gelsight Mobile

SHOT PEENED SURFACE ANALYSIS

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Shot Peened Surface Analysis using GelSight

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Fig. 1 *(a) The GelSight Mobile system. (b) Measuring an Almen strip using GelSight Mobile.*

Introduction

Shot peening is a process of striking a surface with high-speed particles to modify the mechanical properties of the surface. The particles dent the surface in a random fashion with the coverage of dents increasing with time. For many applications, the specification for the shot peening process is to achieve full coverage, often specified as 98% or greater, and it is important to understand when this specification has been achieved. The GelSight Mobile system is a handheld 3D surface scanning instrument that is capable of measuring any surface regardless of the optical properties of the surface. This paper describes a method for analyzing shot peening coverage using the GelSight system.

Shot peening is a fundamentally random process and there is a literature of work on understanding the theoretical relationships between peening time and coverage. It is well understood that the rate of increase in coverage slows down as particles become increasingly likely to hit regions of the surface that are already dented rather than hitting untouched surface regions[1]. It might seem intuitive that to achieve full coverage a shot peener should simply run the process for a long time. However, more peening is wasteful in time and materials and can have adverse effects on the surface[2]. Accurate characterization of the rate of coverage increase can more precisely predict the time required to achieve a desired coverage specification.

One common method for characterizing shot peen coverage and intensity is to insert an Almen strip into the process. The Almen strip can be evaluated under a microscope to track the shot peening process. However, material differences between the Almen strip and the component as well as component geometry can lead to different coverage amounts on the component as compared to the Almen strip[3]. A system that can assess shot peen coverage on the component itself will be a more accurate assessment of the shot peening process.

Publication Date: May 2022

GelSight Technology

GelSight Mobile is a handheld portable 3D measurement system that can be used directly on components to measure microscale 3D surface texture and shape. The system uses a unique elastomeric sensor that conforms to the surface of a component to control the optical properties of the surface during measurement. The system can be used on shiny metals, composites, glass and other optically complex materials without any modifications to the 3D measurement process. With the click of a single button, a detailed 3D measurement can be captured for analysis.

***Fig. 2** (a) Almen strips peened with S390 shot at 60psi for different exposure times (1, 2, 3, 5, 7 and 10 revolutions). The Almen strips were prepared by Electronics, Inc. (b) Rendering of measured 3D surface topography for Almen strip #3.*

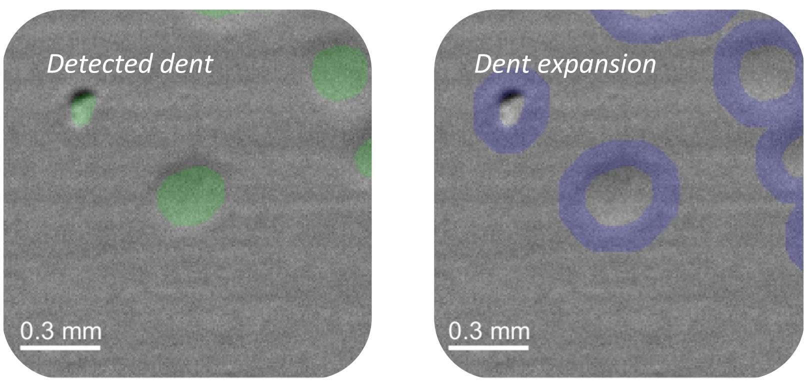


***Fig. 3** The shot peen coverage algorithm detects negative surface regions with a nominal input diameter (left) and expands the detected regions by a fixed percentage of the nominal diameter (right).*

The system, shown in Fig. 1, consists of a handheld probe, built-in analysis software, and a tablet. The probe has a 5 Megapixel CMOS camera, a telecentric lens and six LED light sources at different directions. After the button is pressed, the system captures six pictures at a speed of 50 frames per second with different light directions for each image. Custom 3D processing algorithms convert the images into 3D surface topography within seconds[4]. The telecentric lens has a 0.5X magnification and a fixed focal length. This lens provides a diagonal field-of-view of 17mm x 14mm with an X-Y resolution of 6.9 microns.

