Integrated Master in Dentistry

Faculty of Medicine – University of Coimbra

2013

Ex Vivo Pilot Study on the Performance of Ultrasonic and Rotary Instruments Obtained by the Process of Chemical Vapor Deposition (CVD) in Fixed Prosthodontics

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Abstract

Statement of the problem Recently, and attempting to overcome some limitations of the conventional tools, instruments obtained by a process of chemical vapour deposition (CVD) appeared with promising features and alleged advantages in many applications, such as preparation and finishing in fixed prosthodontics procedures. However, there is still no conclusive evidence of their superior performance.

Objectives The aim of this study is to test different types of CVD-obtained instruments in crown preparations, using profilometric evaluation of surface roughness and three-dimensional form, in order to demonstrate, in a scientific manner, the advantages or disadvantages of these instruments, as well as diagnose possible flaws or confirm the accuracy of the methodology, thus being called a pilot study.

Materials and methods Margin preparations were made, with the aid of a parallelometer, applying different methods of preparation and finishing in a split-tooth model. The margins were photographed with high magnification, and then a 3D profilometric evaluation was made, resulting in values for different roughness parameters, as well as three-dimensional images of the surface.

Results The group prepared and finished with CVD burs achieved the lowest roughness values. The highest scores were associated to the group prepared with high-speed diamond burs and finishing made with CVD ultrasonic tips. Groups 4 and 1 achieved both median scores, whereas the latter presented greater variability. However, in a visual analysis of the three-dimensional images, groups 2 and 4 (both finished using CVD ultrasonic tips) show a more regular and smooth surface, with less relief marks, opposing to the ones corresponding to groups 1 and 3, which show a more pronounced bur path, matching its movements along the margin.

Conclusion Preparations made with CVD burs present the best roughness results, conventional diamond burs presented the most variable ones and the association between conventional diamond burs and CVD ultrasonic tips presented the worst values. Nonetheless, by examining the three-dimensional images and taking in consideration a whole set of success parameters, groups finished using CVD ultrasonic tips seem to deliver better conditions for a positive outcome of fixed prosthodontic restorations by providing more precise, well-defined and sharp margins, which can enhance marginal fit, castability and aesthetics.

Clinical significance Clinically, the definition, sharpness and precision on the margins are more important features than roughness, as dissected on this study. Provided that margins produced with CVD ultrasonic excel on these characteristics, this makes them a valid and important tool in the execution of a successful fixed prosthodontics restoration.

Keywords

CVD
Ultrasonic
Preparation finishing
Dental Marginal Adaptation
Fixed prosthodontics
Surface roughness

Introduction

Dental preparations for fixed prosthodontics are traditionally performed with conventional high-speed diamond burs, made by plating small industrial or mineral diamond particles on stainless steel shanks by a galvanic process[1]. This process is associated with limitations to these burs, such as short lifetime, because of the progressive wear caused by particle loss; lower endurance to repeated sterilization cycles, which can affect the matrix that binds the diamond particles to the shank; and the possibility of Ni^{2+} contamination on the dental substrate[1]. Additional disadvantages of these instruments are the increased heat production, even when irrigated, and patient discomfort[2, 3].

Attempting to overcome these limitations, instruments obtained by a process of chemical vapour deposition (CVD) of a diamond film over a molybdenum substrate appeared, resulting in a uniform coverage of the surface with diamond crystals, without irregularities or any kind of binding matrix[1]. These new instruments have an increased durability and resistance to sterilization processes because there is no particle wearing, also preventing the contamination by metallic ions[1, 4]. This technique can be applied to the production of high-speed burs, but also ultrasonic tips. These leave their almost exact microscopic morphology on the dental surface, with well-defined margins and without sharp edges, which illustrates their cutting precision. Opposing to this smooth aspect, conventional burs produce irregular lines along the dental surface, corresponding to the passage of the different sizes of diamond particles[5, 6].

One of the applications of CVD-obtained ultrasonic tips is the finishing of dental cavities and preparations for fixed prosthodontics. In a pilot study it was observed that finishing crown preparations with these tips produced better-defined axial walls and margin angles, and a smoother marginal surface, compared to the use of conventional high-speed burs[7]. It has also been suggested that finishing preparations with ultrasonic tips grants more precision to a preparation – which improves the quality of the impression and reproduction of its margins, resulting in a better adaptation of the final restoration[8], less marginal micro-leakage and secondary caries while still preserving the enamel[9] – and facilitates the smear-layer removal – obtaining greater bonding strengths with adhesive cementation.

The aim of this study is to test different types of CVD-obtained instruments, applied specifically to the area of fixed prosthodontics, both in the preparation and finishing of permanent teeth, using profilometric evaluation, in order to demonstrate the advantages or disadvantages of these instruments in a scientific, reproducible and somehow quantitative manner.

Materials and methods

Five extracted molars, stored in saline solution, were divided in four sections each (Image 1), using grooves made with a handpiece disc.

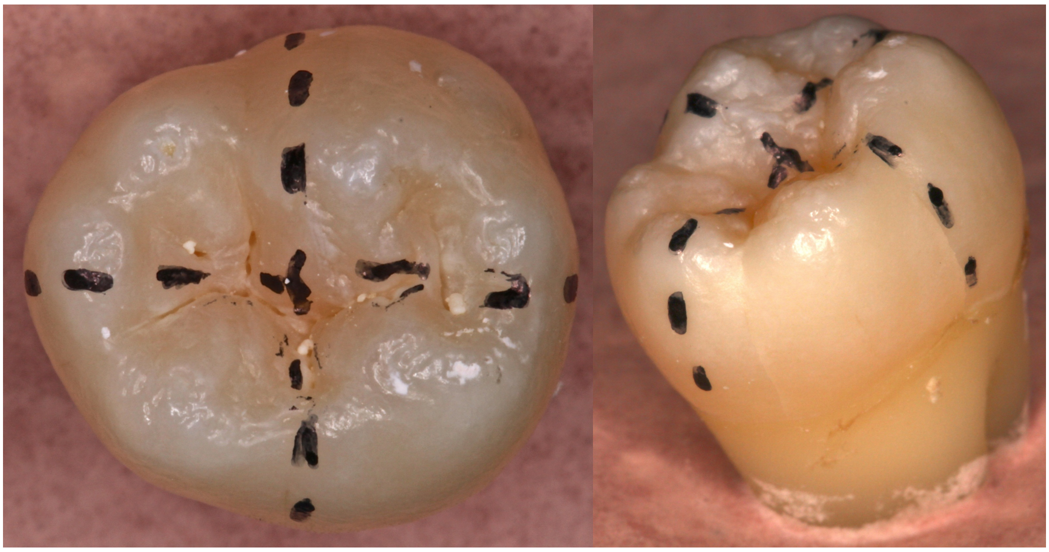

Image 1 – Photographic record of the teeth division prior to the grooves.

To each of the sections was given a number used as a reference to sort the different groups with the aid of a randomization software (http://www.randomizer.org/). The tooth sections were then named accordingly to the random distribution with the corresponding tooth number, followed by the group number (Image 2), obtaining, therefore, a split-tooth model. The teeth were then axially prepared using different methods of preparation and finishing according to the group distribution as follows:

Group 1 – preparation made with high-speed diamond burs and finishing diamond burs

Group 2 – preparation made with high-speed diamond burs, finishing made with CVD ultrasonic tips

Group 3 – preparation made with high-speed CVD burs and finishing CVD burs

Group 4 – preparation made with high-speed CVD burs, finishing made with CVD ultrasonic tips

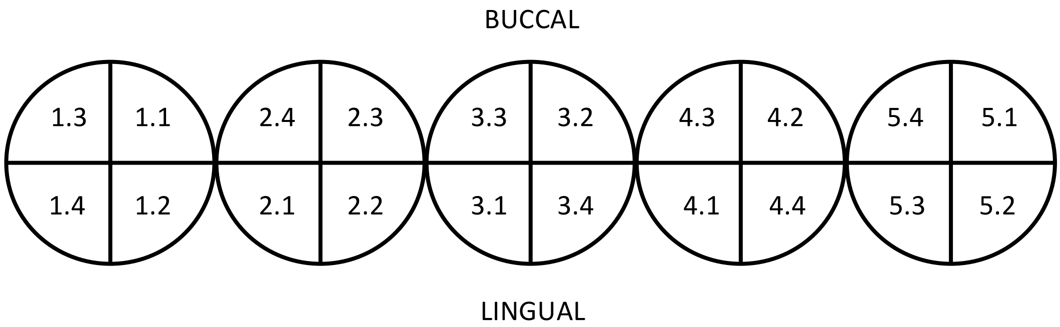

Image 2 – Diagram of the random group distribution, represented with the sample number followed by the group number.

The preparations were made with an air turbine linked to a parallelometer, with vertical movements locked, to prevent operator-related errors and maintain an identical precision and parallelism among groups. Enamel was certified to exist all the way around the margins. A single operator carried out the tooth preparations. The teeth were then embedded in acrylic resin cylinders, so they could be sectioned transversally in discs with a thickness of approximately 2mm, 1mm above and 1mm below the level of the margin.

The disks were photographed using a Canon EOS 600D with a Canon Macro lens EF 100mm 1:2.8L IS USM and a Canon MR-14EX macro ring lite in order to keep an iconographic record, as well as to allow a clinical evaluation of the preparations with all the underlying parameters. Two independent reviewers observed the images without previous knowledge of the study or any of its outlines, as well as absolute blindness regarding the groups or methodology used. They were asked to subjectively select the two portions of the picture (two groups) that they considered superior in terms of margin preparation and the answers were registered for discussion.

The evaluation of the surface roughness was made with Alicona InfiniteFocus® (Alicona Imaging GmbH, Grambach/Graz, Austria), which is an optical 3D micro coordinate system for form and roughness measurement, applying the technology of focus variation. The instrument captures the spectral variation between over-illuminated and under-illuminated surfaces, constructs a detailed three-dimensional model of a surface from a stack of images and incorporates software for high resolution three-dimensional analysis of the reconstructed surface calculating x, y, and z coordinates for any point within the resolution of the scan. Measurement was archived by tracing a 5mm random path, which allows a random and trustworthy roughness analysis[10], as shown in Image 3. The images were taken in areas including both enamel and dentin, and apart from the group division grooves (which, during the preparation, could have caused slight displacements of the instrument).

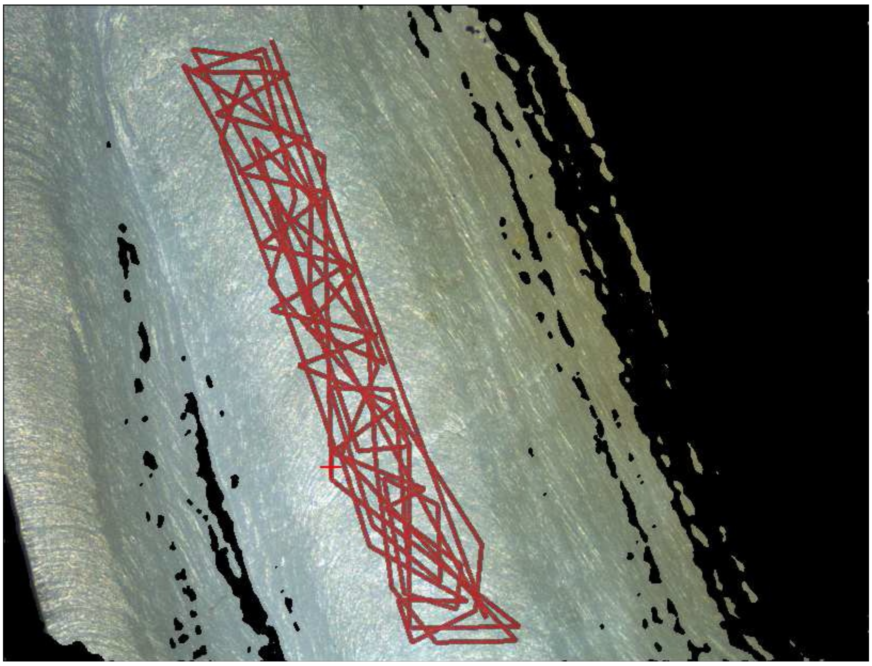

Image 3 – Example of one of the surface images obtained, showing the kind of tracing needed for a trustworthy analysis.

Aiming to evaluate the roughness parameter, the shape factor of the surface has to be eliminated so that the results suffer no influence or misrepresentation and only the surface roughness, as shown in Image 4, is analysed.

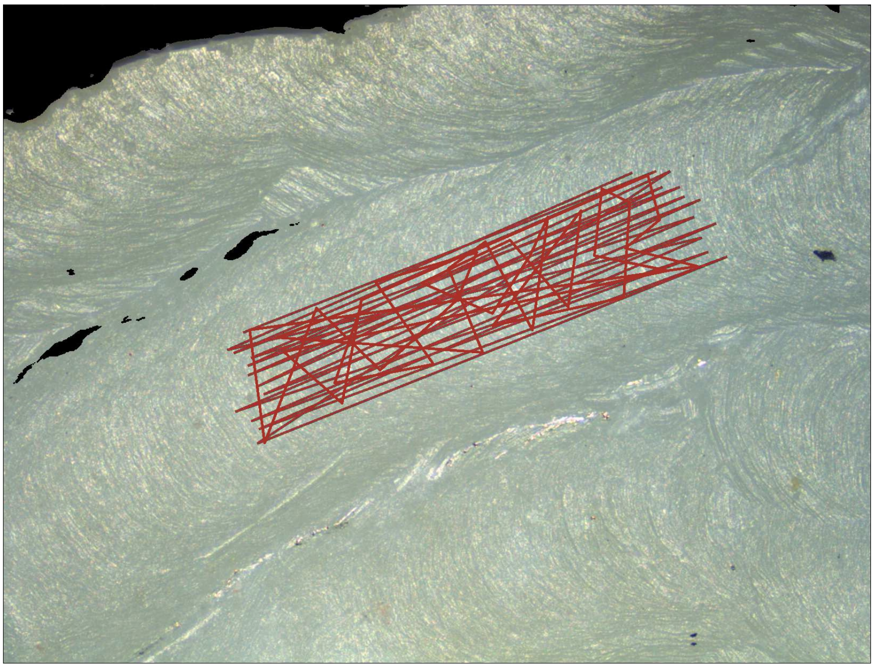

Image 4 – Example of an aleatory path made to calculate the surface roughness parameters; it's located between the relief marks, to eliminate the shape factor, which can produce misleading results.

The random path needs to be made in an area without the shape factor, which means that, for example, in surfaces clearly marked by the passage of the bur (with hilly, bumpy and ridgy shapes), the roughness calculation has to be done between those relief marks. This methodology will directly affect the results, as shown in the discussion.

Three parameters were selected to assess the properties of the surface in terms of roughness: Ra, Rq, and Rz (Ra, roughness average; Rq, root mean square; and Rz, mean peak to valley height of roughness profile). The parameters were calculated using Alicona IFM version 3.5.1.5 software (Alicona Imaging GmbH, Grambach/Graz, Austria).

