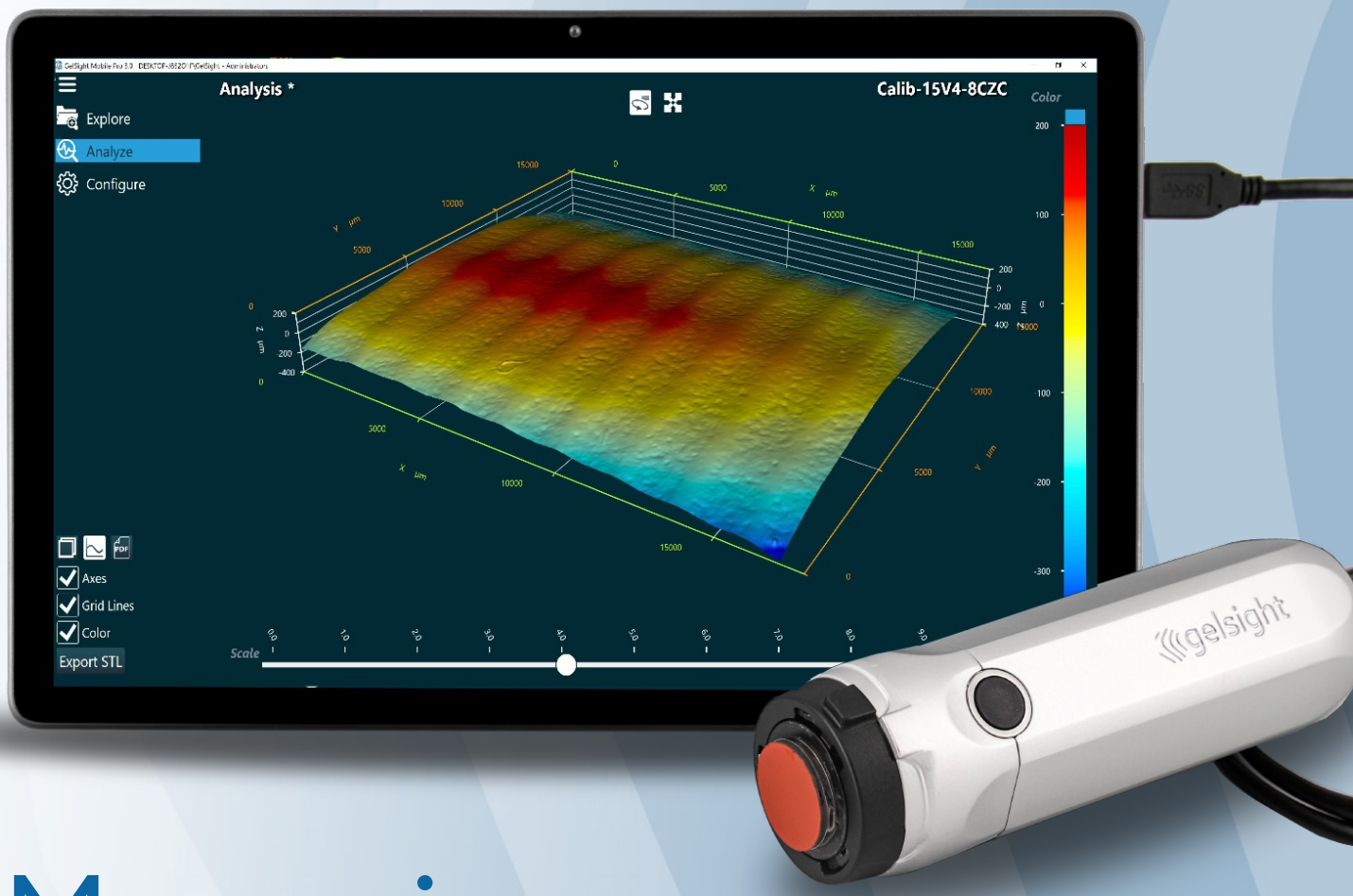
APPLICATION NOTE

September 2022

gelsight



Measuring Profile Roughness

Introduction

The characterization of surface roughness is critical to many facets of engineered products. The surface properties of the surfaces significantly impact friction, wear, fatigue, corrosion, electrical conductivity, and thermal conductivity of the materials. Designers are highly sensitive to surface finishes, which drive brand and quality perception of the end user. Assuring the engineering and industrial design goals of the product are met in production is the task of surface roughness inspection.

