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APPLICATION NOTE

Optical Profilometry Roughness Measurements on Machined Parts

Surface topography affects the appearance, functionality, and performance of a material, which makes it a critical consideration for materials science in a wide range of industries. For example, on a macroscopic scale topography can dictate if a surface appears shiny or matte; or it can determine if a mechanical seal is airtight or if it leaks. In particular, precision machining often requires stringent control of surface topography to meet industry-driven roughness specifications or standards. Common machining processes include milling, grinding, lapping, reaming, and turning. These processes utilize different machines and approaches to controllably remove material from a piece of raw material and create a part with the desired shape, finish and function.

Characterizing surface topography is possible with a technique called Optical Profilometry (OP), which is also known as White Light Interferometry (WLI). OP provides 2D and 3D images of surfaces, critical dimension measurements, and roughness statistics from areas from 2.3mm × 1.7mm[a] in size, down to 60µm × 50µm. The technique offers vertical resolutions of 0.01nm (i.e. 0.1Å) or 6nm and lateral resolutions as low as 490nm, depending on the application and the optics used. During an OP measurement, an interferometric objective creates an interference pattern from the sample surface and then different aspects of the interference pattern (e.g. intensity or phase shift) are converted to height information.

In this application note, OP is used to measure the roughness of reference coupons (Flexbar, Islandia, New York, USA) that were machined in various ways to different roughness specifications. Additionally, the surface finish of a vacuum flange is determined as an example of characterizing the topography of an unknown sample.

EXPERIMENTAL:

OP images were collected using a ContourGT-X8 optical profilometer (Bruker Corporation, Tucson, Arizona, USA). One 2.3mm × 1.7mm area was imaged near the center of each machined piece. Top views and perspective (3-D) views of these areas are shown in Figures 2-11. The topography differences of these images are presented in colors where purple is low and red is high. Average Roughness (R_a)[b,c] values were calculated from the height information in the images and the results are summarized in Table 1.

RESULTS AND DISCUSSION:

Several reference metal coupons and a vacuum flange, shown in Figure 1, were analyzed by OP (Figures 2-11). The Average

Table 1. Roughness Results

Sample ID	*Measured R_a* (µm)
Grinding 0.1µm R_a	*0.103*
Grinding 0.8µm R_a	*0.803*
Lapping 0.2µm R_a	*0.198*
Reaming 0.8µm R_a	*0.796*
Turning 0.8µm R_a	*0.812*
Turning 6.3µm R_a	*6.33*
Horizontal Milling 0.8µm R_a	*0.818*
Vertical Milling 0.8µm R_a	*0.747*
Vacuum flange-face	*0.614*
Vacuum flange -seal	*0.219*

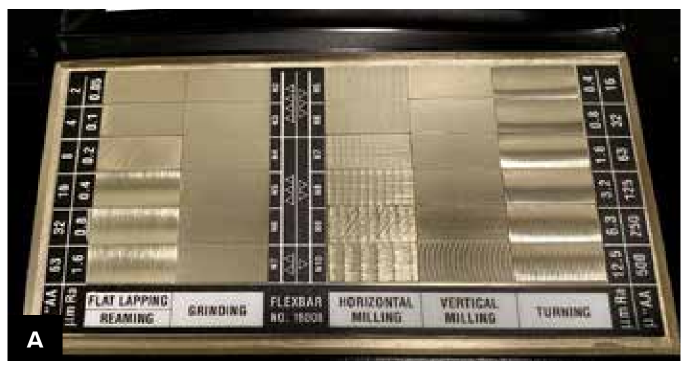

Figure 1: Photographs of (A) the reference metal coupons (Flexbar, Islandia, New York, USA) and (B) the vacuum flange

