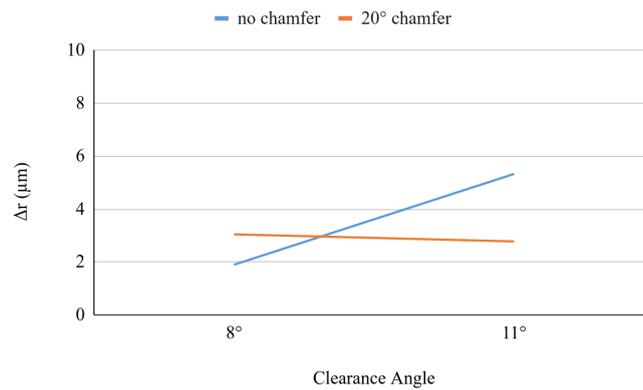
For Rku (Figure 4 (b)) values are mainly close to 3, which means the distribution of valleys and peaks widths is almost a normal distribution ($R_{ku} = 3$); neither clearance angle (p -value = 0.059) or chamfering (p -value = 0.065) shown out to be statistically significant considering a 95% confidence level, but their effect was very close to that; otherwise, the influence of their interaction over this roughness parameter is distinguishable (p -value = 0.010), which is graphically exposed by the crossing lines. This means that grinding a bigger clearance angle (11°) may provide an opposite effect, in terms of Rku, if also a 20° chamfer is ground or not.

Results shown in Figure 4 indicate a trend that grinding a 20° chamfer angle may be useful to improve the repeatability of the profile in terms of the width of valleys and peaks, especially for a 11° clearance angle.

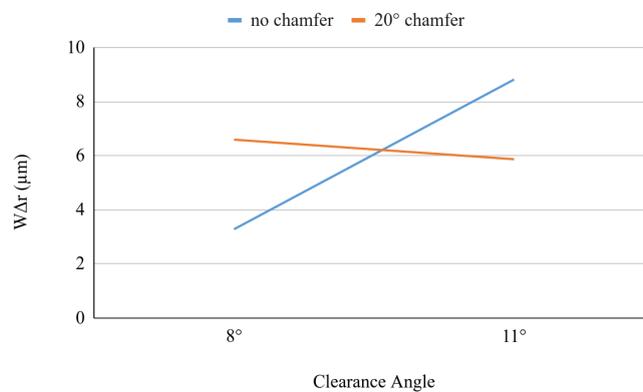
Finally, Figure 5 presents the principal effects diagram for the irregularity parameters in the cutting edge Δr and $W\Delta r$.

For Δr (Figure 5(a)), results show that chamfering may not be considered and influent input variable (p -value = 0.108), but clearance angle (p -value = 0.010) and the interaction between clearance angle and chamfering (p -value = 0.006) are statistically significant considering a 95% confidence level. The effect of the interaction is quite clear as Δr remains very close to 3 μm for chamfered tools with both clearance angles, but increases from below 2 μm (for a 8° clearance angle) to above 5 μm (for a 11° clearance angle) when no chamfer was ground.

For $W\Delta r$ (Figure 5(b)), results are quite similar regarding chamfering (p -value = 0.817), clearance angle (p -value = 0.031) and their interaction (p -value = 0.013). The effect of the interaction is quite clear as $W\Delta r$ remains very close to 6 μm for chamfered tools with both clearance angles, but increases from near 3 μm (for a 8° clearance angle) close to 9 μm (for a 11° clearance angle) when no chamfer was ground.



(a)



(b)

Figure 5. Irregularity parameters in the cutting edge (a) Δr and (b) $W\Delta r$

It may be inferred, based on the results of Figure 5, that the crossed effect between chamfering and clearance angle is substantial in terms of the cutting edge irregularities. Comparing tools with no chamfer, the increase in the clearance angle is prejudicial to the cutting edge. Comparing tools with a 20° chamfer angle, the influence of the clearance angle is negligible, with a trend to its increase to be favorable over cutting edge regularity.

4. CONCLUSIONS

Results shown indicate that the input variables that were chosen in this work are considerably important for the roughness of the clearance surface and also for the cutting edge irregularities. Considering the range of levels tested for clearance angle and chamfer angle, the best combination of factors is large clearance angle with chamfer. This situation provides lower surface roughness, considering a symmetric profile with high repeatability and low cutting edge irregularities. These conditions may improve both tool life and the machined surface integrity for titanium screws.

5. ACKNOWLEDGEMENTS

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