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Original Citation

Young, Christian, Blunt, Liam and Tong, Zhen (2017) Development of an ultra-precision grinding technique for the production of structured micro-patches on ceramics and tool steel. In: euspen's 17th International Conference, 29 May - 2 June 2017, Hannover, Germany.

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Development of an ultra-precision grinding technique for the production of structured micro-patches on ceramics and tool steel

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Abstract

Ultra-precision grinding using super abrasives such as diamond and Cubic Boron Nitride (CBN) is ideally suited to the production of artefacts in hard or brittle materials such as ceramics or hard metals. These materials are well suited to the production of moulds. Conventional ultra-precision machining techniques such as diamond turning or micro milling are of limited use in the production of these moulds due to long processing times and incompatibility with certain materials. Moulds incorporating a variety of functional surface structures are used in the production of low cost items such as optics and micro-fluidics.

Ultra-precision grinding utilising wheels dressed with specialised surface geometries presents an attractive alternative method for the production of structured surfaces. This method has the advantage of being low cost and easy to adapt to a variety of applications. Developing on previous work a series of radial grooves at regular intervals were dressed onto grinding wheels and then used in two perpendicular passes. The technique has been used to create a series of micro-patches on Macor[®] ceramic to a depth of 15µm with side lengths of approximately 200µm to 300µm. The results of the operation have been compared against the ideal model to determine the fidelity of structure transfer and assess the quality of the finished surface and the impact of process control factors.

Ultra-precision, Grinding, Functional Surface, Structured surface, Micro-pillar, Ceramic

1. Introduction

Ultra-Precision (UP) grinding is a technique ideally suited to the production of high value components due to its ability to generate high levels of surface finish and form accuracy. At present UP grinding is primarily used in the production of parts typically with medical, electronic or optical applications and developments have largely focussed on reducing the need for secondary machining processes such as lapping or polishing which dramatically increase manufacturing times and production costs [1]. UP grinding is particularly useful in the production of parts made from hard or brittle materials, such as tool steel or ceramics, which are ~~cab be~~ difficult or impossible to machine using techniques such as diamond turning or micro milling. These materials are often used to manufacture moulds for high value components which may incorporate functional structured surfaces.

There are many different types of functional surface structures which incorporate regular micro scale geometries [2]. Several different processes are typically used to generate these micro structures, such as micro milling or laser ablation. Whilst these processes are highly adaptable and can produce surfaces to a high degree of accuracy, they are often costly and time consuming as the micro features are individually machined. Grinding techniques utilising macro scale wheels with specialised geometry have previously been used in the production of micro scale riblets [3]. These methods are also costly as they require the grinding wheels to be specially manufactured and profiled. Previous experiments carried out as part of this project have used on-machine dressing of standard UP grinding wheels with micro grooves to create

structured riblets [4]. This paper presents further developments into dressing techniques and the use of multiple grinding passes to create more complex structures in the form of micro patches.

2. Methodology

The grinding trial was carried out on a Precitech Nanoform 250 Ultra-Grind diamond turning lathe and grinding machine. The machine used is equipped with two linear axes, X and Z, and a rotational axis, C (a vacuum chuck equipped spindle). To facilitate this grinding process it was necessary to carry out a number of adaptations to the machine. These adaptations primarily consist of mounting systems for equipment and a Nakanishi EM-3060-J electric spindle. This spindle was selected over the standard turbine spindle due to its ability to incorporate a 1:16 reduction gearbox allowing good speed control and low runout (<within 1µm).

The grinding wheel used in this experiment was a Diagrind 1200 grit diamond resin bonded wheel at a concentration of 100 and a nominal outer diameter of 8mm. The workpiece material was Corning Macor[®] machinable ceramic sheet.

2.1. Dressing and Truing Operations

To reduce dressing nib wear the truing and dressing process was carried out with the nib at an angle, $d\theta$, offset from perpendicular to the grinding wheel. As the nib must be positioned at the centre of the rotary C axis this was achieved by placing it below the centreline of the grinding wheel. To further reduce tip wear the nib was rotated at a speed of eight revolutions per minute. The wheel was first trued using a part worn nib to ensure the external radius was concentric to the

axis of rotation and there was no taper. A fresh dressing nib was then used to create the micro grooves. The nib was plunged into the rotating tool, allowed to dwell and then retracted before being moved to the next location. Full details of the dressing and grinding parameters can be found in table 1, while figure 1 illustrates the dressing set up and terminology.

