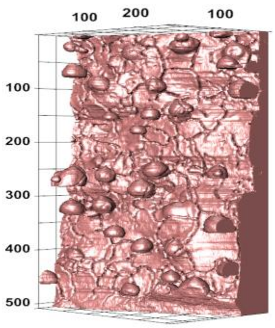
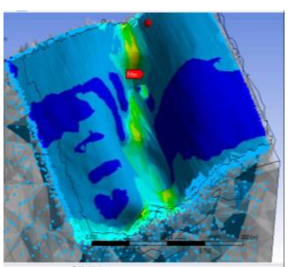
Utilizing VPS-MICRO® to Predict As-Printed Surface Effects on Fatigue Performance in Additive Manufacturing



AM as-printed surfaces contain a multitude of features (image above) that can impact fatigue performance. VEXTEC incorporated the critical features as stress distributions (image below) and as distinct material layers in its VPS-MICRO modeling.



OVERVIEW

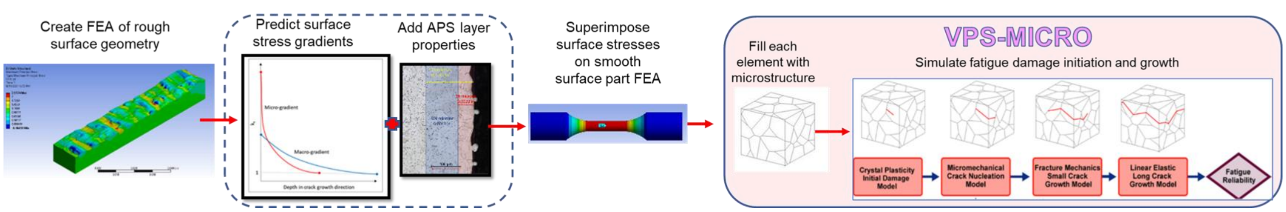
VEXTEC extended the modeling capabilities of its commercial VPS-MICRO software to predict the fatigue life debit of additively manufactured (AM) components due to as-printed surface (APS) features. In addition, a standard work protocol has been developed to integrate these types of computational models within existing certification procedures for critical industries.

THE PROBLEM

Metallic AM technologies offer the potential for 30-60% cost savings on complex, high-value parts in the aerospace industry. Much of this is through reducing machining costs – by some estimates, as much as 20% of a part's cost can be incurred during post-build machining to remove surface roughness effects. Another major potential for savings in AM is the ability to build geometrically complex structures. This allows for an assembly to be made up of fewer individual parts that need to be fastened or jointed together. However, these complex geometries result in hard-to-access surfaces that cannot be easily machined. If an AM part can retain its as-printed surfaces (or be only selectively machined) and still meet its performance requirements, that is a huge win. The problem is, there have been no reliable methods to computationally predict the impact of an AM as-printed surface (APS) on fatigue performance for metal parts…leading to large amounts of testing.

THE SOLUTION

VEXTEC has enhanced the capabilities of our commercial VPS-MICRO® software to accurately predict fatigue performance of AM APS components. Structural finite element analysis (FEA) is used to model the surface roughness resulting from the APS features, expressed as a random field of surface features (peaks and valleys). FEA predicts the statistical distribution of stress concentrations of the roughness. Some of the surface crevices observed in the specimens were so sharp that they act as crack-like features; these were modeled with stress intensity factors at the microstructural size scale. The interaction between the stress concentration and the stress intensity (at both the micro and macro scales) drive fatigue crack nucleation and small flaw crack growth at the rough surface. Microstructural differences between APS layer(s) and the core material are also identified and characterized. The statistics of these stresses and microstructural layers were then used in VPS-MICRO fatigue analysis simulations. The modeling fidelity is robust enough such that selective machining can be evaluated and optimized (i.e., certain surfaces of a component are post-build machined, while others retain the as-printed surface).

