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Effect of Milling Speed on Surface Roughness and Marginal Adaptation of Zirconia Restorations

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USU Operational Gap: IV, C

Abstract

Limited research has been published evaluating the effect of milling speed on the properties of zirconia restorations. Objective: The purpose of this study was to evaluate the effect of different milling speeds (super-fast, fine, extra-fine settings) of a milling unit (Primemill, Dentsply/Sirona) on the surface roughness (Sa), marginal gap, marginal gap volume, and marginal offset of zirconia restorations. Methods: A mandibular molar #30 typodont tooth (Kilgore) was digitally scanned (Primescan, Dentsply/Sirona) and an ideal crown preparation for a zirconia restoration was digitally created (exocad GmbH). A single master model die of the crown preparation was milled out of a layered fiberglass and resin material (Trinia, Bicon) using a five-axis milling unit (I-Mes, iCore). The master die was scanned (Primescan) and a final restoration was designed using the bio-copy feature of the typodont tooth. Ten restorations (Katana STML, Kuraray) were milled (Primemill) per each of the three milling speeds and sintered. The restorations and master die were loaded in a custom mounting jig. Surface roughness, marginal gap, marginal gap volume per 500-micron length, and marginal offset were measured using a non-contact profilometer (Confocal Profilometer, Keyence) separately at all four restoration surfaces (mesial, distal, facial, lingual). A mean of the combined four surface values were determined per property (n=40). Data were analyzed with one-way ANOVA and Tukey's post hoc tests per property (alpha=0.05). Results: Super-fast milling speed resulted in restorations with significantly greater surface roughness and marginal gap volume compared to fine and extra-fine milling speeds. No significant difference in marginal gap or marginal offset were found based on milling speed. Conclusions: Zirconia restorations milled at slower speeds may result in better properties compared to super-fast speed.

Introduction

New ceramic materials provide an excellent balance of strength and esthetics that have driven a steep rise in popularity among dental providers. Computer-Aided Design/Computer-Assisted Manufacture (CAD/CAM) systems have revolutionized how ceramic restorations are manufactured. There are two distinct processes to produce ceramic products: an operator-driven chairside system or a centralized milling site. It is now possible to fabricate zirconia restorations in a single treatment appointment utilizing a chairside system. The speed at which these restorations can be fabricated still poses a time and financial challenge to the dental provider. Processing times are also a concern for the central milling approach.

Two options to reduce the fabrication time of a zirconia crown are to reduce the sintering time and/or the milling time. Speed sintering of zirconia restorations to allow for rapid processing has been shown to produce zirconia restorations with similar hardness, microstructure, and flexural strength (1-4). These findings have allowed for the sintering of zirconia restorations with suitable mechanical properties in less than an hour compared to conventional sintering which can take multiple hours. The other possibility to reduce production time is to reduce the milling time of the restoration. This research will focus on this aspect.

The CEREC CAD-CAM system (Dentsply Sirona, Charlotte, NC) is one of the most popular ceramic manufacturing systems (5). The CEREC system offers a chairside digital acquisition unit as well as a variety of ceramic milling units. In 2020 Dentsply Sirona released the Primemill, their latest chairside milling unit. Similar to all milling systems, the Primemill uses sharp cutting tools to remove material and fabricate the designed product (6). The milling unit has 3 options for milling of Katana 12Z STML blocks: extra-fine, fine, and super-fast. The relative speed of these milling/grinding programs is inferred, but the characteristic of the resultant product is lacking research.

The intaglio surface of ceramic restorations have been shown to concentrate tensile forces that can initiate fracture in the defects on this surface. In addition, the cervical restoration margin demonstrates importance in fracture initiation (7). The machining process for ceramics inherently produces cracks, chipping, subsurface damage, and residual stresses (8). A direct correlation has also been established between surface roughness or surface damage and a reduction in flexural strength (9). Any procedure that alters the margin/intaglio surface of a restoration must be closely examined.

