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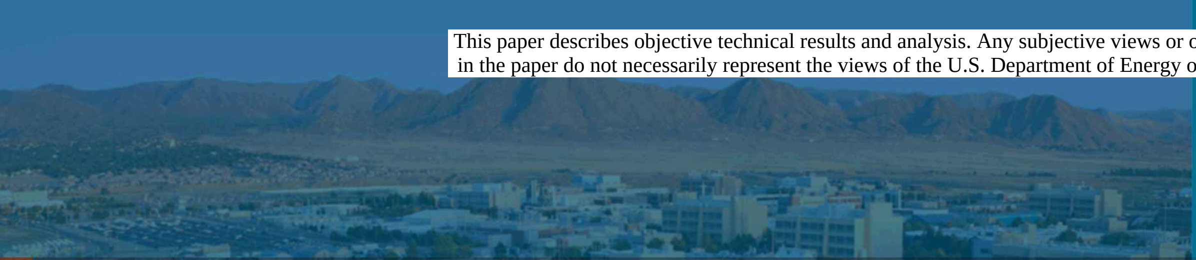

The Effect of Various Geometrical Flaws on Additive Manufactured Component Performance

Christopher Laursen[1], Jay Carroll[1], Stephanie DeJong[1], Jody Bartanus[2], Benjamin Smith[2], Garrett Pataky[2]

[1] Sandia National Laboratories, Albuquerque, NM, USA

[2] Clemson University, Department of Mechanical Engineering, Clemson, SC, USA

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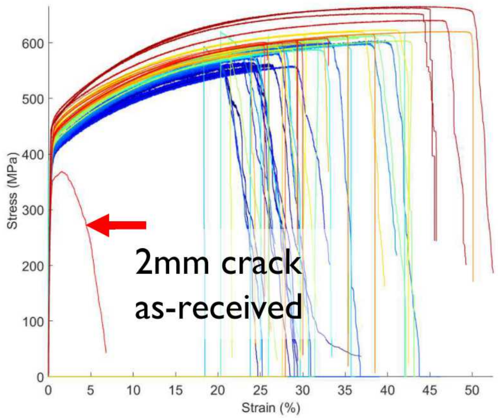
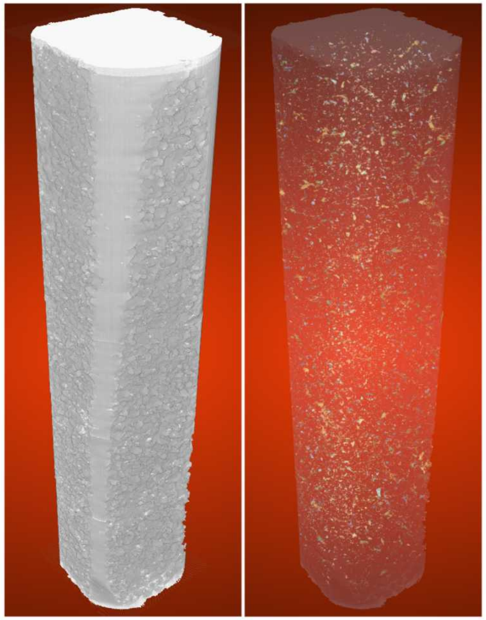
Importance of Flaws in Additive Manufacturing

- Additive manufacturing known to have a variety of internal flaws
  - State of the art equipment and manufacturing processes reduce these flaws, but they are ever present
  - Results in high part rejection and/or avoidance of the technology
- Need alteration in paradigm: Consider a flaw tolerant approach
  - To do so we need to understand what type of flaw needs to be rejected
  - Potential Rejection Parameters
    - Flaw Size
    - Flaw Shape
    - Flaw Density/Proximity
    - Flaw Location
    - …
  - Use non-destructive testing to detect the critical flaw

