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Development of ultra-precision abrasive machining of functional structured surfaces

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Abstract
Current techniques for the manufacture of functional micro scale surface structures are both time consuming and expensive. Techniques for Ultra-Precision (UP) abrasive machining of functional surfaces, using specially manufactured tools, have previously been described for example in the grinding of riblets. However these methods are both costly and limited in their functionality. Using conventional UP grinding tools and a novel dressing technique, adapted from macro scale grinding, provides an alternative solution offering both low cost and ease of adaptability. Such a system would be capable of producing regular deterministic surface textures over a large area to a depth of 10-20µm grinding in single or multiple passes. To achieve this, the grinding wheel surface is shaped with specialised geometries using a single point diamond dressing tool. The required geometry for a given surface texture can be modelled and used to design a dressing solution consisting of a dressing depth and feedrate.

Adapting a conventional grinding machine (Precitech Nanoform 250 Ultra-Grind) for such a process presents many technical challenges to overcome. The quality of the finished surface will be dependent on the accuracy of the dressing process and the tool/workpiece interaction. Methods for controlling and measuring the dressing depth, feedrate, spindle speed and runout have been designed and trialled to determine the feasibility of the process. The results of the trials have been compared against the model to determine the deviation from ideal and hence the quality of the finished surface.

Ultra-precision, Grinding, Functional Surface, Structured Surface

1. Introduction

Ultra-Precision (UP) grinding is a technique yielding high levels of surface finish and form accuracy. It is normally used in the production of parts for electronic and optical applications. Developments in the field of UP grinding have mostly been driven by a desire to replace time consuming secondary processes such as fine grinding, lapping or polishing which dramatically increase production costs [1]. The process is normally used to shape macro scale features using straight, cup or profiled type grinding wheels. Experiments in conventional grinding have shown that wheels with specialized surface geometry can be used in the generation of regular surface textures [2, 3]. UP grinding possesses a number of benefits over other machining processes. In particular is especially useful in the manufacture of parts made from hard or brittle materials which are difficult or impossible to machine using conventional techniques such as diamond turning or micro milling [1].

There are many examples of functional surfaces with regular micro scale geometries [4] which can be produced using a number of methods. Techniques such as micro milling or laser ablasion can be used to machine different profiles individually and are highly adaptable however they are time consuming with high set up costs. Specially shaped diamond tools can also be used to cut profiles directly but these must be specially manufactured and can only be used on a small range of materials. Grinding techniques have previously been used in the production of micro scale structures but these have mostly focussed on off machine manufacture of specialised macro scale wheels which use multiple passes to create the required geometry [4, 8]. Techniques for the production of specialised geometry on grinding wheels have previously been described for the creation of micro discontinuities. Adapting techniques which use single point dressing for use on UP grinding wheels present an opportunity to develop a cost effective and versatile method of manufacturing surface structures on parts. This paper examines a technique for on machine dressing and use of a wheel profiled with micro structures.

2. Methodology

A Precitech Nanoform 250 Ultra-Grind diamond turning lathe and grinding machine has been adapted for this application. The machine used is equipped with two linear axes, X and Z, and a rotational axis, C (the workpiece spindle). The adaptations consist of a tool holder for a single point diamond dressing nib and mounting system for a Nakanishi EMR-3008-K motor and spindle. This spindle is used due to its low runout (within 1 µm) and good speed control, necessary for structured grinding operations. The grinding wheel chosen was a 1200 Grit diamond resin bonded wheel with a nominal outer diameter of 8mm.

2.1. Dressing profile and operation

The wheel was first trued and then dressed with a series of radial grooves using a single point dressing nib with a tip radius of 34 µm. The grinding wheel was rotated at a speed of five hundred revolutions per minute and the nib slowly plunged in to the wheel to a depth of 20 µm. After a short dwell period of two seconds the dresser was retracted and moved to the next position. Figure 1 shows SEM images of grooves generated using this process.

Accurate dressing can be achieved using the X and Z axes on the machine. The dressing tool holder is mounted using the vacuum chuck on the workpiece spindle. This allows horizontal position control through movement of the X axis. The tool spindle and grinding wheel are mounted to the Z axis using on a rig which enables tool height and orientation to be adjusted. The position of the Z axis controls the dressing depth. Dressing is carried out with the spindle held in the horizontal position. Tool alignment is set using a laser displacement sensor to ensure the surface of the grinding wheel is parallel to the motion of the X axis. A USB video microscope is used to set both the X zero, or home position and the tool centre height. A small pointer is fitted into the tool spindle collet and aligned, in 2 axes, with the point of the dresser nib. A truing operation is carried out before dressing to remove any high points from the surface of the wheel.

