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Surface Texture Analysis on DMLM parts

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1. Abstract

Samples were produced with different shapes and sizes using a powder bed additive manufacturing method called Direct Metal Laser Melting (DMLM). Multiple surfaces the samples were analyzed using contact stylus and non-contact profilometry techniques. The two surface roughness analysis techniques were compared using statistical methods to standardize on a procedure of micro-roughness measurement for specifications on DMLM printed components.

2. Introduction

This research was conducted for General Electric's Power & Water – Gas Turbine division under the Materials and Processes Engineering (MPE) team. The group operates from the Gas Turbine Technology Center located in Greenville, South Carolina. MPE supports for materials characterization and process development for fabrication of gas turbine components. . Including, but not limited to: forging, casting, thermal barrier coatings, weldments, brazing, additive manufacturing, material selection and properties, and field/failure analysis.

DMLM is a relatively new technology that allows metal powder (from pure metals, to alloys and super-alloys) to be shaped into solid three-dimensional shapes. Its main advantages are the elimination of subtractive machining steps that add cost and cycle time to produce a component combined with the design space possibilities it opens up for complex internal features and passages to be built as a single piece Some of these shapes could not be built using any other commercially available casting or machining techniques. Figure 1 provides an example of the complexity achievable with such technology. Additionally, as with all additive manufacturing techniques, DMLM allows for rapid prototyping which speeds up processes such as new product development. With such important advantages, it is no surprise that DMLM is growing in use for the production of turbine components.

Figure 1: Demonstration of capabilities of DMLM techniques (image courtesy of?).

As it is with every component on a turbine, tight specification limits must be followed to maintain performance and efficiency. Among several quality control targets, surface roughness is considered for at least two very different purposes. Figure 2 explains the importance of roughness in the macro-scale while figure 3 provides an understanding of the meaning of "micro-roughness".

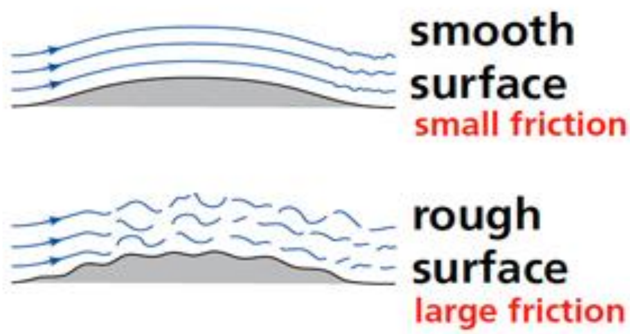

Figure 2: Airflow (whether laminar or turbulent) is affected by large scale surface roughness features

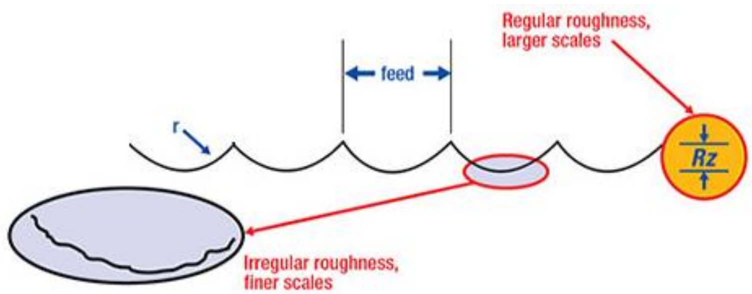

Figure 3: Every surface has irregularities of fine scales. These are micro-roughness surface features.

It is in this second scale that this research is focused. The importance of surface studies in this scale deals with fatigue life analysis. These fine features on the surface behave as stress concentrators. A stress concentration is a location in a material where stress is multiplied and therefore experiences a higher stress than that applied throughout the whole material. As a stress is concentrated, a material may fail even when the stress is well below its yield point, particularly is this applied stress is cyclic. Although it is material dependent, it is commonly understood that the rougher the surface and depending on the shape of the surface profile, it could initiate a crack that then would fail under fatigue mechanisms. Refer to figure 4 see the graphical interpretation of this relationship.

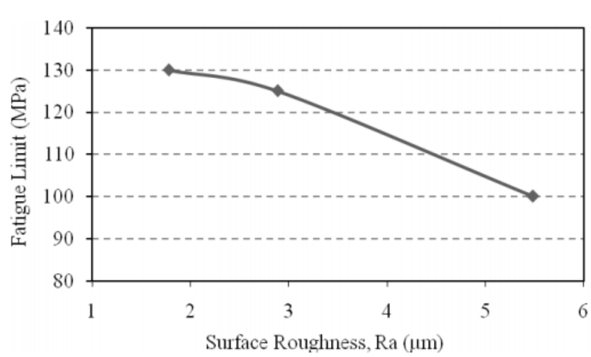

Figure 4: Graphical representation of reduction of fatigue limit with increased surface roughness (unknown material)

Industry's standard unit for roughness in fine scales is measured in micro-inches or micro-meters. Both measuring methods employed in this research are able to obtain several roughness parameters, however Ra (arithmetic mean of roughness) was chosen for comparison between both instruments.