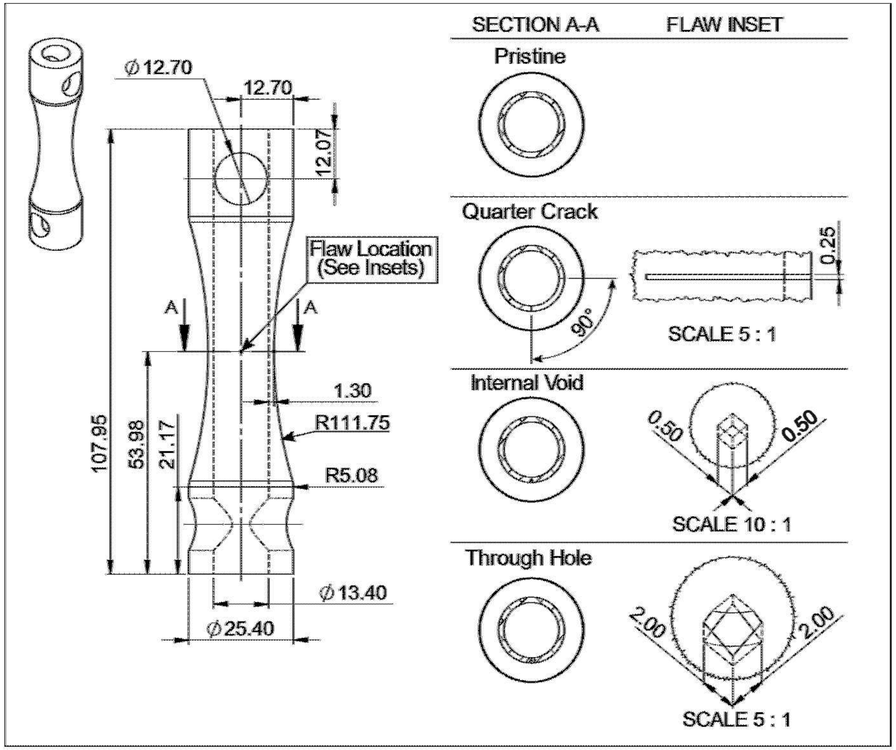
45 AM 304L medium conventional tensiles

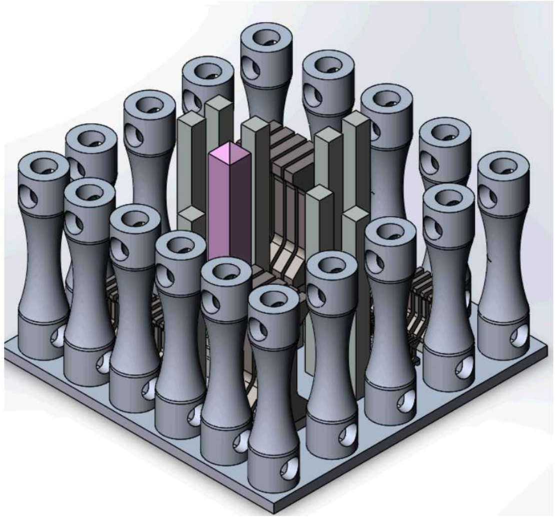




Study Approach: Inclusion of Intentional Flaws

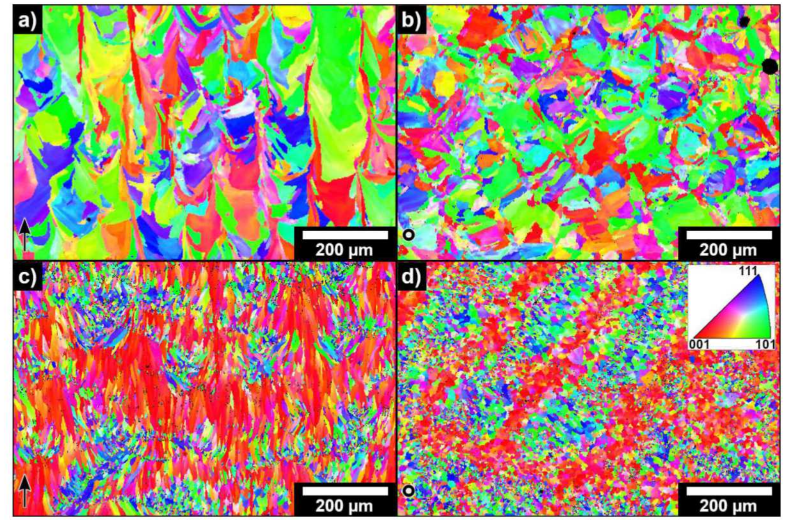
- Design an exemplar component with known failure region
- Add large geometrical flaws which will dominate over uncontrolled flaws
- Observe in two AM materials
  - Ductile 316L Stainless Steel
  - Brittle AlSi10Mg (As-Printed)



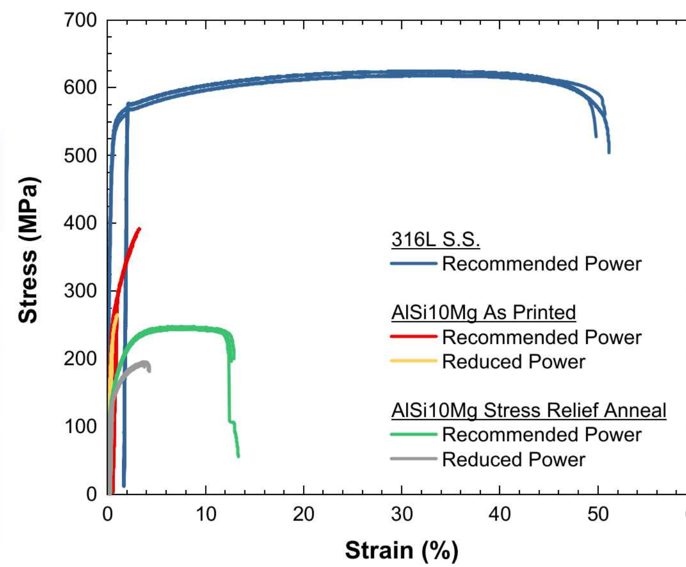


Material Characterization

- Need baseline material characterization before inclusion of flaws
- Testing on coupons adjacent to exemplar components on the build plate
- Experiments included:
  - Tensile testing
  - Compression testing
  - Fracture toughness
  - Charpy impact testing
  - Computed Tomography (CT)
  - Metallurgy/EBSD
  - Archimedes Density



