Direct Metal Laser Melting:
Analyzing Surface Roughness

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Presentation Outline

- Background
- My Fellowship
- My Work
- Importance of DMLM
- Importance of Roughness
- Experiment
- Results
- My future

Background

- Felipe Alberto Betancor Bernasconi Echeto Arredondo
- Punta del Este, Uruguay
- 2007
- UCF
- Environmental Protection and Energy Generation
- Avid Soccer Player and Outdoors Adventurer

Preparation for UTSR

- *Mechanical Engineering Degree*
  - Concentration in Material Science
  - Minor in Mathematics
- ***Materials Characterization Facility***
  - Dr. Yong-ho Sohn
  - Diffusion, TBC, Extreme Environment Mat. (temperature, stress, radiation, etc.)
  - Analytical Techniques: XRD, SEM, EDS, TEM, Nano-mechanical Testing.

Laboratory of Materials and Coatings for Extreme Environment - MCEE

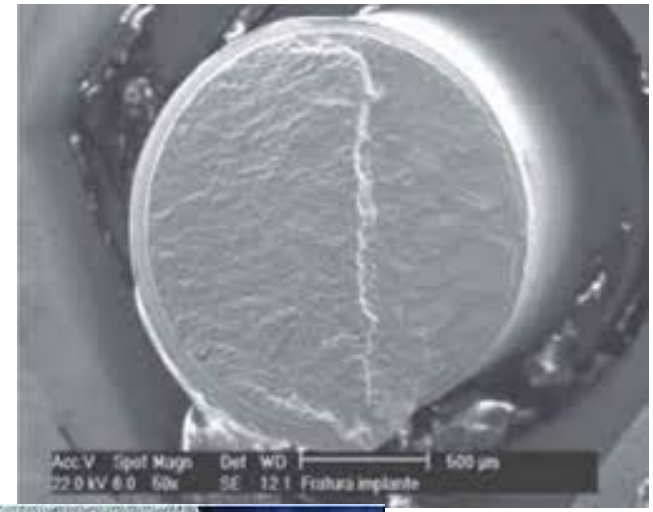
My UTSR Fellowship

- Greenville, South Carolina
- Gas Turbine Technology Center
  - Direct Exposure to Turbomachinery
  - Exposure to all Personnel and Tech.
- Materials Process and Engineering Team
  - Welds / Brazing
  - Coatings
  - Failure Analysis
  - NDT
  - Additive Manufacturing

Experience

Mechanical and Microstructural Analysis of Weldments

Failure Analysis

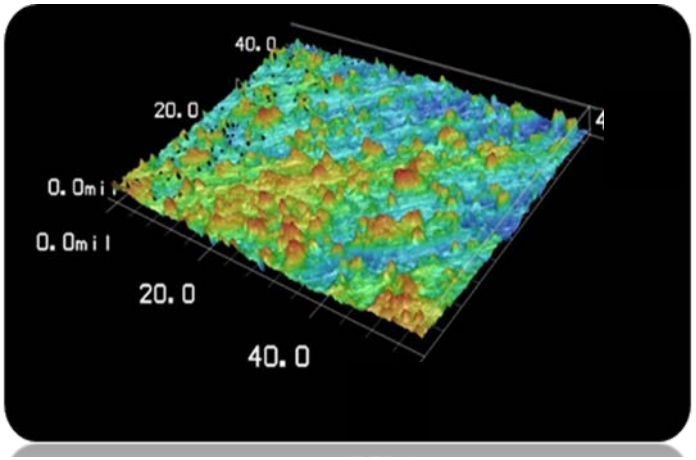


Introduction

Laser Additive Manufacturing offers many opportunities for improvements in efficiency, cost, and time.