3. Experiment

Each of the four surfaces shown in figure 5 were scanned 10 times with a Mitutoyo SJ-210 stylus profilometer in three directions (horizontally, vertically, and diagonally) to account for statistical reasons and remove variability to directionality of the printing process. The same surfaces were scanned using a Keyence Laser profilometer. The process was repeated for four samples as shown in figure 6. All printing parameters were kept constant except for the angle of the inclined surface.

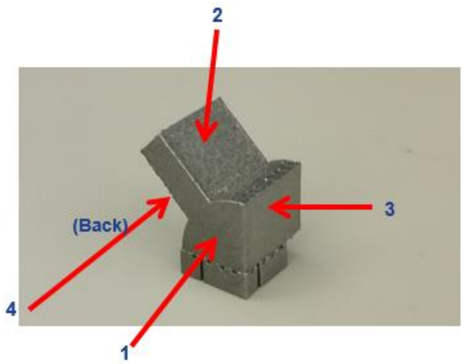

Figure 5: All surfaces scanned

Figure 6: Four samples analyzed

Two main challenges needed to be tackled before any data point could be obtained. For the laser profilometer, understanding of the cut-off filters was a requirements to obtain micro-roughness values. Figure 7 explains what these filters do. As discussed previously in this paper, it is in the small features, or fine-scale roughness that this research focused. Therefore, the high-pass cut-off filter (λ_c) was set to be 1/5 of the scan length. The scan length was approximately 8mm.

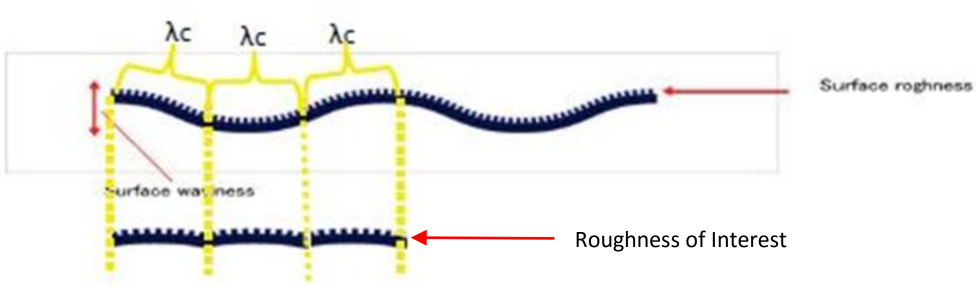

Figure 7: Effect of cut-off filter

For the stylus profilometry to give a measurement, the stylus must be perfectly aligned with the device's sensor. For that, an adjustable-height sample plate connected to the instruments was designed through CAD and then printed. The design, shown in figure 8, allowed to scan all surfaces regardless of the orientation.

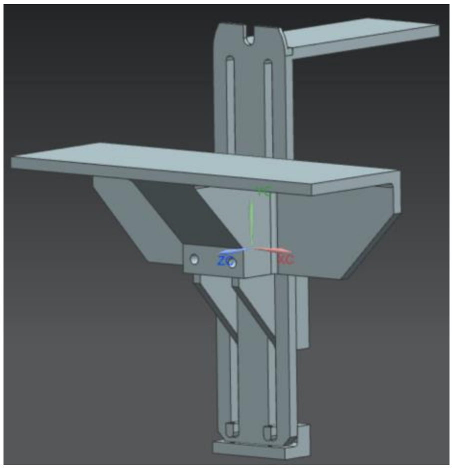

Figure 8: CAD design to allow stylus to scan any geometry

4. Results

The normalized surface roughness data is plotted in figure 9 to compare the roughness values obtained from the each of printed surfaces. Note that surface 4 (from figure 5) is not shown because it was beyond the capability for the stylus profilometer to read.