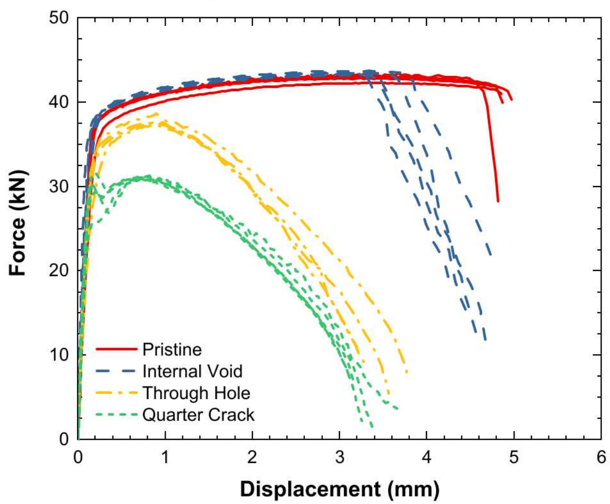
Material		ρ (%)	E (GPa)	σ_y (MPa)	σ_{UTS} (MPa)	ε_{tot} (%)	Impact (J)
316L S.S.		99.2	161	511	620	50.6	63
AlSi10Mg As Printed	Rec.	99.4	63	260	380	3.0	1.5
	Red.	99.4	53	243	261	0.95	1.0
AlSi10Mg Stress Relief Annealed	Rec.	94.5	63	136	245	12.7	11.5
	Red.	94.5	53	130	194	4.1	3.0

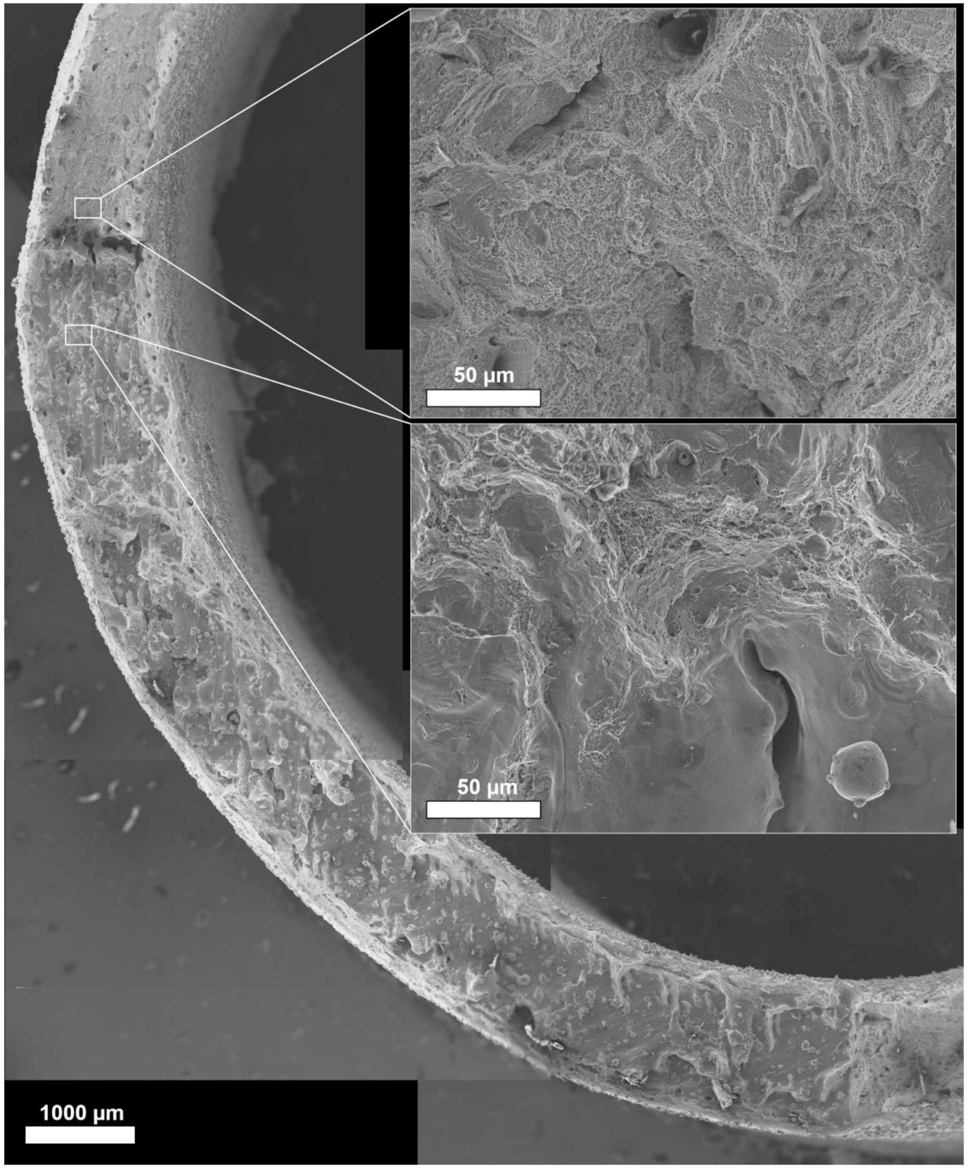


Stainless Steel 316L - Geometric Flaw Dependence

- Ductility qualitatively follows area
- Fractography observes ductile dimples
- Significant strain hardening
- Pop-in event from quarter crack rupture

