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Nano texture generation in single point diamond turning using backside patterned workpiece

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Abstract

A nano-texturing method in single point diamond turning using backside patterned workpiece is presented. The back side of the workpiece is pre-machined to first create a pattern. The front side is then diamond turned on an ultra-precision lathe. After machining down to a certain thickness, periodic bumps and valleys that mirror the back side pattern start to appear on the front diamond machined surface. The periodic wavy/bumpy surfaces have nanometer depths, and possess mirror finish. The results suggest that this technique provides an alternative method to create optical features that are conventionally developed using tool-spindle synchronized cutting motions.

Keywords: Magic mirror; Diamond turning; Nano-texture; Back side patterning; Nano-bumps

Introduction

Generation of periodic wavy surfaces having nano to micrometer sized features are important in a wide range of applications in optics and nanotechnology. In the field of nanotechnology, such features are fabricated using photolithography and e-beam lithography [1–3]. In the area of optics, single point diamond turning (SPDT) involving synchronized tool-spindle motions applied using slow tool servo (STS) and fast tool servo (FTS) systems are generally used to generate micro-lens arrays, freeform and aspherical surfaces with nanometer surface roughness without the need for subsequent post polishing [4–8]. Although these methods have shown remarkable versatility to form precise complex structures, they require complex tool path programming and generally involve longer processing time.

Here, we present a simpler technique using SPDT process but without the aid of STS/FTS to develop periodic wavy/bumpy nano-textures with mirror finish and hundreds of micrometer form accuracy. In this technique, the workpiece is pre-machined on the back side with a pattern and then diamond turned on the front side to achieve a nano-texture pattern on the diamond turned surface. The technique is inspired by the ancient magic mirror. The Chinese magic mirror is a circular, metallic, hand polished mirror having a relief pattern on its back side. The back side relief pattern is normally not visible in the front polished surface except when the front surface of the mirror reflects light on a wall/surface; the reflection shows the pattern on the back side of the mirror [9–11]. Several attempts have been made to replicate the magic mirror through modern machining and polishing techniques. All previous research have focused on polishing by hand or computer controlled machine to create front mirror surfaces [12–15]. In the present study, we have created a regular bumpy/wavy nano-textured surface using SPDT

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on backside patterned workpieces. The nano-textured surfaces produced are characterized using laser interferometer and surface profiler to inspect the effects of back side pattern on the diamond turned surface.

Experimental methodology

A series of face turning experiments are carried out on a 2-axis numerically controlled ultra-precision diamond lathe (Precitech Nanoform 200). All turning experiments were performed with a single point diamond tool with a nose radius of 0.532 mm, rake angle of 0^{o} and front clearance angle of 10^{o}. The workpieces are rectangular in shape ($16 \times 23 \times 3$ mm) and made of polycrystalline aluminum alloy Al6061.

In order to create a wavy texture on the diamond turned surface, the back side of workpiece was pre-machined with CNC wire-EDM to develop two types of relief patterns, rectangular grooves and array grooves, with arbitrary dimensions (Fig. 1).

The pre-machined back side of the workpiece is attached to a circular fixture/adapter with double sided tape and subsequently the fixture is placed on the air bearing spindle of the SPDT machine. This is in contrast to the conventional procedure of workpiece attachment in SPDT where the machine spindle holds the flat back side of the workpiece with/without suitable adapter. Fig. 2 shows the experimental setup and placement of relief patterned workpiece on the machine spindle.

For both types of back side relief patterns, the workpiece samples are machined as follows: a 1000 μm is first removed with a spindle speed of 1000 rev./min, feed rate of 10 mm/min and cutting depth of 20 μm in order to get an optical surface finish. Subsequently, a depth of cut of 10 μm is used, and the workpieces are machined up to a thicknesses varying from 200, 250, 300, 350 and 400 μm. The diamond turned surface topography is then analyzed using a laser Interferometer (Zygo Newview) and surface profiler (Talyscan 150).