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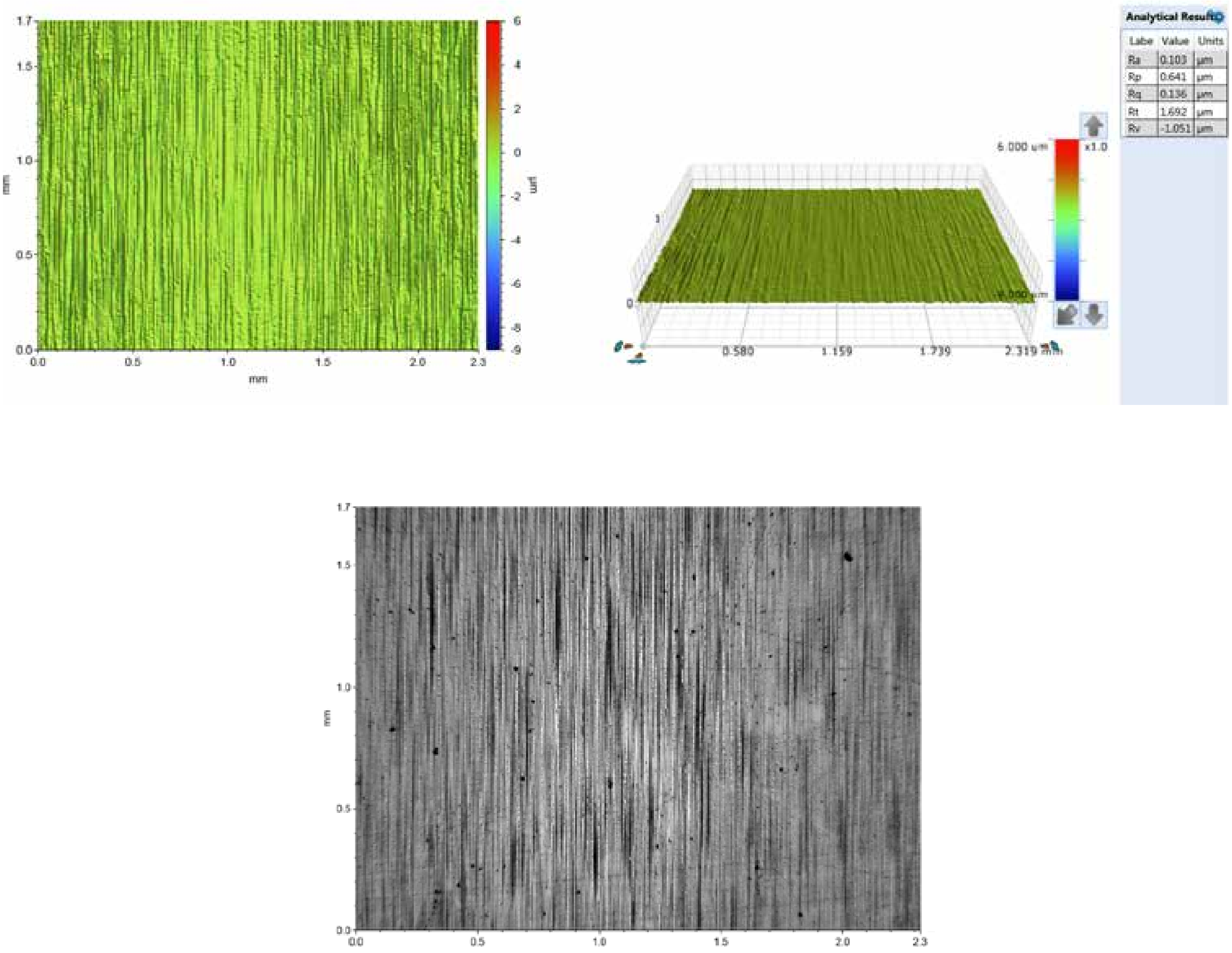

Figure 2: Grinding, 0.1µm R_a

Roughness (R_a) values for these samples were calculated and the results are summarized in Table 1. The measured R_a values for the reference coupons had excellent correlation with the supplied values, ranging from 0.1µm to 6.3µm. The 2D and 3D images showed qualitatively that the topographical appearances of the surfaces differed for the various types of machining. For example, the texture of the turning and milling surfaces had strong directionality, whereas the texture of the lapped sample was more isotropic. The surface texture on the vacuum flange face indicated it had likely been milled to an R_a of around 0.6µm (Figure 10) and the sealing surface was smoother with an R_a of 0.2µm (Figure 11). This demonstrates that OP can be used to determine the likely type of machining used and to determine the roughness on unknown samples.

CONCLUSION

OP is a non-destructive, fast technique for generating 3D images of surfaces and measuring topography with very high vertical resolution. Another advantage is that OP instruments generally have versatile sample-handling capabilities. The Contour GT-X8 can accommodate samples that are up to 300mm in diameter, 100mm in height, and 100lbs in weight. Other instrument models also are available for unusually shaped parts. OP imaging is limited to relatively large areas (i.e. 60µm × 50µm or larger) and the best possible lateral resolution is 490nm. If smaller analysis areas and/or finer detail are required, other complementary techniques,

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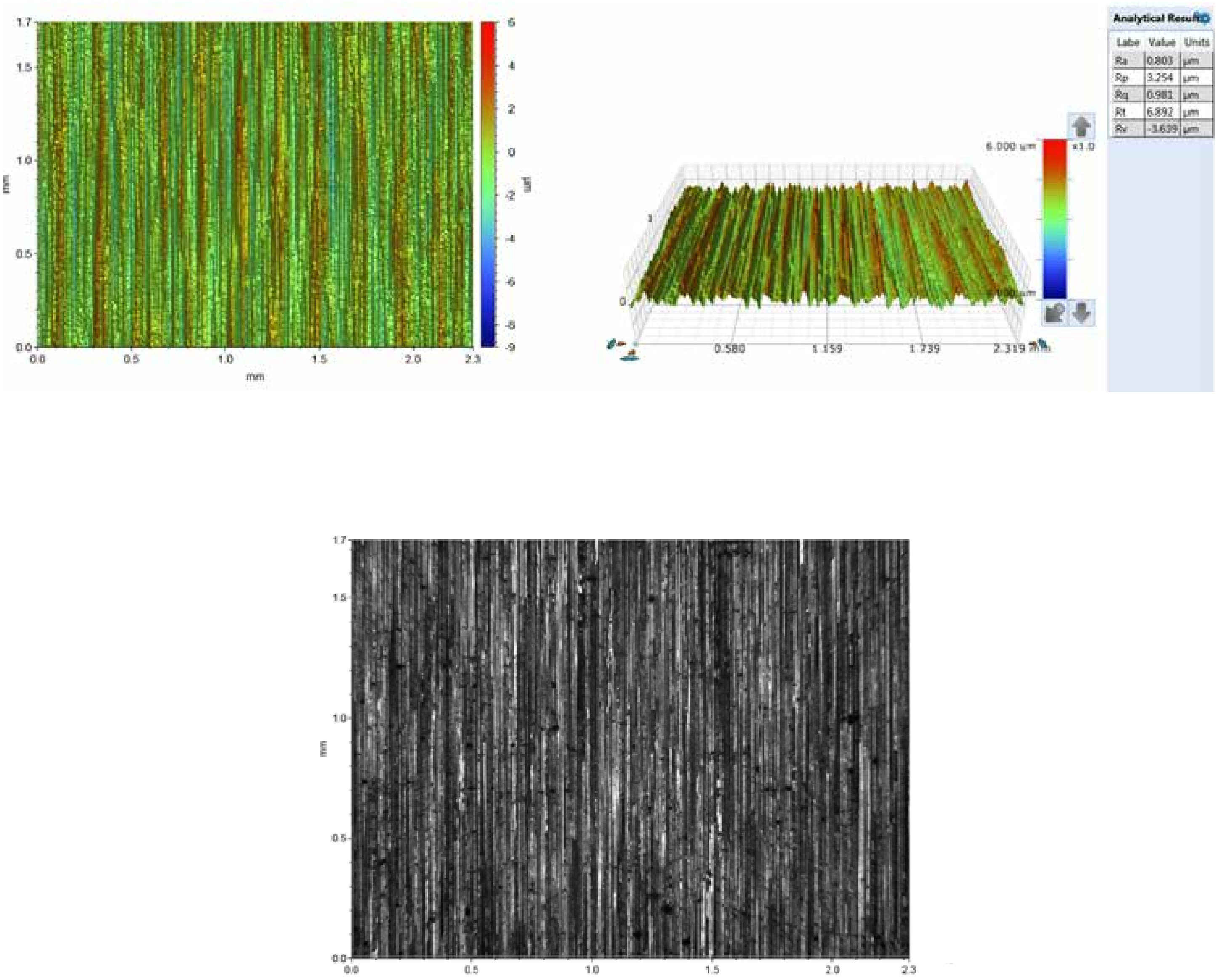