Geometric Feature	Area (%)	Peak Load (%)	Max Disp. (%)
Pristine	100.0	100	100
Internal Void	99.6	100	94
Through Hole	96.1	89	75
Quarter Crack	75.0	73	73

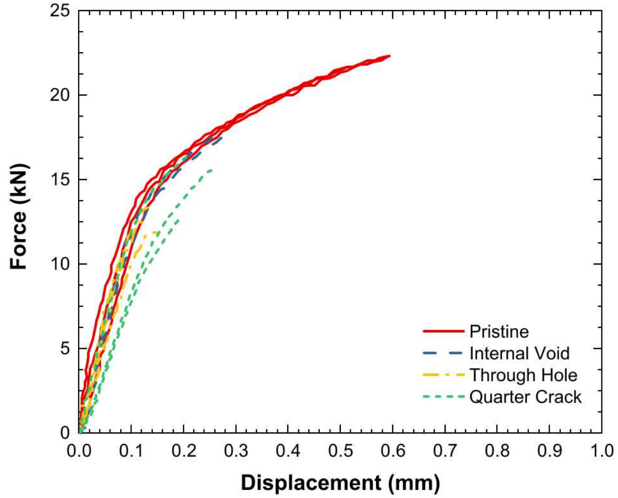


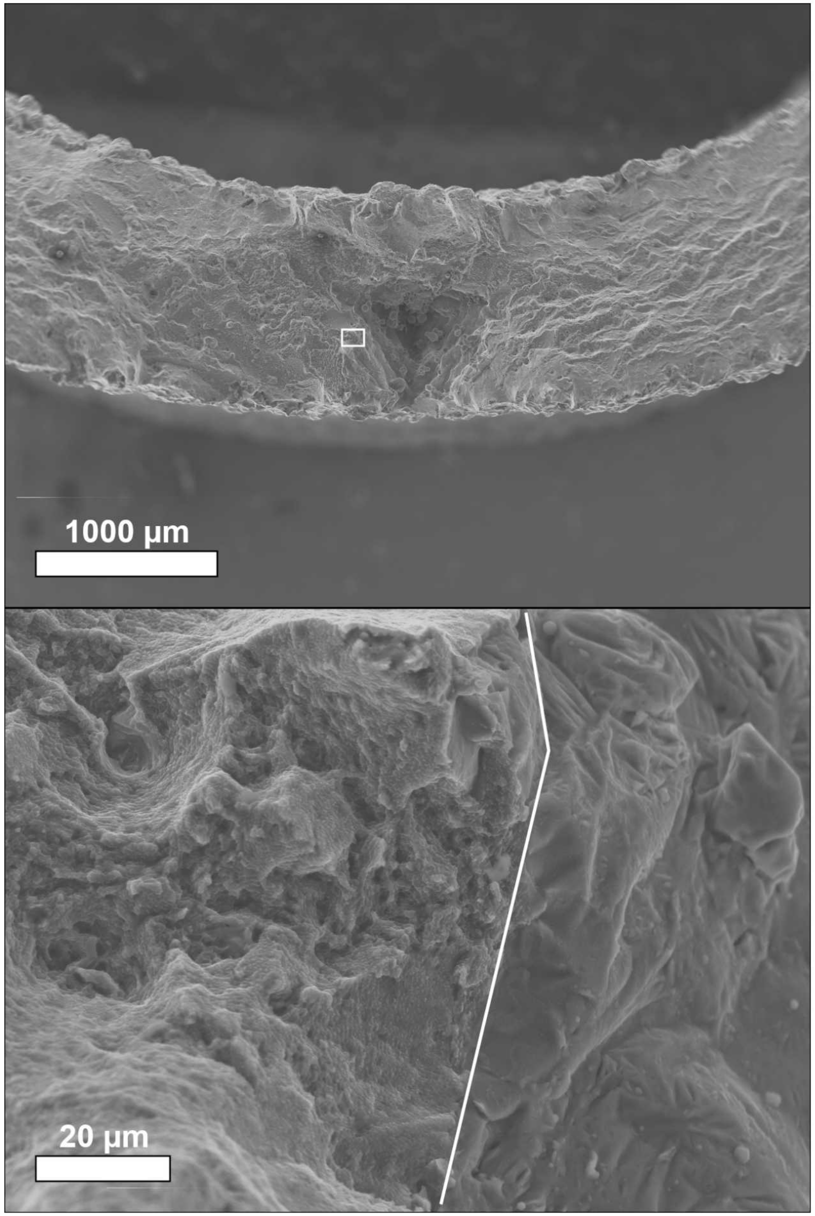


AlSi10Mg - Geometric Flaw Dependence

- No signs of ductile dimples
- Minimal strain hardening
- Adding a flaw (regardless of area) significantly weakens the part