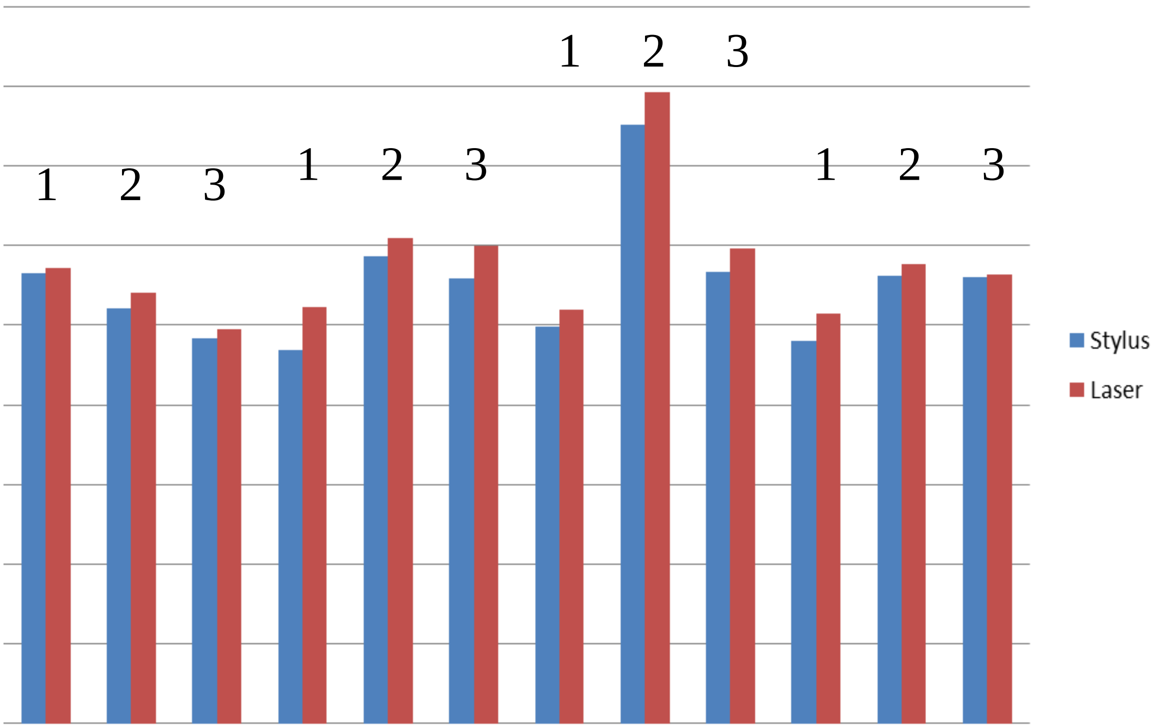

Figure 9: Direct comparison of the average of the results. The Y-axis is in micro-inches. The numbers represent the surface

As stated, statistics played a big part on the results and conclusions. The results of the statistical analysis are as follow:

- True Mean: (Using Surf. 1, 2, 3 as single population) where **X** represent the average of the results from all surfaces.
  - Stylus: $\mathbf{X} \pm 21.1$ (95%)
  - Laser: $(\mathbf{X} + 12.2) \pm 21.7$ (95%)
- Gage R&R:
  - $\%R\&R_{\mathbf{Stylus}}$: 28.1%*
    - *Excluding "obvious" outliers.
  - $\%R\&R_{\mathbf{Laser}}$: 19.5%
- P-test
  - $(\mathbf{X} - 16.8) < (\mathbf{X} + 12.2) < (\mathbf{X} + 7.6)$ (99%)

5. Conclusion and Discussion

Each method has its advantage and disadvantages, table 1 explains the pros and cons of each instrument. Figure 10 is a graphic representation of the interaction between the instrument and the sample explains why the results show that the laser gives higher roughness values. The geometric restrictions of the tip of the stylus does not allow it to enter ever groove in the material, thus, giving a slightly lower value than the actual one.

Stylus Profiler	Laser Profiler
Prone to directionality	Affected by reflectivity
Tip does not get full detail	Small Scan Area
Single Line Scan	Software
Inconsistency (Tip damages and damages sample)	Calibrated from Stylus
Price	Too many parameters
Ease of Use	Detailed Information
Quick (When comparing with single measurement)	Multiple Simultaneous measurements
	Many Many features

Table 1: Pros / Cons comparison of each method

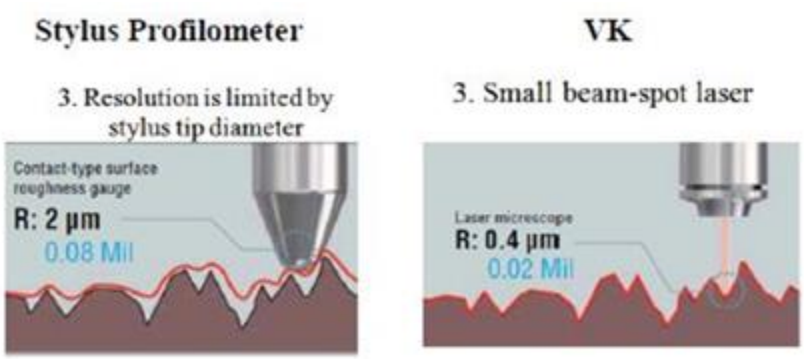

Figure 10: Explanation for difference in results from each method.

Although the laser profilometer is much more capable and accurate, the results show that the difference in the methods for the range of roughness at interest is not significant enough to account for the difference in cost between the two instruments, therefore, stylus profilometry was recommended to be the method of analysis across the industry for these types of samples.

Interestingly, the change in angle did not greatly affect the roughness value of surface 3. This is because the layer thickness of the metal powder is kept constant. (This does not apply for surface 4 since it is "hanging" and powder has nothing to weld to).

6. References

- ASM Handbook Volume 19
- Keyence 3D Laser Surface Analyzer User Manual
- "Understanding Roughness" – Keyence 3D Laser Surface Analyzer Training Manual
- "Six-Sigma" Statistical Analysis Handbook

7. Acknowledgment

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