In addition, the cameo surface characteristics of a restoration have a direct impact on the development of biofilm. Biofilm is directly responsible for the development of secondary caries and periodontal disease (10). When comparing similar or the same restorative material, surface roughness has been shown to be related to the accumulation and composition of biofilm (11, 12, 13). Surface roughness can be reduced by finishing and polishing and its importance has been reviewed in preventing biofilm accumulation (14). It is currently unknown to what extent faster milling affects the surface roughness. A rougher surface may require significantly more time chairside to polish the restoration before insertion.

No definitive value for a clinically acceptable margin gap has been defined, but a range of 39 µm to 150 µm has been used in previous literature (15). A recent systematic review and meta-analysis have shown that single unit zirconia fixed dental prosthesis created with digital scanning has become more accurate at the margin/finish line interface than conventional impression materials (15). One of the identified limitations of this review was that differences in CAM systems must be considered. At present time, no studies have evaluated the superfast mill function in the Dentsply Sirona Primemill system in comparison to fine or extra-fine milling speeds. It is currently unknown what effect that these different milling speeds will have on surface roughness, marginal adaptation, internal gap, or fracture load. The null hypothesis is that there will be no difference in surface roughness, marginal adaptation, or internal gap of a crown restoration based on milling speed.

Methods

An intact typodont tooth (#30) (Kilgore 200, Kilgore International, Coldwater, MI) was scanned using a CEREC Primescan acquisition unit. An ideal crown preparation for a zirconia restoration was designed in exocad (exocad GmbH, Darmstadt Germany) following the manufacturer’s recommendation for a cubic-containing zirconia material

(Katana STML, Kuraray Noritake, Tokyo, Japan) for posterior crown restoration: 1mm occlusal reduction, at least 4mm preparation height with axial convergence of 10%, 1 mm uniform axial reduction and 1mm wide circumferential shoulder finish line with rounded internal angles. The design was exported and saved in standard tessellation language (STL) format as the “master” file for milling duplicate tooth preparation dies. The STL file was imported into milling software (iCAM V5, I-Mes, iCore, Eiterfeld, Germany). Thirty model specimens of the preparation were milled in a five-axis milling unit (I-Mes, iCore) using a fiberglass and resin material (Trinia, Bicon, Boston, MA) with an elastic modulus similar to dentin. (15).

One single master die was scanned with the CEREC Primescan acquisition unit. A virtual restoration was designed following the contour of an unprepared typodont tooth (#30) using the copy feature in the CEREC Primescan software (version 5.2, Dentsply Sirona). The restoration spacer was standardized at 100um. Thirty identical crowns (n = 10 per group) were milled from Katana STML zirconia blocks (size 12Z) utilizing new milling burs per group on a calibrated Primemill unit. Three groups based on milling speeds of fine (F), extra fine (EF), and superfast (SF) were utilized in this study (n=10) (Figure 1). The milling time for a crown in each group was recorded. All crowns were sintered in a zirconia furnace (Programat S1 1600, Ivoclar Vivadent) following the manufacturer’s instructions. Samples were steam cleaned following sintering.

A custom mounting jig was fabricated to orient and seat the restoration accurately and consistently on the master die. Surface roughness, marginal gap, marginal gap volume per 500-micron length and marginal offset were measured using a non-contact profilometer (3D Laser-Scanning Confocal Profilometer, Keyence, Itasca, IL) and then analyzed using its proprietary software. All parameters were measured once on the buccal, lingual, mesial, and distal surfaces for each crown (n=40). A small notch was created on the master die away from the margin on all four surfaces to standardize the measurement location. Surface roughness (S_a) was measured 2mm coronal to the margin.

A mean and standard deviation for all properties were determined for all three groups. Data were analyzed with a one-way analysis of variance (ANOVA) and Tukey's post hoc tests to determine any differences in surface roughness, marginal gap, marginal gap volume per 500-micron length, and marginal offset of the zirconia crowns based on milling speed (alpha=0.05).