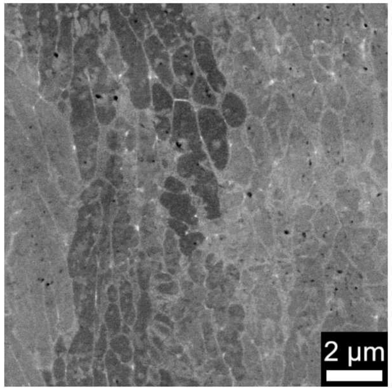
Geometric Feature	Area (%)	Peak Load (%)	Max Disp. (%)
Pristine	100.0	100	100
Internal Void	99.6	77	47
Through Hole	96.1	56	23
Quarter Crack	75.0	67	38





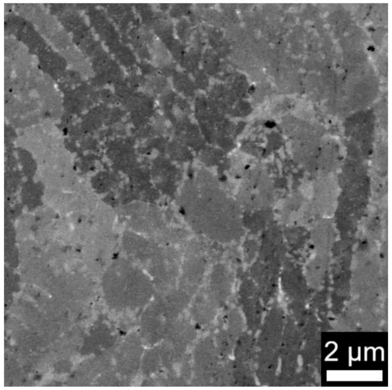
Stress-Relief Annealing of AlSi10Mg

- Stress-relief annealing heat treatment breaks down silicon cellular network, increases ductility
- Material behavior transitions from brittle to ductile
- Flaw dependence begins to transition from geometry to cross-sectional area dependent

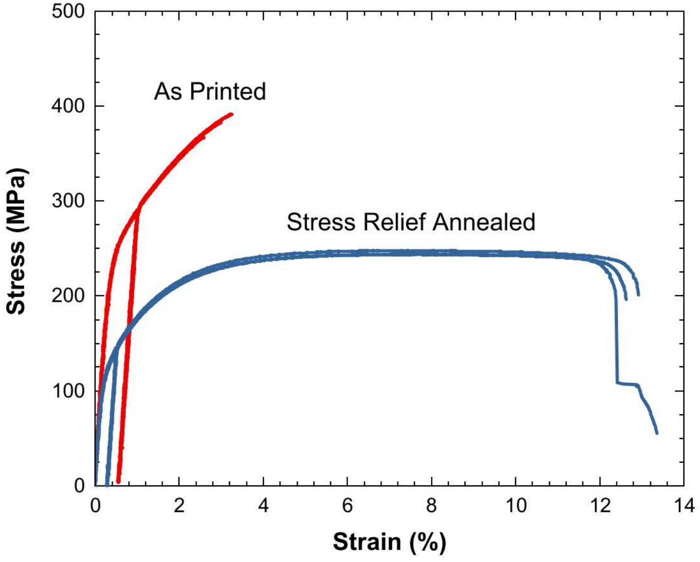


S.R.A.

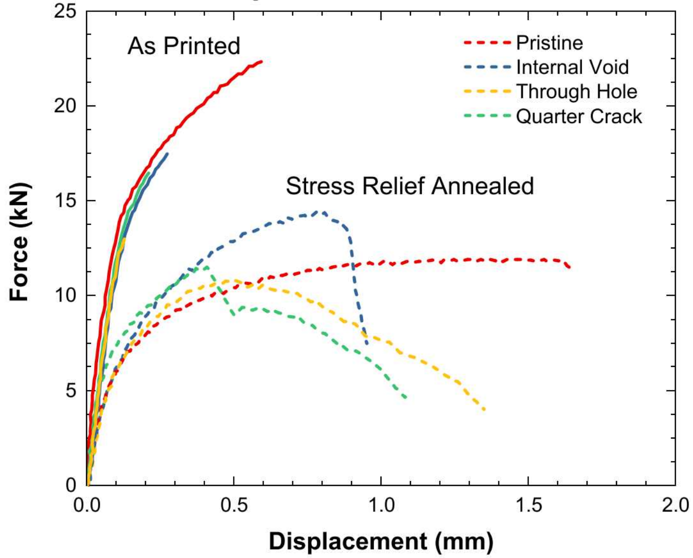
200°C
2 Hrs.