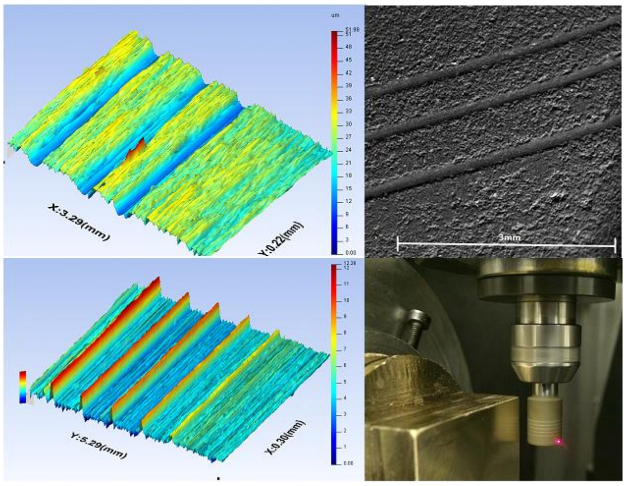

Figure 1. Top: Measured profile and SEM image of wheel dressed with three radial grooves. Bottom: Five ridges ground into surface and grinding set up in position.

2.2. Experimental Set Up

The workpiece was face turned on the machine to ensure that it would provide a flat surface upon which to grind. The radii were then milled of to leave a straight edge at the point where the grinding wheel would make contact. Tool deflection was measured throughout the grinding process using a laser displacement sensor. The grinding process was carried out with the tool spindle in the vertical position. Tool setting proved to be challenging after reorienting the spindle and several passes were required before the wheel surface was parallel to the surface of the workpiece; with each pass moving forward incrementally until the whole surface of the grinding wheel was in contact with the workpiece. Once this had been achieved the grinding wheel was moved off the face of the part, advanced forward to a depth of 20 µm and passed over the workpiece. The grinding wheel was rotated at 2 000 revolutions per minute and the feedrate was set at 50 millimetres per minute. Coolant was not used however an air jet was aimed at the surface of the part to clear debris. Upon completion the workpiece was rotated 180 degrees using the C axis and a second grinding patch was generated using the same wheel and process.

3. Results

With the grinding wheel in place no load tool run out at the end of the grinding wheel was measured at less than 3 µm. Tool deflection during the grinding process was determined to be approximately 35 µm however, despite the slow grinding speed and fast feed rate, there was no evidence of tool chatter. The ground surface yielded an Sa of 1.035 µm however Ra values vary significantly depending on the orientation of the part. The profile of the wheel was successfully replicated with all 5 ridges present along the whole length of both grinding patches. However, the height of the ridge on the first groove is only 10 µm rather than the predicted 20 µm. Some loss of height was expected due to dressing tip wear resulting in slightly shallower grooves. This effect is shown in the lower left image of Figure 1. There is evidence that the wheel wears significantly between uses. Figure 2 shows a comparison of the profiles generated by one of the radial grooves on the first and second grinding patches. It can be seen that the ridge created on the second grinding pass is approximately 5µm lower. The profile is also less well defined with steeper flanks and a significantly flatter top. Measurements taken from the wheel after use confirm significant wear with a reduction in groove depth to less than 10µm

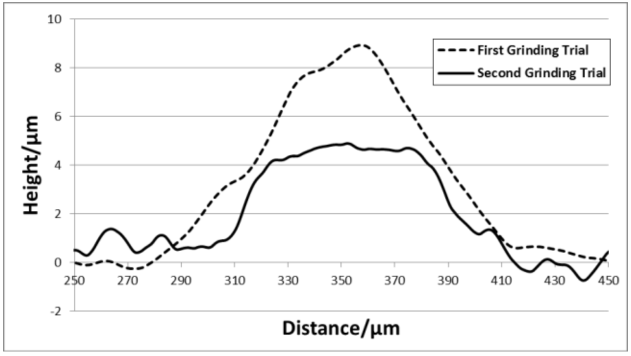

Figure 2. Comparison of linear profiles of the middle ridge.

4. Summary and Conclusions

This paper details the preliminary results from trials of a novel dressing technique for the production of specialised geometry on UP grinding wheels. The technique has been used to successfully dress a profile of radial grooves into a wheel which was subsequently used to grind ribs onto a flat brass surface in a single pass. The unique advantage of grinding over other machining processes such as diamond turning is that the technique is not limited to ductile, easily machinable materials. This is of significant benefit to the production of moulds and stamps which are usually made from hard tool steel.

Over two grinding operations tool wear has been demonstrated to significantly affect the fidelity of transfer of the profile. Tool setting proved a significant challenge, in particular tool alignment in the vertical position and distance from the workpiece. Future work will focus on improving the accuracy of these processes which will improve the repeatability of the dressing procedure, compensate for tip wear and eliminate the need for multiple shallow setting passes. This will enable the production of complex geometries such as single or double helical grooves which can be used to produce of different surface textures such as micro pillars.

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