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Influence of clamping technique on the resulting surface roughness in diamond machining of CaF_2

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Abstract
Single crystal calcium fluoride (CaF_2) is widely used for transmissive optics in the ultraviolet and vacuum ultraviolet (UV and VUV) spectral regions because of its high optical transmission. Optical components made of CaF_2 are usually manufactured by precision machining to generate high quality surfaces with low surface roughness. However, the influence of the clamping technique on the resulting surface roughness of diamond machined CaF_2 has not been reported. In this research, two clamping techniques, vacuum clamping and gluing with wax, are used in off-axis diamond turning experiments with zero degree and negative rake angle diamond tools. Surface characterization by white light interferometry and atomic force microscopy show surfaces with low surface roughness. Furthermore, a significant influence of the clamping technique on the generated surface topography is observed.

Single crystal calcium fluoride CaF_2, precision specimen alignment, ultra-precision diamond machining, surface roughness

1. Introduction

Single crystal calcium fluoride (CaF_2) is widely used for transmissive optics in the ultraviolet and vacuum ultraviolet spectral range (UV and VUV) because of its high optical transmission. Optical components made of CaF_2 are usually manufactured by precision machining to produce high-quality surfaces with low surface roughness [1-4]. This involves, for example, the use of specially developed specimen alignment fixtures and clamping to hold the specimens [5]. However, the influence of the clamping technique on the resulting surface roughness of diamond machined CaF_2 has not yet been investigated. In this study, two clamping methods, vacuum clamping and gluing with wax, in off-axis diamond turning experiments with diamond cutting tools were investigated.

2. Experimental setup and methods

To investigate the influence of the clamping technique on the generated surface roughness, off-axis diamond turning experiments were carried out on a 5-axis ultra-precision machine tool Nanotech 350FG from Nanotechnology Systems, Keene, NH, USA.

Single crystal CaF_2 workpiece specimens with dimensions of 10 mm x 10 mm x 1 mm and (111) surface orientation from Carl Zeiss Jena GmbH, Germany, and Korth Kristalle, Germany, were used. All specimens were VUV or Raman grade material with pre-machining of steps chemo-mechanical polishing and MRF polishing to create minimally damaged surface and near surface material. The cutting direction was <10-1>.

For the cutting experiments single crystal diamond round nose tools were used. The diamond cutting tools had a nose radius r_e of 1 mm and 3 mm and rake angles γ of 0° and -20°.

With repeated adjacent cuts and step-overs f of 3 µm and 5 µm, an area of 5 mm width was generated. The cutting speed v_c was 50 m/min The process parameters and experimental settings are listed in Table 1.

Table 1 Experimental settings.

Parameter	Variation
Step over f	3, 5 µm
Cutting tool radius r_ε	1, 3 mm
Rake angle γ	- 20°, 0°
Clamping technique	Vacuum clamping, gluing with wax

The specimens were clamped by vacuum in a specifically designed specimen holder and aligned perpendicular to the cutting direction (see Fig. 1a). In the second set of experiments the specimens were glued to the specimen holder (see Fig. 1b).

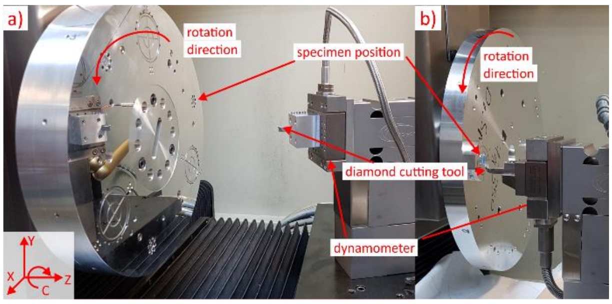

Figure 1. Experimental setup with (a) vacuum clamping and (b) clamping with wax.

The surface roughness was characterized by white light interferometry (WLI) and atomic force microscopy (AFM).

3. Results

Single measurements on chosen areas of the surface roughness using white light interferometry were carried out at 20x magnification measuring an area of 0.83 mm x 0.83 mm. The roughness parameters Sa and Sq are considered. Table 2 gives an overview of the values obtained.

Table 2. Surface roughness measured by white light interferometry.