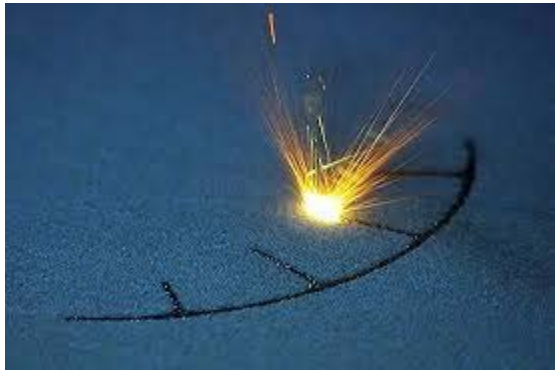
Roughness is a critical feature in metal 3D printing as it is related to a part's fatigue life.

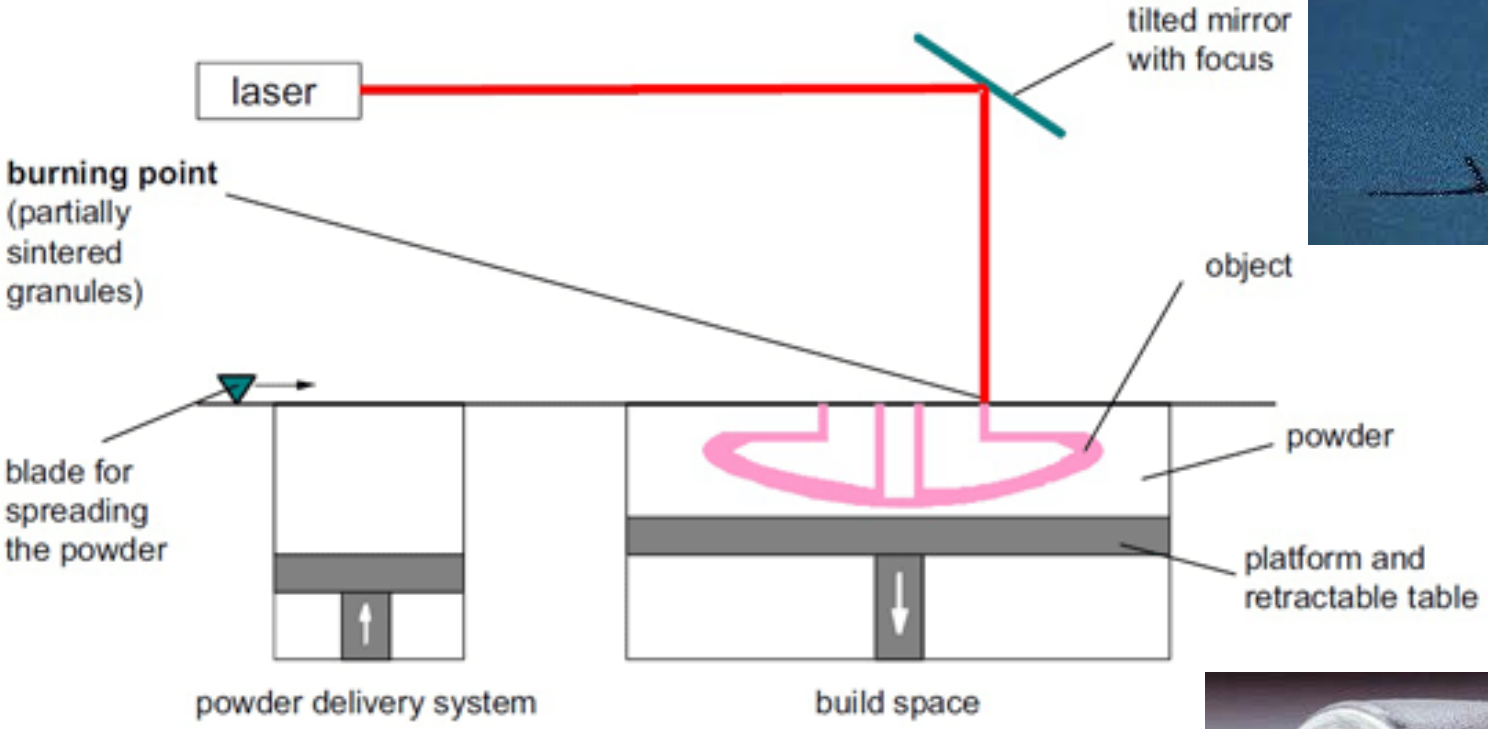
Main Project Goals

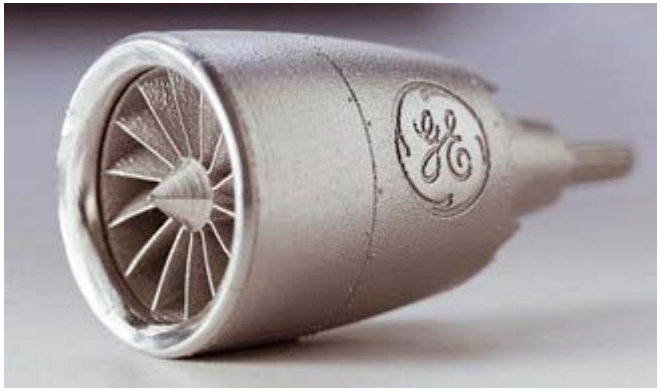


- Study analytical methods of roughness measurements.
