Three-Dimensional Reconstruction of Defects and Structures in Additively Manufactured Parts with Automated Serial Sectioning

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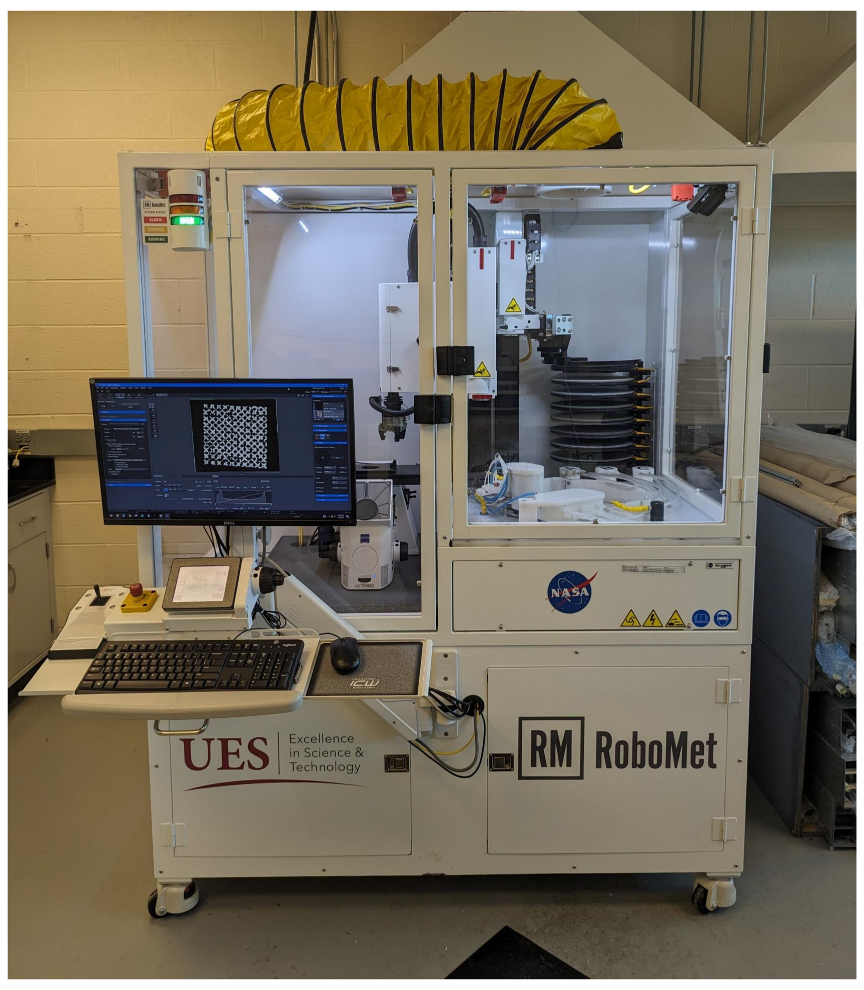
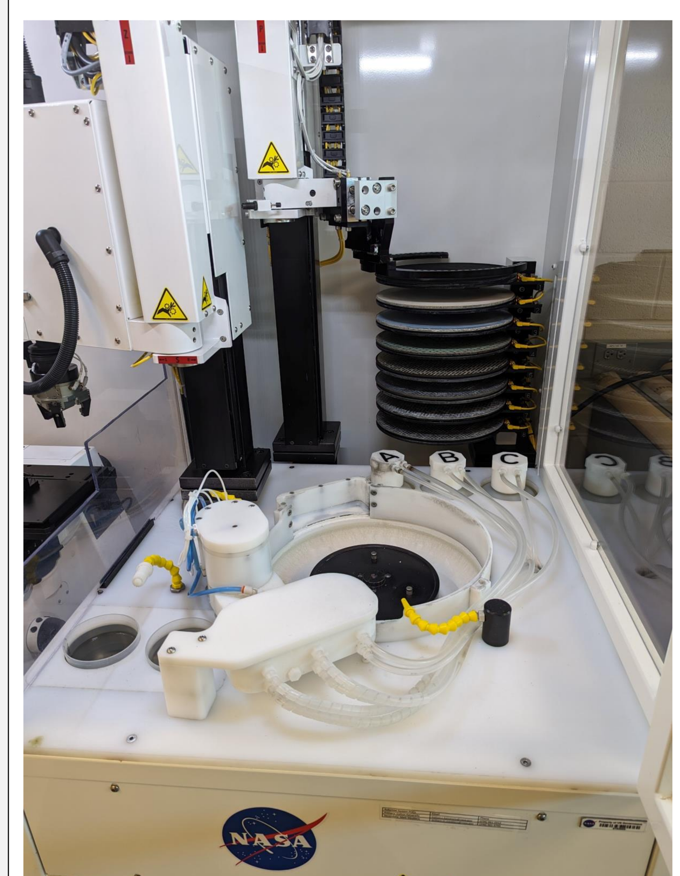