Material Behavior

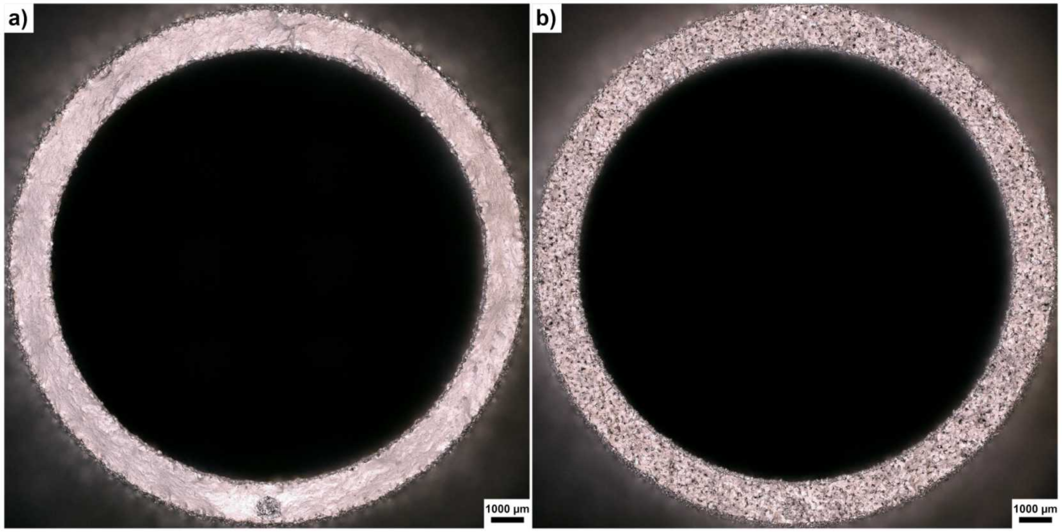


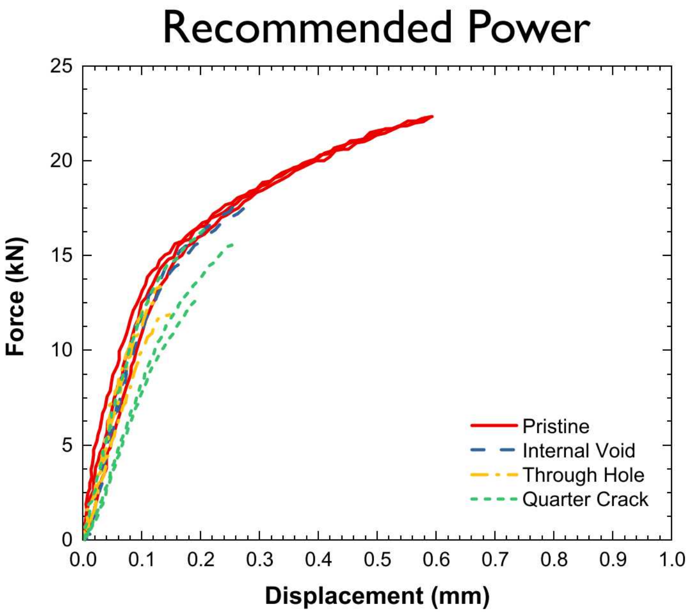
Component Behavior

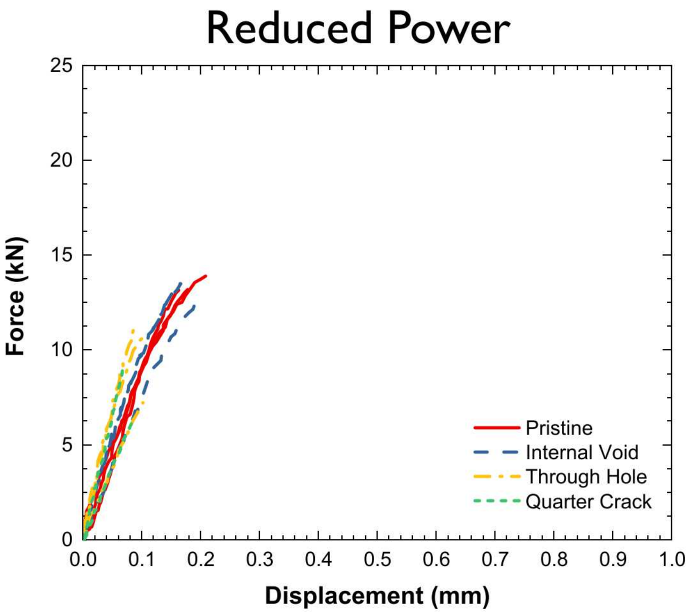


Bulk Porosity in Exemplar Components

- Build parameters have large effect on bulk porosity
- Observe two build plates of AlSi10Mg
  - Recommended power condition
  - Reduced power condition (50% of recommended power)
- High sample porosity will dominate over a single, large, geometrical flaw

