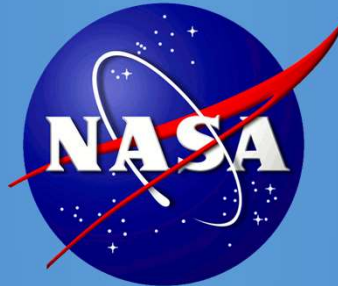


# Characterizing Effects of Witness Marks in L-PBF

Omar Mireles, William Tilson, Omar Rodriguez.  
NASA Marshall Space Flight Center (MSFC)

Jonaaron Jones and Devon Burkle  
Volunteer Aerospace Inc. (VAI)





# Background

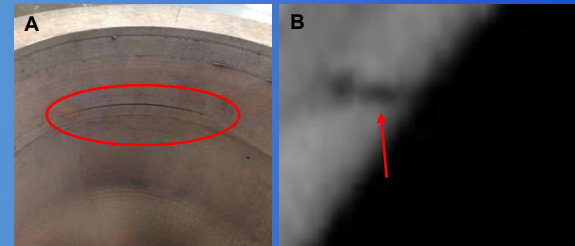
- Additive manufacture (AM) is utilized for production of rocket engine components due design, property, cost, and schedule advantages.
- Laser Powder Bed Fusion (L-PBF) machines rates vary from a few to tens of \$k/week; therefore, minimizing scrap rate is important for cost and schedule control.
- Witness marks: horizontal lines across the surface of AM parts resulting from planned build pauses to add powder.
- Formation mechanisms between witness mark and a planar lack of fusion build defects are substantially different but considered by some to be grounds to scrap a part.
- Objective: Characterize the effect of witness marks generated by intentional build pauses on AlSi10Mg parts.



Additive Manufacture Demonstration Engine (AMDE).



Witness marks (horizontal lines) via the L-PBF process.



Example of short feed induced LOF defect (A) and CT image of LOF defect (B).



# Test Approach

- Design of Experiment

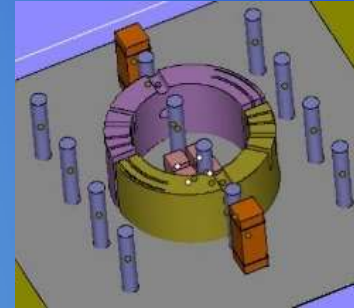
- Develop methodology to determine the impact of witness marks on L-PBF AM components as a function of perceived severity.

- Specimen Design and Build Layout

- CT gauge blocks.
- CT bars (engineered defect radii from 0.25-1.0 mm).
- Metallographic cubes.
- Mechanical test cylinders.

- Build Process

- VAI parameters for AlSi10Mg.
- Build 1: no pause (build plate at 200 °C, argon).
- Build 2: 1 hr pause (build plate at 200 °C, argon).
- Build 3: 1 hr pause (build plate heat turned off, argon).
- Build 4: 24 hr pause (cooled to RT, exposure to air).



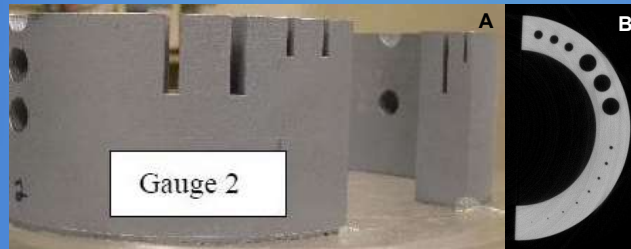
Specimen Build Layout



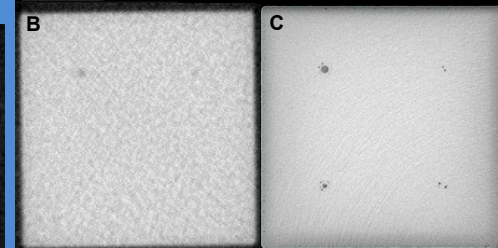
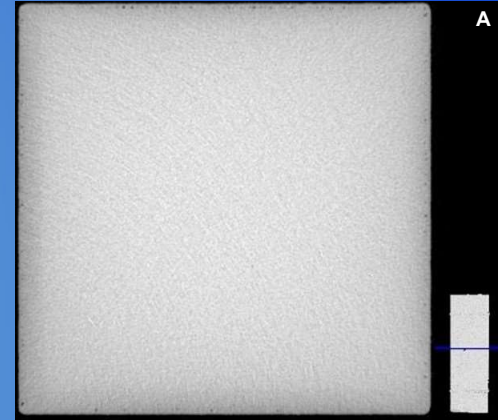
VAI Concept Laser X-Line 1000R