Figure 3: Grinding, 0.8µm R_a

such as Atomic Force Microscopy (AFM) and Scanning Electron Microscopy (SEM) are recommended. The excellent agreement between measured and known R_a values on several reference samples highlights the accuracy of OP and its usefulness for measuring roughness.

FOOTNOTES

a Even larger composite images sizes are possible by stitching together multiple individual images.

b Roughness Average (R_a) is the mean value of the surface relative to the center plane and is calculated using the formula: $R_a=(1/N)\Sigma|Zi|$

c It is possible to calculate many other roughness parameters. Some common parameters include (1) Root-Mean-Square Roughness, R_q; (2) Maximum Peak Height, R_p; (3) Maximum Valley Depth, R_v; (4) Maximum Height, R_t; (5) Roughness Skewness, R_{sk}; (6) Roughness Kurtosis, R_{ku}; (7) Fastest Decay Autocorrelation Function, S_{al}; (8) Texture Aspect Ratio, S_{tr}; and (9) Texture Direction of Surface, S_{td}.

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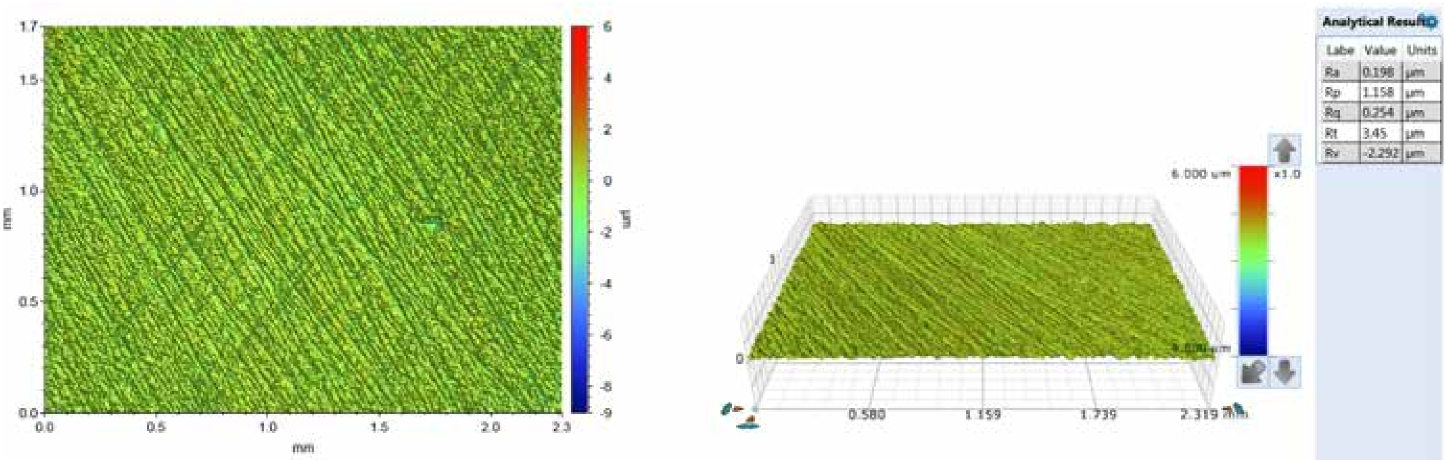