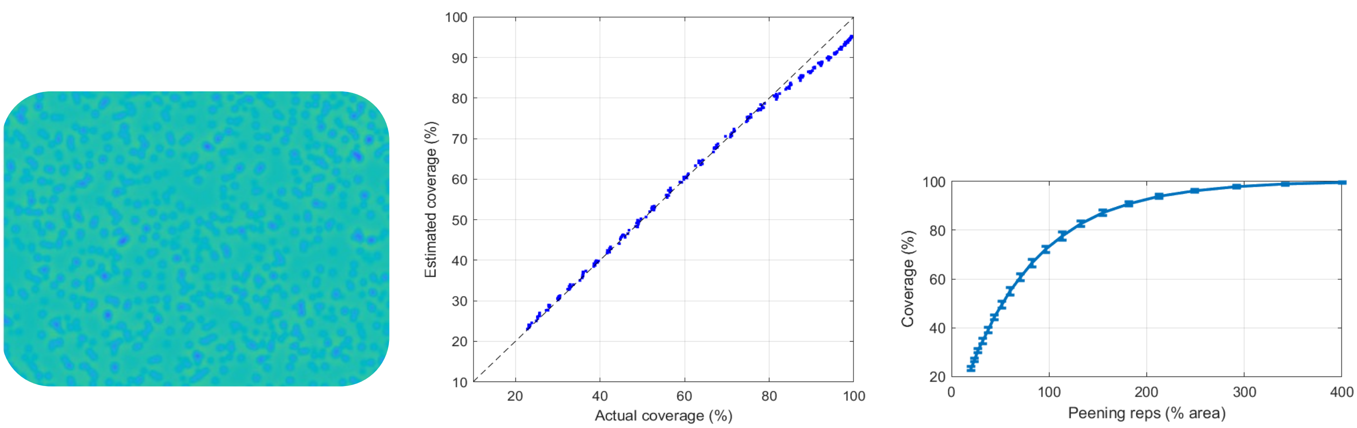
After the 3D measurement is captured, custom image processing algorithms can be developed to extract information of value to different industries. For this paper, a custom method for characterizing shot peened surfaces was developed to demonstrate the capabilities of the system.

Publication Date: May 2022

Shot Peening Coverage Analysis

A custom analysis method was developed to assess the shot peen coverage. The method has two input parameters: the expected dent diameter and a dent expansion parameter. These two parameters can be tuned to match a visual assessment of coverage. For the Almen strips processed with S390 shot, the nominal dent diameter was 0.3 mm and the dent expansion parameter was set to 33% (0.1 mm). Close-up views of the detected and expanded regions are shown in Fig. 3. The coverage algorithm detects dents by finding regions that have negative depth as compared to the surrounding region. The algorithm then expands these dents by a fixed size to estimate the influence region of the dent—a region including both the crater and crater rim. The crater rim is not detected in the first step since it consists of the positive regions displaced from the crater.

The coverage algorithm was analyzed for accuracy using a shot-peening simulation. The simulation picked random locations on a surface to dent with a virtual dent shape at a depth randomly selected within a narrow range of depths. The dent shape had equal positive and negative volume so that no material was lost in the simulation. An example simulated surface is shown in Fig. 4(a). The coverage algorithm could accurately estimate the known coverage within a few percent. As shown in Fig. 4(b), a slight bias is introduced for coverages above 80% since the reference surface can no longer be accurately measured from the dented surface. It is also interesting to observe that as the coverage approaches 100%, the probability of hitting undented surface decreases. Under the parameters of the simulation, 100% coverage was achieved after denting the surface with dents that would cover 400% of the surface area if arranged without overlap, as shown in Fig. 4(c).



***(a)** Shot peening simulation* ***(b)** Estimated vs. actual coverage* ***(c)** Time required to achieve coverage*

***Fig. 4** (a) A shot-peening simulation was developed to evaluate the coverage algorithm. (b) The coverage algorithm was able to accurately detect and measure the coverage on simulated surfaces. (c) The stochastic nature of the shot-peening process leads to diminishing returns as the surface approaches 100% coverage.*

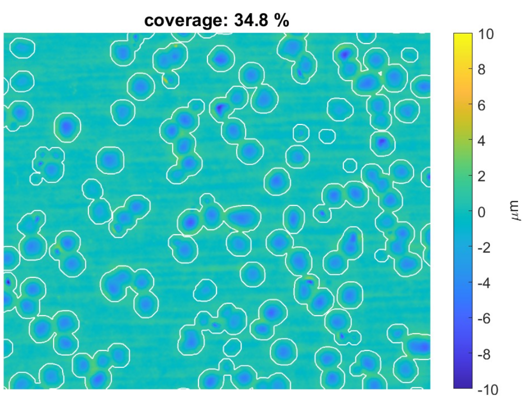
Measurement System Analysis

The coverage algorithm was evaluated following a traditional measurement systems analysis with multiple parts and operators. For this study, a batch of Almen strips was prepared using S390 shot at 60 psi using ten different exposure times. The samples were prepared by Electronics, Inc. following a standard shot-peening process with the number of revolutions (exposure time) indicated on the back of each strip. The ten revolutions used were 1, 2, 3, 5, 7, 10, 15, 20, 30, and 50. The samples for 1, 2, 3, 5, 7 and 10 revolutions are shown in Fig. 2. These samples were measured using the GelSight Mobile 0.5X system to produce a detailed 3D map of the surface, as shown in Fig. 2(b).