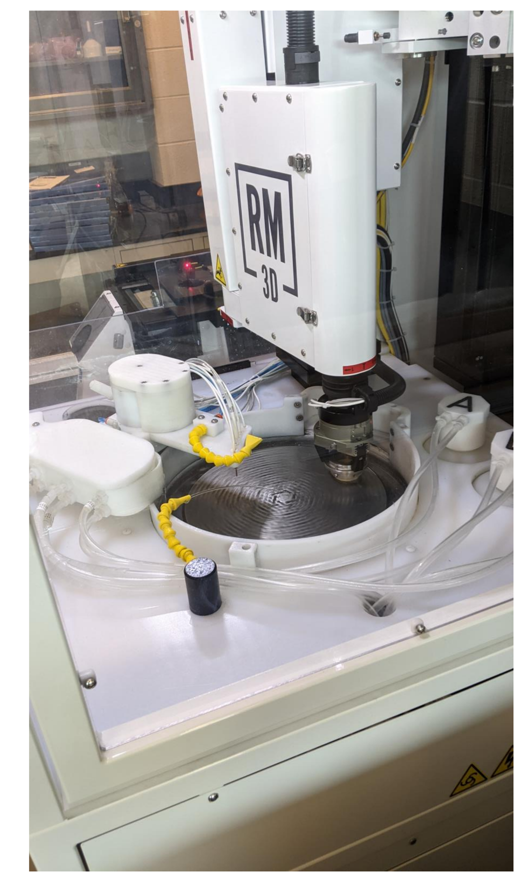
RoboMet.3D Overview

- The RoboMet.3D automated serial sectioning system is designed to automate the serial polishing process to analyze materials in 3 dimensions
- Manual serial polishing is extremely tedious and time consuming to perform with consistent removal rates
- RoboMet automates the process allowing the work to be done in days with limited interaction

System Information:

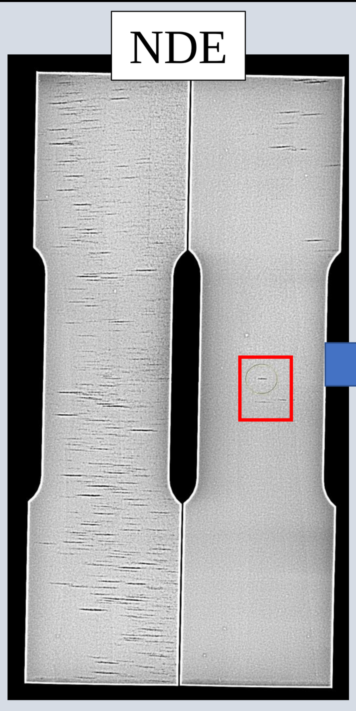
- 1 robot head to move sample between polishing, cleaning, and imaging steps
- 1 robot head to replace polishing/grinding platens
- 8 platen holder for grinding and polishing pads
- 6 solution dispensing heads for polishing solutions
- 3 dip wells for cleaning or etching solutions
- 2 ultrasonic dip wells for sample cleaning
- Platen and sample rinse nozzles for water cleaning during and after polishing
- Zeiss AxioObserver metallograph for automated imaging of samples each slice