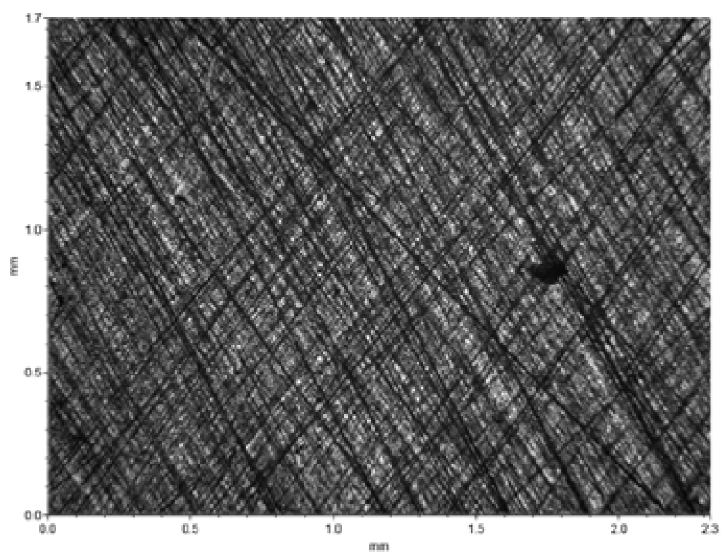

Figure 4: Flat lapping, 0.2µm R_a

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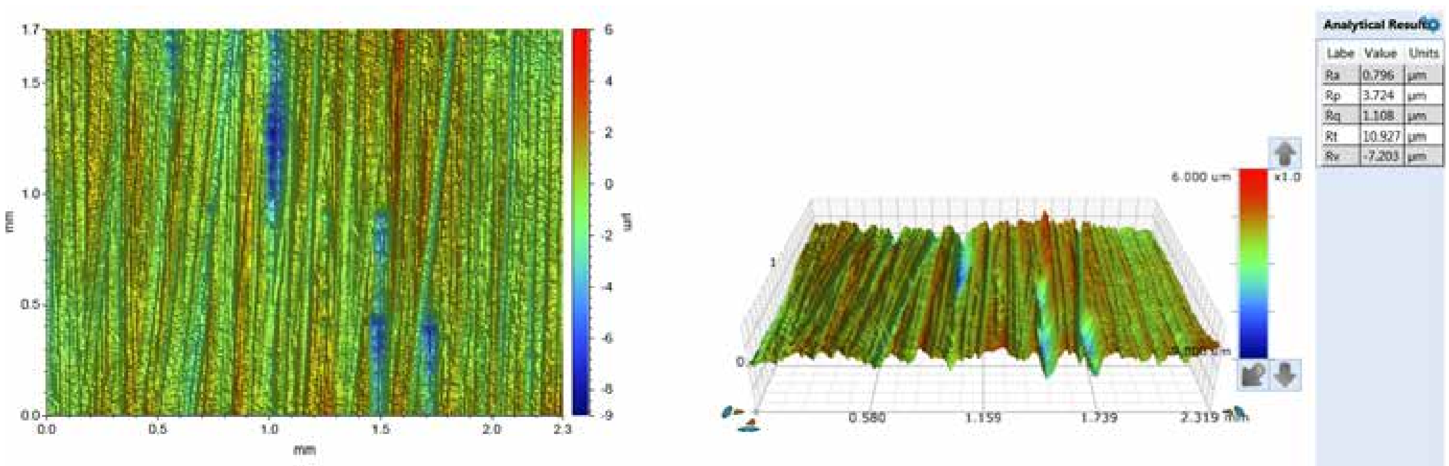

