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Variable Length Scale Surface Finish Assessment of Machined Grade 4 Titanium Alloy

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Abstract

Conventional surface roughness measurements provide surface topography information at one length scale only. Many applications, including osseointegration performance in the biomedical field, may require surface topography information at reduced length scales to improve performance. This paper presents an evaluation of surface roughness for length scales down to 5 microns for outside turned Grade 4 titanium alloy. The effect of cutting speed and feed rate are also evaluated. Surface roughness, skewness and kurtosis are evaluated at different length scales for different cutting parameters and compared to the theoretical expected behaviour. It was concluded that there exists a significant sub-micron surface roughness component that is not fully captured by the conventional roughness measurement techniques. It was also found that the variable length scale surface topography was affected by certain cutting parameters.

Keywords: Surface Analysis, Titanium , Topography

1. Introduction

The topography of a parts surface can influence performance in a wide range of engineering applications. The surface topography over various length scale ranges, from a fraction of a micron up to several tens of microns has been found to affect titanium part performance in a wide range of biomedical applications [1, 2, 3]. Currently expensive finishing techniques such as polishing, blasting, laser pitting and plasma deposition are used to control fine scale surface topography [1].
Titanium is an important engineering material often used for its high strength to weight ratio and corrosion resistance in oxygenous and hydrogenous environments [4]. Grade 4 titanium is a commercially pure titanium alloy with higher percentages of interstitial elements than grades 1 – 3. Grade 4 titanium alloy is a commonly used biomedical and dental material because of its compatibility with human physiology [5, 6].

The turning process is often used to create components for biomedical applications. Turning may impart unique surface irregularities onto the material which are dependent on the cutting parameters [7, 8]. Research performed by van Trotsenburg [7] and Mawanga [8] found that cutting speed, depth of cut and feed rate all have an effect on the surface finish of turned titanium alloys.

Various investigations have shown that different levels of surface roughness affect different osseointegration parameters. Osseointegration refers to the functional connection between living bone and the surface of an implant. Guehennec et al showed that different length scales of roughness (macro, micro and nano) each affect different characteristics of osseointegration and that an ideal osseointegration surface consist of pits of a 4 μm diameter and a 1 μm depth [6]. Other researchers have shown an increase in short term cell adhesion and protein absorption with an increase in low level roughness (≈0.1µm) while higher level roughness values affect long term adhesion [2]. Variable length scale (VLS) roughness implies roughness measurement over length scales different

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from conventional techniques to measure surface topography. The Variable Length Scale (VLS) technique can be used to quantify Root Mean Square (RMS) roughness, skewness and kurtosis of a surface at different levels. Chauvy et al found that a linear resolution of at least 10 times less than the minimum scale length investigated is required. Diminishing gains or a reduction in accuracy improvement were experienced at a point density of 10 or greater samples. Therefore a minimum point density of 10 is recommended for VLS analysis [1].

2. Experimental program

Conventional outside turning (flood cooling) was conducted on a 75 mm Grade 4 titanium alloy bar at various cutting parameters for 1 cm segments. The bar was then sliced and segmented into different samples. The samples were measured and the data was analysed. The tests were performed at the following parameters:

- 0.25 mm depth of cut
- 0.1, 0.2 and 0.3 mm/rev feed rates
- 50, 100, 150, 200, 250 and 300 m/min cutting speeds
- Tool geometry and cut length were kept constant
- The tool was a CNMX 43A2 SM Grade H13A tool insert with a 0.8 mm diameter round nose

Depth of cut was kept constant as the depth of cut should theoretically have less of an effect on the surface properties than feed rate or cutting speed.

Roughness data was obtained by conventional trace surface roughness measurement (Hommel T500) and Atomic Force Microscopy (AFM) (Nanosurf Easyscan 2). Due to the high resolution (1 nm) but limited range (70 µm) of the AFM scan-head individual scans had to be combined to capture the full extent of a typical groove,100 to 300 µm dependent on the feed rate. Dedicated code was developed to correctly align and combine such scans by utilizing Scilab, an open-source matrix based computation package available at http://www.scilab.org/. This created a detailed topographical map at high resolution that could be further evaluated at various length scales.

Roughness, skewness and kurtosis can then be calculated for a scale length ε according to:

$$R_\varepsilon = \frac{1}{n_\varepsilon}\sum_{i=1}^{n_\varepsilon}\sqrt{\frac{1}{p_\varepsilon}\sum_{j=1}^{p_\varepsilon} z_j^2} \quad (1)$$

$$Sk_\varepsilon = \frac{\frac{1}{n_\varepsilon}\sum_{i=1}^{n_\varepsilon}\left[\frac{1}{p_\varepsilon}\sum_{j=1}^{p_\varepsilon} z_j^3\right]}{(R_\varepsilon)^3} \quad (2)$$

$$Ku_\varepsilon = \frac{\frac{1}{n_\varepsilon}\sum_{i=1}^{n_\varepsilon}\left[\frac{1}{p_\varepsilon}\sum_{j=1}^{p_\varepsilon} z_j^4\right]}{(R_\varepsilon)^4} - 3 \quad (3)$$

RMS Roughness (R_ε) quantifies the average deviation of a surface from a mean line. Skewness (Sk_ε) describes the symmetry of a surface profile. $Sk_\varepsilon > 0$ implies sharp, high peaks with wide valleys, $Sk_\varepsilon < 0$ implies the opposite while $Sk_\varepsilon = 0$ implies equal distribution. Kurtosis describes the frequency of change. $Ku_\varepsilon > 0$ implies frequent, thin peaks (leptokurtic) and valleys while $Ku_\varepsilon < 0$ implies the opposite (platykurtoic). $Ku_\varepsilon = 0$ implies normally distributed peaks and valleys (mesokurtic).

3. Results and Discussion

3.1. General Surface Topography

Fig. 1 shows a typical optical plan view of a turned surface at a feed rate of 0.1 mm/rev. The turning groove sides are clearly visible along with the internal micro grooving which forms the focus of the current investigation.

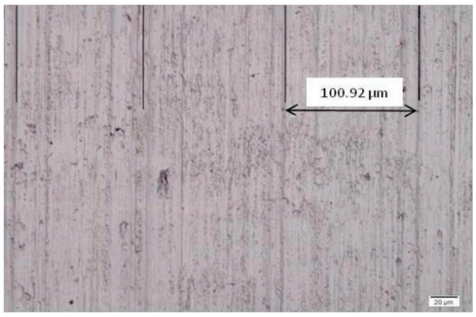

Fig. 1, Optical Microscope image of a Grade 4 titanium surface turned at a feed rate of 0.1 mm/rev (250x Magnification)

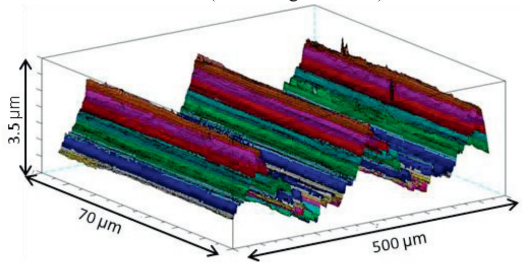

Fig. 2, AFM plot of a turned titanium surface at a feed rate of 0.2 mm/rev (*Generated in Scilab*)

Fig. 2 shows a typical AFM plot generated by *Scilab* after alignment and combination of multiple smaller scans at a feed rate of 0.2 mm/rev. The method uses a gradient based repetitive search function to find the best fit location on two separate sets of data. The process is streamlined by limiting the search parameters to a 5 µm