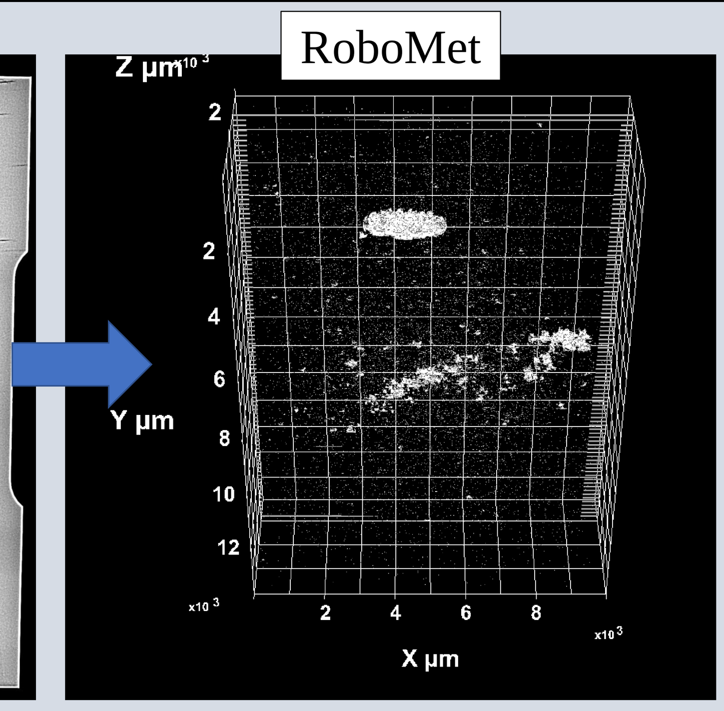


Non-Destructive Evaluation (NDE) Validation

NDE

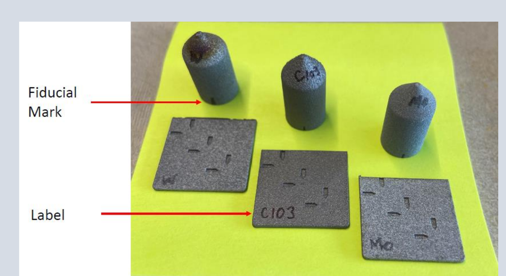


RoboMet

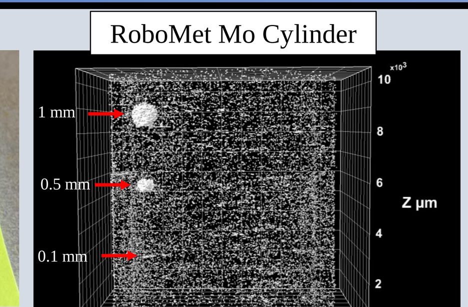


- A study using L-PBF NASA HR-1 examined the detectability of various diameter and thickness cylindrical seeded defects
- RoboMet data was used to determine the actual size of the seeded defects built by skipping layers or changing the laser power
- Initial RoboMet runs determined that many of the designed defects were shorter than intended which helped to explain why many were undetected by NDE
- After seeded defect redesign and rebuild, defects were detected by NDE and RoboMet. These often appeared as rings due to material sintering/remelting of subsequent layers above the defects

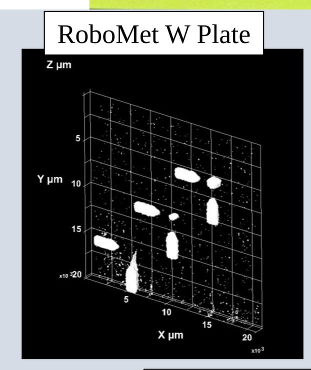
- Used in tandem with NDE, the RoboMet can evaluate the finer details of defects in parts and determine more accurate sizes of defects
- Seeded defect studies have been utilized in additive manufacturing (AM) to identify the limitations of NDE techniques on AM parts, however validating the data often required destructive analysis to know the actual sizes of defects
- In one study of L-PBF JBK-75 (left), additional process related defects were induced during the build which were picked up by low resolution radio tomography and found to be large lack of fusion defects surrounded by smaller micro-cracks not detected in NDE