GelSight is pleased to announce the launch of a Profile Roughness analysis routine in GelSight Mobile 3.0. GelSight technology combines the advantages of contact and vision measurement while eliminating the risks of surface damage created by dragging a stylus across a surface or the challenges of contrast, reflectivity and long set up times of traditional non-contact computer vision systems. GelSight can be used to capture the roughness (Ra, Rz, and Rt) of a surface in-situ, with no need to create a sample or wait for lab results. No fixturing is required, and there is no risk of damage to the surface that might occur with typical stylus techniques. In a single scan, five million data points are captured on a surface of 17x14mm in less than 100 milliseconds, with full 3D surface reconstruction in seconds. In a single analysis, up to 21 profilometer measurements are captured at the same time, with configurable orientations and spacing. Results are quick and easy to share, and all measurements are compliant with the following industry standards: ISO 4287:1997, ISO 21920:2019 and ASME B46.1:2019.

Profile Roughness in GelSight Mobile

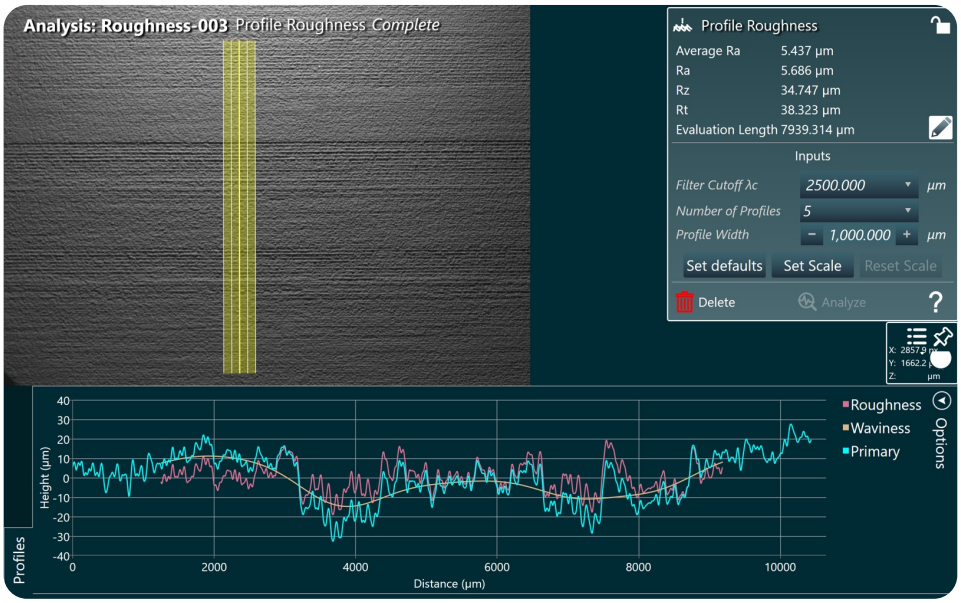


Figure 1: Profile Roughness analysis function in GelSight Mobile 3.0.

The GelSight Mobile software can be used to repeatably measure the roughness (Ra, Rz, and Rt) of a profile, as well as the average Ra of multiple profiles. The roughness data can be exported into a PDF or as a CSV, and the entire 3D model can be exported as an STL file.

Processing

In the GelSight Mobile software, a line is defined by the user and a profile is extracted from the measured surface. The user may select for a combined measurement of up to 21 profile lines, with the initial line acting as the center. The image below describes the processing pipeline applied to the extracted profile.