# CT and $\mu$ -CT NDE

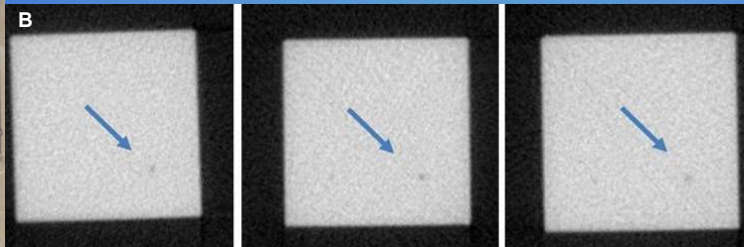
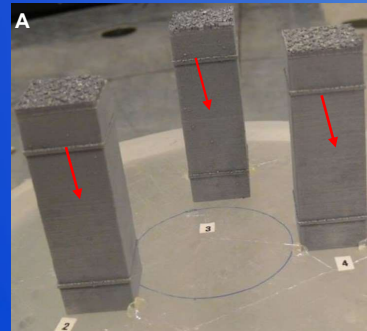
- CT (MSFC) was unable to detect the witness marks on gauge blocks even at known locations. The larger engineered defects were detected in the CT bars.
- $\mu$ -CT (3D Engineering Solutions) was able to detect the engineered flaws, edge porosity, and witness marks on the surface but no indications within the parts.
- AlSi10Mg has low radio-opacity and is easy to CT. Difficult to detect defects in radio opaque materials (Fe, Ni, Co, Nb, Mo, W base alloys).



CT gauge specimens (A) and 2 MeV Linatron image in the XY plane (B).



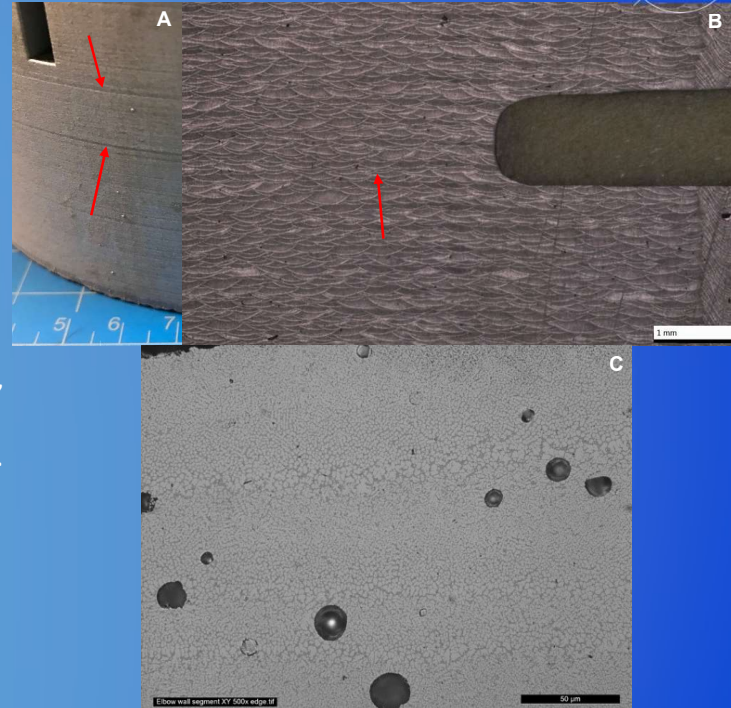
$\mu$ -CT of Bar 4 at witness mark location in XY (A). Comparison of Bar 4: 2 MeV CT image (B) and  $\mu$ -CT image (C), both in XY plane.