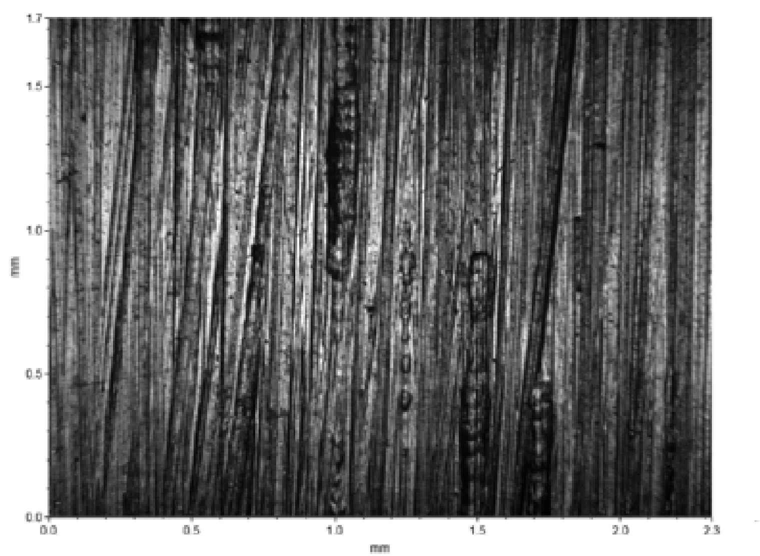

Figure 5: Reaming, 0.8μm R_a

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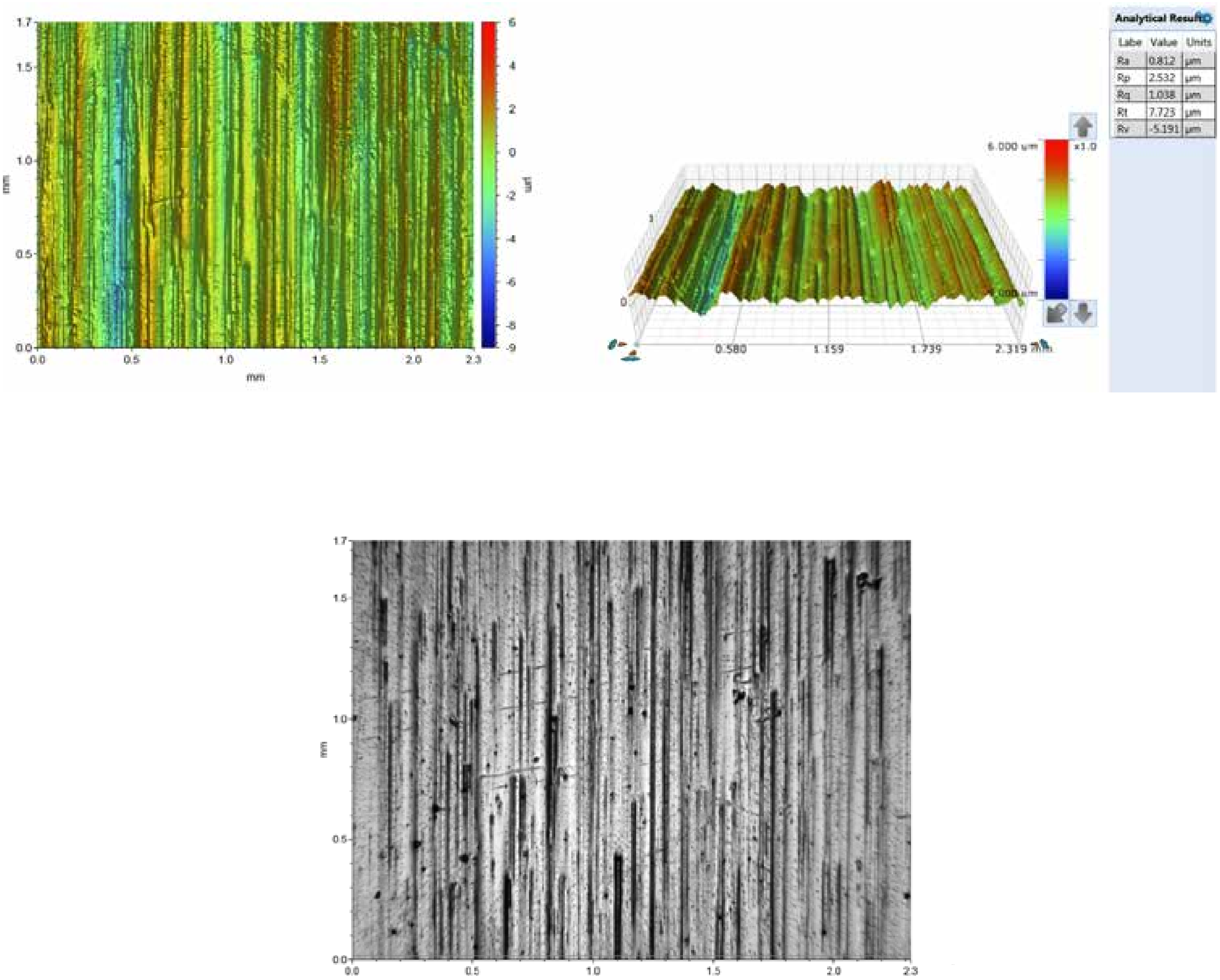

Figure 6: Turning, 0.8µm R_a

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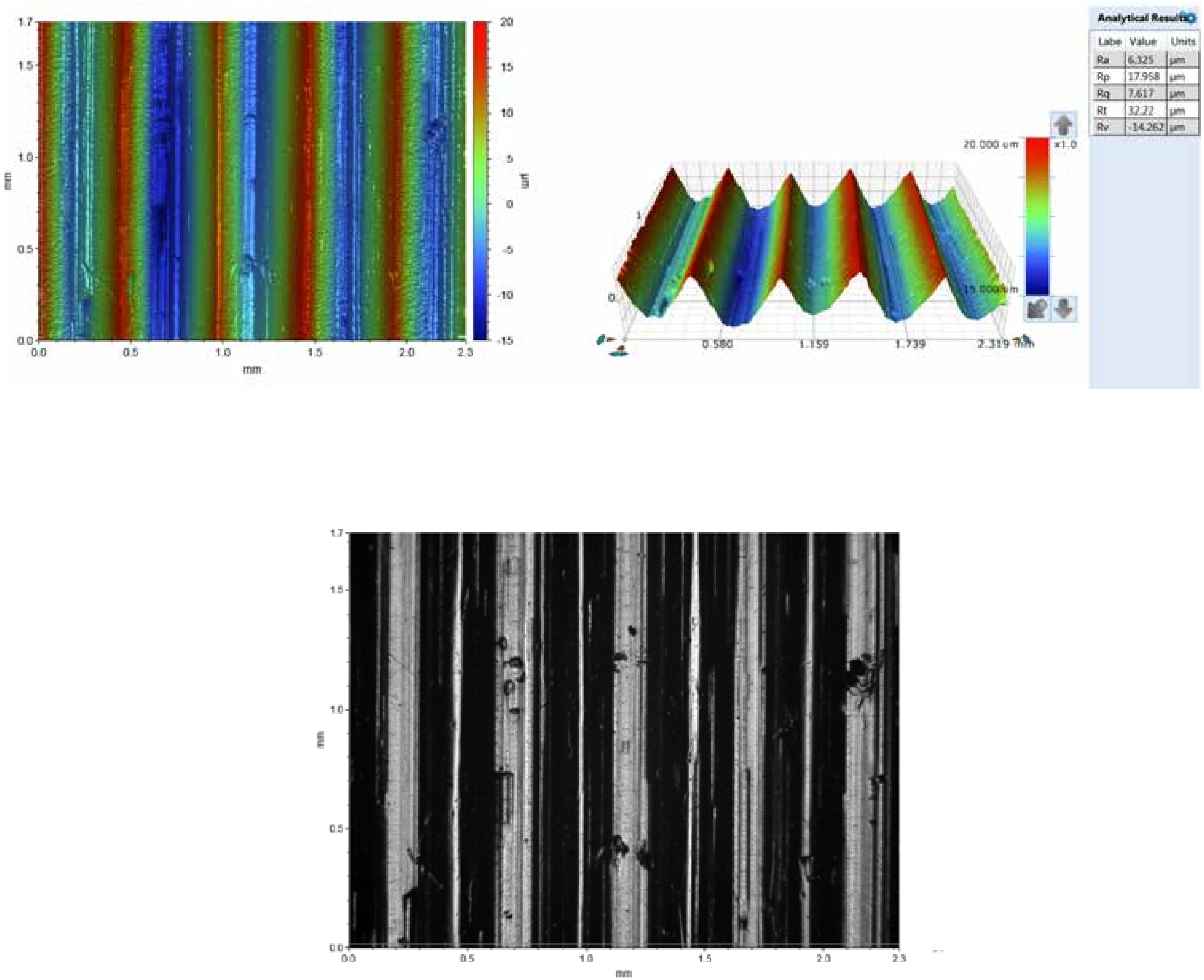