- Examine several additive manufactured parts printed with different parameters.
- Compare methods of analysis.
- Develop technique to be implemented across GE departments.

3D Printing Technology (Brief Overview of DMLM)







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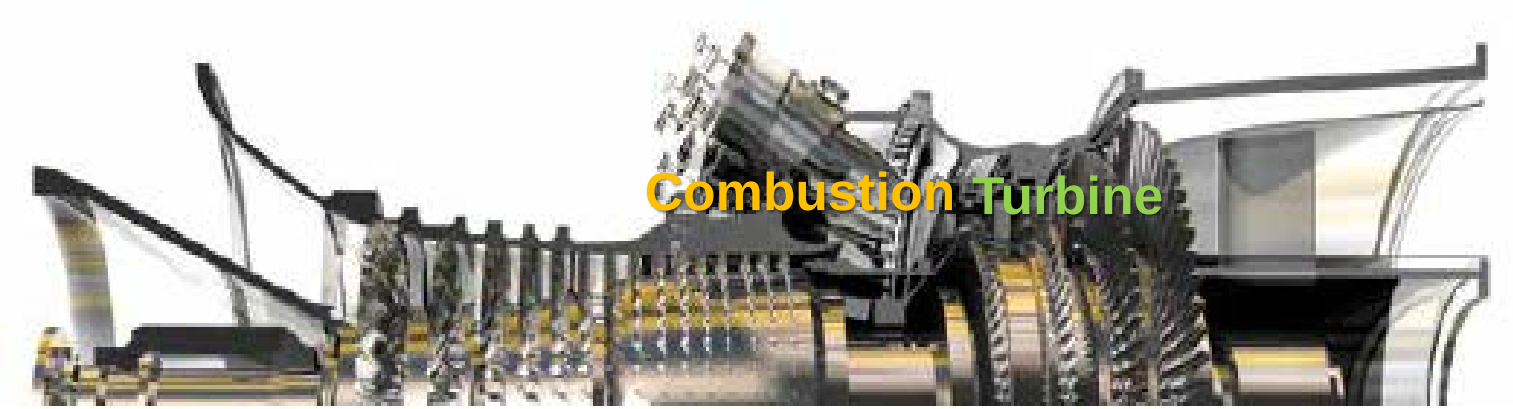
Application to Turbine

