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Cutting tool wear during precision boring operations in lathe of a grade 4 titanium for biomedical implants

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Abstract

The titanium devices manufacturing present some challenges to be aborded, specially to produce biomedical implants. Considering machining, there are issues to be solved to improve part quality and production. The finishing produced by boring in lathe is related to the part precision during titanium machining, which can be affected by tool wear. This work aims to evaluate the cutting tool wear during boring in lathe of a grade 4 titanium. A combination of roughness parameters and radius of machined hole measured by 3D laser microscopy was applied to establish a relation between surface topography, workpiece geometrical deviations and tool wear. Cylindrical bars of grade 4 titanium with diameter of 4.2 mm were machined with 11 and 16 m/min cutting speed, 15 µm/r feed, 70 µm depth of cut and 2 500 µm length of cut per workpiece. Uncoated and TiN coated carbide cutting tools were applied for machining tests. Tool wear was evaluated by optical microscopy after machining of 3 000 workpieces per cutting tool. Results indicated a strong correlation between pairs Rq/Ra-Kurtosis and Rp/Rz-Skewnees for machined surface formed by worn out tools. Coated tools machined a rougher surface than uncoated ones. Crater wear and flank wear was noticed as well as geometrical deviations increased with higher cutting speed. The combination of uncoated cutting tools with lower cutting speed to machining grade 4 titanium showed a good agreement to increase production of biomedical implants.

Biocompatible titanium; Turning operation; Tool coating; Production.

1. Introduction

The use of biomedical implants has grown in recent decades, mainly using biocompatible titanium [1]. The manufacture of these devices requires the application of subtractive processes at some stage[2]. The machining of titanium and its alloys still presents challenges due to their high specific strength, low Young´s modulus and poor thermal conductivity [3].

Precision boring in lathe is one of the machining processes applied to increase the diameter of holes in titanium parts to produce cilindrical biomedical implants [4]. Geometry control is important to quality of subquential machining operations as thread milling i.e [5]. The progressive wear of the cutting tool tends to decrease the hole diameter, and after producing a certain amount of parts a replacement is needed [6].

Selecting cutting parameters and using coated tools has been adopted to increase tool life [7]. However, the efficiency of these approaches depends on the cutting tool size, titanium workpiece and machine tool [8].

In this research, precision boring operations in lathe performed a step of biomedical implants production. Coated and uncoated cutting tools and cutting speed were considered to evaluate tool wear during machining of a grade 4 titanium.

2. Experimental procedure

Precision boring in lathe machining were made using a STAR 20R II CNC Swiss-type Automatic Lathe with maximum rotation of 7 000 rpm. Carbide K40 cutting tools were made using a Schutte 305 Linear CNC Tool and Cutter Grinder. The diamond grinding wheels show grain sizes of 64 µm for the roughing operation and 46 µm for the finishing operation.

The cutting tools present a 2° back rake angle, 3.5° side rake angle, 20° end relief angle, 20° side relief angle, 12° side cutting edge angle and 3.5° end cutting edge angle. In the machining tests, cutting tools uncoated and coated with titanium nitride (TiN) were used for boring in lathe. The wet machining was adopted with a cutting fluid suitable for machining titanium and its alloys. Cutting tools were evaluated after machining of 3 000 parts per tool using a Leica DM750M optical microscope.

The cutting parameters are 11 and 16 m/min cutting speed, 15 µm/rotation feed, 70 µm depth of cut and 2 500 µm length of cut. Figure 1 presents the setup of machining operations. Machined surfaces were evaluated using a Oympus OLS4000 3D laser microscope. Surface curvature radii were measured, as well as roughness parameters Ra, Rq, Rp, Rz, skewness and kurtosis, which were applied for a complete investigation of machining surface formation.

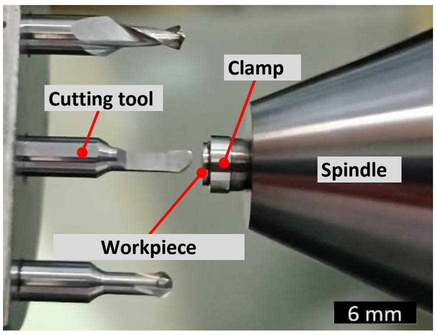

Figure 1. Setup of precision boring in lathe procedure.

The material used to manufacture the biomedical implants is a grade 4 titanium (ASTM F67). The workpieces are round bar with a ground finish and thermally treated by annealing. The mechanical properties are elongation of 36 %, yield strength of 574 MPa and tensile strength of 800 MPa. The average grain size is 10 µm.