Figure 7: Turning, 6.3µm R_a

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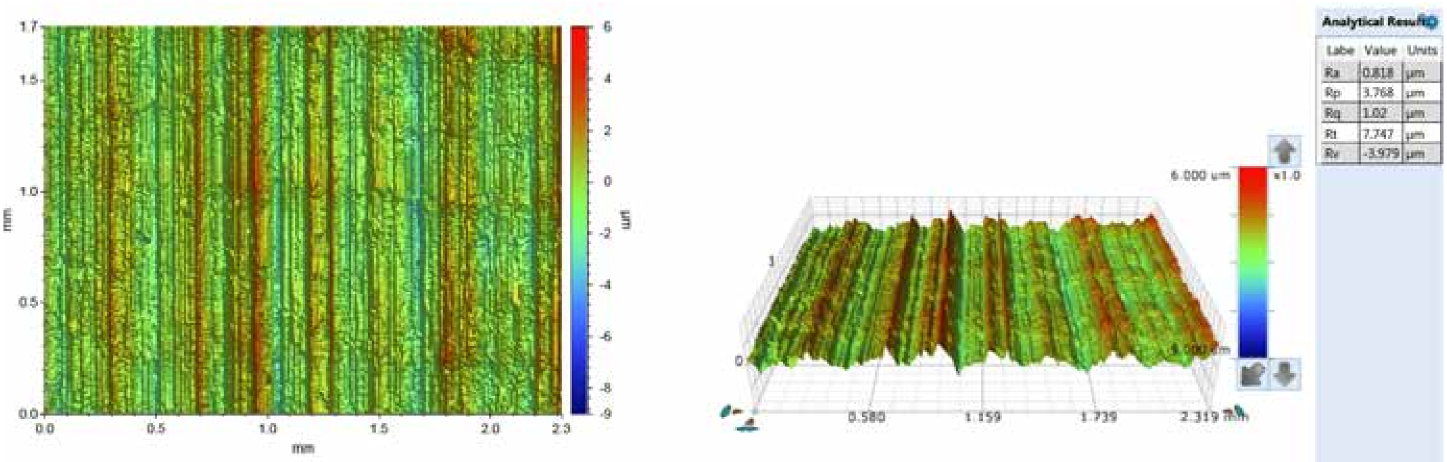