Apart from the roughness measurements, the optical system also allows a three dimensional view of the surface and an evaluation of its characteristics. These 3D images may be analysed in real and artificial colours as shown in Image 5. For the purpose of the study, this analysis reveals itself of extreme importance to understand the numeric results and take well-grounded and accurate conclusions.

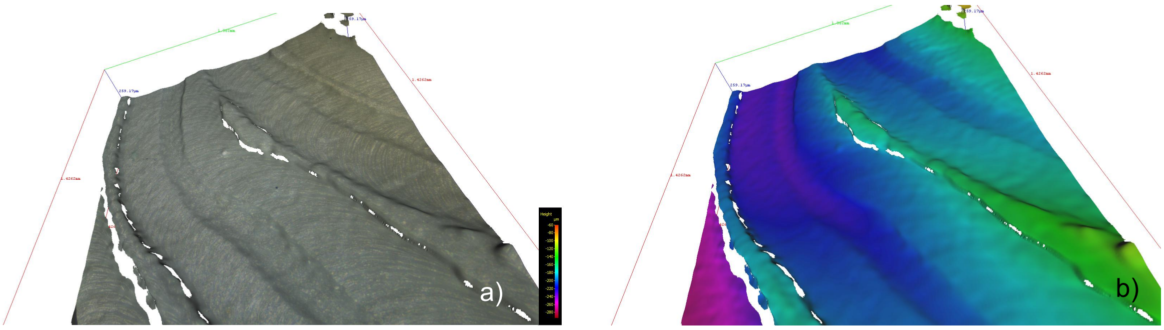

Image 5 – Examples of 3D images a) in real colors; b) in artificial colors, which vary according to the relief. The white areas represent surfaces that are too reflective to scan, or that present very abrupt relief changes.

The statistical analysis started with the determination of the correlation coefficient (Pearson correlation coefficient) between the Ra and Rq values since, being amplitude parameters which characterize the surface based on the vertical deviations of the roughness profile from the mean line, they are normally correlated. The correlation between Ra and Rz was also calculated. As expected, there was a very strong correlation (cc = 0.998; $p < 0.001$) between Ra and Rq, and between Ra and Rz (cc = 0.969; $p < 0.001$). The dispersion diagrams illustrate these correlations. (Image 6)

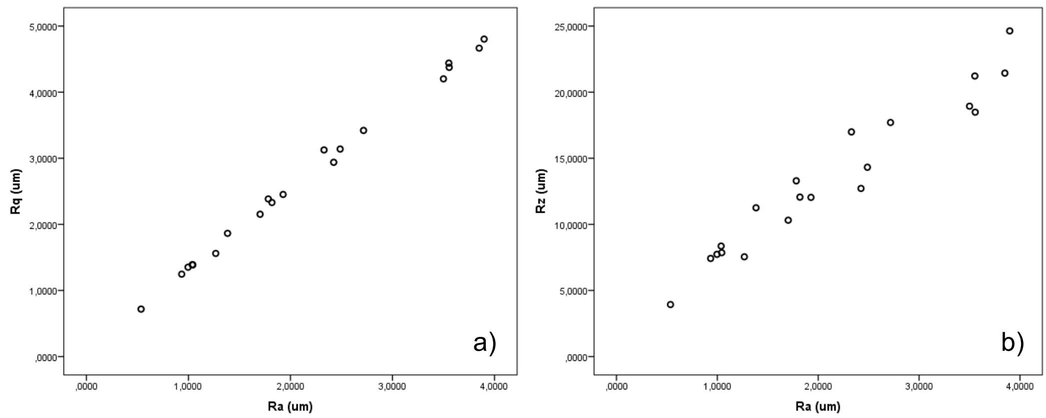

Image 6 – Dispersion diagrams for the correlation between a) Ra and Rq; b) Ra and Rz. These illustrate the positive correlation between the pairs of parameters, which means that, when one of the parameters increases, the other one does too.

The existence of statistically significant differences in the roughness values in the groups was determined using a Kruskal-Wallis test – a non-parametric test for independent or non-related samples – with the Ra measurements (Rq and Rz values were not used because they are correlated to Ra). The test indicated that there are statistically significant differences ($\chi^2(3) = 10.211$; $p = 0.017$) in roughness values among the groups, so, in order to determine what group pairs present statistically significant differences between each other, a Mann-Whitney test – also a non-parametric test for independent samples – was made.

The option for non-parametric testing was due to not knowing if the sample followed an identified distribution form. Also, the samples are independent because there isn't any kind of relation or uniting factor between them, alas, for one subject, the probability of belonging to more than one group is null.

Results

Table I shows some of the statistics obtained from the roughness values of the different groups.

The graph represented in Image 7 shows the distribution of values in the boxes-and-whiskers form.

			Ra (µm)	Rq (µm)	Rz (µm)
Group	1	mean	2,3073	2,8933	13,7532
		sd	1,1556	1,3314	4,9394
		cv	5,.0845%	46,0166%	35,9145%
		min	0,9962	1,3519	7,7331
		max	3,5559	4,3756	18,9390
	2	mean	2,8484	3,5273	16,3476
		sd	0,8150	0,9723	4,6255
		cv	28,6125%	27,5649%	28,2946%
		min	1,9281	2,4524	12,0390
		max	3,8501	4,6662	21,4410
	3	mean	0,9634	1,2601	7,0213
		sd	0,2685	0,3232	1,7644
		cv	27,8700%	25,6487%	25,1292%
		min	0,5355	0,7173	3,9315
		max	1,2675	1,5605	8,3546
	4	mean	2,4291	3,1089	16,5278
		sd	0,9640	1,1317	5,3635
		cv	39.6854%	36,4019%	32,4513%
		min	1,3834	1,8640	11,2520
		max	3,8983	4,8030	24,6320

Table I – Mean, standard-deviation (sd), coefficient of variation (cv), minimum (min) and maximum (max) values of the roughness parameters testes in the samples.

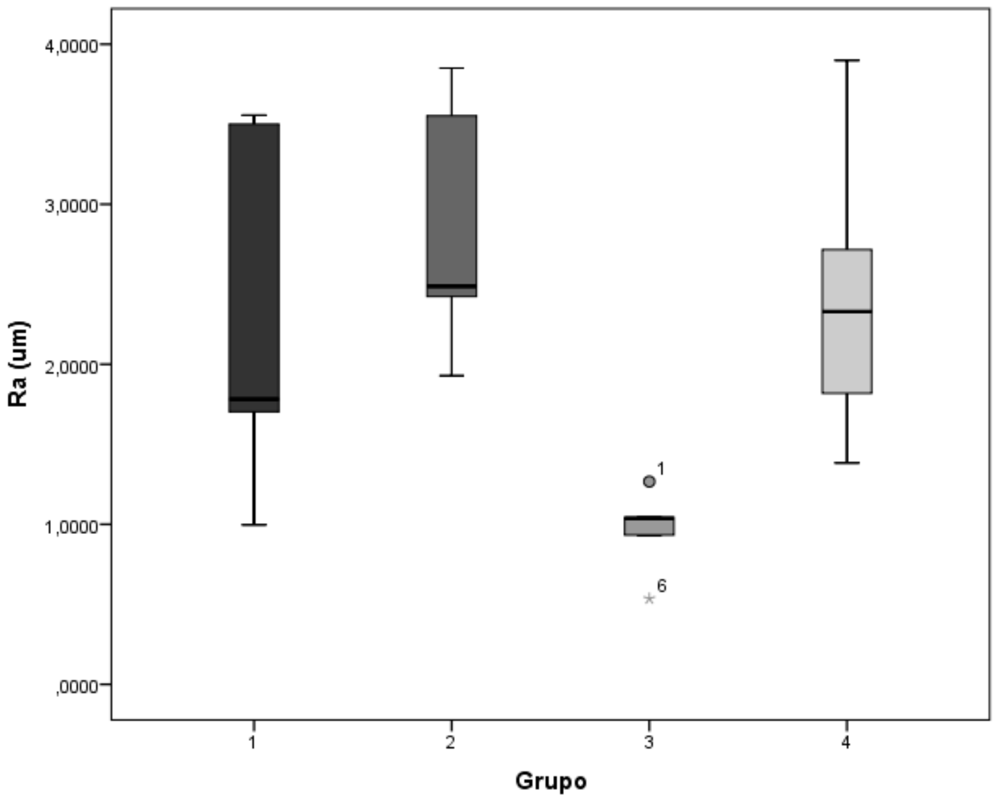

Image 7 – Boxes-and-whiskers graph showing the distribution of the values in relation to the median and comparing the four groups. The symbols marked with 1 and 6 are outlier values.

The groups which present statistically significant differences are:

- 2 e 3 (U = 0.00; Z = -2.611 p = 0.009);
- 3 e 4 (U = 0.00; Z = -2.611 p = 0.009)

The groups which don’t present statistically significant differences are:

- 1 e 2 (U = 7.00; Z = -1.149; p = 0.251);
- 1 e 3 (U = 3.00; Z = -1.984; p = 0.047);
- 1 e 4 (U = 10.00; Z = -0.522; p = 0.602);
- 2 e 4 (U = 9.00; Z = -0.731; p = 0.465);

Group 3 presented better results in all three of the roughness parameters, with a mean Ra of 0.96 and standard deviation of 0.26, with one outlier and one extreme outlier. The group with greater values in roughness parameters was group 2. The group with more variability in the Ra scores was group 1, as seen by the coefficient of variation (standard deviation/mean*100) of 50.08%.

The photographic records are shown below, in image 8 and in greater definition, quality and magnification in the Appendix 2 section.

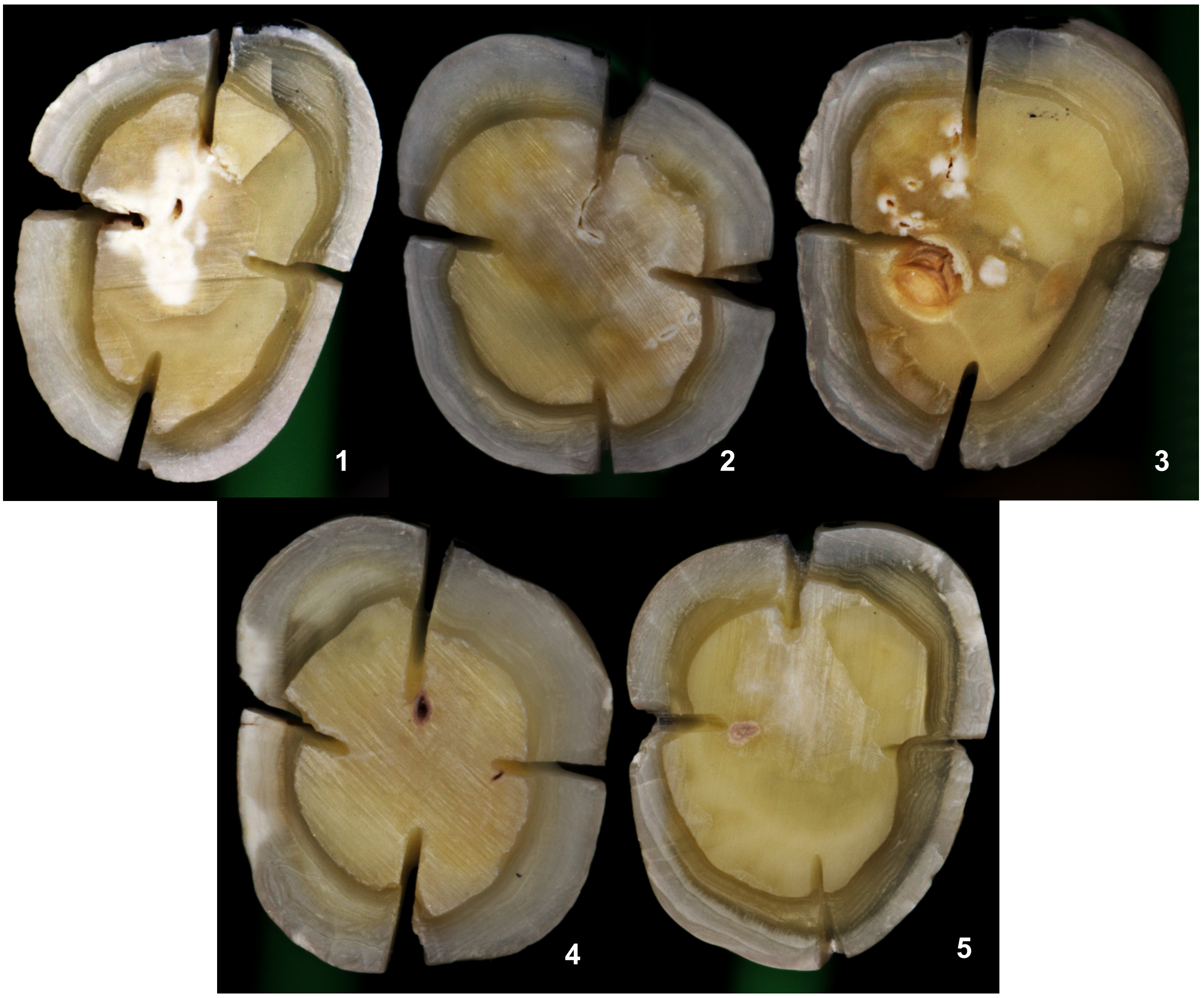

Image 8 – Photographic records of the samples. See Appendix 2 for better visualization.

As for the three-dimensional surface acquisition, table II presents the results of all samples, in real and artificial colours.

The three-dimension images corresponding to groups 2 and 4 represent a visually more regular and smooth surface, with less relief marks. The ones corresponding to groups 1 and 3 show a clearer bur path, matching its movements along the margin.