3. Results and discussion

Figure 2 depicts the correlation graphs between roughness parameters and machined surface considering cutting speed and cutting tool condition. It is well-known that a strong correlation exists between Rq/Ra-kurtosis and Rp/Rz-skewness [9]. However, when cutting tools are used to machine initial parts, the effects of coating, cutting speed, and their interaction tend to promote distinct surface formations for each machining condition. This results in a lower adjusted linear regression between Rq/Ra and kurtosis, with an R_2 = 50%. On the other hand, when cutting tools are near the end of their tool life, the roughness of machined surfaces shows a better correlation, resulting in a higher adjusted linear regression with an R^2 = 91%.

Machining with new tools favors feed marks and skewness close to zero, resulting in a uniform distribution of peak and valley heights. As a result, there is a lower correlation between the Rp/Rz and skewness parameters with an R^2 = 58%. However, worn-out tools tend to produce irregular machined surfaces with a predominance of peaks or valleys, which are dependent on the machining conditions. This leads to an increased correlation between Rp/Rz and skewness, with an R^2 = 83%.

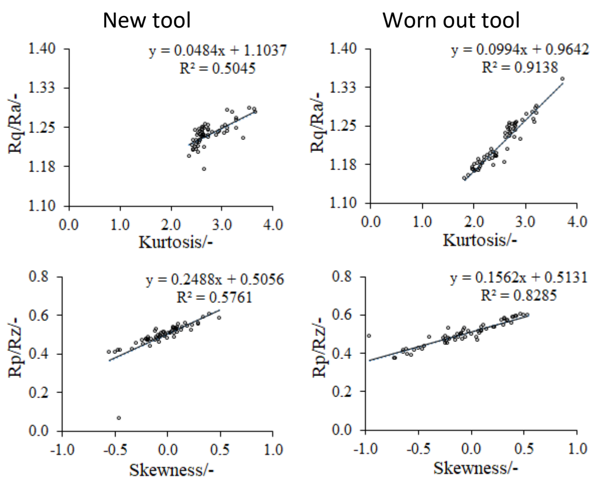

Figure 2. Correlation between roughness parameters.

Figure 3 illustrates how cutting tool wear affected the curvature radius of the machined surface. The Rz parameter was adopted because it shows changes in the machined surface faster than Ra. During the production of initial parts, the radius curvature for tools and cutting conditions is similar, around 1 050 µm. Coated tools showed higher Rz values. The TiN coating reduced friction on the tool rake face, affecting both chip and surface formation. The roughness did not indicated any effect of cutting speed on the machined surface formation.

At the end of the tool's life, higher cutting speeds led to increased geometrical deviations after machining. The curvature radius was close to 800 µm, while a cutting speed of 11 m/min tended to keep a radius around 1 000 µm, which is the minimum geometry necessary before the next machining operation. A higher roughness was observed for coated tools, but it did not affected the workpiece curvature radius.

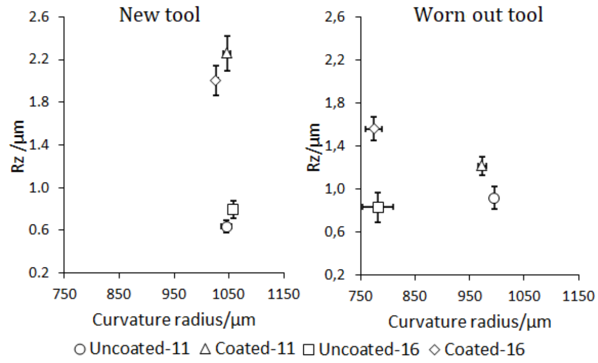

Figure 3. Relation between parameter Rz and curvature radius.

In Figure 4, optical images of a representative tool at the end of its life are presented, where both crater and flank wear were noticed. No dependencies were found between the type of wear and the cutting tool's condition. However, a higher wear was noticed in tools used under 16 m/min cutting speed.

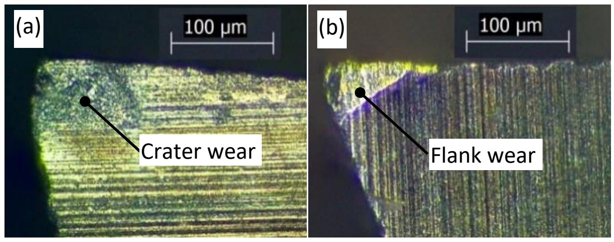

Figure 4. Tool wear optical images of (a) rake face and (b) flank face.

4. Conclusions

In this research, machining tests were carried out using uncoated and TiN-coated cutting tools, along with variations in cutting speed, to study tool wear during precision boring in a lathe of biocompatible titanium. The correlation between Rq/Ra-kurtosis and Rp/Rz-skewness is an approach to evaluate tool life. Cutting speed has a high influence on tool wear than the tool's condition, and the predominant type of tool wear are crater and flank wear. Considering performance and production costs, using uncoated tools under 11 m/min is recommended for machining grade 4 titanium.

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