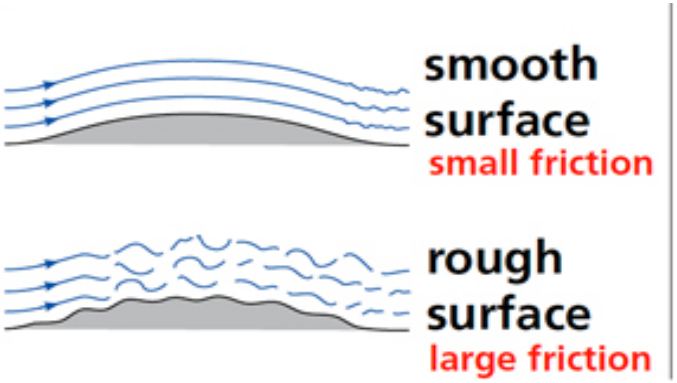


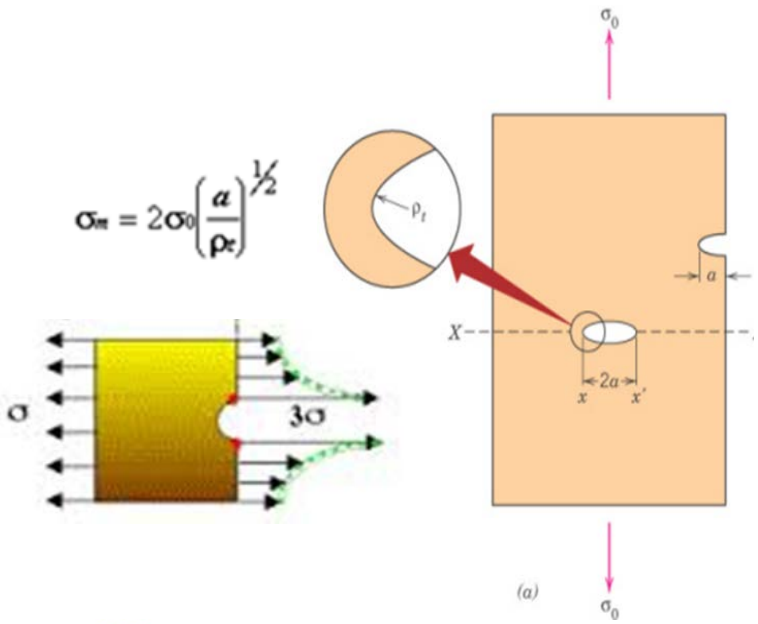
BUSINESS CASE FOR 3D PRINTING :*VALUE ADDITION*

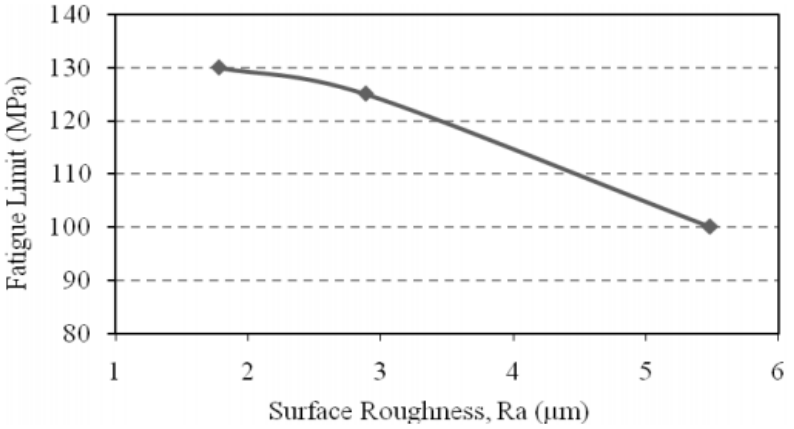
- Potential for **advanced Heat Transfer and Fluid Dynamic features**.
- Design & Test – ***NTI Speed***
- Production – ***NPI Speed***

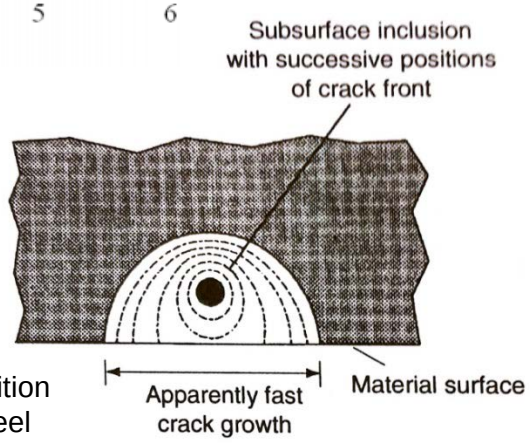
Why is Surface Analysis Important?