Two gel cartridges were calibrated using the standard calibration procedure in the GelSight Mobile software. One gel cartridge was used for an experiment to assess precision and the second gel cartridge was used for a three-operator gage repeatability and reproducibility (GRR) study.

	#1	#2	#3	#5	#7	#10	#15	#20	#30	#50
mean	36	57	66	78	83	87	89	91	93	93
standard uncert.	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
U	**0.5**	**0.6**	**0.4**	**0.4**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.3**

Table 1 *The uncertainty U is calculated by expanding the standard uncertainty term at a 99% confidence level. All values are displayed in percent (%).*



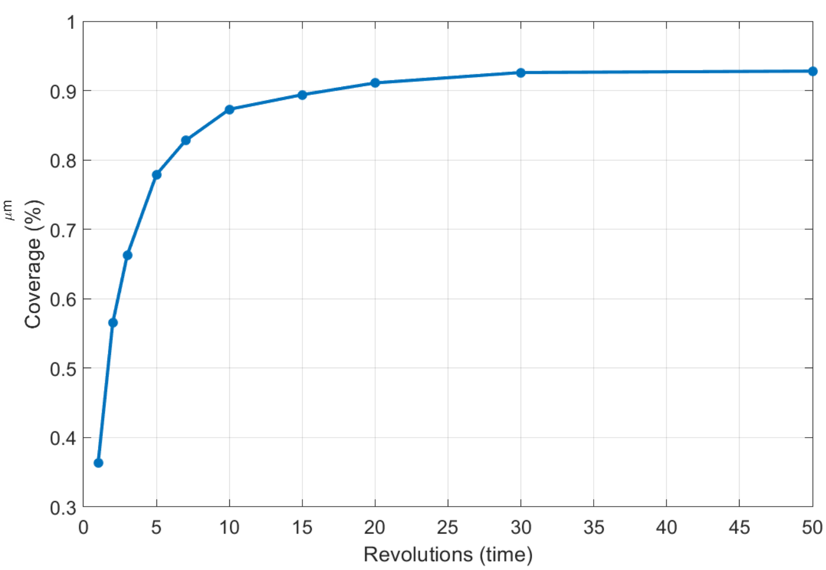


Fig. 5 *(a) Coverage analysis on Almen strip #1. (b) The estimated coverage saturates after 30 revolutions of shot peening.*

Precision Study

Each Almen strip was measured twenty times by the same operator. The coverage algorithm was run on each measurement. From the twenty coverage estimates, the standard uncertainty u was calculated as follows:

$$u = \frac{s}{\sqrt{n}}$$

Where s is the estimated standard deviation and n is the number of samples, in this case 20. The expanded uncertainty U is calculated by multiplying the standard uncertainty by a coverage factor k to provide a specific level of confidence, usually 95 or 99 percent[1]. Due to the limited number of measurements being used in the statistical analysis, the coverage factor is chosen from the t-distribution with n-1 (e.g., 19) degrees of freedom[2]. The coverage value k99 for 99 percent confidence with 19 degrees of freedom in the t-distribution is:

$$k_{99} = 2.86$$

The uncertainty measurements are shown in Table 1. They are all below 1% indicating good precision in the coverage estimate.

Gage Repeatability and Reproducibility Study (GRR)

To assess repeatability and reproducibility, a three-operator GRR study was conducted. Each operator measured the ten Almen strips three times each. The coverage algorithm was run on each measurement using a dent diameter of 0.3 mm and a dent expansion of 33%. A tolerance of 20% was used for the study. The GRR analysis of variance was calculated using Minitab software with the results shown in the table below. The Total GRR as a percent tolerance is below 20% in this study.

Gage Evaluation

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0.005959	0.03576	3.21	17.88
Repeatability	0.004950	0.02970	2.67	14.85
Reproducibility	0.003319	0.01991	1.79	9.96
User	0.000000	0.00000	0.00	0.00
User*Part	0.003319	0.01991	1.79	9.96
Part-To-Part	0.185414	1.11248	99.95	556.24
Total Variation	0.185510	1.11306	100.00	556.53

Summary

This report describes a measurement system analysis study for quantifying the accuracy of estimating shot peening coverage from a surface measurement using the GelSight Mobile system. The system provides a digital and repeatable method for assessing coverage as part of a shot peening quality control process.

References

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[4] M.K. Johnson, F. Cole, A. Raj and E.H. Adelson, Microgeometry capture using an elastomeric sensor, ACM Transactions on Graphics (Proc. ACM SIGGRAPH), 30(4): pp 461-468, 20