Results

Super-fast milling speed resulted in the greatest surface roughness (3.8 ± 0.7 μm) and it was significantly greater than fine (2.8 ± 0.4 μm, p<0.001) or extra-fine (2.9 ± 0.3 μm, p<0.001) milling speeds. The greatest marginal gap was found with super-fast milling speed (88.3 ± 30.3 μm), but it was not significantly different from fine (74.6 ± 22.0 μm, p=0.088) or extra-fine (74.8 ± 32.6 μm, p=0.093) milling speeds. Super-fast milling speed produced significantly greater marginal gap volume (0.46 ± 0.23 nL) than fine (0.31 ± 0.22 nL, p=0.004) or extra-fine (0.32 ± 0.19 nL, p=0.006) milling speeds. The greatest marginal gap offset was found with super-fast milling speed (65.2 ± 43.4 μm), but it was not significantly greater than fine (48.1 ± 27.2 μm, p=0.067) or extra-fine (48.5 ± 28.7 μm, p=0.076) milling speeds. There were no significant differences (p>0.89) between fine and extra-fine milling speeds for any of the properties tested. See table 1.

Property	**Milling Speed** Mean (SD)		
	Super-Fast (5.5 min)	Fine (18 min)	Extra-Fine (20 Min)
Surface Roughness (µm)	3.8 (0.7) A	2.8 (0.4) B	2.9 (0.3) B
Marginal Gap (µm)	88.3 (30.3) A	74.6 (22.0) A	74.8 (32.6) A
Marginal Gap Volume (nL) per 500 µm length	0.46 (0.23) A	0.31 (0.22) B	0.32 (0.19) B
Marginal Offset (µm)	65.2 (43.4) A	48.1 (27.2) A	48.5 (28.7) A
Groups with the same letter per row are not significantly different (p>0.05)			

Table 1: Values of each property tested based on milling speed.

Discussion

The demand for same day dentistry has pushed technology to be more convenient and rapid. Software advances have improved the speed of designing restorations. The speed sintering process for zirconia restorations has allowed zirconia to become an option for same day dentistry without a sacrifice in physical properties (1-4). The Primemill has allowed for faster milling of zirconia restorations. It is important to analyze this production method to ensure that quality is not sacrificed for speed.

The null hypothesis was partially rejected. A statistically significant difference was found for surface roughness and marginal gap volume between super-fast milling and fine/extra-fine milling. No significant difference was found between the groups for marginal gap and marginal offset.

Topographical images produced by the Keyence software revealed stark visual differences in surface roughness between super-fast and fine/extra fine samples (Figure 1). The super-fast samples had a distinct repeating pattern that appeared to be created by the exclusive use of the 2.5 ZrO_2 CS bur on the external surface. This was also evident visually (Figure 2). Surface roughness (S_a) was utilized for this study and is defined as a parameter that measures the finely spaced micro-irregularities and topographical textures such as roughness, waviness, and form on a material's surface. Sa is calculated by the following mathematical expression:

$$S_a = \iint_0^l |Z(x,y)|\, dx\, dy\,,$$

where *Z (x, y)* is the difference between the actual height at the position of *(x, y)* and the mean height of the sampling area. Although S_a is an extension of roughness average (R_a), S_a differs from R_a in which data are sampled in different spatial dimensions. Unlike R_a, S_a measures the arithmetical mean height of a 2-dimensional surface, whereas R_a measures the arithmetical mean height of a 1-dimensional line.

These differences were confirmed with a statistically significant greater surface roughness for super-fast samples. All restorations produced by milling require finishing and polishing to provide a clinically suitable surface. This can be done in either the sintered or pre-sintered state for zirconia.

Of the three measurements analyzing the margin interface, only the marginal gap volume was significantly greater for super-fast milling. Marginal gap and marginal offset were greater for super-fast milling although not significant. The marginal gap for all three groups was within the accepted range of 39 µm to 150 µm (15). The extra-fine group had two samples with a large marginal defect (Figure 3). The remainder of samples had uniform margins free of large defects. Milling on fine/extra-fine settings produced a better marginal adaptation than super-fast. The clinical significance of these findings is unknown. The user must consider the possible clinical benefits versus the reduced production time.

