Additive Manufacture of a 3 Meter ROC Mirror from Titanium Material

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ASTS :Tony Harrison, Tod Rynders, Joe Sims
NASA / MSFC: Samantha Hansen, Ron Eng

Introduction

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Phase I SBIR

- **Material Selection Study**
  - Identify Performance Benefits
- **Verify Material Capability for Infrared Spectrum**
  - Traditional Raw Stock
  - MSFC and ASTS Assessments
- **Build 3-Meter ROC Mirror Via Selective Laser Melting (SLM)**
  - Additive Manufacturing via Powder Bed Fusion Process
    - Layer-wise, laser welding operation to create 3-D components
  - Concept Laser M2 (soon to have another M2 and a M-lab machine)
  - Optimize SLM Process for Titanium (Ti6Al4V)
- **Deliver Mirror to MSFC**
  - Perform carbide tip machining
  - Polish as required
  - Interferometry evaluation

Material Selection Study

Selection Criteria

- Weight performance
- Mirror surface roughness / reflectivity
- SLM material development risk

Materials Considered

- Inconel 718
- Aluminums
- Titanium (Ti6Al4V)

Material Selection Result

↑ - Good ↓ - Bad

Material \ Criteria	Weight	Reflectivity	SLM Development Risk
Inconel 718	↓	↑	↑
Aluminum	↑	↑	↓
Titanium (Ti6Al4V)	↑	?	↑

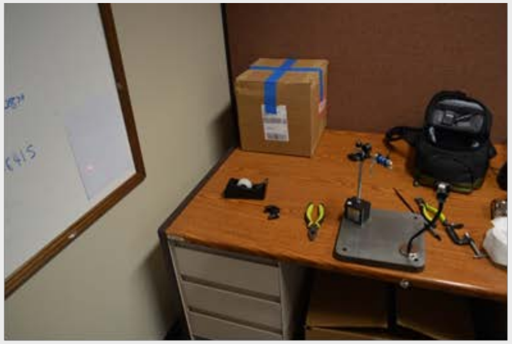
<u>Selected Titanium with follow-up actions</u>

Suitability in the Infrared Spectrum

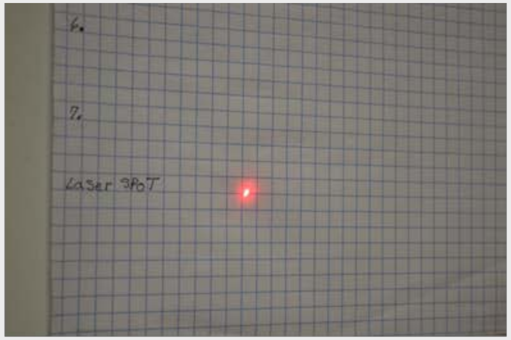
ASTS Performed Automated Polishing of Ti6Al4V Bar Stock

- 3 polishing cycles of 3 increasing grit silicon carbide sandpapers
- Polishing using polishing pads in a 0.05 micron alumina suspension
- Final polishing using 0.04 micron colloidal silica

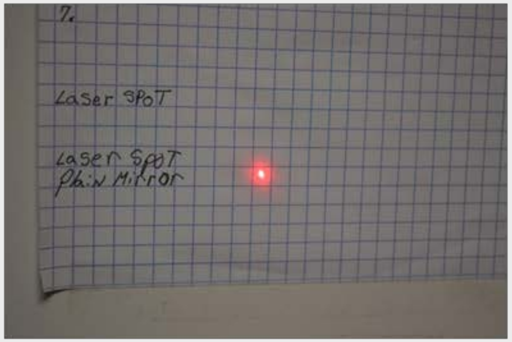
ASTS Qualitative Polishing Results



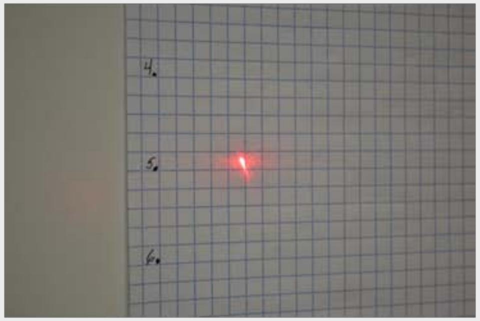
Experiment set-up



Straight laser spot



Laser reflection plain mirror



sample no. 5 reflected laser light

MSFC Ti6Al4V Surface Reflectivity Assessment

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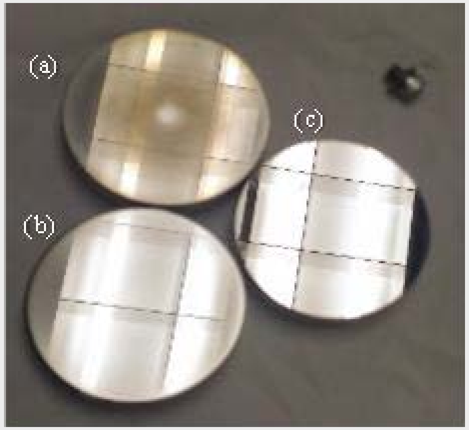
Received 2 Samples, 2” Dia., ½” Thick Bar Stock