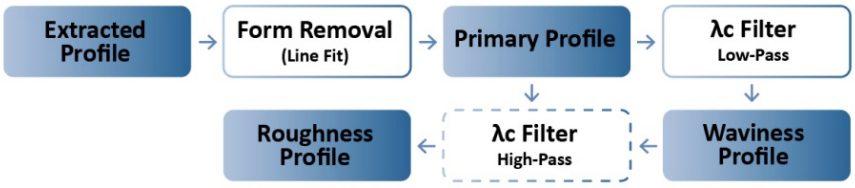


Figure 2: Profile processing pipeline

The length of the line, Ln, must be at least 4 * λc.
Filter cutoffs, λc, for Ra values default to:

Ra <=	0.02 um, λc = 0.08 mm, Ln >	0.40 mm
0.02 < Ra <=	0.1 um, λc = 0.25 mm, Ln >	1.25 mm
0.10 < Ra <=	2.0 um, λc = 0.80 mm, Ln >	4.00 mm
2.00 < Ra <=	10.0 um, λc = 2.50 mm, Ln >	12.50 mm

Figure 3: Recommended filter cutoff (ISO 4288-1996)

Filtering is an operation that removes wavelength content that is longer or shorter than a specified wavelength (cut-off). The recommended cut-off is based on the expected Ra measurement range. This is defined in the image below.

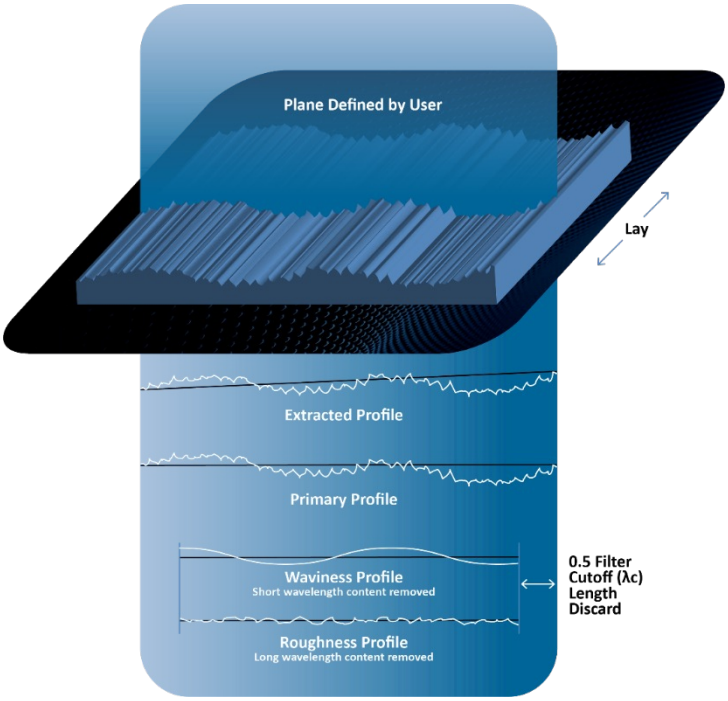


Figure 4: Profile extraction and filtering

The filter used in GelSight Mobile software is a Gaussian filter. The profile containing the wavelength content longer than the filter cut-off is known as the waviness profile. The profile containing the wavelength content shorter than the filter cut-off is known as the roughness profile.

The Gaussian filter implemented in the GelSight Mobile software requires that one-half filter cutoff length be discarded from each end of the roughness and waviness profiles.

Output Parameters

GelSight Mobile 3.0 currently computes and displays three surface texture parameters: Ra, Rz, and Rt. It will also display the Average Ra when using multiple profiles.

Ra – Average Roughness
Ra is computed as the arithmetic mean of the absolute ordinate values Z(x) within a sampling length.

$$Ra = \frac{1}{l}\int_0^l |Z(x)|\,dx$$

Standard	Description
ISO 4287: 1997 ISO 21920-2:2019 ASME B46.1:2019	The parameter is computed over the total length of the roughness profile.

Average Ra – Average Roughness
The 'Number of Profiles' and the 'Profile Width' inputs are used to define a zone in which 3-21 profiles can be extracted from the surface. The Ra parameter for each profile is computed and the average Ra is displayed. More information regarding Average Ra is described in 'Number of Profiles'.

Rz – Average Maximum Height of Profile

Standard	Description
ISO 4287: 1997 ISO 21920-2:2019 ASME B46.1:2019	The average of successive values of Rt calculated over each sampling length. In the image below, Rz is the average of Rt1 + Rt2 + Rt3 + Rt4 + Rt5.

Rt – Maximum Height of Profile

Standard	Description
ISO 4287: 1997 ISO 21920-2:2019 ASME B46.1:2019	The vertical distance between the highest and lowest points of the roughness profile within the entire length of the roughness profile.