CT bars 1, 2, and 3 with red arrows indicating the witness marks (A). CT images show low density areas in XY plane as indicated by the blue arrows (B).

# Microstructural Characterization

- Four met blocks printed in each of four builds
  - Optical microscopy
  - Scanning electron microscopy (SEM)
  - Determine extent witness marks have on microstructure.
- Results
  - Homogeneous microstructure.
  - Density representative of L-PBF.
  - Porosity primarily observed within 500  $\mu\text{m}$  of the surface, typical for L-PBF core/counter scan interface zone.
  - Spherical gas-type pores (with a mirror-like finish) typical.
  - No indication of excessive porosity, LOF defects, etc.
  - No evidence that witness marks propagate into the bulk or induce microstructural irregularities and indicate they are a surface feature phenomenon.



Witness marks across gauge block (A), cross section optical micrograph at 50x (B) and SEM micrograph at 500x showing edge and gas porosity but no indications of the witness mark (C).



# Mechanical Testing

- Tensile Tests

- 12 cylinders ( $\varnothing 16 \times 75$  mm) printed with the semi-major axis aligned with the vertical (Z) direction.
- Cylinders machined into tensile bars per ASTM E8.
- Tests conducted by MSFC and Element Materials Technology.

Table 1: Mechanical properties between builds 1 (control), 2, 3, and 4 (exhibited witness marks).

Build	YS <sub>avg</sub> (MPa)	UTS <sub>avg</sub> (MPa)	ε <sub>avg</sub> (%)
1	170.19 ± 4.01	342.50 ± 4.66	6.5 ± -
2	171.68 ± 5.44	339.85 ± 4.86	7.08 ± 1.41
3	176.33 ± 4.45	346.40 ± 4.83	6.83 ± 1.13
4	178.86 ± 3.61	343.36 ± 3.68	6.88 ± 0.77

- Results

- Yield strength (YS), ultimate tensile strength (UTS), elongation at fracture (ε), and elastic modulus (E) were within the expected values for as-built AlSi10Mg.
- Witness marks had no statistically significant impact on YS, UTS, ε, and E.

Table 2: Mechanical properties of witness mark across specimen gauge section.

Data Set	YS <sub>med</sub> (MPa)	UTS <sub>med</sub> (MPa)	ε <sub>med</sub> (%)	E <sub>med</sub> (GPa)
VAI - 3	176.33 ± 4.45	346.40 ± 4.83	6.83 ± 1.13	-
MSFC - 1	163.75 ± 0.69	337.71 ± 0.90	6.24 ± 0.84	72.19 ± 2.96



# Conclusions

- Conclusions

- AlSi10Mg specimens were produced through L-PBF and paused for various time intervals.
- CT,  $\mu$ -CT, metallographic, and mechanical test results indicate that witness marks are a surface phenomenon that do not propagate into the bulk of an L-PBF AM component.
- No statistically significant change of mechanical properties in AlSi10Mg parts associated with the location of a known witness mark.
- Results help differentiate between acceptable features of the AM build process from unacceptable flaws such as LOF defects and cracks.
- The ability to accurately assess build quality issues has the potential to improve build success rate and reduce production costs.
- Results be utilized by acceptance criteria guidelines for better informed decisions on when to scrap AM parts with witness marks vs. when continue with post-processing.

- Recommendations for future work

- Witness mark impact on low cycle fatigue (LCF) and high cycle fatigue (HCF) is unknown.
- Surface finish influences fatigue life and witness marks could act as fatigue initiation sites.
- The impact of witness marks on LCF/HCF and post-process surface finish modification to mitigate potential negative impacts should be investigated.



# Acknowledgements

- The authors would like to thank Marvin Barnes, Jeffrey Clouch, Ken Cooper, Samantha Mcleroy, David Myers, and Jason Turpin of NASA MSFC; Element Materials Technology; and 3D Engineering Solutions.
- This project was funded under NASA Cooperative Agreement Notice #NNM16567212C.
- The opinions expressed in this presentation are those of the author and do not necessary reflect the views of NASA or any NASA Project.