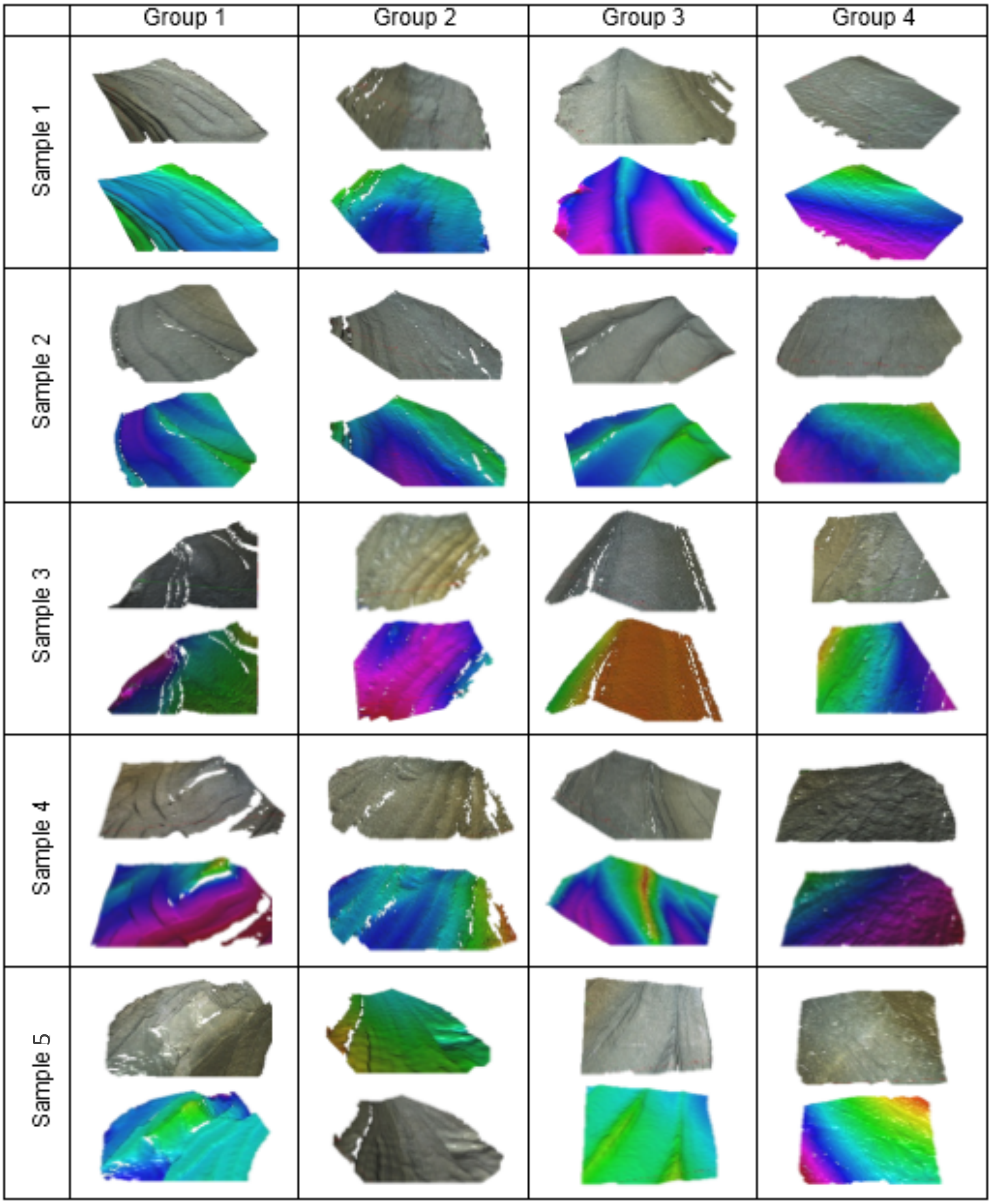

Table II – Table showing the iconographic results in small magnification. See Appendix 1 for a better visualization.

The subjective observation of the photographic records, performed by the blind reviewers, revealed that both of them point out groups 2 and 4 as those presenting superior margin preparations in 100% of the samples.

Discussion

The literature is scarce in studies that compare or simply analyse ultrasonic finishing of the margin in the fixed prosthodontics field.

This discussion will use a systematized approach and start by presenting the different studies followed by the integration of our results.

To evaluate whether finishing procedures are effective, Giampaolo et al., 2003, concluded that a diamond bur, used at high speed, produces a very rough enamel surface, but all finishing procedures tested produced an enamel surface similar to the unpolished original enamel. This study doesn't compare the results between the different types of finishing procedures, but only between finishing and not finishing the preparations[11].

Although roughness evaluation is considered by some authors as a valid instrument to predict the success of fixed prosthodontics elements due to an alleged influence on the accuracy of the impression and adaptation of the crown, as well as in the quality of the bonding forces, the margin topography reveals itself with an even greater importance, as will also be shown in this discussion[7].

Ellis et al., 2012, concluded, through SEM and µTBS testing, that the use of ultrasonic instruments provides an extremely precise preparation margin and improves the quality and accuracy of crown preparations, which may lead to better impressions and closer adaptation of restorations[12].

The fit of a cast restoration depends on precise successive steps in the indirect process, hence, irregularities in the walls and margins may lead to undersized castings because reproduction of the sharp peaks becomes reduced with the successive steps of impression, die, wax pattern, investment and casting[13]. A smooth surface is important for a well-fitting restoration and assists in strengthening the ceramic margin of a restoration[7]. The axial wall/margin angle prepared with ultrasonic instruments was found by Horne et. al, 2012, to be smooth and close to 90°, forming a well-rounded shoulder, which can enhance marginal fit, castability, and aesthetics[7]. A well-defined, sharp external line angle without a lip of unsupported enamel is also critical to the fit of a restoration[7].

In terms of cementation of fixed prosthetics, contrary to the conventional and old-fashioned cementation protocols using zinc phosphate and polycarboxilate, which retentive abilities rise with increasing surface roughness[14], adhesive cementation procedures, on the other hand, do not depend on this mechanical retention related to surface roughness[15-22]. This surface property has also no significant influence on the wettability of distilled water in dentine and enamel which could affect the adhesion process[23].

Ellis et al, 2012, also found that bond strengths to composite resins achieved with the use of the PMS ultrasonic tips were similar to those with traditional diamond burs, much alike Cardoso et al, 2008, with CVDentus burs and ultrasonic tips[11, 12, 16].

According to Santos et al, 2009, the ideal thickness of cement in an adhesive cementation should vary not far from 25µm[24]. This precision depends not only on the cement and cementation technique used but mainly on the accuracy of the tooth preparation and, more specifically, the margin preparation and finishing. Although ultrasonic finishing of preparations, as shown before, is not directly related to adhesion strength, their influence on the restoration adaptation is greatly recognized and essential to allow a thin layer of cement, as desirable[25].

This kind of instruments has another advantage related to their capability of not harming soft tissues. Although this parameter was not evaluated on this study, its importance is great to understand the methods available to polishing subgingival finishing lines and, therefore, it is well-suited for further investigation. The common use of these tools may be determinant for aesthetic restorations in the anterior dentition, which often demand a preparation with a subgingival finish line, because their oscillating action reduces trauma to the soft tissues during subgingival margin preparation, facilitating accurate impression taking[9, 26, 27]. That's also why, in groups 2 and 4, the finishing wasn't made with polishing cups or brushes, since they can't reach a subgingival space the way the ultrasonic tips can. The finishing was, because of that, made with fine diamond burs, taking us not only to the justification of the methodology used in this pilot study, but also to the projection, as mentioned above, of future research.

Having walked through the scarce available literature on the subject, we shall now focus on the study results, discussing them and comparing to what has been previously investigated.

In terms of roughness analysis, the preparations with the lowest scores were the ones prepared with high-speed CVD burs and finishing CVD burs – group 3 – with a mean Ra value of 0.9634μm and standard deviation of 0.2685. The highest roughness scores were obtained in group 2, prepared with high-speed diamond burs and finished with CVD ultrasonic tips, with a Ra mean value of 2,8484μm and standard deviation of 0,8150. Group 4 obtained median scores, as well as group 1, which showed great variability (with a coefficient of variation of 50,0845%).

The difference between group 1 and group 3 was found to be borderline to statistically significant ($p = 0.047$), but it can't be considered as so because of the reduced sample size and the variability in those groups. The two outlier values for group 3 also show this variability, but because there is one superior and one inferior outlier, their influence doesn't damage the results in a great way. In a wider sample, the outliers of group 3 could have been more disperse and frequent and therefore not considerate outliers, but in spite, their values were included in the statistical calculations.

These results support the conclusion made by Laufer et al., 1996, that ultrasonic finishing increases roughness in shoulder preparations, comparatively to diamond burs, using only SEM technology[28].

On the other hand, Horne et al, 2012, found that ultrasonic finishing produced smoother shoulders, with lower Ra values. However, in a critical analysis, this study was conducted with a small group, even for a pilot study (n=4), and the results were obtained using only 1D and 2D roughness evaluation[7].

No other studies were found that touched this crucial theme in prosthodontics rehabilitation and, therefore, this leads to one of the main breakthroughs of our study, that is, apart from adding a great amount of information to what is currently known, a new and innovative methodology with an optical 3D micro coordinate system for form and roughness measurement is introduced to evaluate the margin of tooth preparations that not only takes in consideration the roughness analytical values but also, and more importantly, the surface topography in an unprecedented manner.

Bearing this in mind, in our analytical roughness evaluation, as explained on the Methods section, the sampling took in consideration that the shape and topography should be disposed of, in order to obtain accurate values of roughness without the interference of more macroscopic features such as relief markings created by bur passage which were then separately analysed using the 3D imaging, as shown below. To illustrate and justify this appreciation, we shall attend to Image 9 that represents a surface analysed purely in terms of roughness measurements accordingly to the values presented for roughness in this study (A) in contrast to the same location analysed without ignoring the bur created relief (B). Attending to the analytical roughness values ($Ra_{(A)}$= 535.5nm; $Ra_{(B)}$= 9.4976µm) without any further information, one would easily appoint the surface represented by the letter *A* as a very smooth and well-defined margin, opposed to a "rough" and undefined margin in the surface represented by *B*.

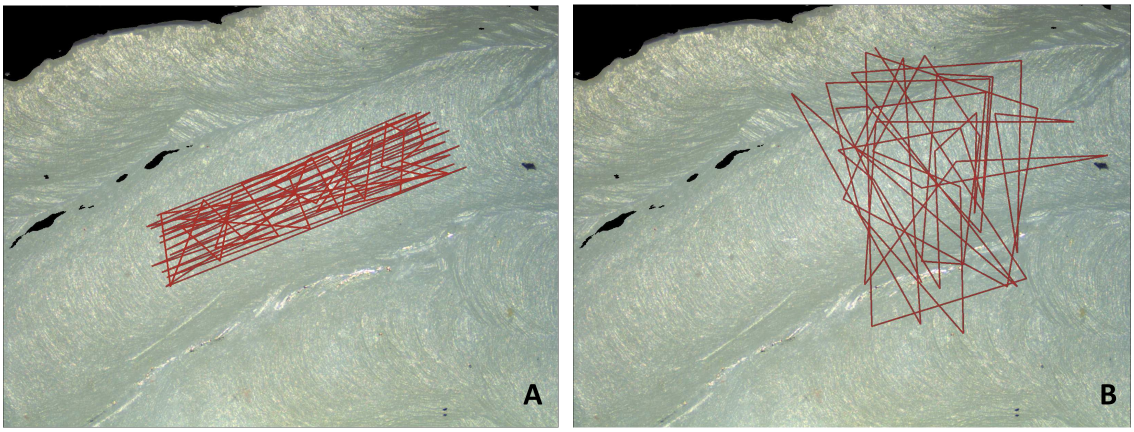

Image 9 – Different paths made to evaluate roughness parameters (A) between the relief marks, eliminating the shape factor; (B) all over the surface, without ignoring such relief.

This is an explanation to why, as shown on the Image 7 in the Results section, the group 2 and 4 present significantly better margin definition, well-rounded surfaces, and overall improved sharpness and delineation. In fact, interestingly and as a curiosity, using a clinical diagnostic microscope (Leica M300®, Leica Microsystems, Switzerland) this is somehow visible, as well as magnifying the preparations in a photography using a Canon 600D camera with a 100mm Macro lens.

Although negligible due to the subjective nature of the photographic evaluation for a scientific study, it is interesting to see that in 100% of the samples and always in agreement, both blind reviewers identified groups 2 and 4 as presenting superior clinical characteristics in terms of margin preparation and finishing. In spite of non-analytical, this data enforces the three-dimensional imaging findings from a specialist's viewing angle that bears in mind the clinical outcome.

At this point, it becomes easy to grasp why the roughness measurements are important but also highly ineffective. Therefore, the need of an alternative evaluation method that responds and overcomes the flaws of the previous one becomes clear.

Another one of the strengths of this study is the use of a split-tooth model, which provides a robust control and reduces factors related to the teeth that may influence the results. All tooth preparations were executed by a single specialized operator, with the aid of a parallelometer, which further reduces possible variations and greatly increases the internal validity of the study.

Conclusions

Several scientifically important conclusions can be drawn from this study.

In terms of analytical roughness measurements, group 3 presented the best results, group 1 presented the most variable ones and group 2 presented the worst values.

However, by examining the three-dimensional images and taking in consideration a whole set of success parameters, groups 2 and 4 (both finished using CVD ultrasonic tips) seem to deliver better conditions for a positive outcome of fixed prosthodontic restorations by providing more precise, well-defined and sharp margins, which can enhance marginal fit, castability and aesthetics - more important features than roughness.

Attending to the methodology used and comparing to the existing studies, it is clear that roughness analytical measurements may cause faulty assumptions due to the frequent flaws and necessity to eliminate surface shape, topography and relief, that are often essential for correct and complete result evaluation. Hence, the inevitable breakthrough of the study being the optical 3D micro coordinate system for form and roughness measurement, applying the technology of focus variation to allow accurate evaluation of surfaces and, thus, presenting a solution for the common roughness analysis scientific gaps.

In spite of already displaying some scientific conclusions, one should overlook that this is a pilot study and, therefore, its purpose is to lead the way into a new promising stage of research on this field, enhancing the necessity of more investigation with a larger sample and, thus, greater statistical value.

Acknowledgements and Disclosure

-Professor Fernando Guerra, DMD, MSc, PhD, Head of the Fixed Prosthodontics Department of the Faculty of Medicine – University of Coimbra, for the guidance and knowledge passed not only during the execution of this project but also in the past 5 years.

- Assistant Professor Rui Isidro Falacho, DMD, MSc, for the tireless efforts to make this project possible, the availability, support and encouragement, the well-intentioned reprimands, the inspirational teaching, and the invaluable friendship;

- Professor João Carlos Ramos, DMD, PhD, Head of the Dentistry Department and Director of the Biomechanical Tests Laboratory of the Faculty of Medicine – University of Coimbra, for the precious advices and helpful contribution in the conception and development of the study, as well as for the incomparable knowledge in the field of biomechanical tests and specially in sample preparation;

- Assistant Professor Paulo Palma, DMD, MSc, for the crucial collaboration in the elaboration of the study;

- Professor Francisco Caramelo, MSc, PhD, for the unbelievably good willing help with the statistical analysis;

- Dear colleague João Cavaleiro, for the shared knowledge and the crucial cooperation;

-Dearest colleague Pedro Ferreira, for the infinite patience even in the most stressful moments of this journey, and for the most treasured partnership.

A special acknowledgement to the Laboratory of Biomechanical Tests of the Faculty of Medicine – University of Coimbra, for providing the means and know-how to accomplish this study's protocol and objectives.

The authors are also grateful to CVDentus® for providing the ultrasonic generator, and CVD instruments.

The authors do not have any financial interest in the companies whose materials are included in this article.