The three separate milling speeds utilize different tools during milling. Variations in the tools allow for faster or more detailed milling. Tool integrity was monitored during milling. Fifteen samples were initially milled with the super-fast speed. One of the tools reached 0% integrity after milling sample fifteen. Fifteen samples were then milled using the fine and extra-fine settings to compare tool integrity. Only the first ten samples from each speed were used for subsequent testing. Table 2 demonstrates the tool integrity after milling fifteen samples. As an average for the use of four tools, super-fast milling used tools at a rate 2.85 greater than fine milling and 2.44 greater than extra-fine milling. The milling times for the first sample milled for each group were also recorded. Super-fast: 5 minutes 31 seconds. Fine: 17 minutes 59 seconds. Extra-Fine: 19 minutes 33 seconds. The time difference may be significant for same day dentistry and the provider should weigh the cost of additional tools versus time saved.

Conclusion

Super-fast milling speed resulted in restorations with significantly greater surface roughness and marginal gap volume compared to fine and extra-fine milling speeds. No significant difference in marginal gap or marginal offset were found based on milling speed. Zirconia restorations milled at slower speeds may result in better surface roughness and marginal adaptation compared to super-fast speed.

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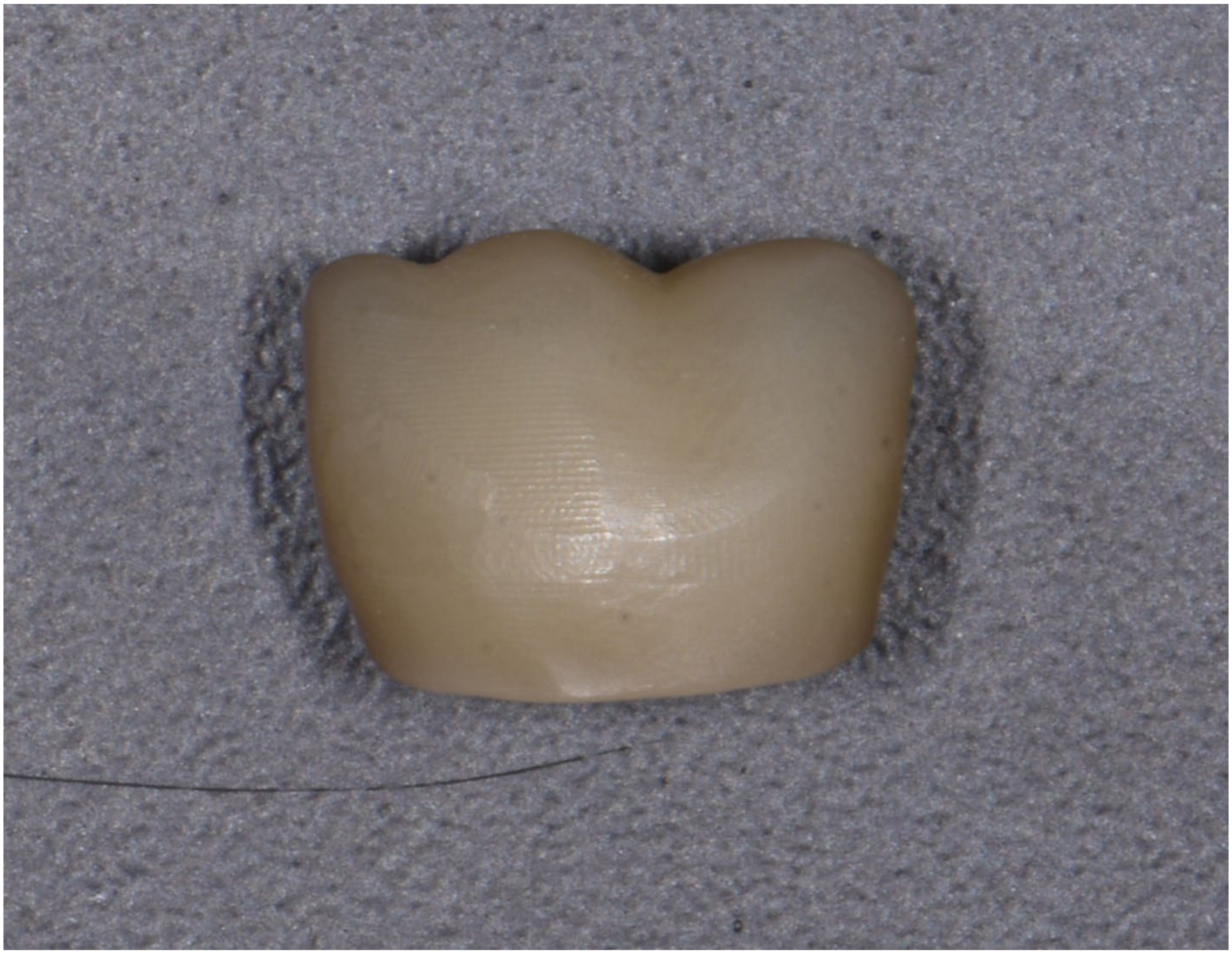
Super-Fast	Bur	Integrity (%)		**Fine**	Bur	Integrity (%)		**Extra-Fine**	Bur	Integrity (%)
	Bur 2.5 ZrO2 CS	32			Bur 2.5 ZrO2 CS	21			Bur 2.5 ZrO2 CS	21
	Bur 2.5 ZrO2 CS	0			Bur 1.0 CS	75			Bur 1.0 CS	75
	Bur 1.0 CS	35			Diamond 1.4 CS	100			Bur 0.5 CS	58
	Bur 1.0 CS	37			Diamond 1.2 CS	100			Diamond 1.4 CS	100
Average		26				74				63.5