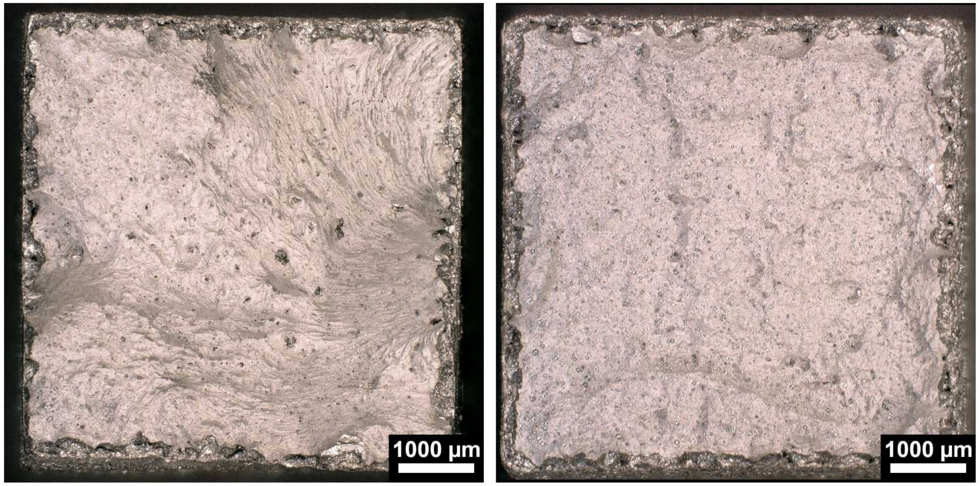


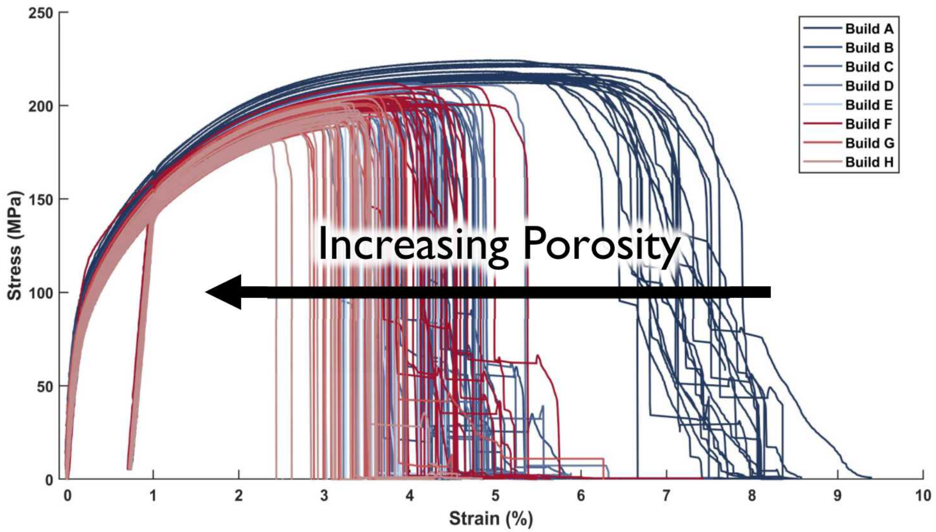


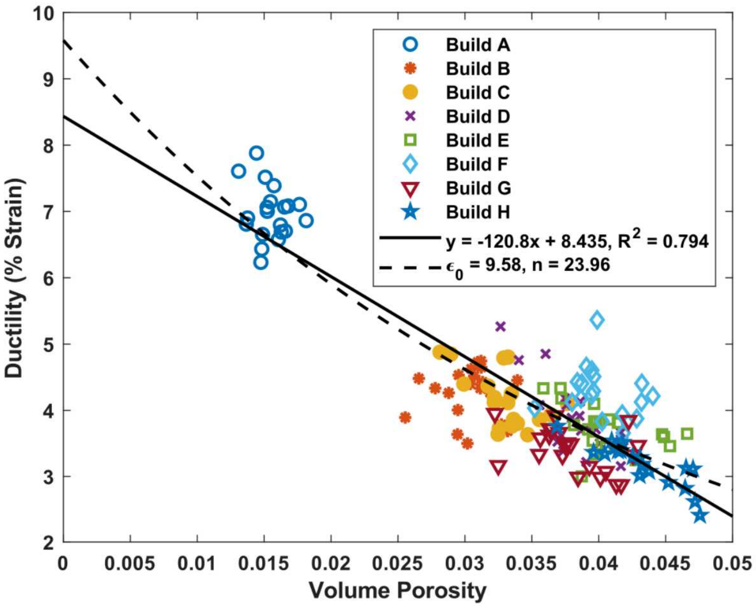


Bulk Porosity Effect on Mechanical Properties

- Compare mechanical results to a known decrease in porosity on tensile samples off eight AlSi10Mg build plates
  - Porosity increase due to powder re-use in subsequent build plates
- Strongest correlation: Ductility and Porosity