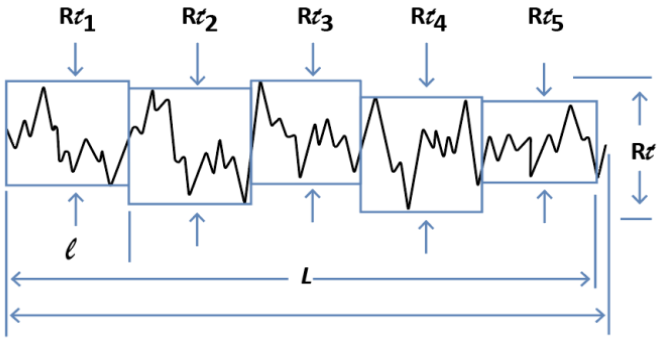


Figure 5: Rz and Rt parameters, where ℓ = sampling length (λc filter cutoff length) and L = evaluation length (n x ℓ). The evaluation length for non-averaged parameters is the total length of the filtered profile.

Number of Profiles

The Number of Profiles and Profile Width inputs work together to allow a series of a parallel profiles to be extracted from the surface. The Profile Width determines the width of a region around the User drawn line, and the Number of Profiles determines how many profiles are extracted from the surface.

For example, with the Profile Width input set to 5.0mm and the Number of Profiles input set to 5, five parallel lines will be used to extract the profiles used to compute the Averaged Ra parameter.

Figure 6: Profile Width and Number of Profiles

Scale Factor

If correlation is needed between GelSight and results provided from a different measurement system, a scale factor can be applied to the profile data. The 'Set Scale' feature can be considered a way to calibrate the results to an existing known value or standard. Click the 'Set Scale' button and enter the expected Ra value.

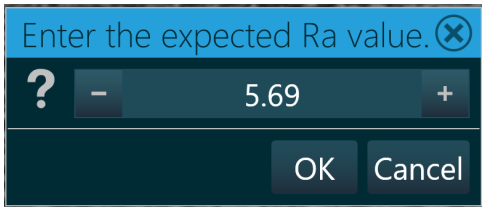


Figure 7: Set scale

The scale factor to compute the entered value of expected Ra will be automatically calculated and applied to all further Profile Roughness measurement results. To set the scaling factor back to the default value (1.0), click the 'Reset Scale' button.

Accuracy and Repeatability

The goal of the experiments performed is to characterize system accuracy and repeatability for measurements of this type. The GelSight Mobile Series 2 0.5x system was used with the Flexbar no. 16008 Calibrated Roughness Standard for all measurements in the study.

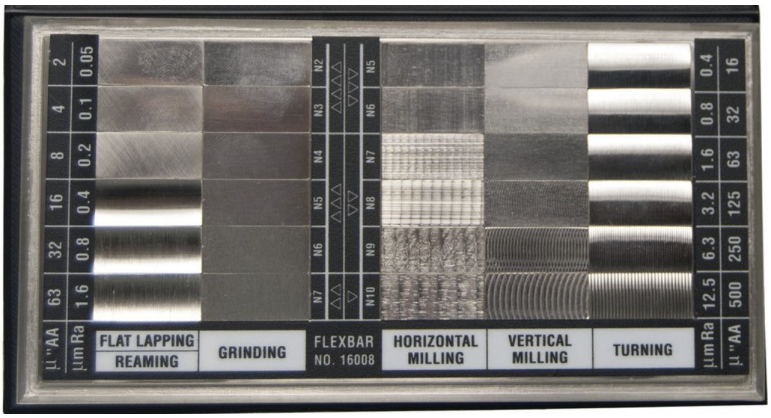


Figure 8: Flexbar Roughness Standard

Repeatability and Reproducibility Study

The Number of Profiles and Profile Width inputs work together to allow a series of a parallel profiles to be extracted from the surface. The Profile Width determines the width of a region around the User drawn line, and the Number of Profiles determines how many profiles are extracted from the surface.

Ten patches on the Flexbar plate were selected as part of the study. The patches and their standard Ra values as measured by a contact profilometer with a 5μm stylus are listed in the table below.