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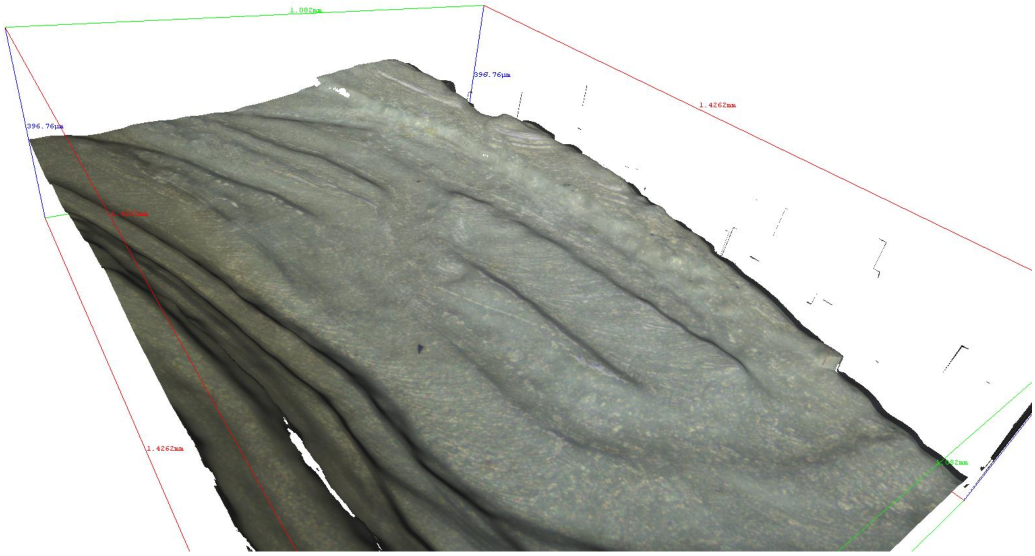
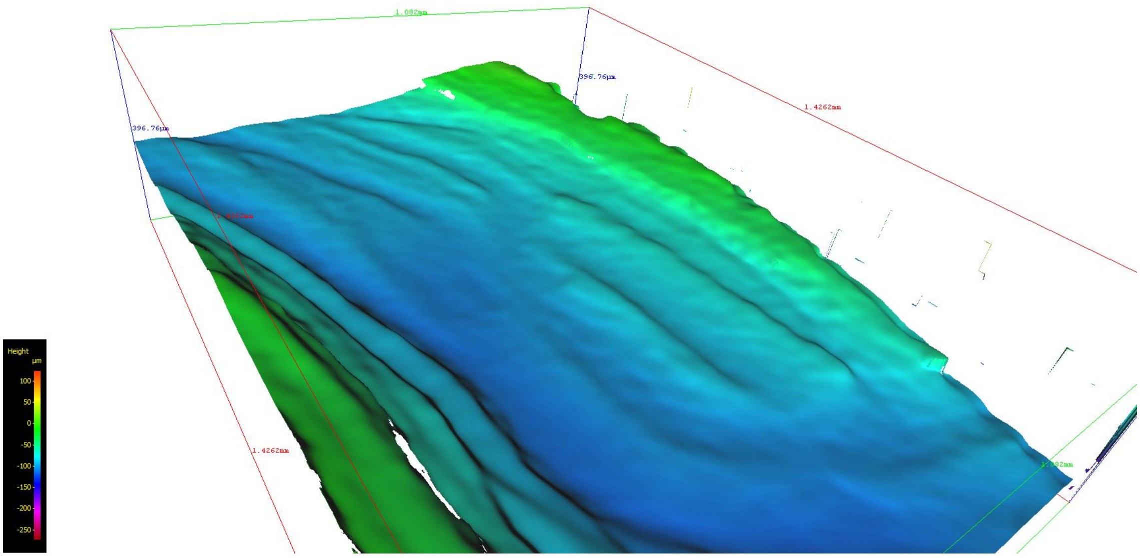
Appendix 1 – 3D images

Sample 1, Group 1





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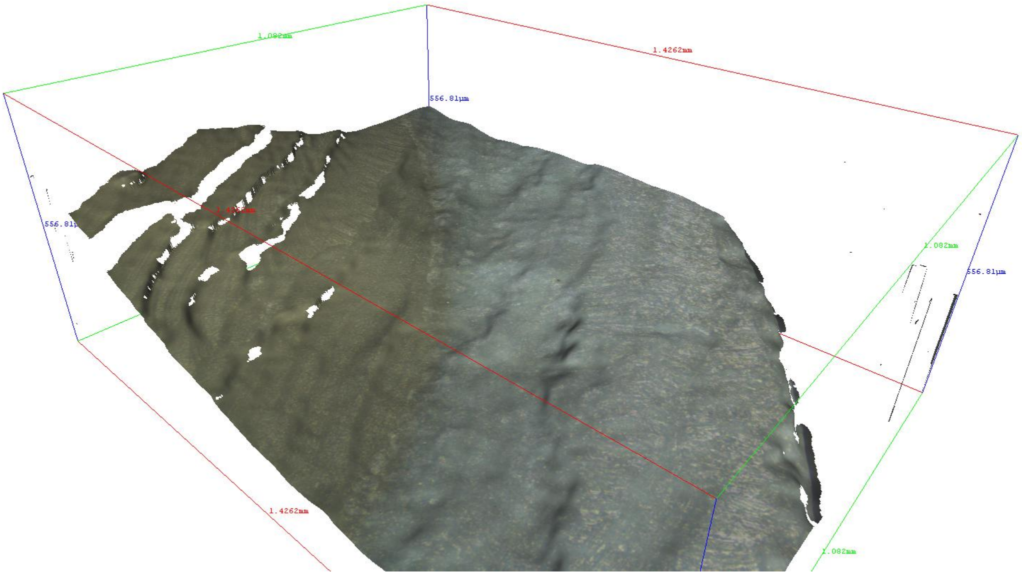

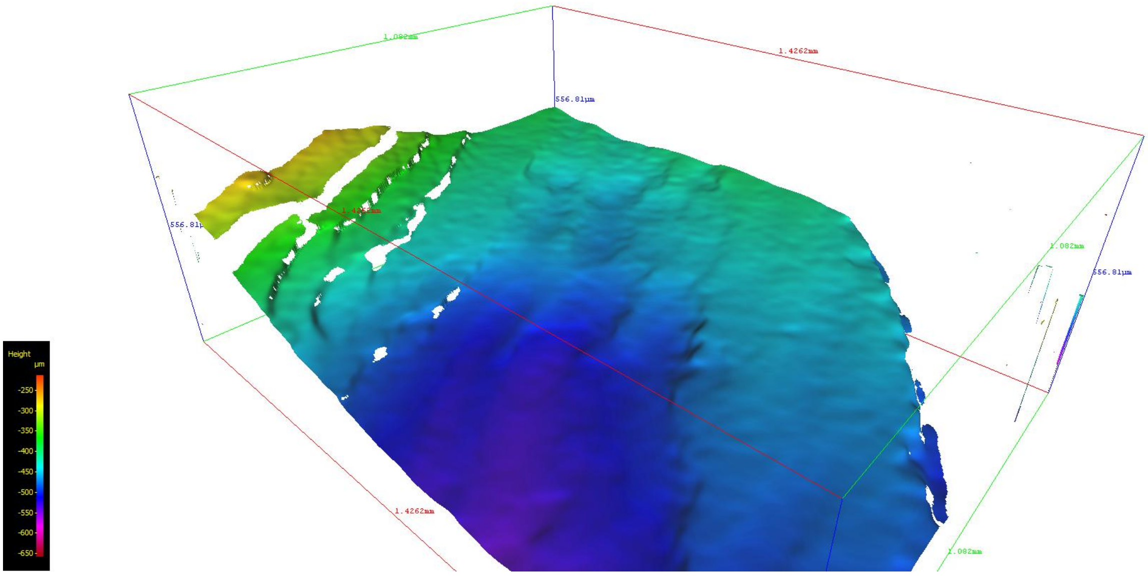

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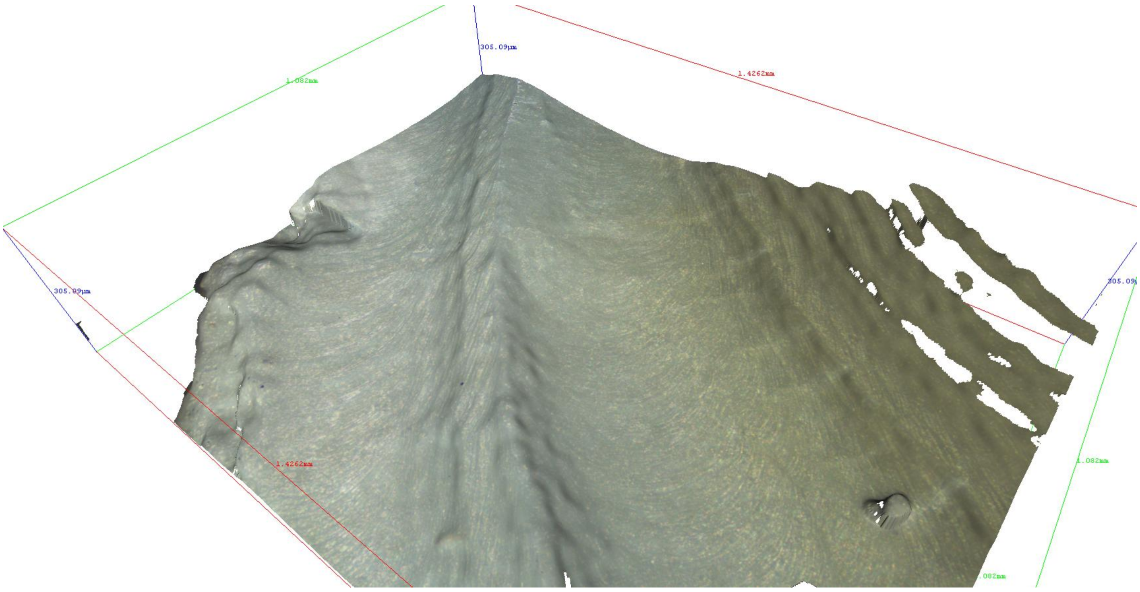

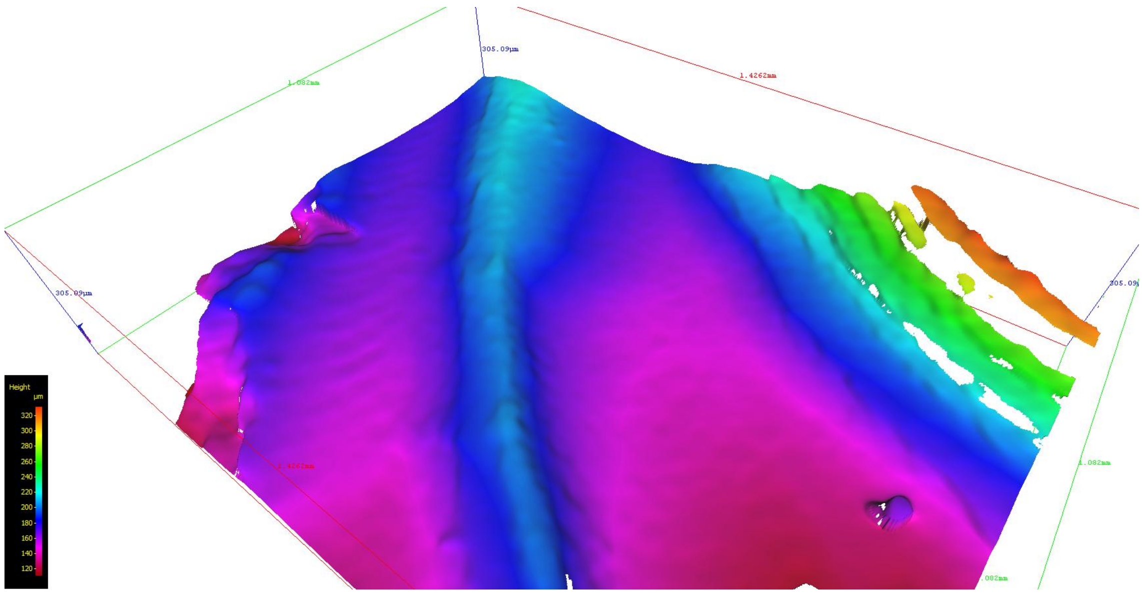

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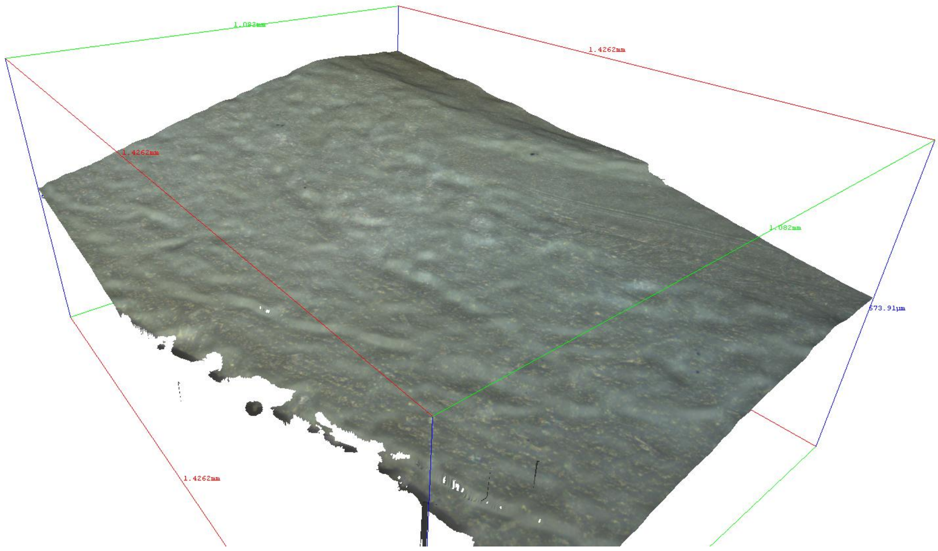