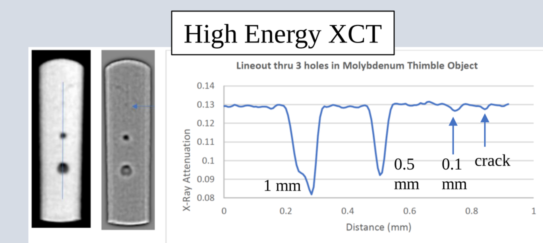
RoboMet Mo Cylinder



RoboMet W Plate



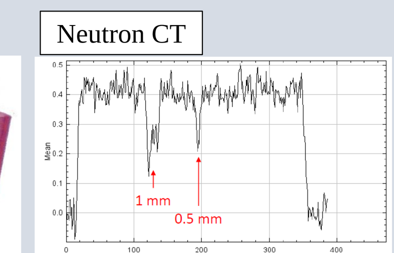
High Energy XCT



RoboMet Detection

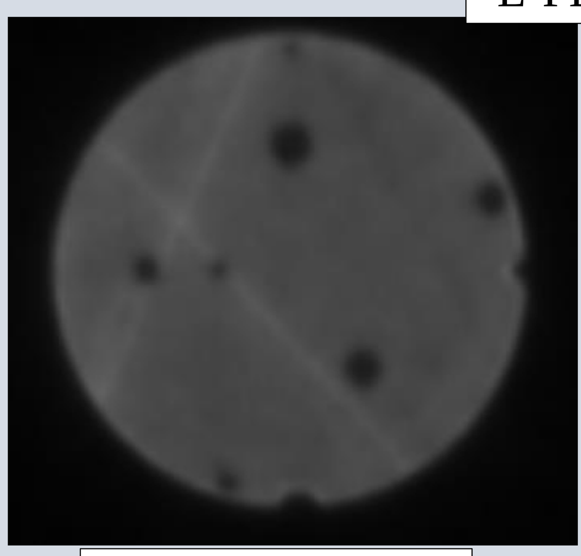
Sample Material	Sample Design	0.1 mm	0.5 mm	1.0 mm	PLOF
Mo	Plate				N/A
	Thimble				N/A
	Step-Cake	Crack	N/A	N/A	
C103	Plate				N/A
	Thimble				N/A
W	Plate				N/A
	Thimble				N/A

Neutron CT

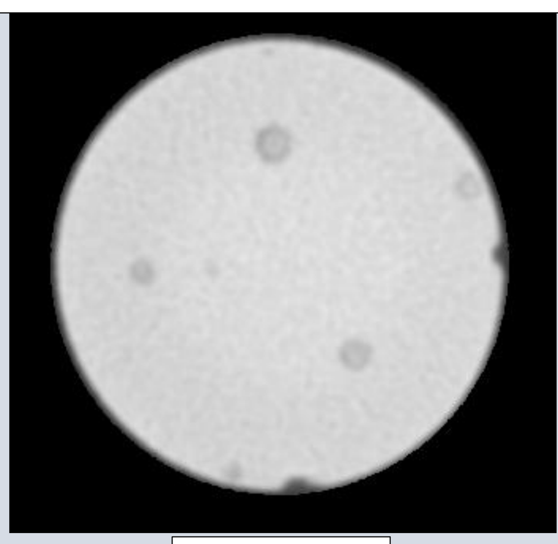


- With the increasing interest in refractory alloys in AM, methods for part NDE need to be evaluated to determine the limits and accuracy for use with alloys known for x-ray and neutron absorption
- In a study comparing high energy x-ray computed tomography (XCT) and neutron CT, RoboMet data was used as a control to determine the actual size of designed defects and if they were printed for comparison to XCT and neutron CT
- While some of the smallest seeded defects didn't build to designed size, the comparison of RoboMet data and NDE data was able to determine a threshold region of detectable defect sizes for W, Mo, and C103. RoboMet data was also able to inform future seeded defect sample designs