- Airflow:
  - Reynold's number – Turbulence
- Failure:
  - Stress Concentration -> Crack Propagation -> Fatigue









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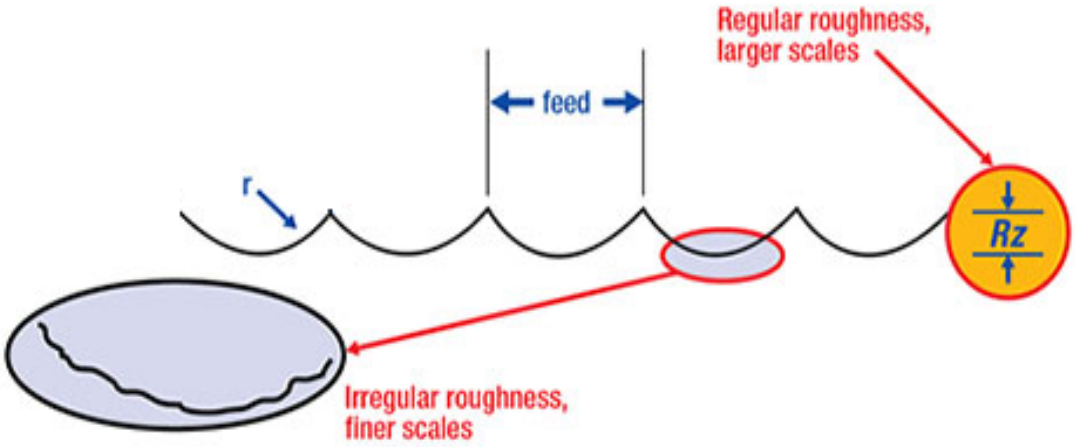
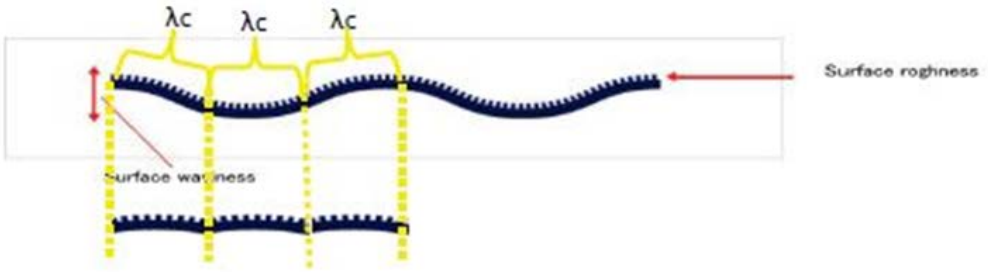
W. D. Callister Jr., Materials Science and Engineering - an Introduction. 8th Edition
N.A.Alang Effect of Surface Roughness on Fatigue Life of Notched Carbon Steel

Reading Roughness

- Waviness = Macro-roughness
  - *Flow*
- Roughness = Micro-roughness
  - *Cracks*



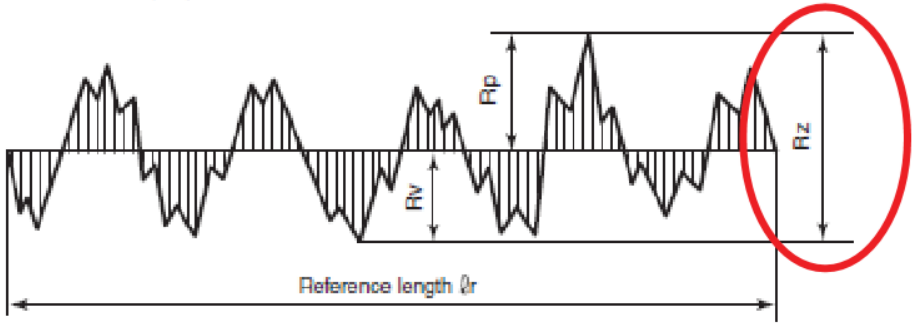
- **Correct parameters must be employed based on application of interest**
  - Cut-off filters
  - Scan Length