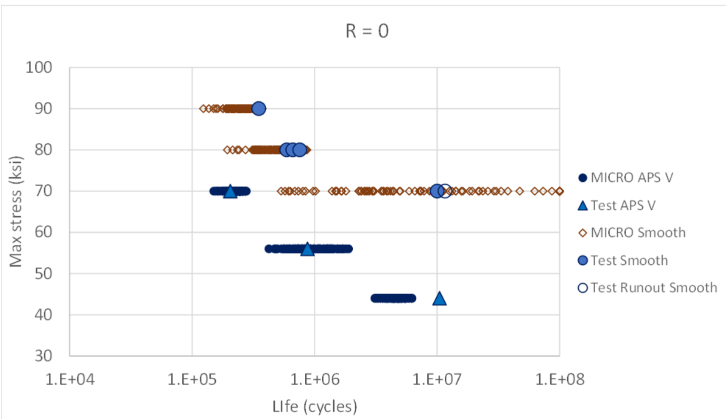


VEXTEC's AM APS modeling methodology in VPS-MICRO is unique because it simulates the interaction between the surface roughness and the material's microstructure.

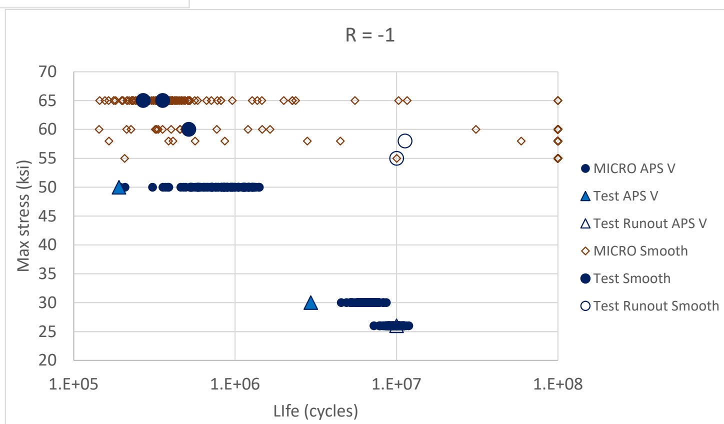
THE RESULTS

VEXTEC and OEM partner Aerojet Rocketdyne collaborated in a U.S. Air Force Research Laboratory Small Business Innovation Research (SBIR) program to evaluate typical APS features on Laser Powder Bed Fusion (LPBF) IN625 specimens, and predict their impacts on fatigue performance. Without modifying the initial VPS-MICRO model calibrated to smooth (machined) fatigue test bars, VEXTEC demonstrated that by incorporating the macro-structural geometric effects (build orientation) and micro-structural geometric effects (APS roughness, material grain size, defect size, etc.), VPS-MICRO efficiently predicted the knock-down (debit) in fatigue life for as-printed surfaces in AM specimens. The important APS features that were included in the model were:

- Micro stress gradients (at a microstructural size scale) due to crevices and pits on the specimen surface
- Macro stress gradients (at a component size scale) due to build orientation surface undulations
- Differentiation of the material APS layer from the inner core using gradient microstructures



The VPS-MICRO model was first calibrated to R = 0 load ratio machined round bar fatigue specimens, then predictions were made for the fatigue knock-down due to APS (image above). The model was then extended to R = -1 load ratio (image right), and shows good agreement for predicting fatigue lives for APS knock-down and different load ratio.



VPS-MICRO software takes advantage of efficient Monte Carlo methods in simulating large populations of components to predict the risk of fatigue failure. This is a key benefit for using computational modeling; many more simulations can be run than could ever be accomplished by physical testing. VPS-MICRO predicts fatigue behavior of test specimen geometries as well as complex AM components. After first calibrating a VPS-MICRO model to a limited number of specimen-level testing data, the software can then be used to predict the spread in fatigue performance of complex geometry components at a fraction of the time and cost of physical testing.

ABOUT VEXTEC

VEXTEC'S VPS-MICRO® software is a unique combination of engineering analysis and material science protected by seven patents. VEXTEC helps companies predict and enhance the reliability and performance of critical components during design, manufacturing, testing, and service. Since 2000, we have provided solutions for hundreds of different products across many industries including aerospace, automotive, heavy machinery, medical devices, and energy development.