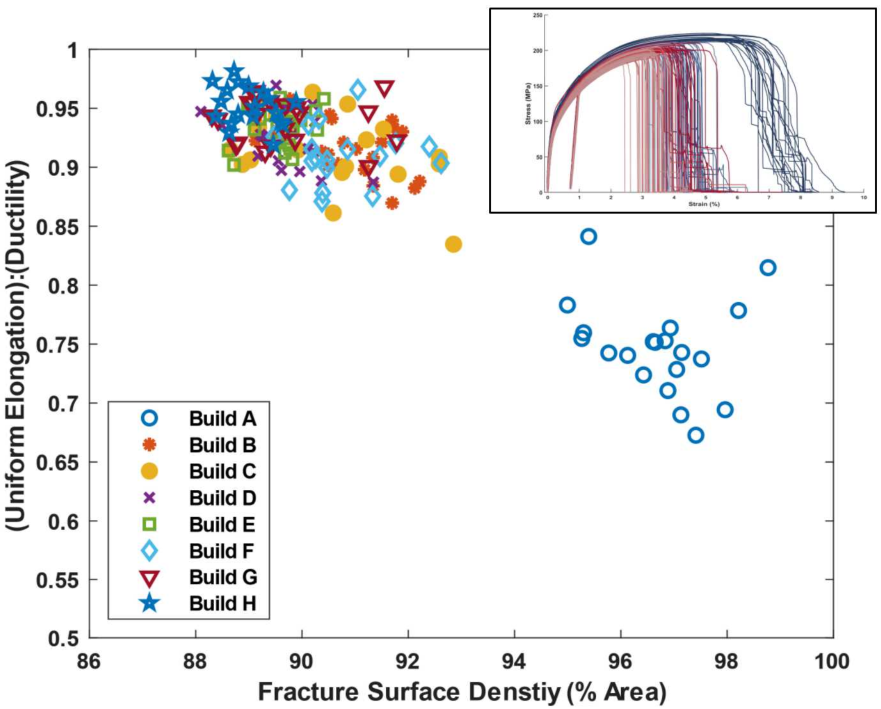


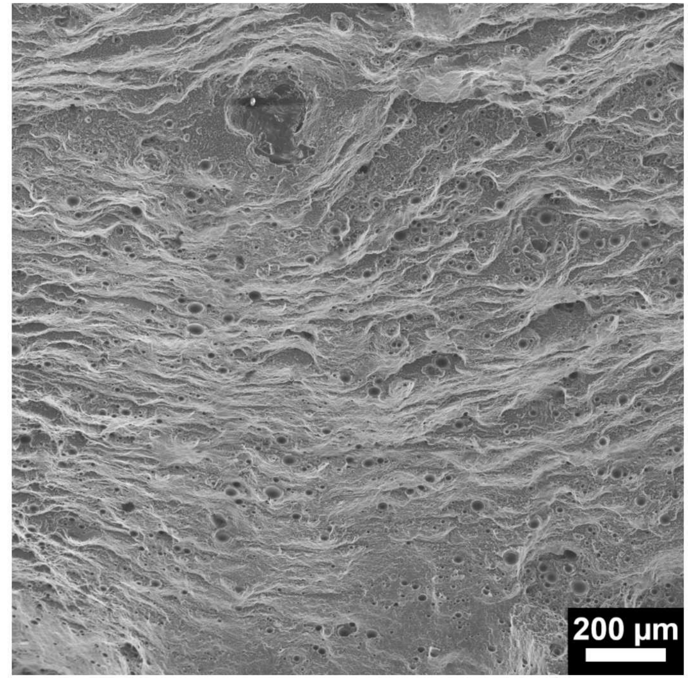


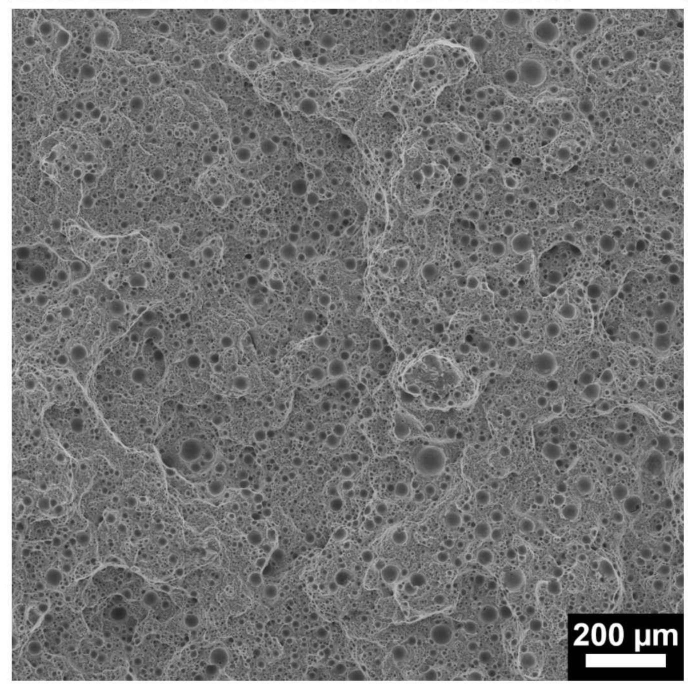


Reduction of Necking

- As part density decreases, ratio of uniform elongation to ductility approaches 1
  - Indicates no necking of parts
  - Attributed to transition in failure type from void nucleation, coalescence, and growth to coalescence of small voids







Conclusions

1. Inherent material ductility matters to flaw sensitivity in AM parts
   1. Ductile materials show dependence on area
   2. Brittle materials show a dependence on flaw shape (stress concentration)
2. A high concentration of small pores can dominate behavior over a single, large flaw
3. Ductility and failure type can be predicted by the porosity levels