Measuring Roughness

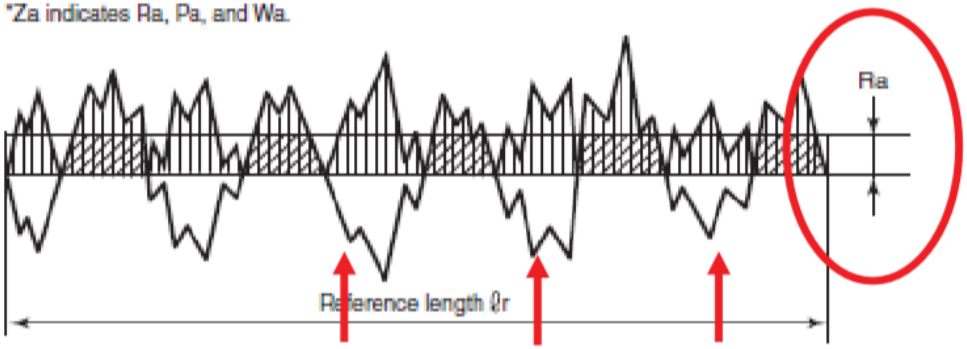
$$Zz = Zp + Zv$$

*Zz indicates Rz, Pz, and Wz.



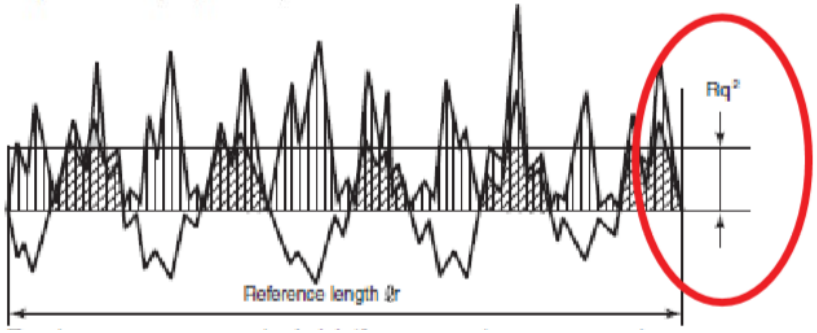
$$Za = \frac{1}{\ell r}\int_0^{\ell r} \left| Zn \right| dx$$

*Za indicates Ra, Pa, and Wa.



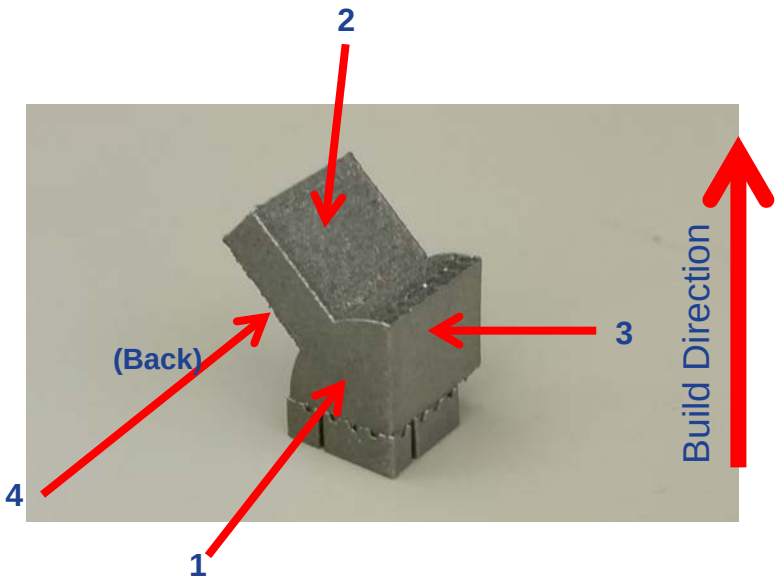
$$Zq = \sqrt{\frac{1}{N}\sum_{n=1}^{N} Z_n^2}$$