Grinding N4	Grinding N5	Grinding N6	Turning N5	Turning N6	Turning N7	Turning N8	Vertical N6	Vertical N7	Vertical N8
0.212	0.359	0.752	0.270	0.570	1.590	2.724	0.678	1.404	2.01

Table 1: Ra(μm) values of Flexbar roughness standard patches

In this experiment, three operators scanned each of the ten specified roughness patches three times for a total of ninety scans. A single low-friction TPE gel cartridge and calibration was used for all measurements in the study. The Ra value was calculated as an average of eleven roughness profiles taken 200μm apart with a trace length of 5* λc, The λc used in the algorithm was selected per the standard defined in the Processing section of this application note. The focus of the system is particularly important when measuring small Ra values, so the focus of the GelSight Mobile Series 2 system was adjusted as needed throughout the study using the focus control in the GelSight Mobile software.

The Ra results were exported and entered into a Gage Repeatability and Reproducibility (GRR) template. A process tolerance of 2.8μm was selected. Note that the selection of 2.8μm as the tolerance is arbitrary and usually depends on a customer specification for the process being evaluation. The statistical results for the GRR study are shown in the table below.

	Enter Process Distribution Width in Sigma's (Typically 5.15 or 6.00) =				6.00	
SOURCE	**SIGMA**	**6.00 SIGMA**	**PERCENT CONTRIBUTION**	**PERCENT OF TOTAL VARIATION**	**PERCENT OF TOLERANCE**	VARIANCE
Repeatability	0.0806	0.4835	0.76%	8.70%	17.27%	0.01
Reproducibility	0.0854	0.5124	0.85%	9.23%	18.30%	0.01
Appraiser x Part	0.0725	0.4349	0.61%	7.83%	15.53%	0.01
Gage R&R	0.1380	0.8279	2.22%	14.91%	29.57%	0.02
Parts	0.9154	5.4922	97.78%	98.88%	196.15%	0.84
Total	0.9257	5.5542	100.00%		198.37%	0.86

Number of Distinct Categories	9

Table 2: Gage repeatability and reproducibility analysis of variance. The process tolerance was set to 2.8μm for the analysis.

Accuracy Study

Ten patches on the Flexbar plate were selected as part of the study. The patches and their standard Ra values as measured by a contact profilometer are listed in the table below.

Grinding N6	Grinding N7	Horizontl aN10	Turning N7	Turning N8	Turning N9	Vertical N7	Vertical N8	Vertical N9	Vertical N10
0.75	1.48	2.76	1.59	2.72	6.34	1.4	3.01	9.02	12.98

Table 3: Ra(μm) values of Flexbar roughness standard patches

In this experiment, a single operator scanned each of the ten specified roughness patches three times for a total of thirty scans. A single TPE gel cartridge and calibration was used for all measurements in the study. The Ra value was calculated as an average of eleven roughness profiles taken 200μm apart with a trace length of 5* λc, The λc used in the algorithm was selected per the standard defined in the Processing section of this application note. The focus of the GelSight Mobile Series 2 system was adjusted as needed throughout the study using the focus control in the GelSight Mobile software

This GelSight measured Ra value was plotted against the stylus profilometer measured Ra value referenced as the standard. The orange dashed line represents the ideal result – GelSight measured Ra equal to the stylus profilometer measured Ra. The distance away from the ideal line represents the difference between the GelSight measured Ra and the profilometer result considered standard.