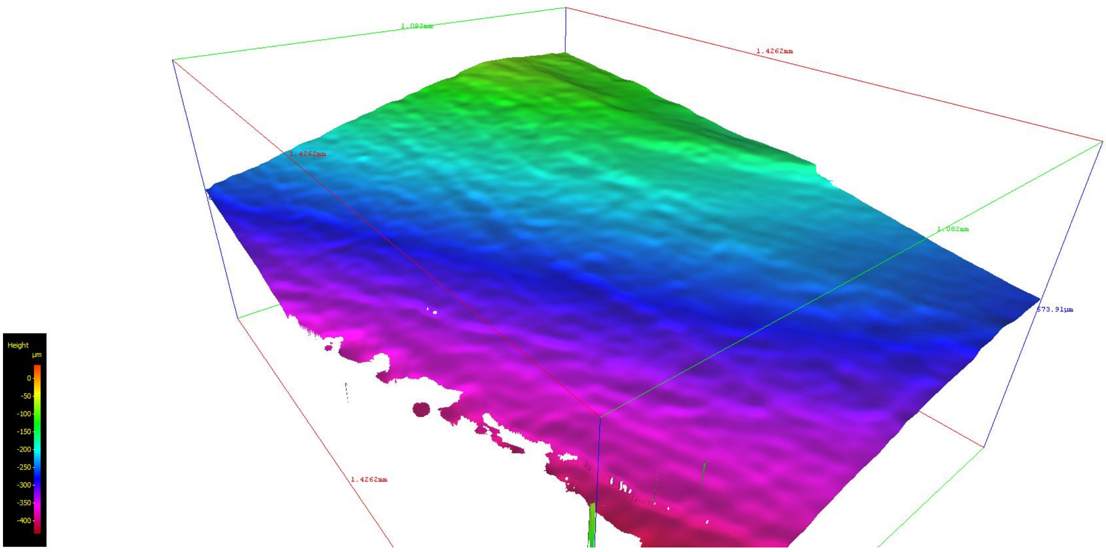

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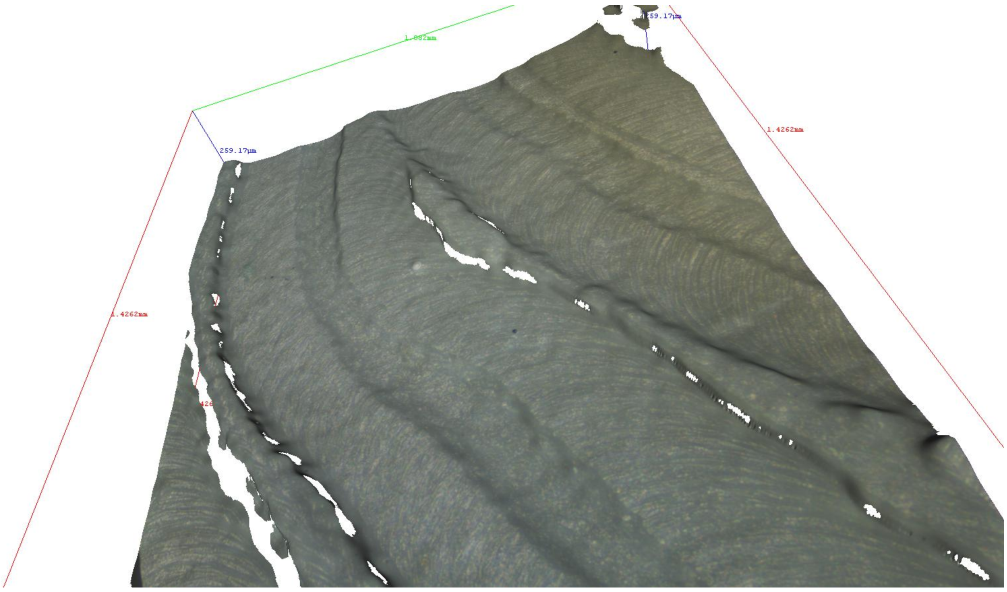

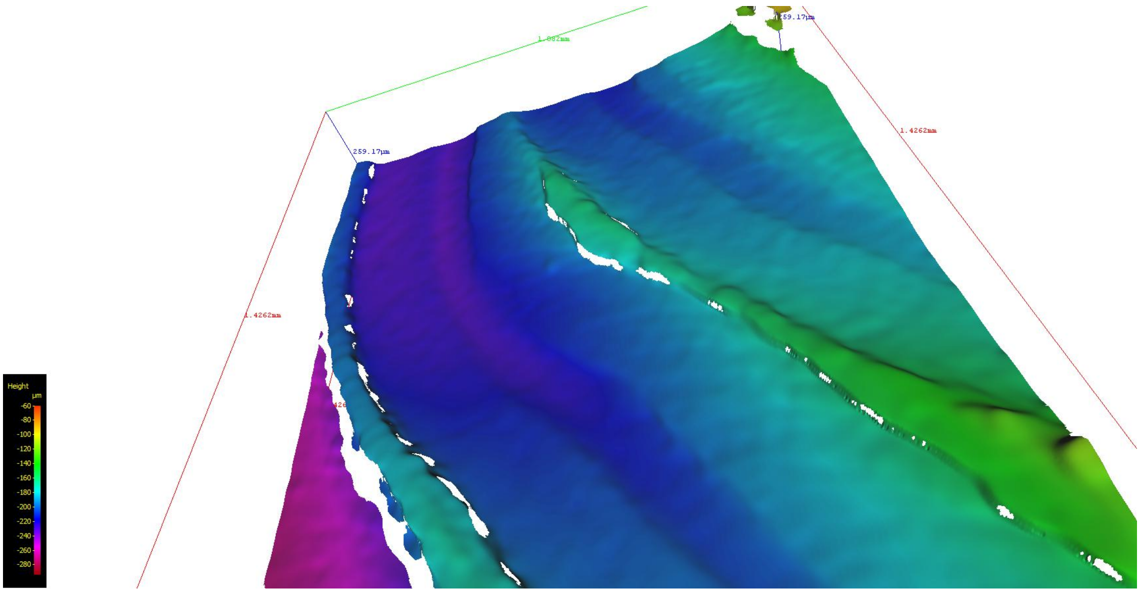

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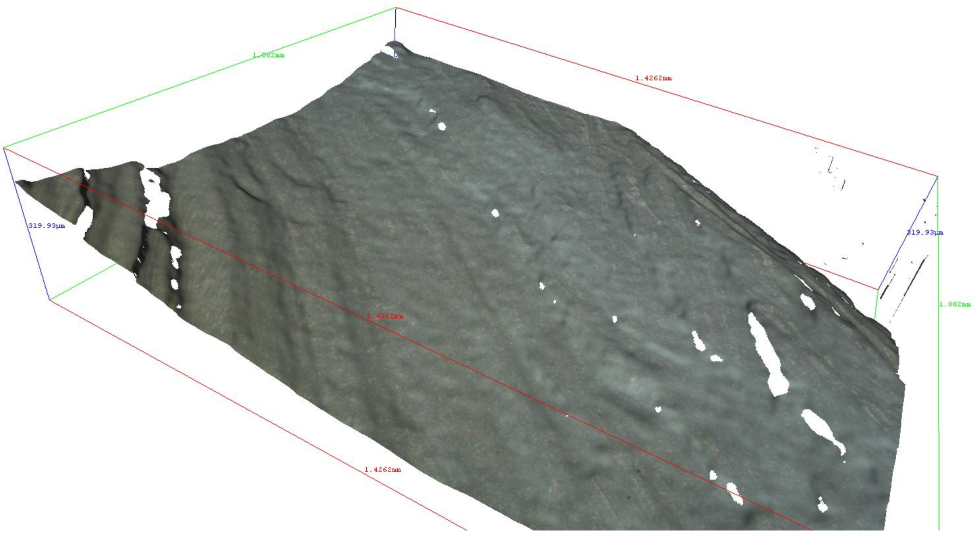

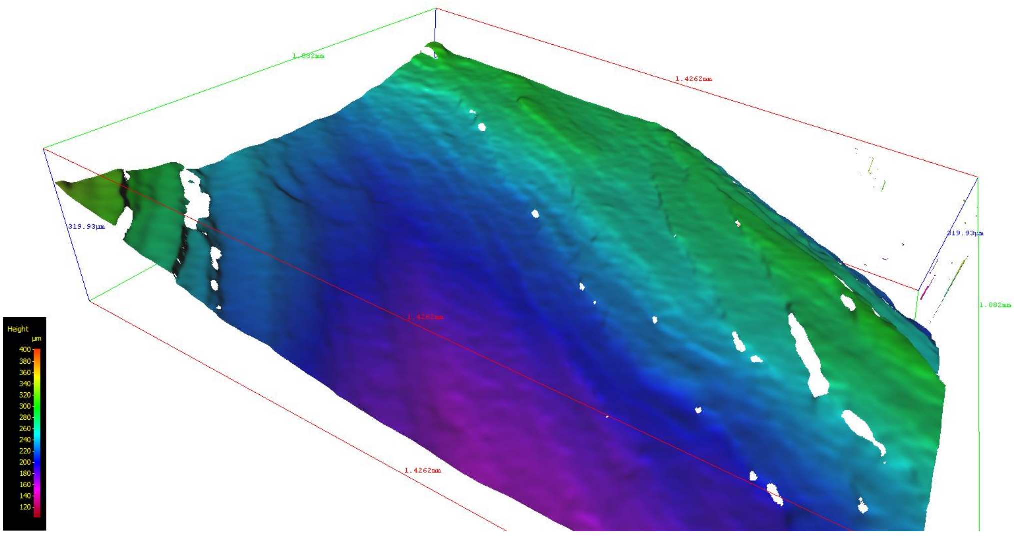

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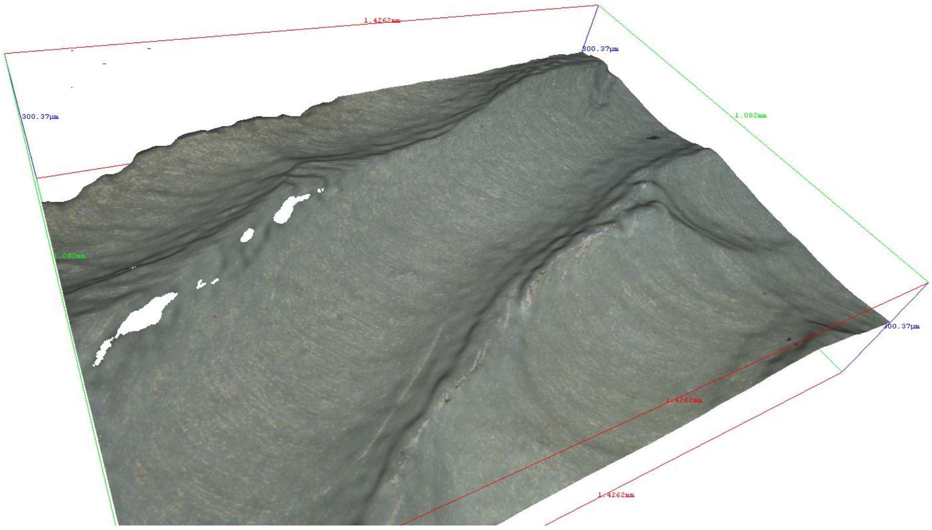

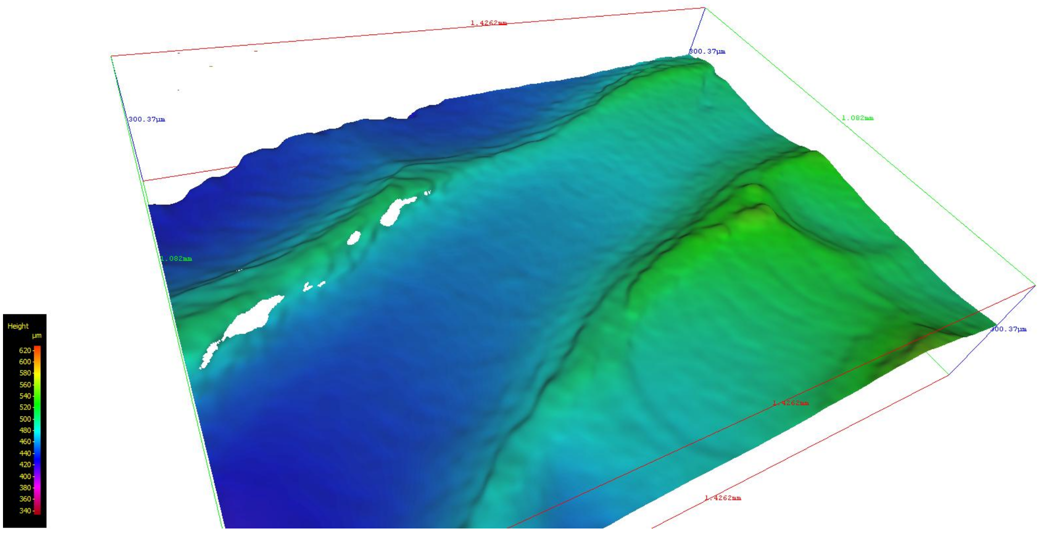

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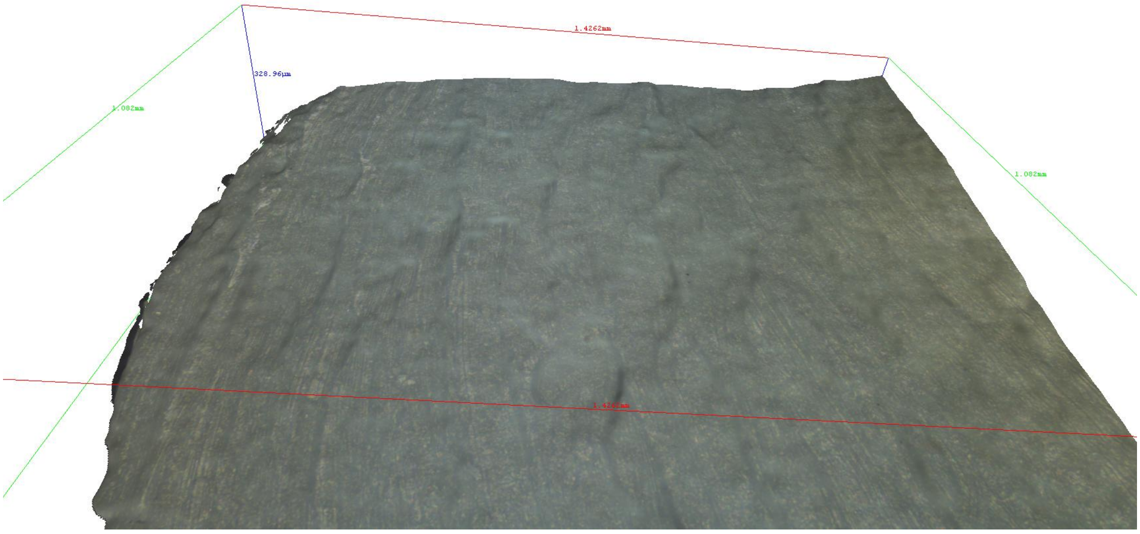