Results and discussion

Periodic wavy/bumpy surface started to appear on the diamond turned surface when the workpiece thickness reached 250 μm. When the thickness reached 200 μm after another 5 cutting passes with a cutting depth of 10 μm per pass, strong periodic wavy/bumpy nano-texture appeared on the diamond turned surface corresponding to the back side pattern. Fig. 3 shows the waves/bumps on diamond machined surface of the workpiece with the rectangular groove pattern (Zygo Interferometer image) at a thickness of 200 μm. For array type relief pattern workpieces, the diamond turned surfaces were neither flat nor spherical and hence interferometry imaging was not possible; we then resorted to surface profilometry for imaging this surface as explained next.

Fig. 4 shows the 3-D surface and 2-D curve profiles of the diamond machined surface for workpieces with rectangular and array groove pattern. The figure confirms the presence of the periodic wavy/bumpy surface nano-texture of overall shape corresponding to the back side pattern in both types of workpieces.

The peak to valley distance of the created wavy surface for rectangular and array groove pattern is in the range of

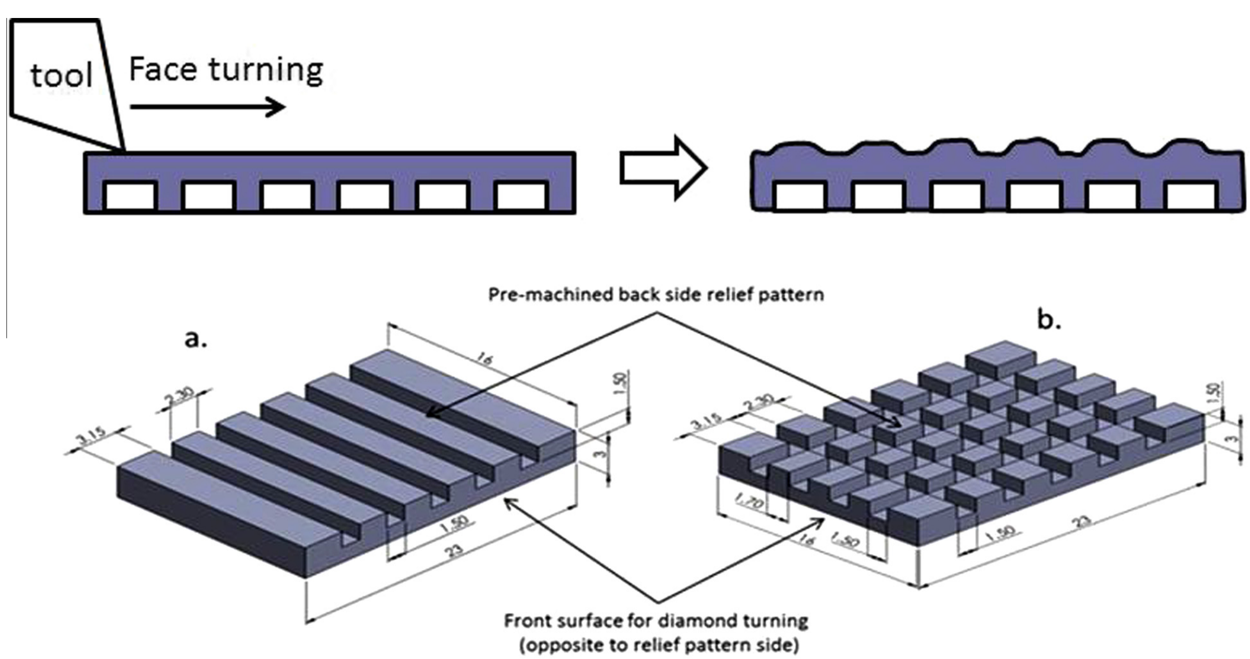

Fig. 1. (Top) Basic concept of the texturing method. (Bottom) Schematic of pre-machined Al 6061 workpiece, showing pattern generated using wire EDM cut (a) rectangular grooves and (b) array grooves on back side of the workpiece. (All dimensions are in ‘mm’).