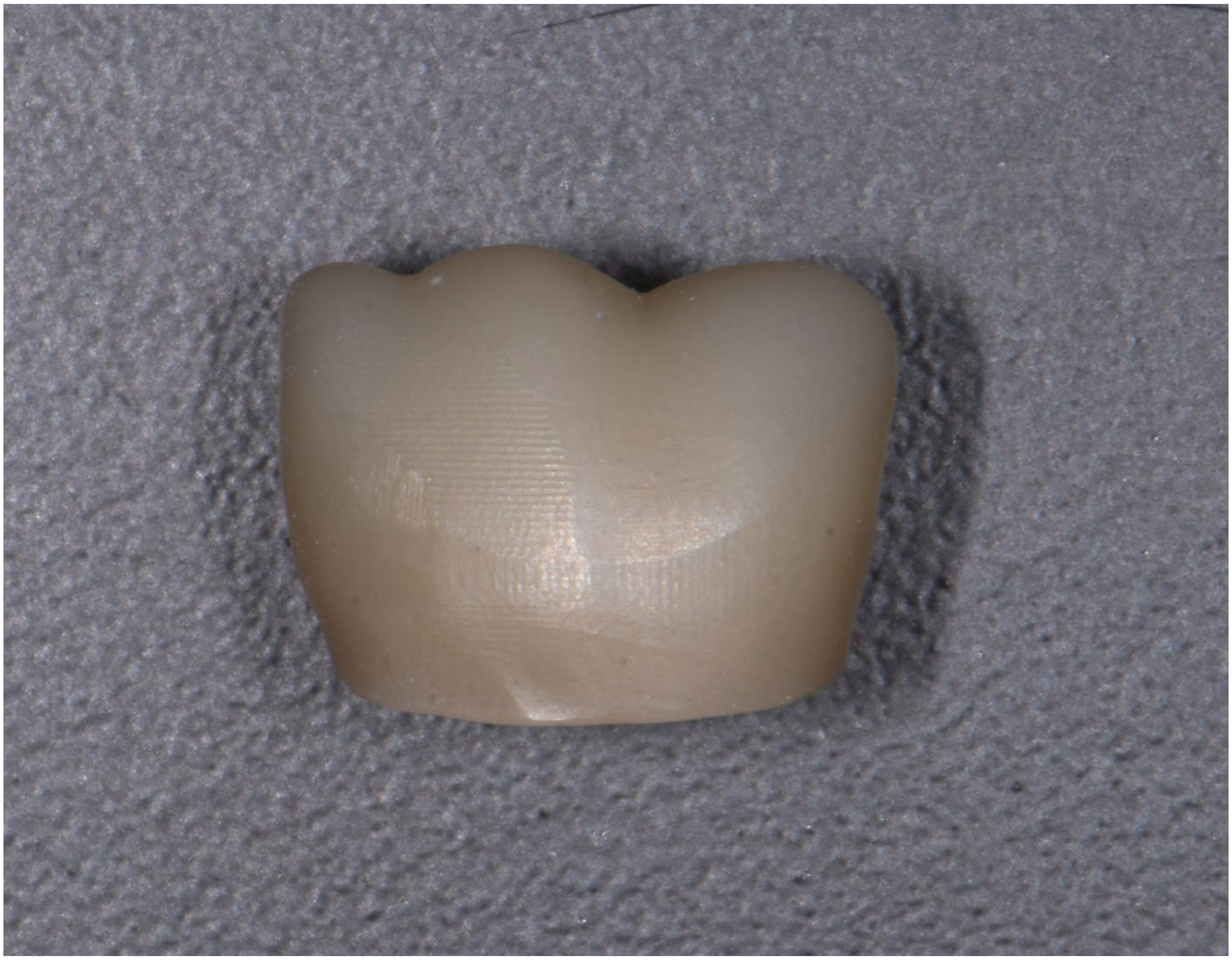
Table 2: Tool integrity after 15 samples