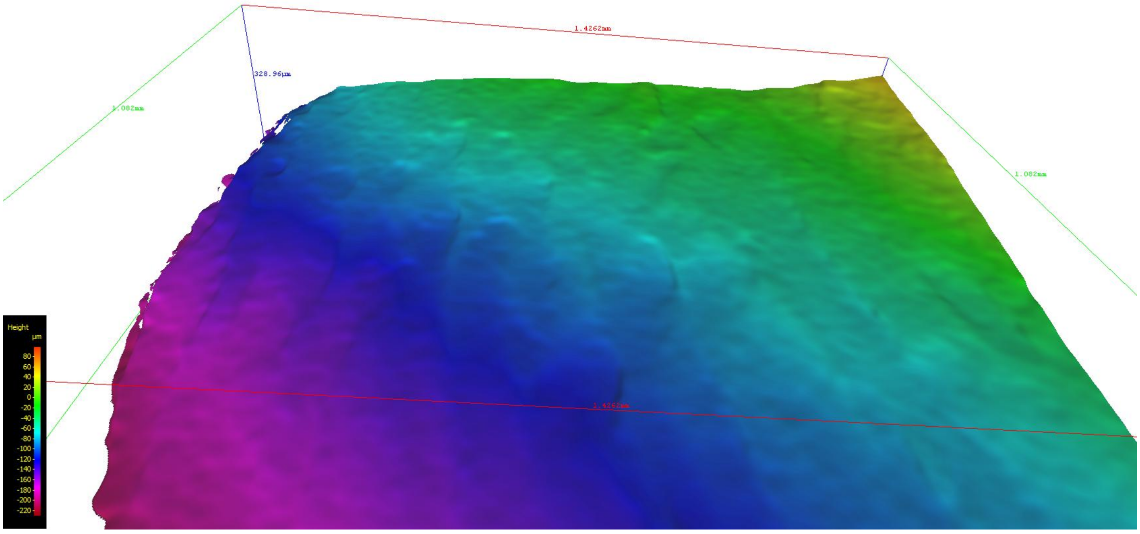

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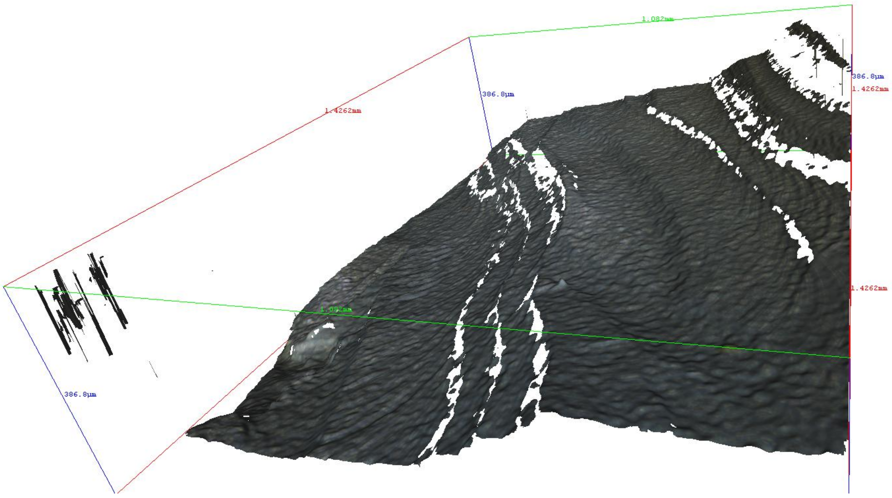

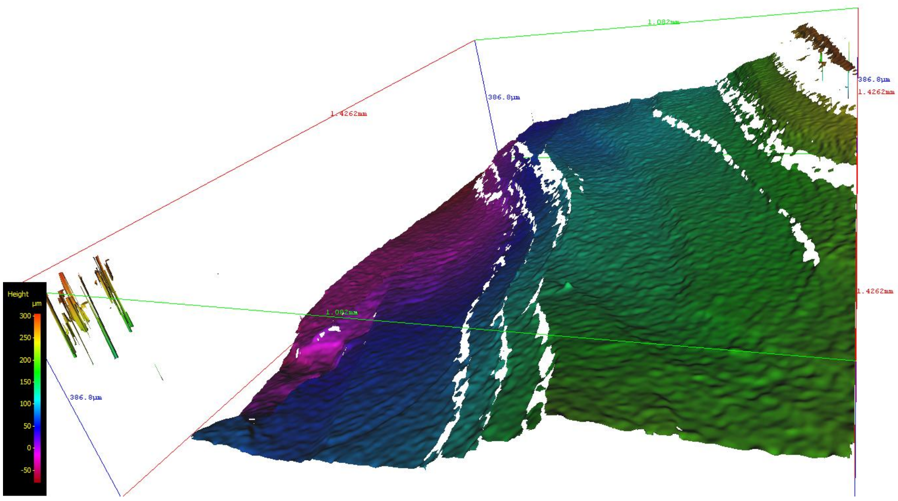

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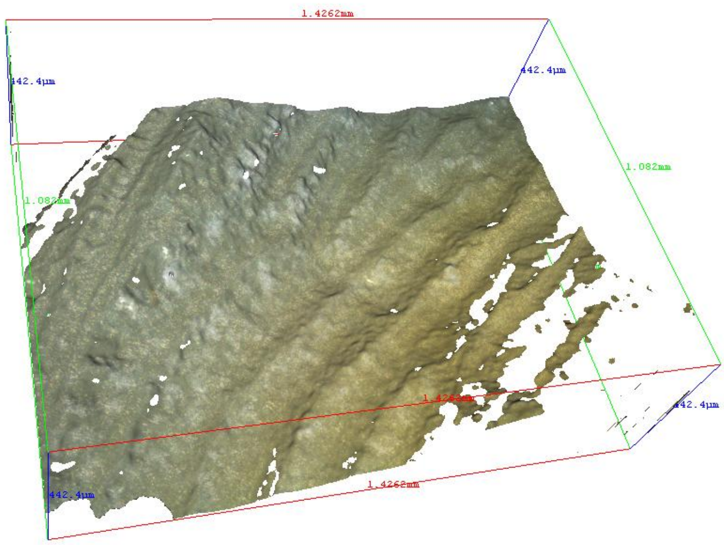

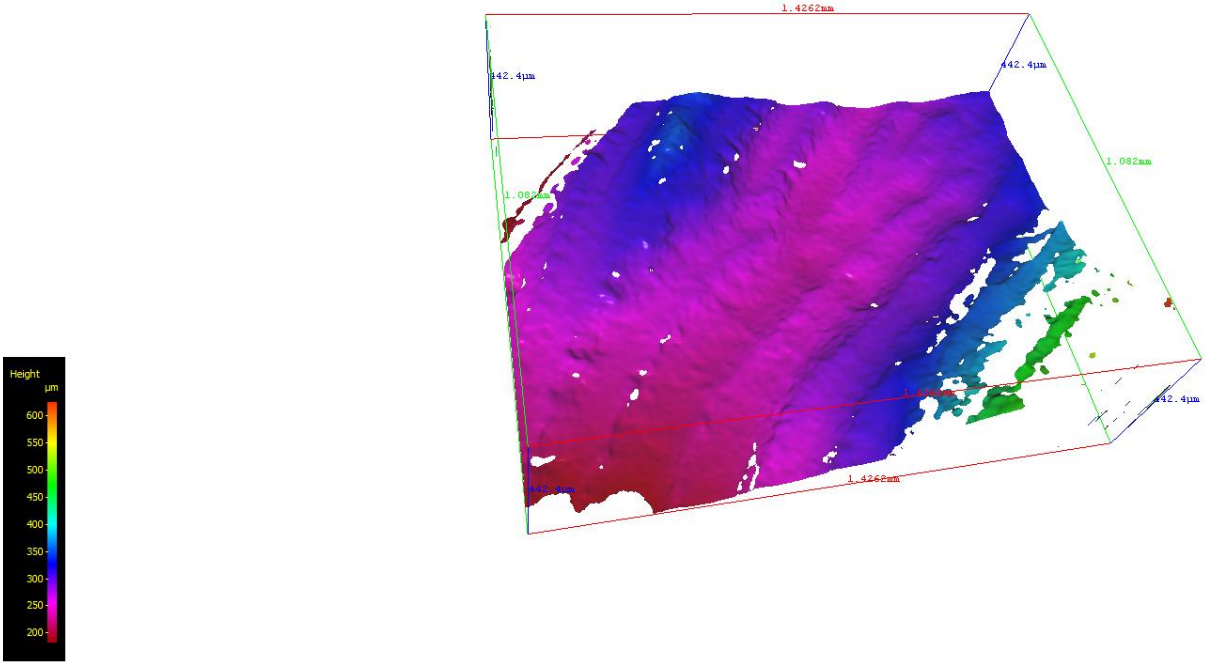

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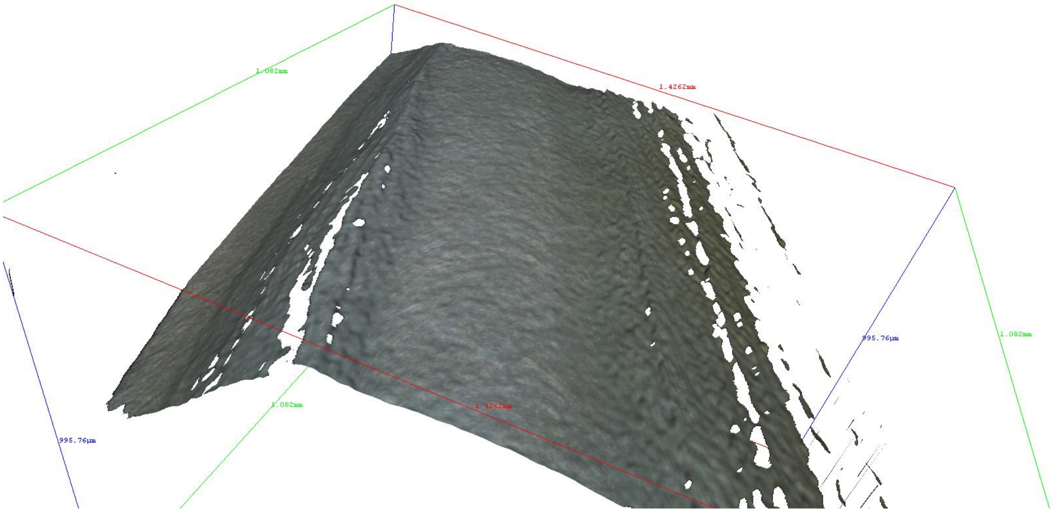

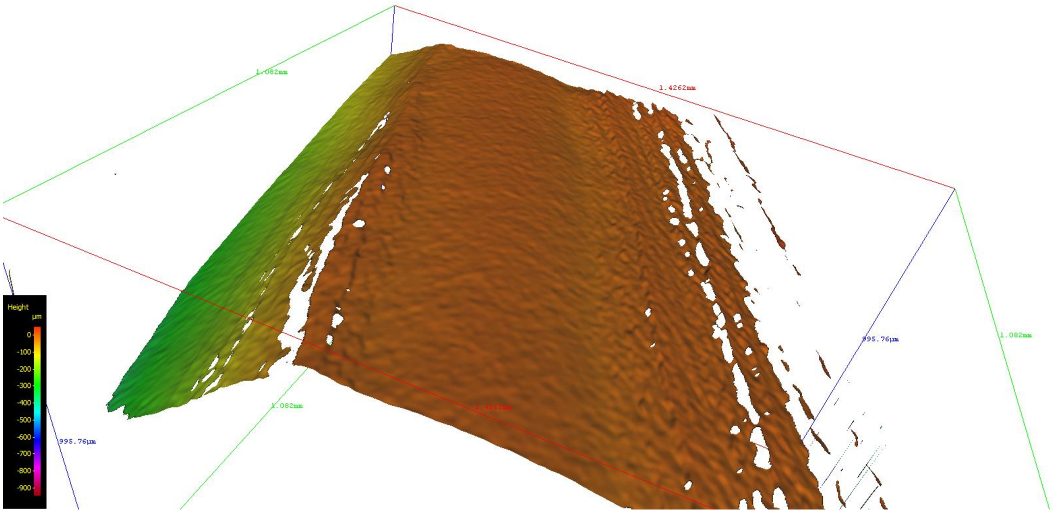

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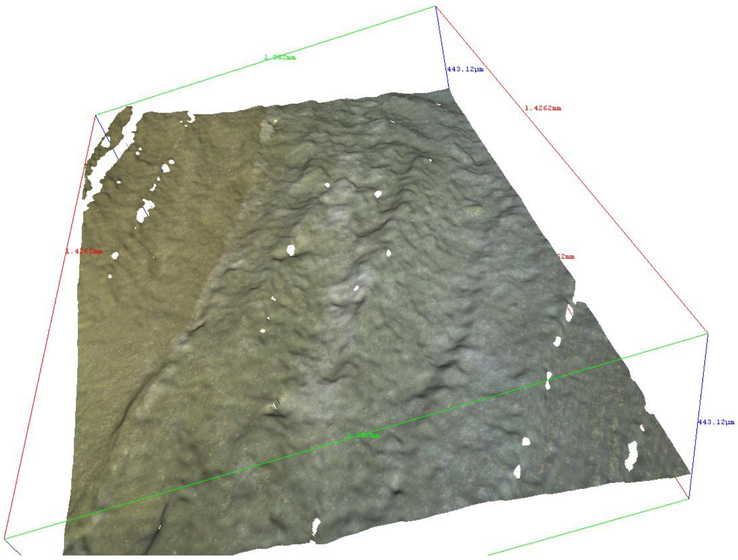

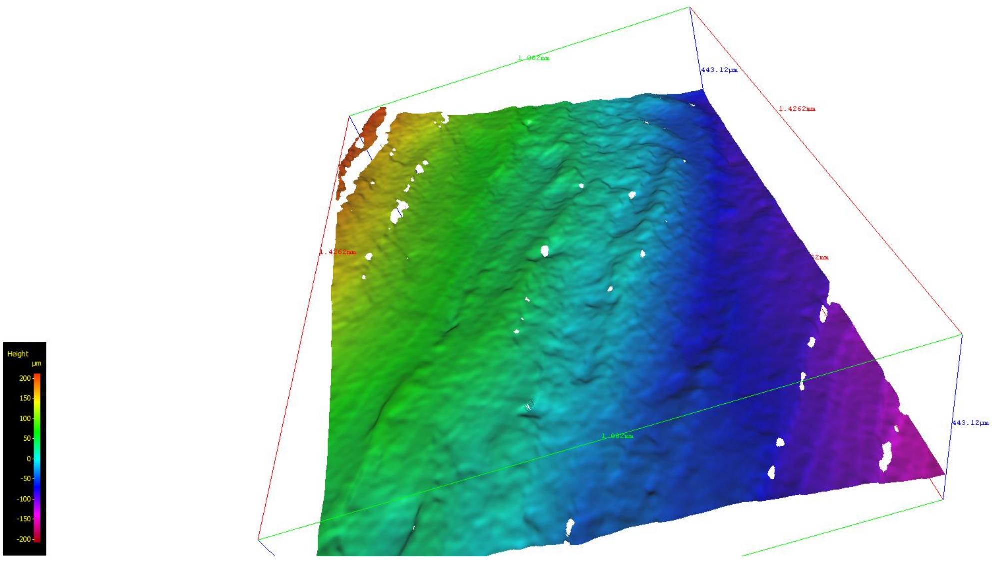

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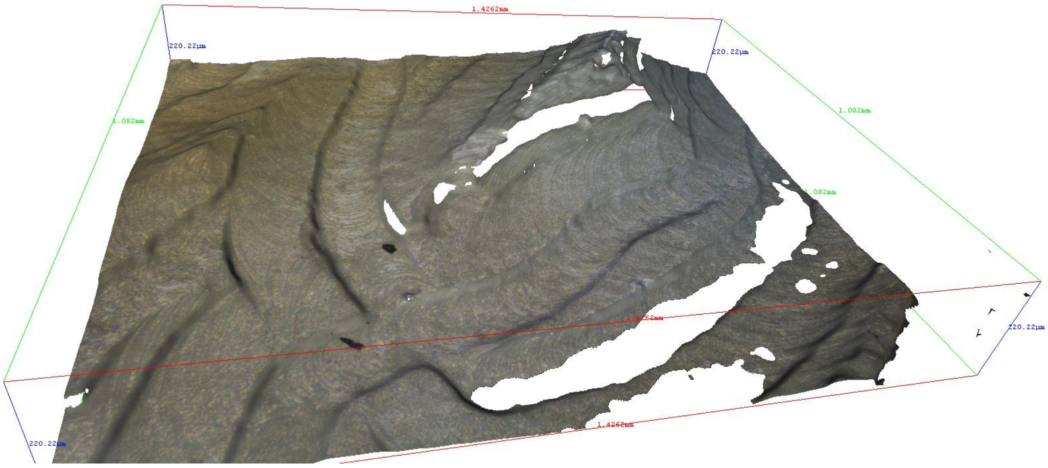