- One sample had machining performed with a carbide bit and then polycrystalline diamond bit tool with evaluation for surface figure immediately after each process
  - Diamond bit turning results were marginally superior surface figure but with greater standard deviation compared to the carbide bit turning
- Second sample was Wire EDM by ASTS and MSFC ground on a lap using 30 µm and 15 µm Aluminum Oxide micro-grit
- Both samples subsequently polished using a series of 9 and 3 micron diamond suspension on a rubber polisher and then an aluminum oxide (AlO_3) slurry of 0.5 µm grit turned on a pitch polisher

(a) Diamond bit and polished
(b) Wire EDM and polished
(c) Aluminum coated with nickel plating and polished



Note: grinding lap was convex shaped resulting in uneven polishing on sample (a)

Ref.: Ti6Al4v Polishing Results from MSFC; Samantha Hansen and Ron Eng, NASA/MSFC

Ti6Al4V SLM Material Process Development

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Optimized Parameters for Titanium Not Existent for SLM

- 27 Unique Parameter Settings to Manipulate on the SLM Machine
- Our Focus is on Quality, not Speed
  - High Density, Smooth Surface Finish
- Understanding Each Parameter’s Influence on Final Part Quality is Critical

Desired to Minimize Post Processing

- Goal of SLM is Net Shape Production
- Post Processing = Increased Part Cost / Lead Time

Focus of Process Development

Examples of Detrimental Effects on Critical Properties

- Non-optimal Delay Settings
  - Keyhole Porosity
- Incorrect Energy Density at Surface
  - Porosity due to Vaporization or Incomplete Melting
- Beam Compensation Incorrect
  - Linear Surface Defects causing Stress Risers
  - Poor Geometry Replication

All Above Result in Reduced Part Performance / Service Life

- Lower Strength Values, Fatigue Cycles, Etc.

Component Quality is Critical to Wider Acceptance of Additive Manufacturing Technologies

Baseline Parameter Development

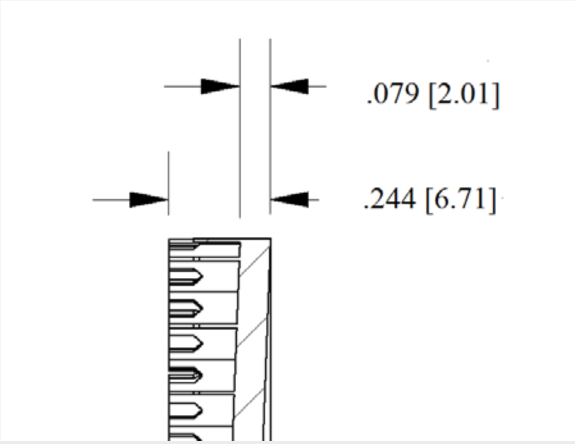
Initial Focus on Density

- Near-100% Theoretical Density Insures Excellent Tensile Properties
- Cube Specimens Fabricated Using Parametrically-Varied Power/Speed Settings
- Density Measured First Using ASTM Optical Method
- Once Optimum Processing Region Identified, Torbal Balance and Density Kit Used for Final Parameter Tuning (Archimede’s Principal)

Followed by Focus on Strength, Surface Finish

- Once Full Density Achieved, Focused on Measurement of Tensile Properties and Achievement of Excellent Surface Finish
- Tensile Specimens Produced to ASTM E8/E8M-13a, Figure 1
  - Built at 0° and 90°
- Surface Finish Specimens Measured Using Digital Profilometer

ASTS Ti6Al4V Mirror Design



As-built weight before MSFC machining: 491 grams

Weight reduction after MSFC machining : 78.7%

Conclusions

Titanium (Ti6Al4V) Shows Promise as a Mirror Substrate

- Comparable in density of aluminum
- Much stronger material characteristics than aluminum
- Designing for additive manufacturing appears cost viable compared to traditional machining
- ASTS design meets the areal density of 1-10 kg/m2 goal by NASA

Next Task is to Optimize Material Process for SLM

Build Mirror Substrate for Delivery to NASA/MSFC

- **MSFC to perform carbide tip machining, polish as necessary, and perform interferometry testing**

Thank You for Your Attention

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