Effect of machining parameters on precision machining of zirconia ceramics using heated cutting tools

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Abstract

Yttria-stabilised tetragonal zirconia polycrystal (Y-TZP) is a promising biomaterial for use in dental and femoral implants because of its biocompatibility, wear resistance, chemical inertness and superior mechanical properties. The current method for machining Y-TZP involves grinding after sintering. However, the grinding process is time-consuming and therefore costly, thus, a new Y-TZP machining method that is highly precise, efficient and inexpensive is desired. Although Y-TZP is generally difficult to cut, its hardness and fracture toughness sharply decline at high temperature, so the machinability can be expected to be enhanced. Thus, this paper proposes thermally assisted machining of Y-TZP using heated cutting tools. The cutting tool is heated up to several hundred degrees Celsius using the induction heating method: the tool is surrounded by the induction heating coil and heated by a high-frequency magnetic field generated by the electrical current within the coil. The heat generated in the cutting tool is transferred to the Y-TZP workpiece to locally enhance the machinability. In the experiments, grooves with a width of approximately 100 μm, depth of approximately 10 μm and length of 20 mm were generated. The feed speed was varied in order to investigate the effect of different parameters. The results revealed that the proposed method reduced the cutting force and improved the surface roughness.

1. Introduction

Yttria-stabilised tetragonal zirconia polycrystal (Y-TZP) is a promising material for biomedical applications such as dental restoratives. It possesses a high hardness of 1200 HV and high fracture toughness of 8 MPa/m^2 which is higher than that of other engineering ceramics such as alumina. In industry, current machining methods involve machining pre-sintered soft material or machining the final sintered material. However, the form accuracy of the machined workpiece is low and these methods are time-consuming. In order to realise a Y-TZP machining process that is highly precise, efficient and cost-effective, a cutting process that uses a heated cutting tool is proposed. In the proposed method, the cutting tool is heated with an induction heating method up to several hundred degrees Celsius in several tens of seconds. The heat is conducted toward the workpiece from the cutting tool via the rake face. The effectiveness of this method over the conventional non-heated cutting process was presented in [1]. In this paper, the experimental results for the method conducted at different feed speeds are presented.

2. Methods

Figure 1(a) shows the experimental setup. A cutting tool with a cubic boron nitride insert (Kyocera Corporation, VBGW110302T00815ME) was placed in an induction heating coil (Nippon Future Co., Ltd). An oscillating electrical current generated an oscillating magnetic field in the cutting tool. The generated induction current within the tool subsequently produced heat. A high-pressure air flow was used to cool the heating coil itself. The temperature of the tool tip was monitored with a pyrometer (Japan Sensor Corporation, “TMC50”). The emissivity of the adopted cutting tool was 0.43 which was determined by using a black-coloured reference sticker. In order to keep the temperature of the cutting tool equal to the target temperature, the duty ratio of the electrical current provided to the heating coil was controlled according to the measured tool tip temeparature. During the process, the cutting force was measured using a force sensor (Kistler Instrumente, AG9129AA). The Y-TZP workpiece had dimensions of 20 mm × 20 mm × 4 mm. For each machining, the cutting distance was 20 mm. The feed speed was varied between 100 and 10 000 mm/min.

3. Results and discussions

Figure 1(b) and (c) present representative images of the grooves generated during the cutting. As shown in the figures, the proposed method suppressed cracks at the bottom of the groove. Figure 2(a) shows the surface roughness on the grooves.

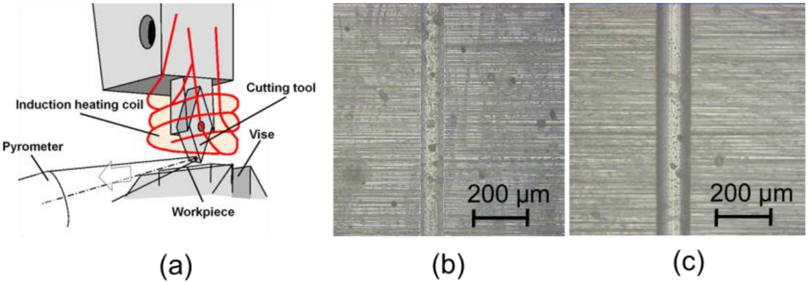

Figure 1. (a) The experimental setup [1]. (b) A groove generated by conventional non-heated cutting. (c) A groove generated by the proposed heated cutting.

The arithmetic average roughness was measured using the laser microscope (Keyence, VK9500). With conventional non-heated cutting, the roughness became maximum at a feed speed of 1000 mm/min. Further increasing the feed speed decreased the roughness. With the conventional method, the peak roughness was observed at 5000 mm/min and decreased at 10 000 mm/min. The difference between the conventional non-heated cutting and proposed heated cutting decreased with increasing feed speed. In particular, when the feed speed was 5000 mm/min and 10 000 mm/min, the roughness of the proposed method was 97.9 % and 98.5 %, respectively, of the conventional method. The proposed method heated the workpiece with the cutting tool, which reduced the material strength and improved the machinability. The degree of reduction depends on the workpiece temperature around the tool tip. As the feed speed increased, the workpiece temperature around the tool decreased due to the shorter contact time between the rake face of the cutting tool and the workpiece.

The specific cutting force was calculated as follows. First, the depth of cut of three different positions (approximately 0 mm, 10 mm, and 20 mm from the starting point of the process) was measured using a laser microscope. The contact area between the rake face and workpiece was calculated based on the geometry of the tool tip. The principal force measured during the process was averaged for 2 mm around each position, and the specific cutting force was calculated by dividing it by the contact area. Figure 2(b) summarises the specific cutting force for each feed speed. The graph shows that the proposed heated cuting required a lower specific cutting force at every feed speed.

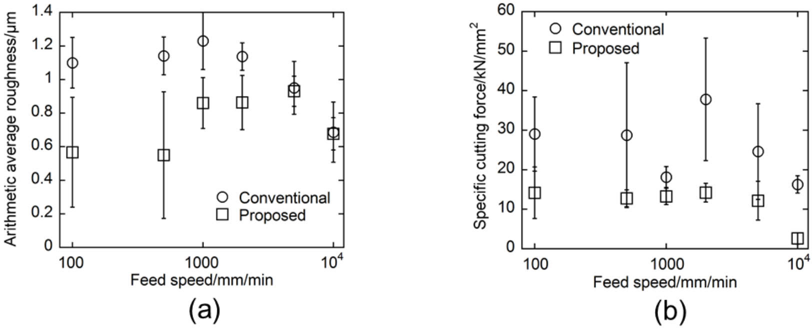

Figure 2. (a) The arithmetic average roughness. (b) The specific cutting force.

With the proposed heated cutting, the specific cutting force stayed almost constant from 100 mm/min to 5000 mm/min and decreased at 10 000 mm/min.

4. Conclusions

Y-TZP was cut with a heated cutting tool that was heated by induction heating up to 500 °C. The experiments were conducted at different feed speeds from 100 mm/min to 10 000 mm/min. The proposed heated cutting method improved the surface integrity and reduced the micro-cracks generated on the groove surface as observed through a microscope. Although a reduced surface roughness was observed, the difference between the proposed and conventional methods decreased with increasing feed speed. The proposed heated cutting method was observed to require a lower specific cutting force.

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References:

[1] Kizaki T, Sugita N and Mitsuishi M 2012 Thermally assisted machining of yttria-stabilized tetragonal zirconia polycrystals using heated cutting tools *Proc. JSPE Semestrial Meeting* (Tokyo) pp 221–222