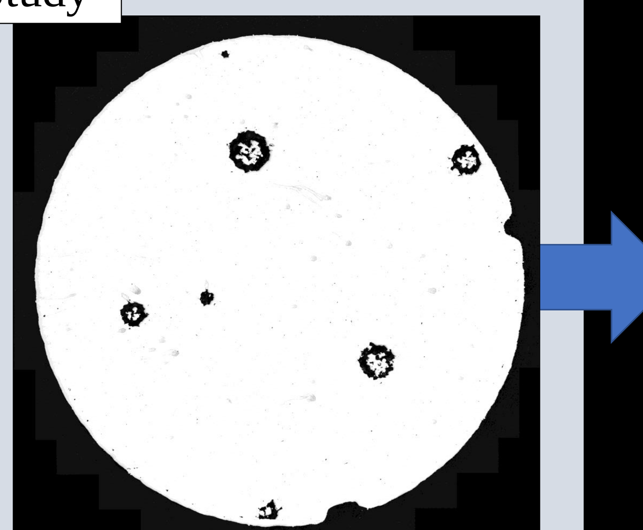
L-PBF NASA HR-1 Seeded Defect Study



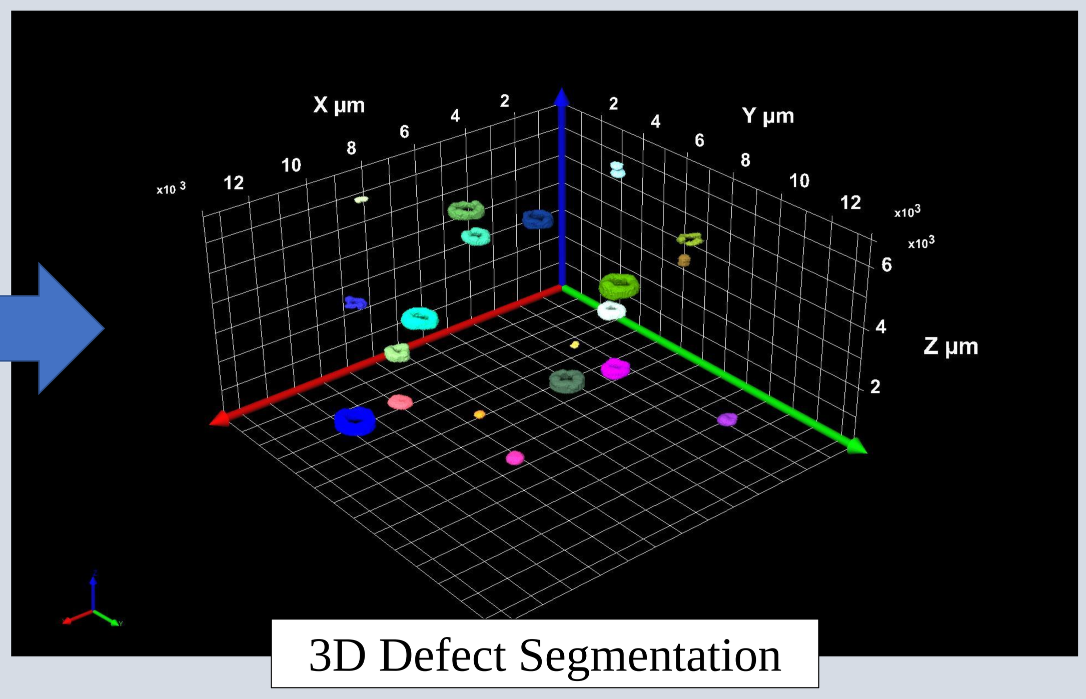
In-Situ Monitoring



CT Slice



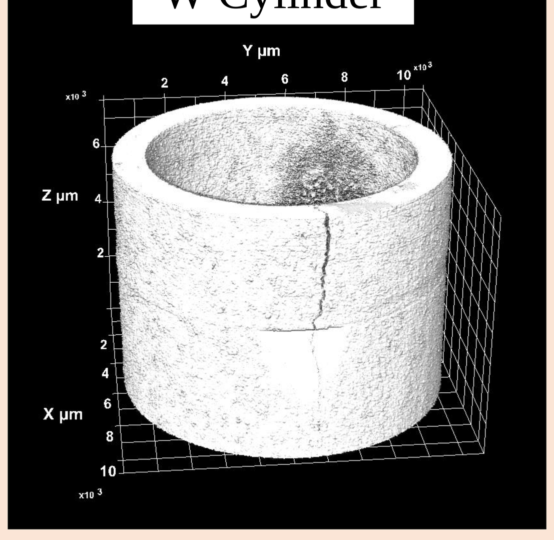
RoboMet Slice

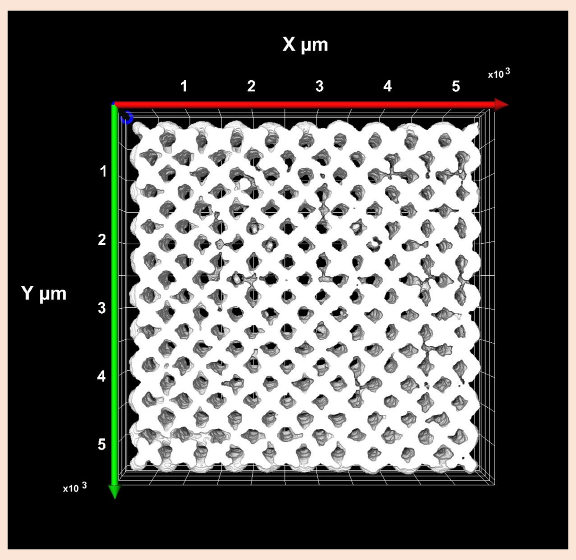


3D Defect Segmentation

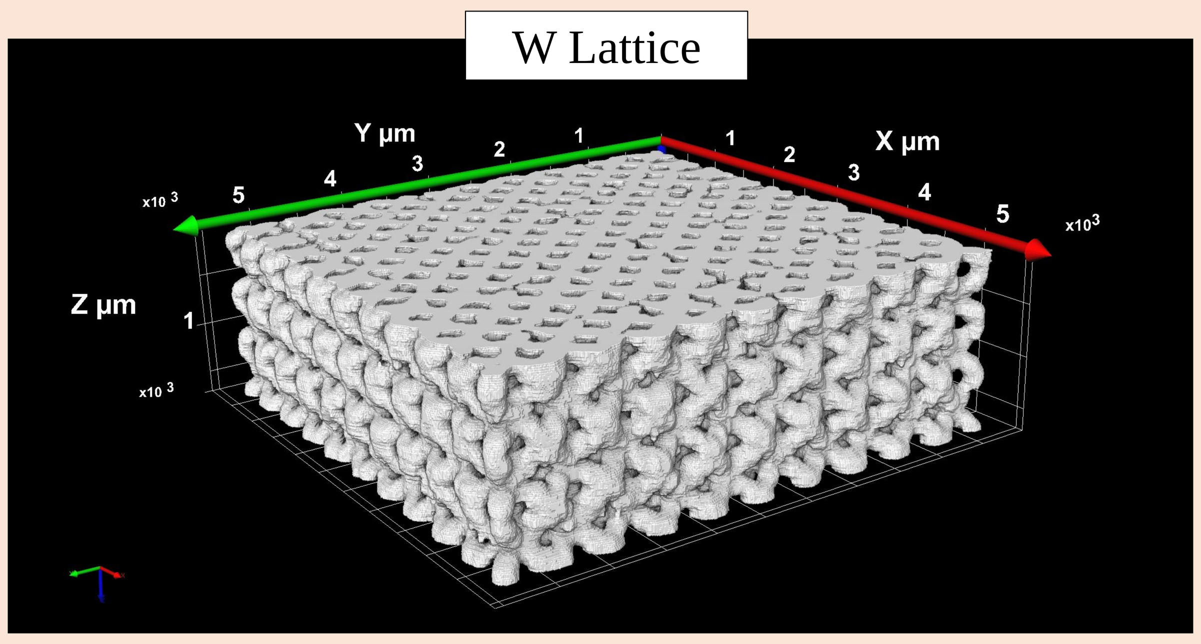
3-D Surface Reconstruction

W Cylinder





W Lattice



- Slice data from the RoboMet is also used to examine and measure external structures and surfaces as well as internal structures.
- Fine lattice structures can be built with laser powder bed fusion (L-PBF) AM for applications such as catalysts and heat exchangers where high surface area is needed in small volumes.
- To confirm the size of the lattice struts, 2D analysis through scanning electron microscopy has been used, however 3D reconstruction through serial sectioning has been utilized to examine larger volumes of lattices to confirm quality of the built design
- Reconstruction of AM surfaces from automated serial sectioning has also been utilized by external companies to create inputs for modeling tools used to examine the influence of internal and surface features on fatigue properties of AM parts

Additional Work

- Studies to utilize the etching capabilities of the RoboMet are planned. Safe and consistent automated procedures need to be developed for full examinations
- These efforts will examine changes in the grain structure throughout a volume of thin walls to determine potential weak areas where few grains form across a wall of a nozzle in LP-DED
- Additional studies of seeded defects could also include etching to examine the grain structure in and around seeded defects before and after heat treatment to characterize how large defects may appear in practice

LP-DED JBK-75 Thin Wall

Large Seeded Defect Post HT