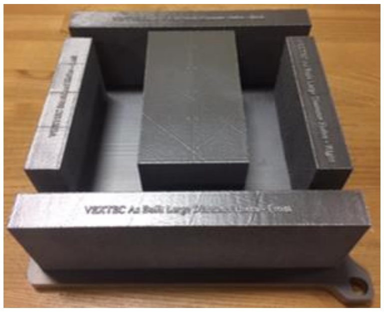
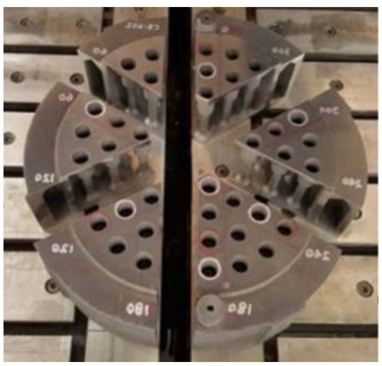
VEXTEC®

Unlocking the Power of Additive Manufacturing with VPS-MICRO®



Additive Manufacturing has the potential to revolutionize how we design, produce, and deploy complex components for critical applications. VEXTEC has worked with AM leaders in R&D (Ti-6-4 alloy blocks at Oak Ridge National Laboratory; image above) and in industry (nickel superalloy rocket nozzle at Aerojet Rocketdyne; image below).



OVERVIEW

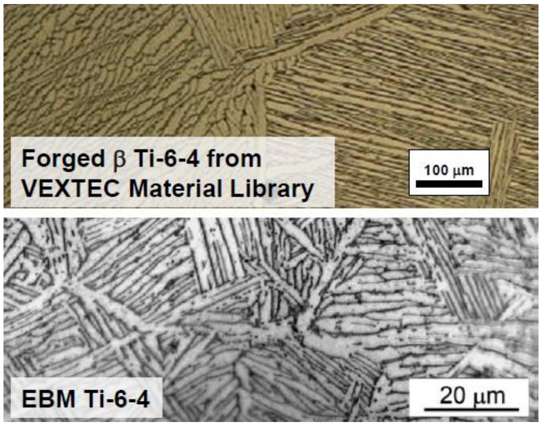
While the concept of 3D-Printing – or Additive Manufacturing (AM) – is not necessarily new, it has certainly gained much more traction in the last decade. This is because digitization is continually drawing the design and manufacturing domains closer together. AM methods like powder bed fusion processes (direct metal laser sintering [DMLS], electron beam melting [EBM], selective laser melting and sintering [SLM and SLS]) as well as newer techniques like directed energy deposition [DED] and binder jetting, are based on the translation of 3D computer design information to the physical build space. The thought of creating the right-sized component, just when it's needed, and without waste nor the need for much further machining is very appealing. Robotic manufacturing certainly impresses with its ability to repetitively perform tasks, and when linked to CAD/CAE files via AM, this would theoretically give way to more complex geometries, tighter process control and lower part-to-part variability. In reality however, this is not always the case. Many sources of variability persist in AM, just as they do in traditional manufacturing processes, and have substantial impact on the durability performance of the final components. What are the primary types of variability seen in AM and the obstacles to widespread adoption? How does our predictive VPS-MICRO® technology help companies and organizations gain confidence in working with these powerful manufacturing methods?

THE PROBLEM

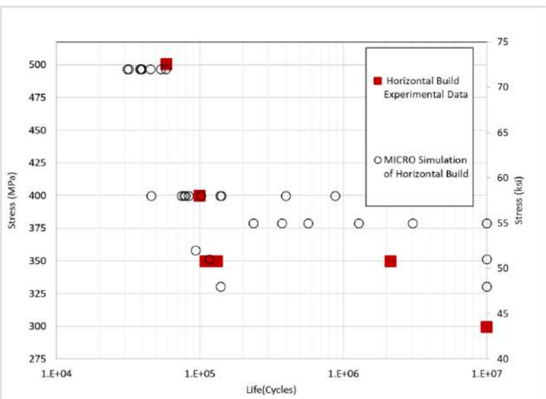
The recent rise of AM is thanks, in large part, to innovations along many fronts: 3D modeling/design, suitability of processed raw material, and AM machine development. Each type of AM method requires a different machine, and the multitude of settings on each machine must be dialed-in through exacting, repeated trials in order to create viable parts. To add complexity to the issue, researchers and industry colleagues alike have found any given type/brand of AM machine that makes parts in one facility will NOT make those same parts in another facility (even with the same machine settings). The machines themselves are highly sensitive to a host of factors, including location, time of day, and raw material feed powder stock characteristics. For example, an entire sub-industry is centered around AM metal powder recycling: how many times can it be recycled before substantial degradation in properties is apparent, best practices for mixing and homogenizing virgin powder with recycled powder; etc. Depending on the "speed and feed" parameters of the machine, there will be defects built into the parts (voids, non-fused powder, layer melting/re-melting zones). Corner, edge, and overhang effects are magnified by these process variabilities. The challenges that face international standardization groups like ASTM F42 are put succinctly: how can AM "processes" be certified when AM "machines" demonstrate such wide sources of variability? Both static (overload bursting conditions) as well as cyclic (fatigue at nominal loads) performance are critical metrics for determining how useful and robust AM methods can be to the industry at large. Engineers at Oak Ridge National Laboratory (ORNL) and Aerojet Rocketdyne tackle these issues daily, and each have recently partnered with VEXTEC to help quantify and manage the risks to performance that are associated with Additive Manufacturing.