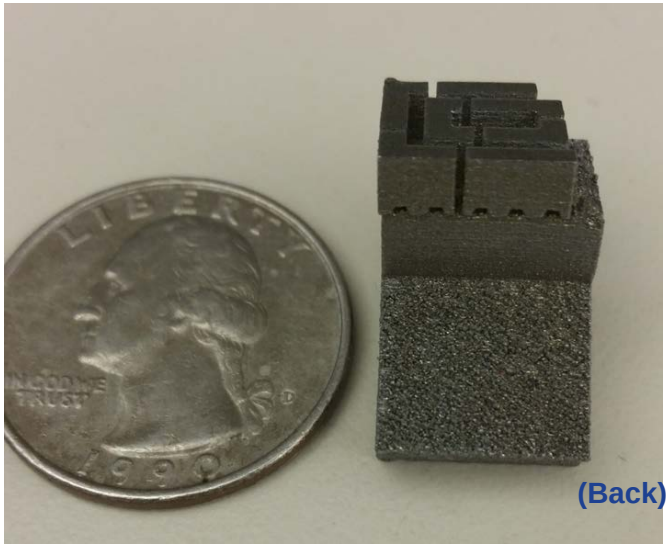
*Zq indicates Rq, Pq, and Wq.



Experiment:

- DMLM Co-Cr-Mo
- Printed with varying angle (30º-45º)
- 4 Surfaces
- Measured with Stylus and Laser
- Compilation of Vertical, Horizontal and Area scans.





Comparison of Laser to Stylus

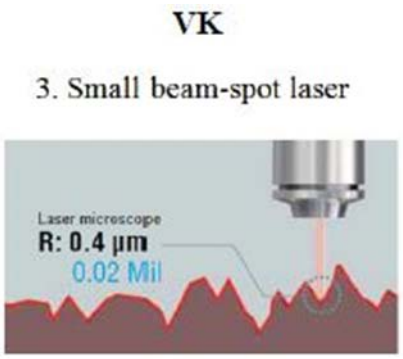
Pros and Cons

Stylus Profiler

- Prone to directionality
- Tip does not get full detail
- Single Line Scan
- **Inconsistency** (Tip touches and damages sample)
- **Price**
- Ease of Use
- Quick (When comparing with single measurement)

Laser Profiler

- Affected by reflectivity
- Small Scan Area
- Software
- Calibrated from Stylus
- Too many parameters
- Detailed Information
- Multiple Simultaneous measurements
- Many features