Cutting tool radius r_ε [mm]	Rake angle γ [°]	Step over f [µm]	Clamping technique	Surface roughness	
				Sa [nm]	Sq [nm]
1	0°	3	vacuum	3.9	5.2
		5		2.5	3.2
		3	gluing	3.6	6.7
		5		3.2	4.0
3	-20°	3	vacuum	2.7	4.5
		5		1.6	2.8
		3	gluing	8.7	28.1
		5		14.3	44.4

Figure 2 shows the measured mean arithmetic surface roughness Sa of the generated surfaces. The lowest surface roughness Sa of 1.6 nm was achieved using a diamond tool with a tool radius r_ε of 3 mm, a rake angle γ of -20° and step-over f of 5 µm. With a tool radius r_ε of 1 mm, only slight differences in roughness were observed. With a tool with a radius r_ε of 3 mm, significantly higher surface roughnesses were generated for glued specimens. However, the high roughnesses Sa in the range of 9 nm to 15 nm cannot be attributed solely to the clamping technique. The specimens exhibited surface fracture, which increased the roughness significantly.

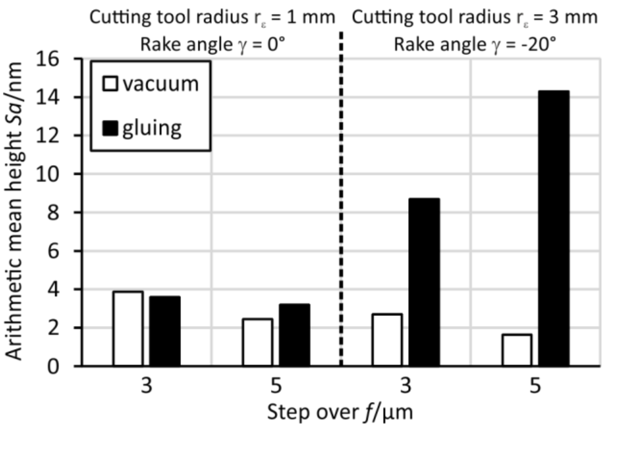

Figure 2. Arithmetic surface roughness *Sa* of the generated surfaces.

With the help of atomic force microscopy, further statements can be made about the influence of the clamping technique on the generated surface roughness. The atomic force microscopy measurements are carried out on an area of 50 µm x 50 µm. Figure 3 shows two particular AFM measurements. The specimens were vacuum clamped (Fig. 3 a) and clamped by gluing with wax (Fig. 3 b) and machined with a diamond tool with a radius r_ε of 1 mm, a rake angle γ of 0° and a step-over f of 3 µm. Clear adjacent cuts are visible in both measurements. Furthermore, periodic changes in the height of individual cuts can be identified. In the case of the vacuum clamped specimen (Fig. 3 a), however, these height changes are distinct to such an extent that the nominal step-over f of 3 µm is not reproduced unambiguously, but a step-over of 6 µm is visible. With the glued specimen (Fig. 3 b), these periodic height differences of the adjacent cuts are significantly less distinct and the nominal step-over f of 3 µm is clearly visible.

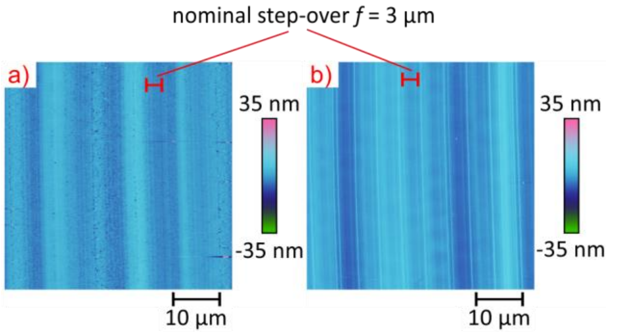

Figure 3. AFM images of vacuum clamped specimen (a) machined with a tool radius r_ε = 1 mm at a step-over f of 3 µm and glued specimen (b) machined with a tool radius r_ε = 1 mm at a step-over f of 3 µm.

4. Conclusions

The aim of the work was to investigate influence of clamping technique on the generated surface roughness in diamond machining of calcium fluoride. Based on the results presented, only a minor influence of the clamping technique on the surface parameters Sa and Sq can be determined. Surface roughnesses in the optical or near-optical range were generated in all experiments. An influence of the rake angle is, however, observable.

For surface topography measured by atomic force microscopy, however, an influence of the clamping technique can be seen. On the basis of the measurements, periodic differences in the height of the profile caused by vibrations can be seen with a step-over f of 3 mm and vacuum clamping. This is less significant observable when clamping with wax. This is due to the stiffer clamping by gluing with wax.

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