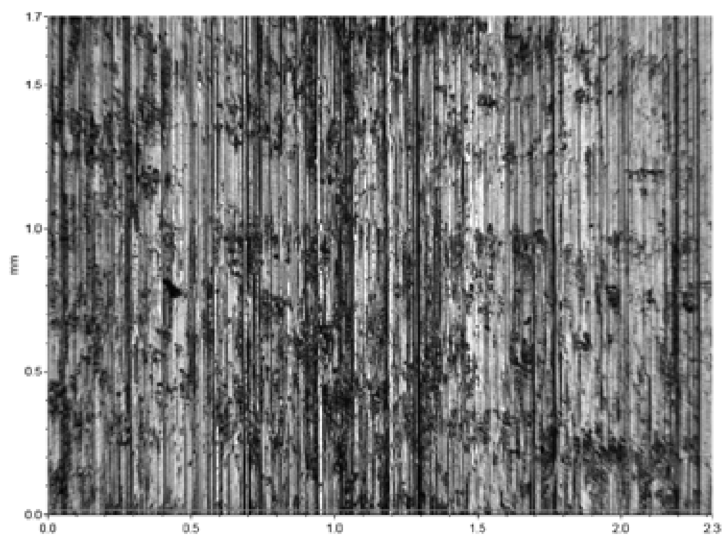

Figure 8: Horizontal Milling, 0.8μm R_a

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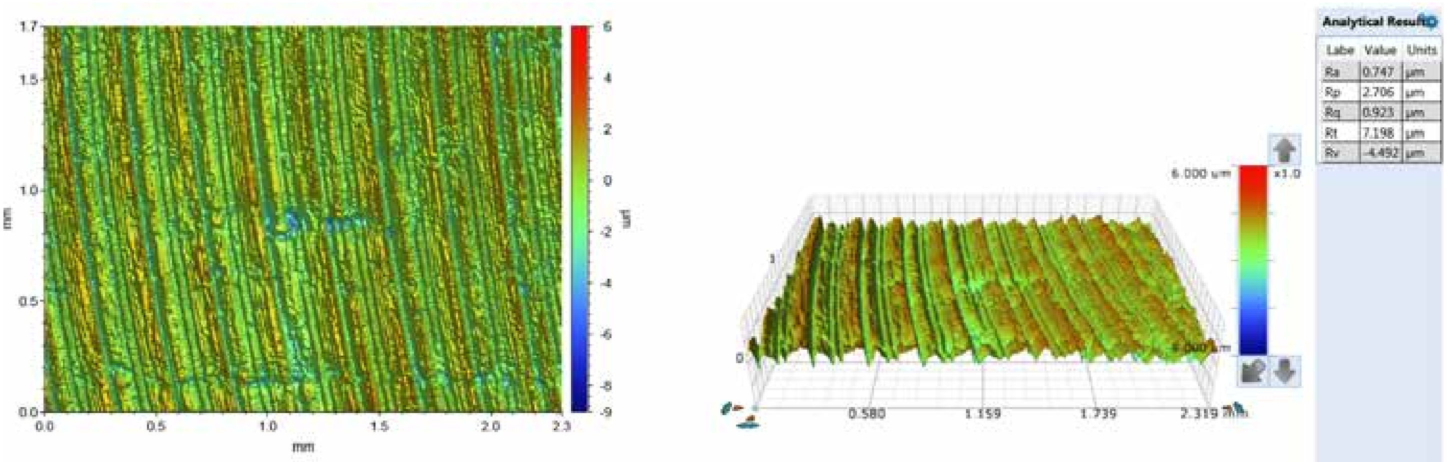

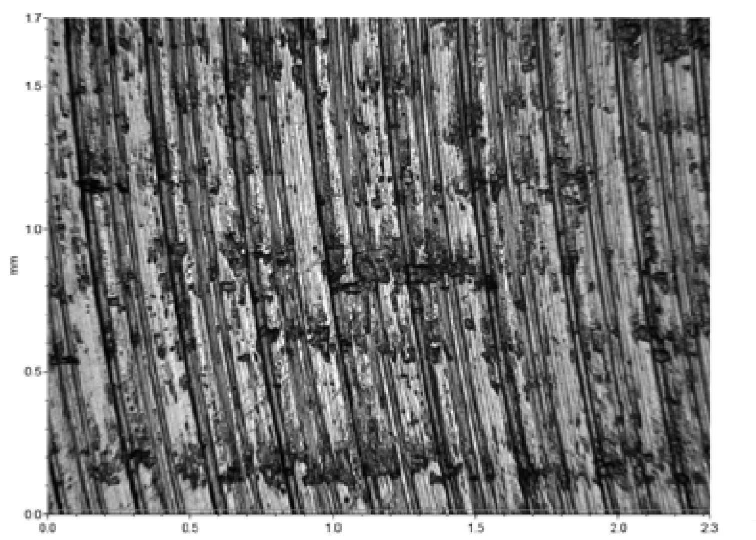

Figure 9: Vertical Milling, 0.8µm R_a

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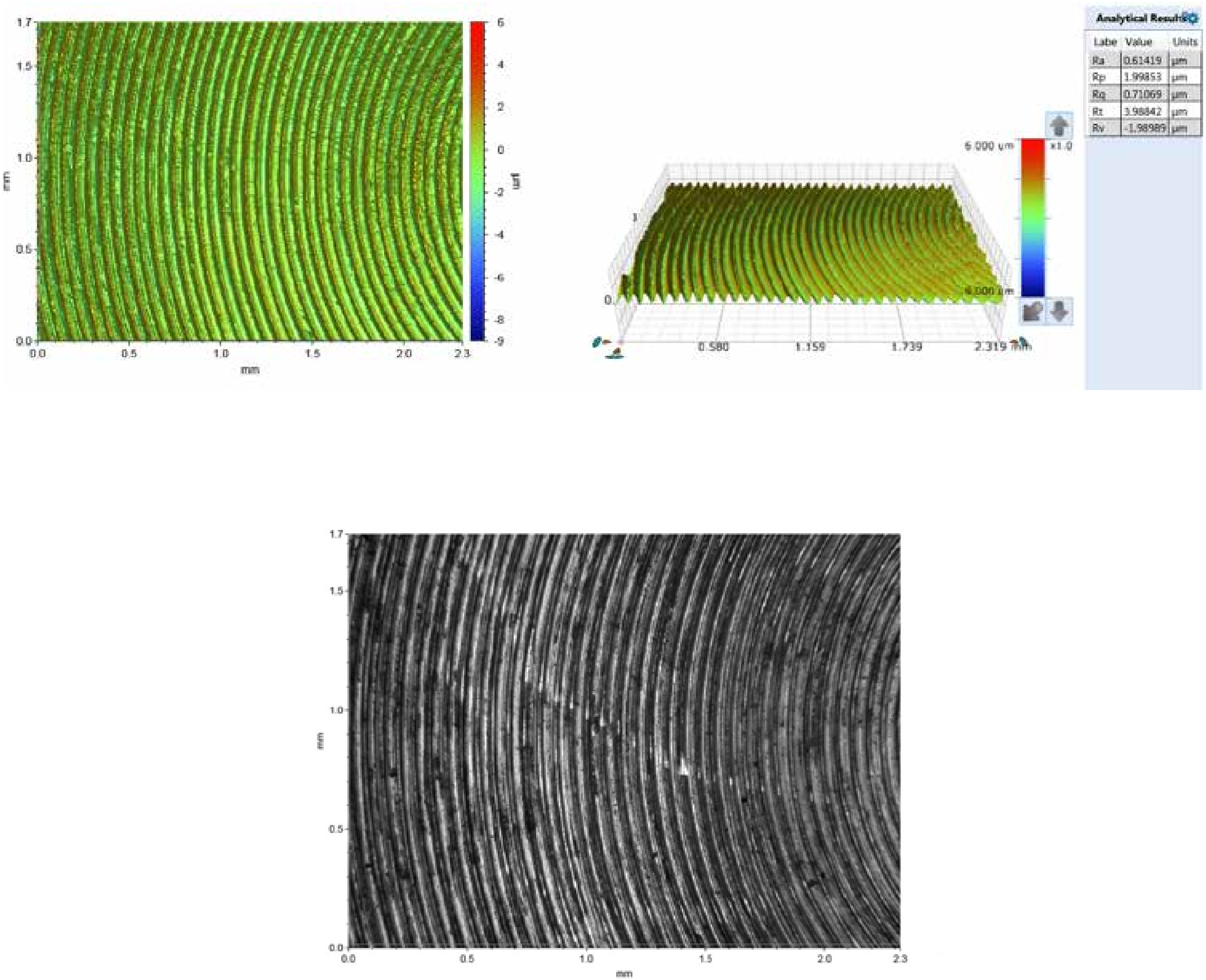