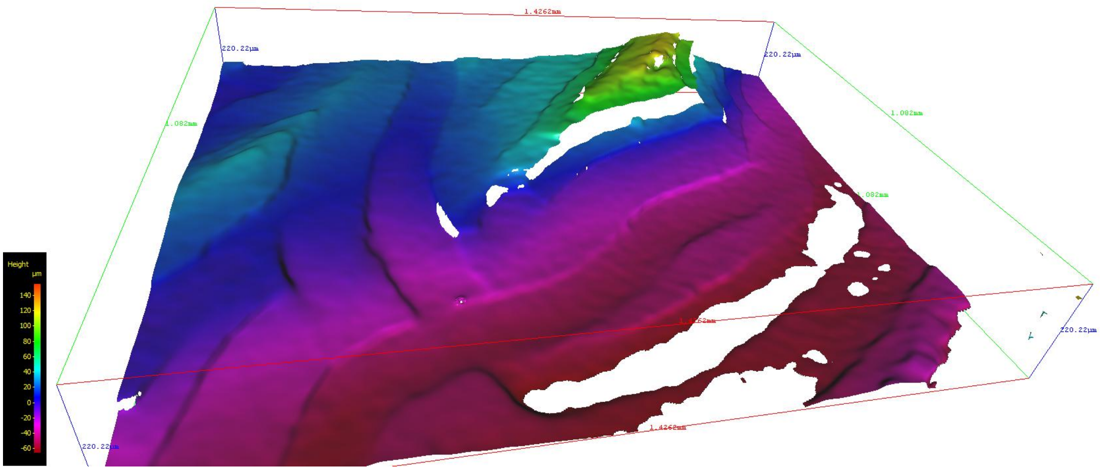

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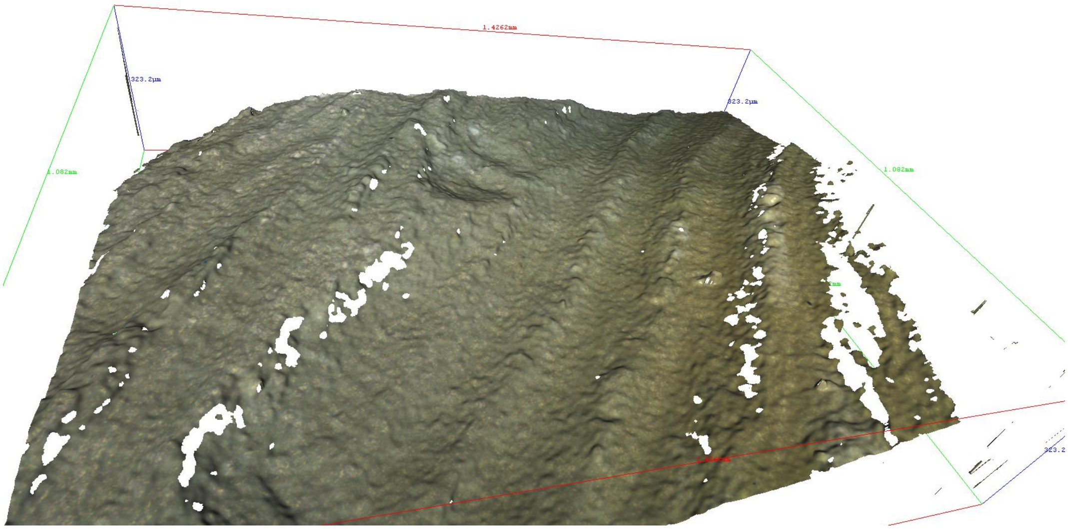

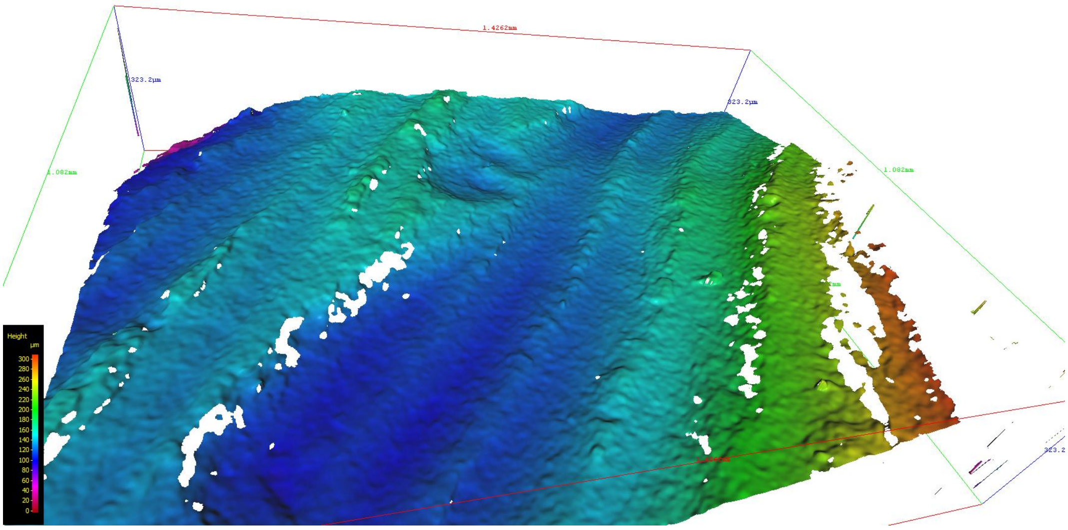

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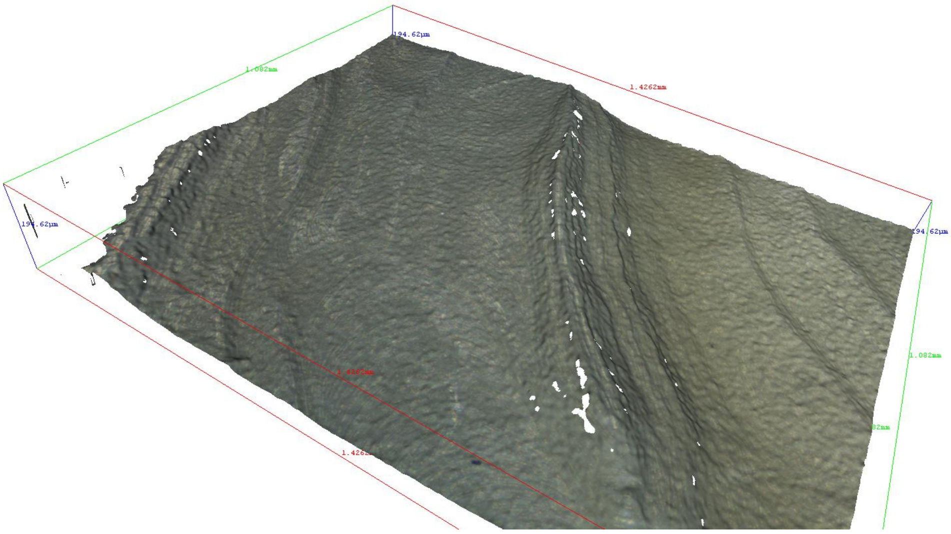

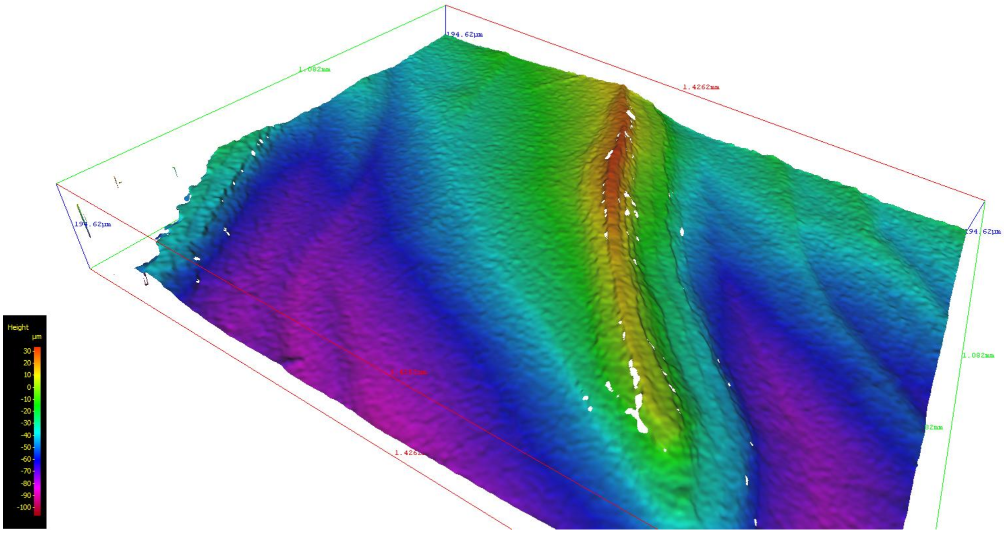

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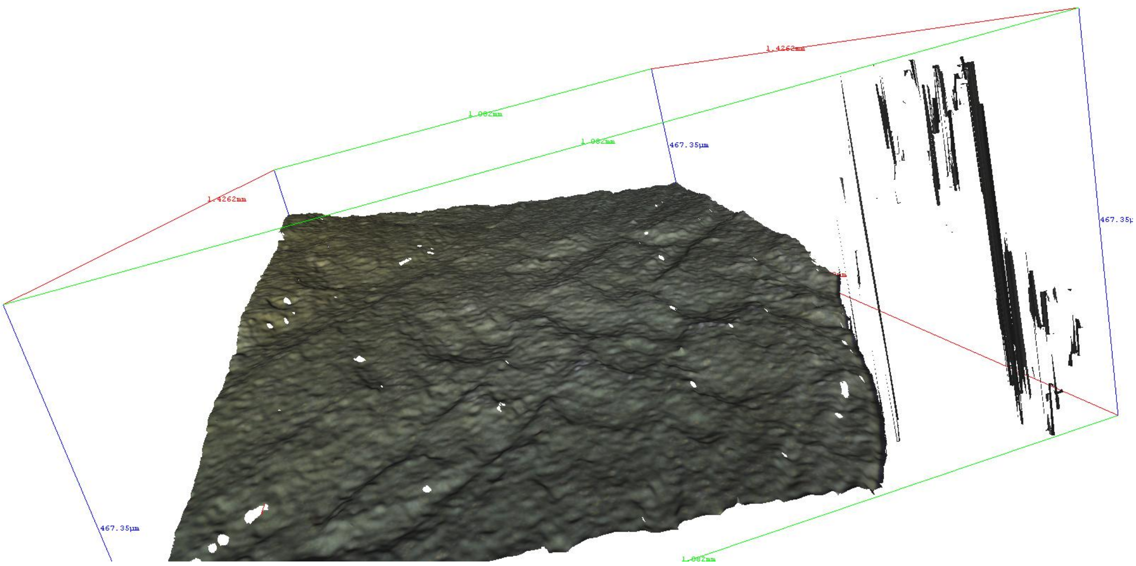

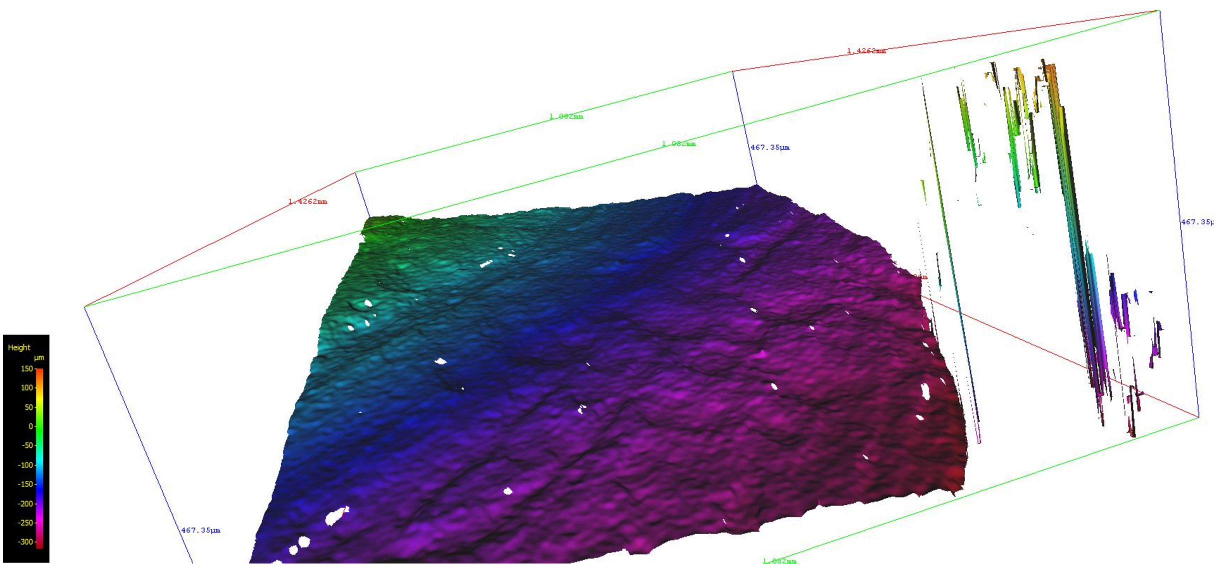

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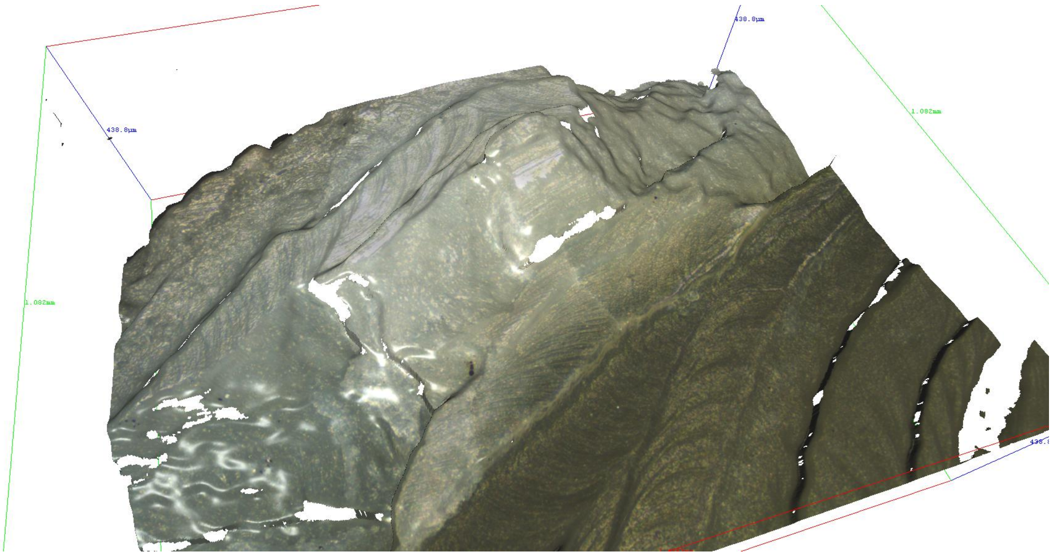