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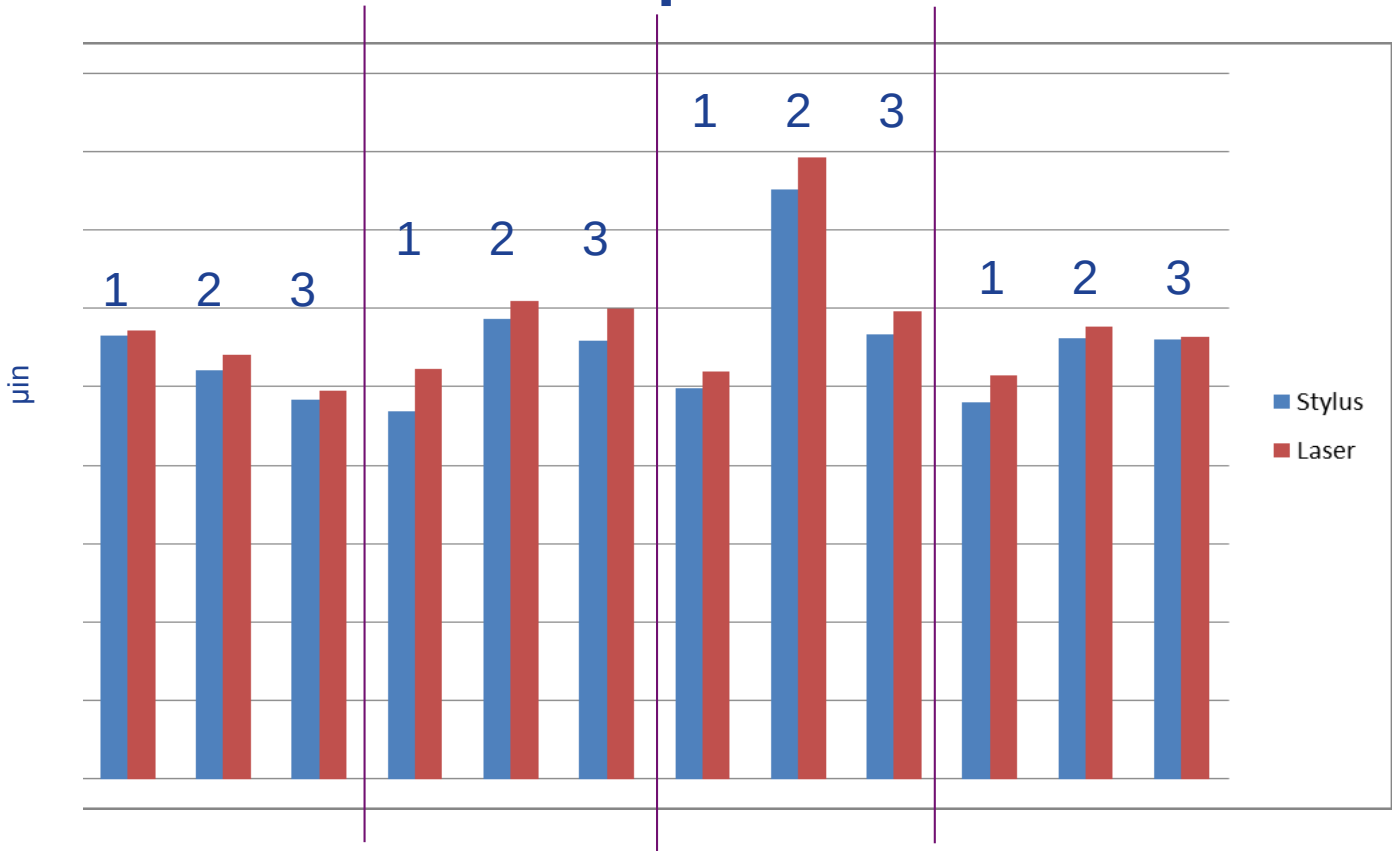
Results and Comparison (X represents average of all results)



True Mean as Single Population (Surf: 1, 2, 3)

Laser: (**X** + 12.2) ± 21.7 (95%)

Stylus: **X** ± 21.1 (95%)

Back Side (4):

Unreadable with Stylus

Gage R&R

$\%R\&R_{Laser}$: 19.5%

$\%R\&R_{Stylus}$: 28.1%*

*Average of two runs and subtracting obvious Outliers

Inferential Statistics

(Does stylus mean meet target (laser) mean?)

(**X** – 16.8) < (**X** + 12.2) < (**X** + 7.6)

(99%)

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Conclusions

- Laser is more capable and more accurate
- Differences in methods for the range of roughness studied is not significant enough to account cost difference.
- Roughness of surfaces 1-3 are not significantly affected within the range of angles printed.
    - Surface 4 showed noticeable change with different angles.

My Future

- Connection between my passion for the environment and my career as an engineer.
- Importance of Gas Turbines in our society and the role they are playing for the economy and the environment.
- Enter the industry to continue learning and contributing to advancements in gas turbine technologies.

Acknowledgments

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  - MCF team
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- **SwRI: UTSR**
- **DOE- NETL**