Figure 10: Flange face, 0.614µm R_a

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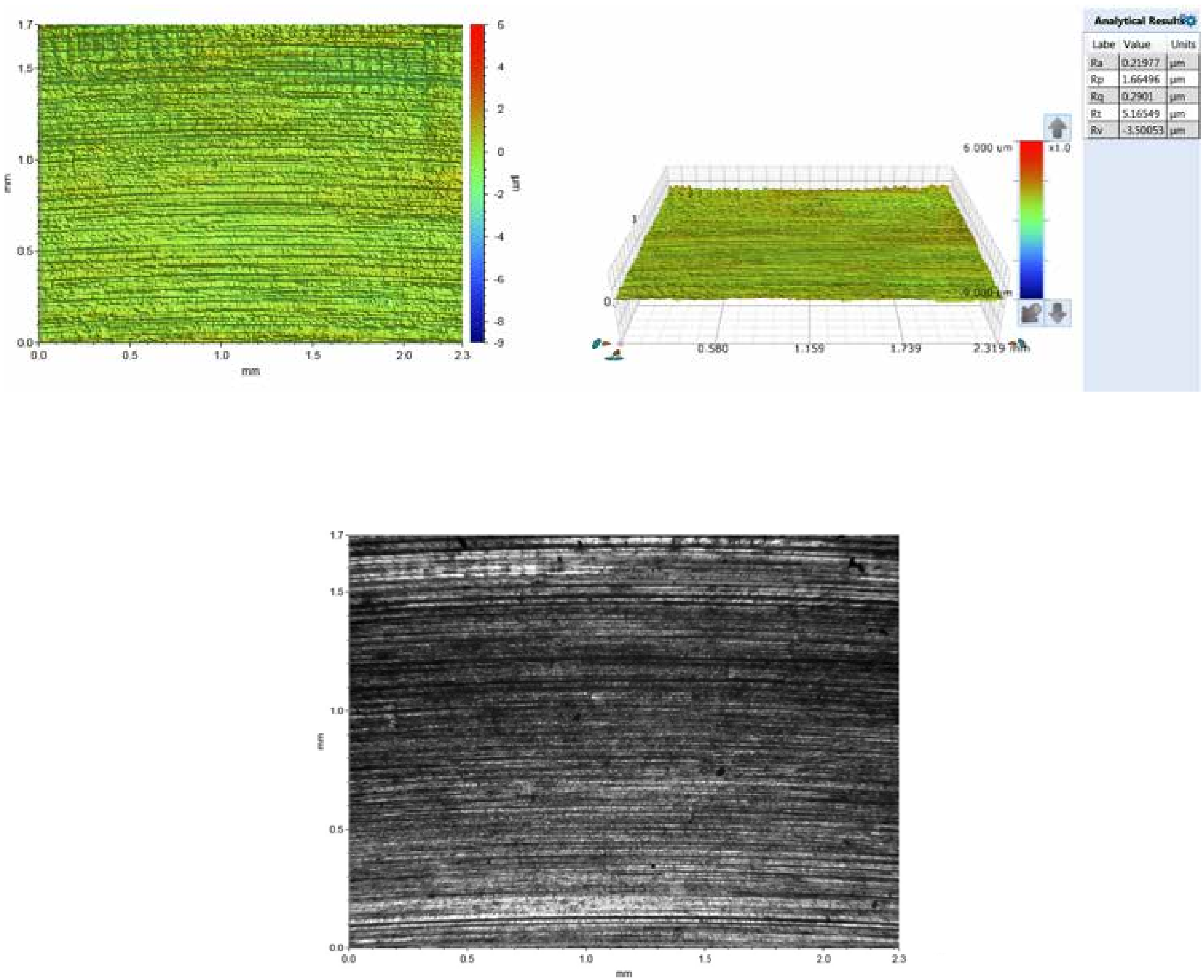

Figure 11: Flange sealing surface, 0.219µm R_a