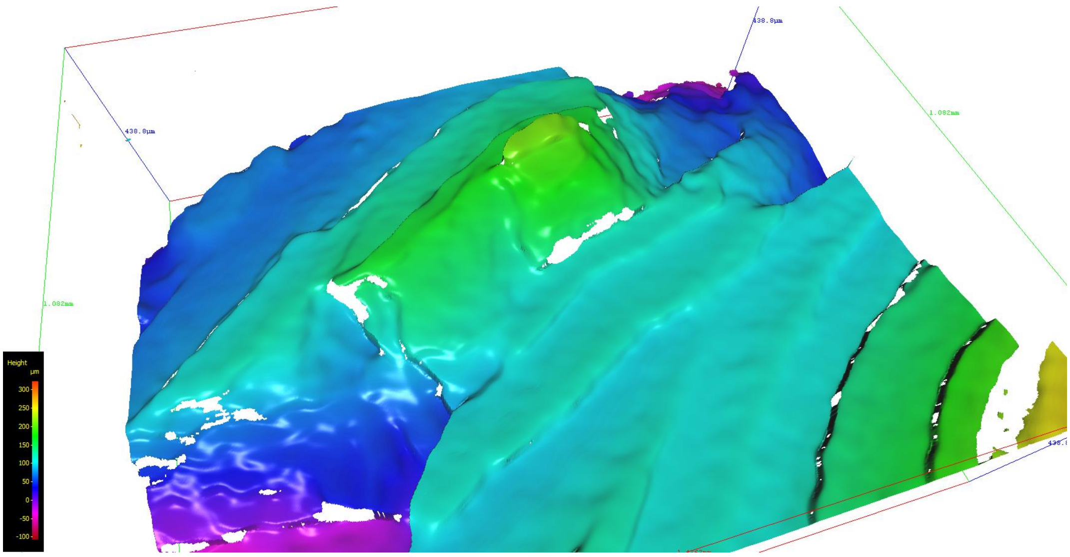

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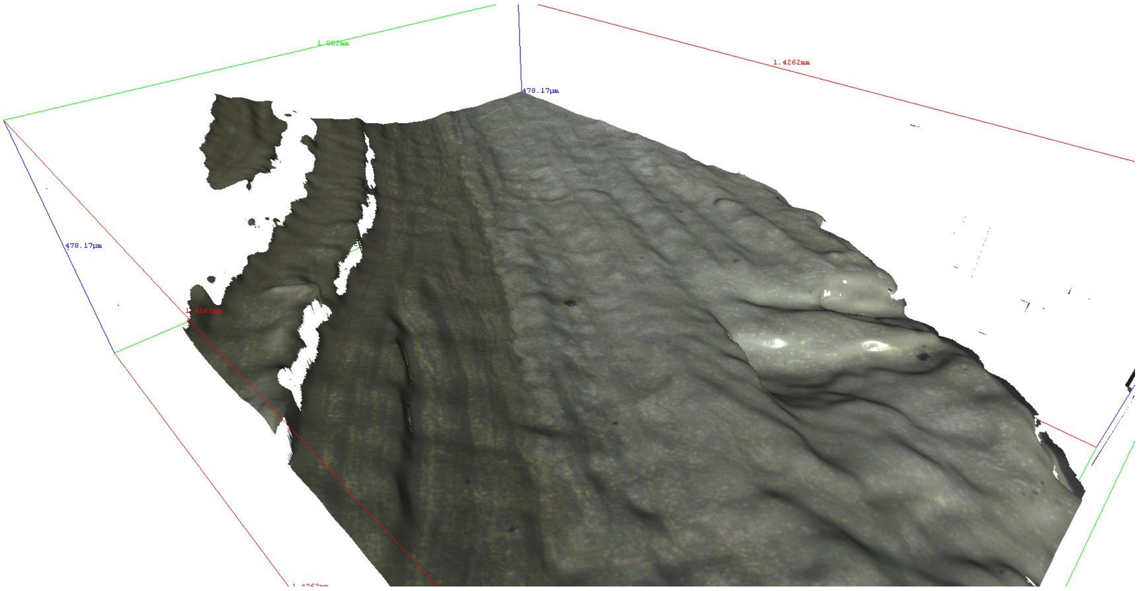

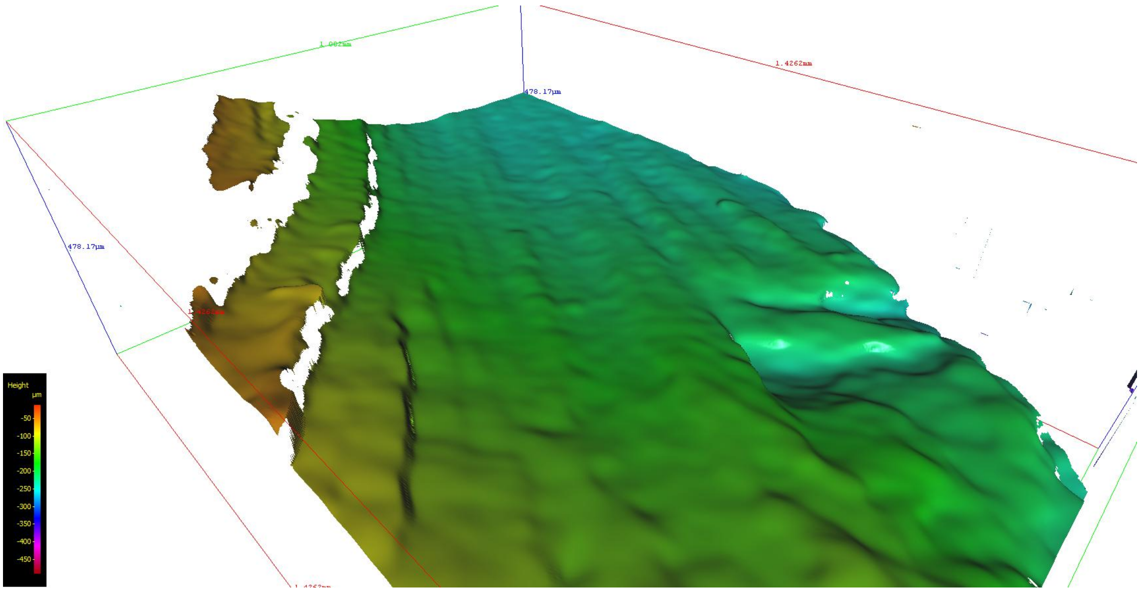

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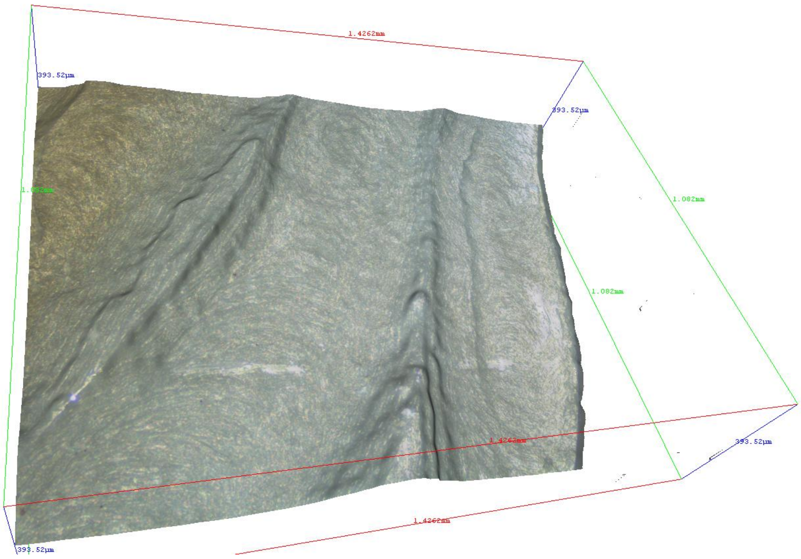

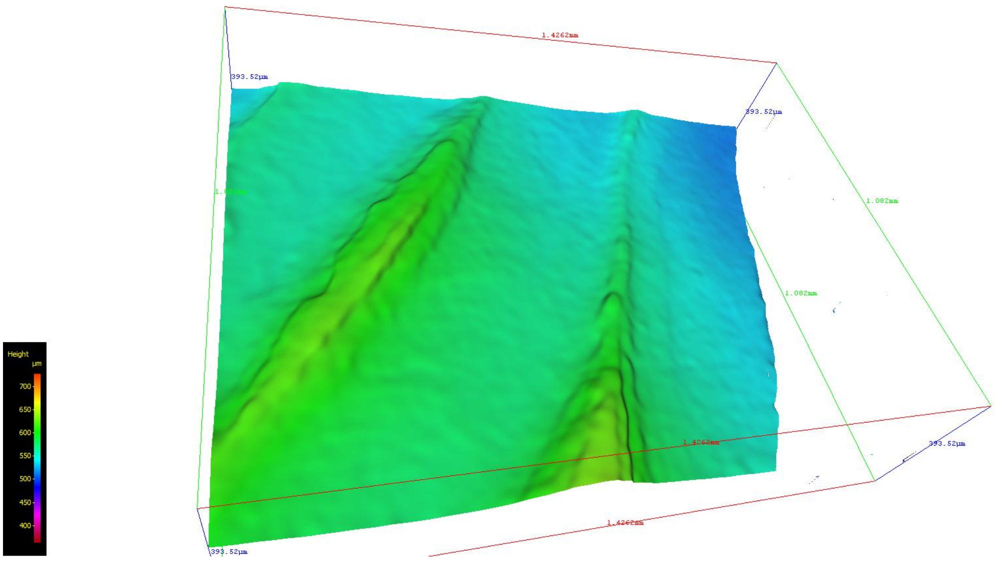

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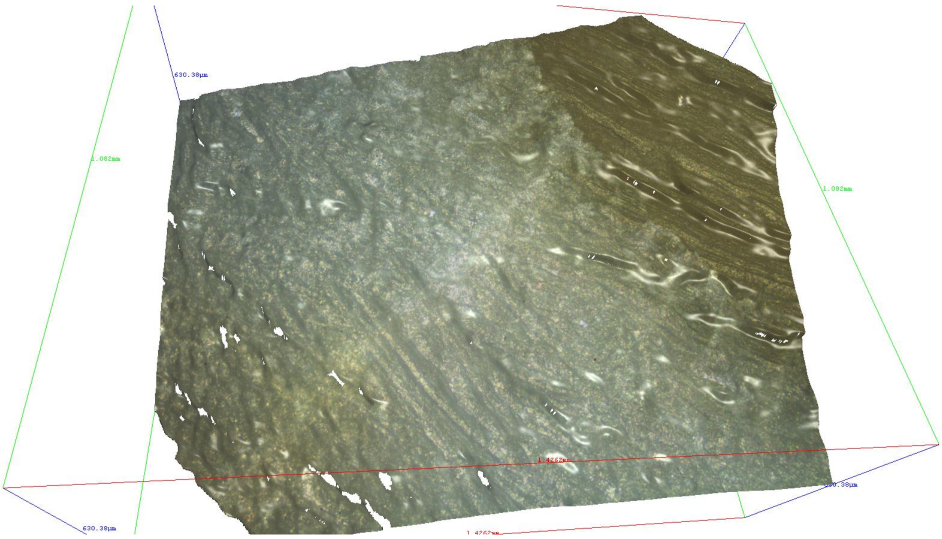

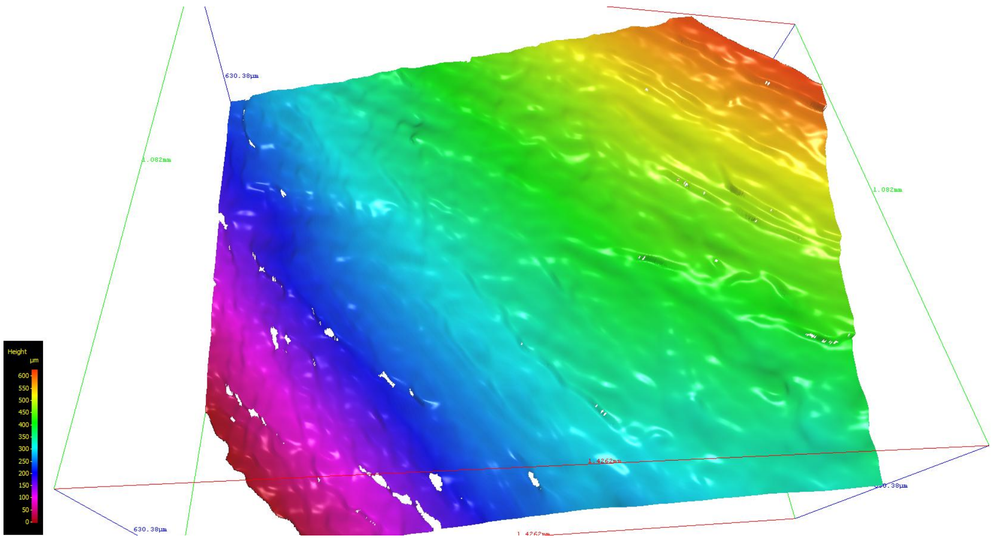

Appendix 2 – Photographic records

Sample 1

Sample 2

Sample 3

Sample 4

Sample 5