THE SOLUTION

VEXTEC used its experience in material modeling, in concert with our predictive VPS-MICRO software, to evaluate the effects of AM on simple geometry specimens (ORNL) and complex geometry parts (Aerojet). As with any manufacturing, the signature of a component's processing history lies within its material microstructure. Grain size, orientation, defect size and population distributions, strengthening mechanisms…they are all products of the specific AM technique and raw materials used. VPS-MICRO is a mechanical behavior modeling technology (not a process modeling technology), and it uses these quantifiable microstructural parameters to build a virtual representation of the material in a 3D digital space. The software computationally marries this material information with established design/structural analyses (finite element modeling packages like ANSYS and Abaqus) to provide durability predictions that capture the true physics of failure.



Above: example of microstructural differences in forged titanium alloy vs. Additively Manufactured (EBM) titanium alloy of the same chemical composition. Below: predicted fatigue lives using VPS-MICRO compared to experimental testing of EBM-produced titanium alloy specimens.

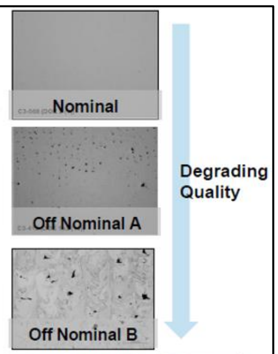


THE RESULTS

At ORNL's Manufacturing Demonstration Facility, test blocks of Ti-6Al-4V alloy were created via EBM. The goal was to predict the fatigue performance of specimens harvested from these blocks. Previous VEXTEC work included modeling of conventionally-forged/heat treated Ti-6-4 material. By understanding the microstructural differences between the EBM and the forged material, VEXTEC adapted the modeling parameters of the conventionally-produced alloy in order to capture the nature of the variabilities introduced by the AM technique. VEXTEC then used VPS-MICRO with this adapted material model to predict fatigue durability.

Aerojet Rocketdyne was evaluating the effects of "off-nominal" SLM machine settings on the resulting microstructure for a rocket nozzle. The component was made from Mondaloy, a nickel-based superalloy that exhibits high strength in oxygen-rich environments and thus a prime target for rocket engine manufacturers. Aerojet determined there were a multitude of distinct microstructural states arising from the transitions between the "nominal settings" and the "off-nominal settings". At each setting, the microstructure varied throughout the part. VEXTEC employed VPS-MICRO to input those material parameters, and accurately predicted both the burst test location and the range of static burst test pressure for various AM machine settings. Studies like these allow us to build on current understanding of material engineering, to help create computational methods for AM certification.

Unit	Operating Pressure	Proof Pressure	Vextec Calculated Burst	Actual Burst
Nominal	6.5 KSI	7.8 KSI	>13 KSI	15.022KSI
Off-Nominal A	6.5 KSI	7.8 KSI	11-13 KSI	12.218 KSI
Off-Nominal B2	6.5 KSI	7.8 KSI	11-12 KSI	In Process
Off-Nominal B3	6.5 KSI	7.8 KSI	11-12 KSI	10.555 KSI



VEXTEC partnered with Aerojet Rocketdyne to use computational modeling via VPS-MICRO, to help predict the effects of the variable processing nature of AM. As the machine settings move "off-nominal", the material microstructure becomes more degraded (more voids/defects present). The VPS-MICRO material modeling capability captures the variability seen in the material microstructure, and the subsequent effects on performance.