Table 1 Grinding Parameters

Feature/Parameter	Symbol	Value
Dressing Depth	h	50 μm
Groove Pitch	F_d	400 μm
Nib Radius	r_d	46 μm
Nib Angle	$r\theta$	65 Degrees
Dressing Speed	S_d	62.5 RPM
Nib Rotation	S_n	8 RPM
Dressing Angle	$d\theta$	18.79 Degrees
Grinding Speed	S_g	2000 RPM
Feedrate	V_w	20 mm/pm
Grinding Depth	d	10 μm (1 st Pass) 20 μm (2 nd Pass)

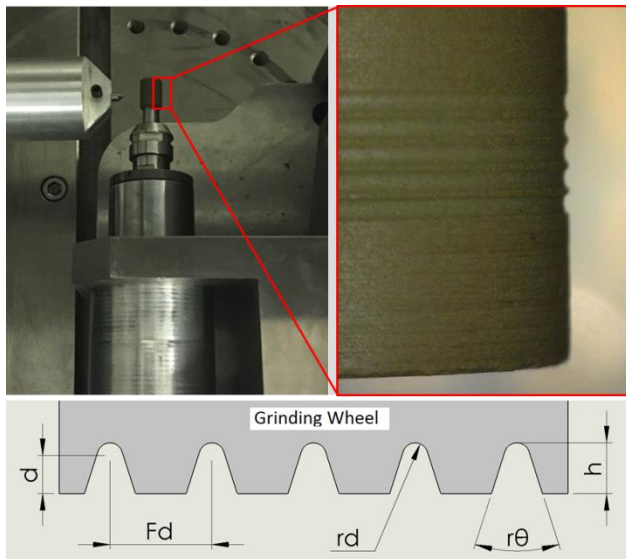


Figure 1. Top: Dressing set up and grinding wheel dressed with radial grooves. Bottom: Grinding wheel dressing terminology

2.2. Experimental Procedure

The workpiece was retained in a specialised vacuum chuck with the C axis enabled to allow the edge to be held vertically. The grinding spindle was shifted from the horizontal dressing position to a vertical orientation and alignment adjusted by means of a 50 μm plastic feeler strip passed between the workpiece and grinding wheel. A shallow first pass of 10 μm was used to check tool alignment and then a single pass at 20 μm depth was made over the surface at a feedrate of 50 millimetres per minute and grinding wheel speed of 2000 revolutions per minute. Coolant mist was used throughout and the process was monitored using a small USB microscope. Upon completion the workpiece was rotated through 90° and the procedure was repeated creating a second grinding pass perpendicular to the first. This process yields a series of micro ridges along the entire length of the workpiece and the micro pillars illustrated below where these ridges intersect. The workpiece was rotated three times to create a set of micro patches on each corner.

3. Results

A mould of the micro patches was created using Microset replicating compound to facilitate measurement on an Alicona infinite focus microscope. The results from one corner can be seen in figure 2. The results show good fidelity of transfer with well-defined patches at a consistent height above the bottom of the ground surface.

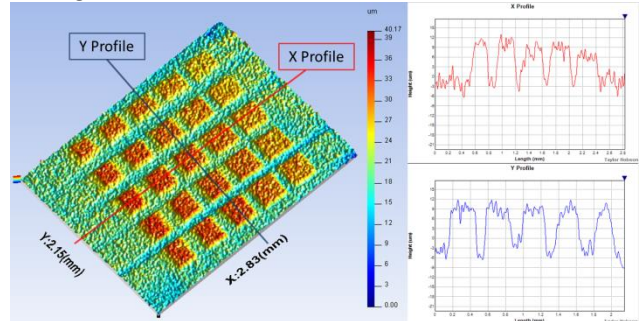


Figure 2. Measured ground surface and linear surface profiles

The height of the patches varied between a minimum of 9 μm to a maximum of 22 μm across all corners. However a maximum height variation of 9 μm was only observed on the first corner, with the remaining corners displaying decreasing variations down to a minimum of 2 μm . This indicates that the grinding wheel has worn by approximately 7 μm .

The centre of each micro patch has been estimated by using the centre point between the bases of two sides. Using this method the distance between centres ranged from 394 μm to 402 μm which indicates good positional accuracy of dressing. However it can be seen from figure 2 that there is some variation in the size of each patch. The side lengths range from 201 μm to 334 μm which is more than double the expected length of 84 μm . Two separate mechanisms cause this increase. Eccentricity in the rotating nib was observed, increasing the groove width during the dwell phase whilst wheel wear caused the width to increase with each successive pass.

4. Summary and Conclusions

This paper details the results of *initial* trials of a novel method for the production of micro-scale surface structures using grinding wheels incorporating specialised geometry. Such a process would represent a significant advantage in the production of moulds incorporating functional surface structures.

This procedure represents a marked improvement over previous results with both a high fidelity of surface generation and improvement in tool setting accuracy. However, nib wear and dressing accuracy continue to present significant challenges. Future work will focus on measuring the rate of nib wear and developing compensation strategies to enhance accuracy and enable production of more complex geometries. The process will also be repeated on tool steel for comparison.

Acknowledgments

This project is funded by the Engineering and Physical Sciences Research Council (EPSRC)

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