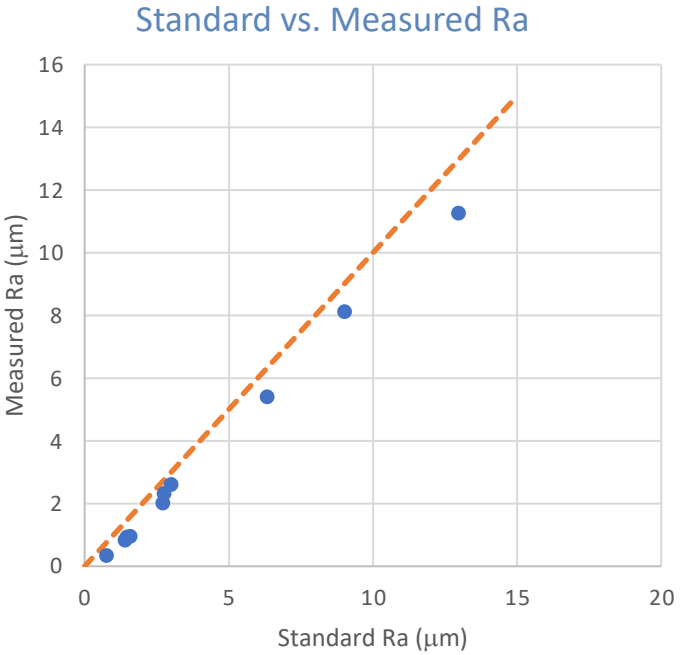


Figure 9: Standard vs. Measured Ra

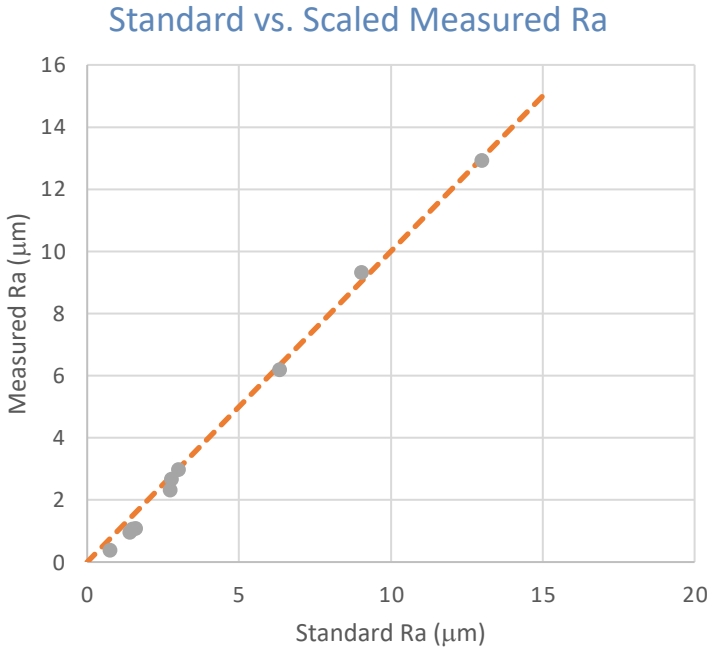


Figure 10: Standard vs Scaled Measured Ra. Scaling factor is 1.15.

The Profile Roughness function of the GelSight Mobile software can scale (or calibrate) the results, to a known value. Set Scale is described in the Scale Factor section of this application note. Using a scaling factor of 1.15, the results can trend even closer to the ideal line as shown below.

Conclusion

GelSight Mobile Series 2 0.5X with LF-TPE and TPE gel is accurate and repeatable within the 2-15µm Ra range. Using the Set Scale functionality, GelSight roughness results can be correlated to roughness results from other technologies. GelSight's technology has demonstrated the value of industry compliant standards, while combining the advantages of traditional contact and non-contact roughness characterization methodologies.

Recommended Qualification Procedure

All test methodologies are different. Contact stylus based profilometers, white light interferometers, confocal microscopes, and GelSight use fundamentally different technologies which can measure the same physical standard to varied computed roughness values using the same industry standard algorithm. GelSight's ability to measure multiple profiles from each capture, offers the end user greater surface intelligence which may lead to differing value to approaches which evaluate single profiles due to a dramatically increased data set. GelSight recommends that a customer performs their own correlation study if required. GelSight's recommended process for this study is outlined below:

1. Select 10 sample parts – the samples should be real samples with the roughness created using the same process that the customer will measure, not created with a different surface finishing technique. It is critical when assessing a technology for an application that you test on parts representative of that application, and not of a standard specimen that has a different type of surface finish.
2. Have three users scan each sample part three times – this will account for operator-to-operator variability
3. Perform the same measurements (three users, three scans) with the other technology
4. Compare the results of the study using a Gage Repeatability and Reproducibility template or program or compare the average results from the GelSight to the average results from the other technology.
5. If correlation is needed between GelSight and a different measurement system, use the Set Scale feature to scale the GelSight results as needed