Figure 1: Superfast (1), Fine (2), Extra-fine (3) crowns before polishing

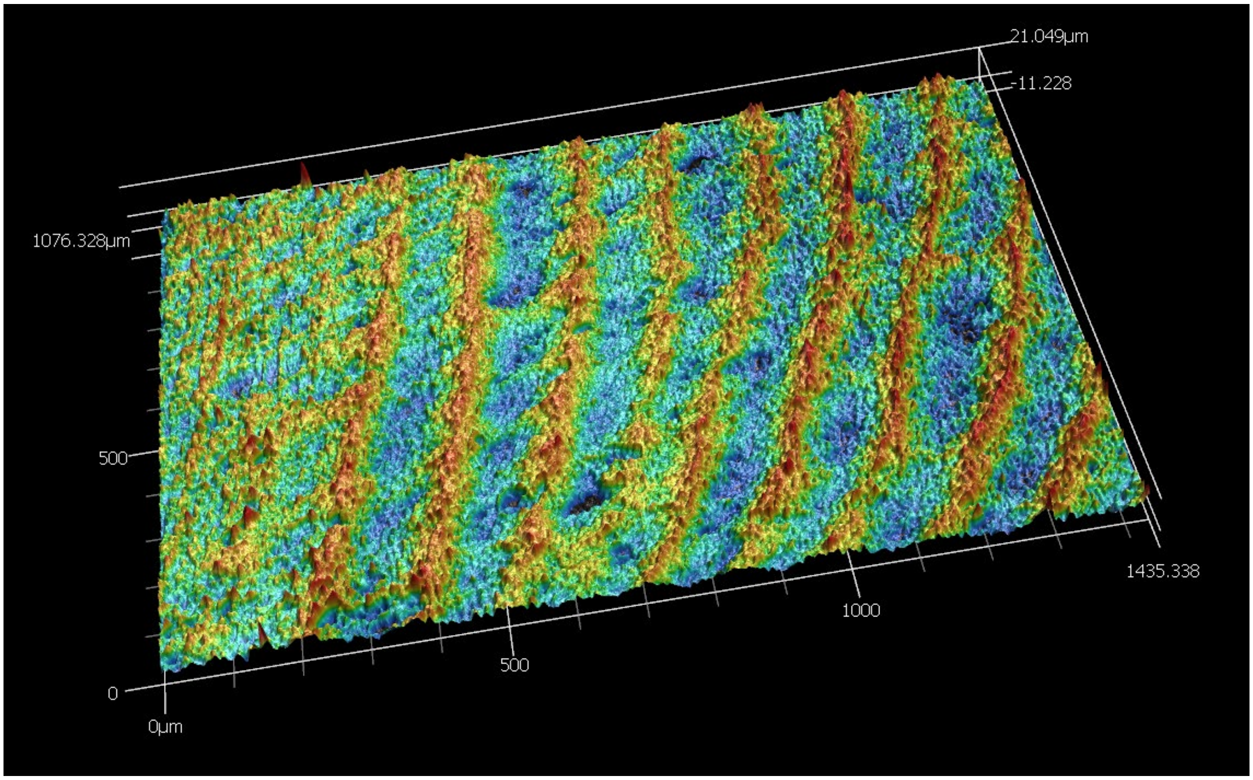
(1)



(2)



(3)



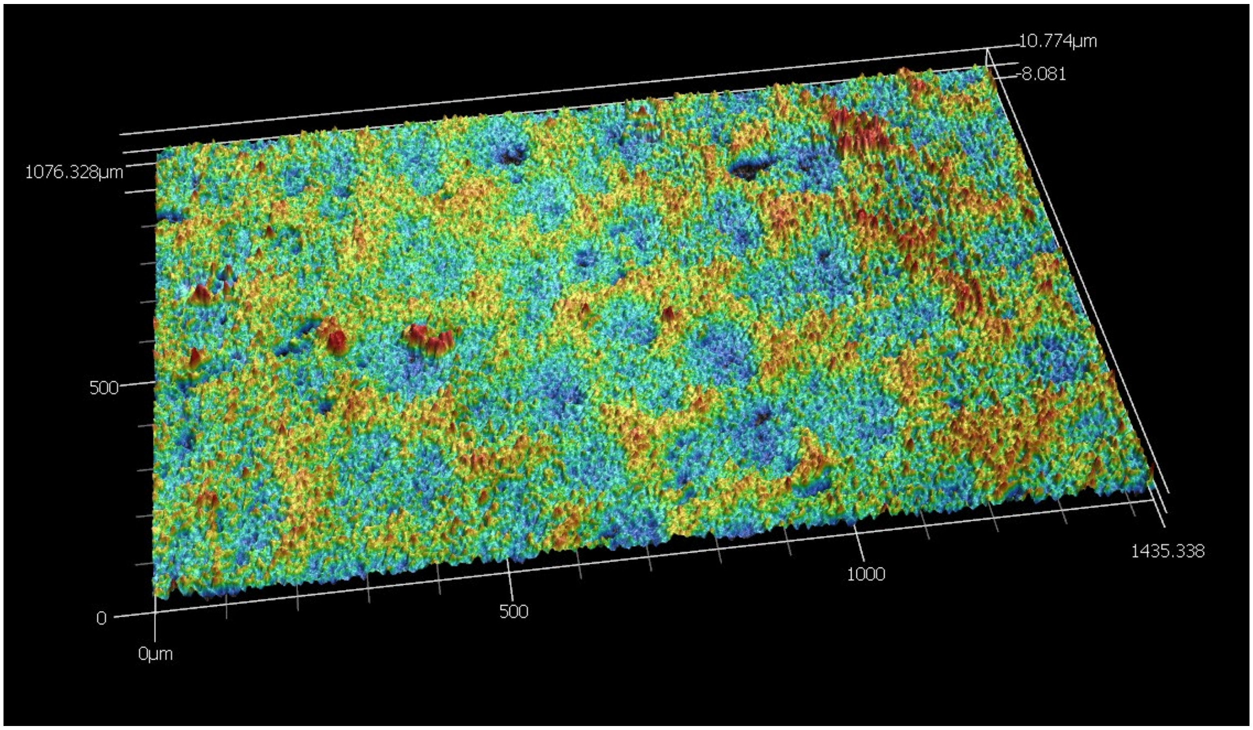


Figure 2: Topographical surface roughness for super-fast (top) and fine (bottom)

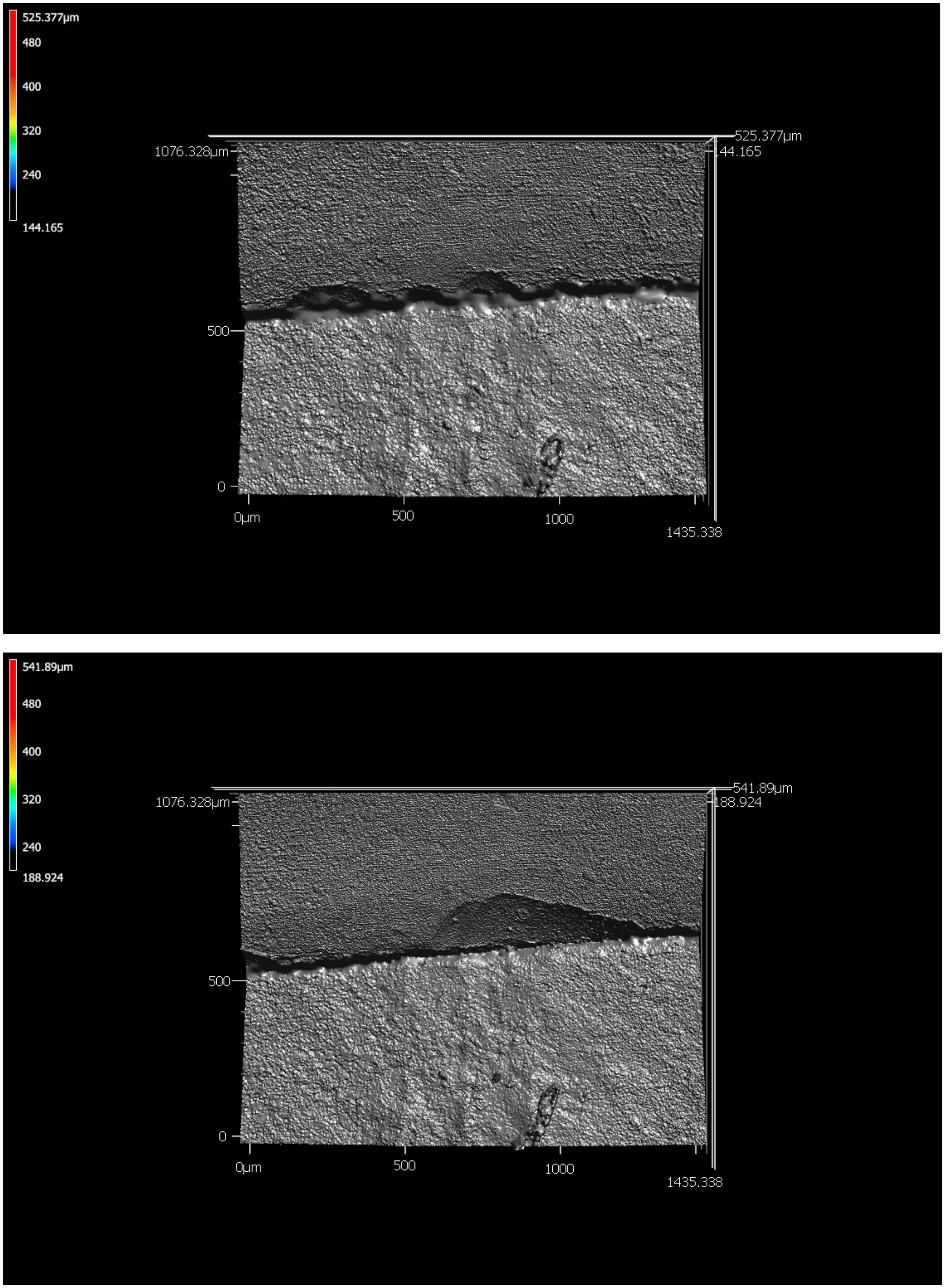


Figure 3: Extra-fine marginal defects

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