8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

Three Dimensional Tomography for Fluid Flow Modelling in Dendritic Structures of Directionally Solidified Nickel-Base Superalloy

***Jonathan D. Madison[1], J. Spowart[2], D. Rowenhorst[3], K. Thornton[4], T.M. Pollock[5]**

[1] University of Michigan
3062 H.H. Dow
2300 Hayward St.
Ann Arbor, MI 48109-2136
jonnymad@umich.edu

[2] Air Force Research Laboratory
RXLM Bldg. 655
2230 Tenth St., Ste. 1
Wright-Patterson AFB OH 45433
jonathan.spowart@wpafb.af.mil

[3] Naval Research Laboratory
Code 6350 Multifunctional Materials Branch,
4555 Overlook Ave. SW
Washington, DC 20375
david.rowenhorst@nrl.navy.mil

[4]University of Michigan
3062 H.H. Dow
2300 Hayward St.
Ann Arbor, MI 48109-2136
kthorn@umich.edu

[5] University of Michigan
3062 H.H. Dow
2300 Hayward St.
Ann Arbor, MI 48109-2136
tresap@umich.edu

Key Words: *Directional Solidification, Dendrites, Mushy Zone, Serial-section*

ABSTRACT

Nickel-base superalloys have long stood as highly favored materials for the design and production of components for high temperature turbine applications. Components that experience high temperatures and stresses within land-based power systems, space propulsion systems and aircraft turbine engines are of particular importance. While the advent of directional solidification has brought substantial improvement to the creep and fatigue performance of this alloy class[1], alloying elements must still be carefully controlled to mitigate segregation and produce microstructures that optimize the mechanical properties. Alloying elements such as rhenium and tungsten have been shown to increase strength at elevated temperatures while at the same time increase the occurrence of defects such as mis-oriented grains and freckles during directional solidification of these alloys[2]. However, the details of the thermosolutal convective flow instabilities that create these defects are still not well understood.

In an effort to improve the solidification behavior of these alloys, modelling of the fluid flow processes at the scale of the dendritic structure has been performed. This is of particular interest as conventional methods of defect prediction typically rely on application of the Rayleigh Criterion to predict initiation of convective instabilities. Unfortunately, obtaining Rayleigh numbers requires a number of assumptions concerning the length scale, the dendritic structure and the connectivity of liquid within the mushy zone. This research effort utilizes a new approach that involves characterization of dendritic structures, rendering them as three-dimensional volumes and directly evaluating them in computational fluid flow models.

Alloys are directionally solidified using a Bridgman furnace to isolate and produce dendritic structures. Next, using the prototype RoboMET.3D system, high resolution

serial sections of dendritic structures are obtained, then segmented with ITT's Interactive Data Language (IDL) and rendered as a three-dimensional volume. After a representative volume of dendritic structure has been reconstructed to reliably characterize the mushy zone, sections of near uniform volume fraction are isolated and using MIMICS by Materialize and software by ANSYS, volume meshes are generated to embody the interdendritic liquid and full Navier-Stokes simulation of fluid flow in the liquid is simulated.

The features of the dendritic reconstruction are consistent with two-dimensional sections and with those expected based upon casting parameters of withdrawal rate and solidification front velocity. For the commercial alloy René N4, volume fraction solid as a function of height does not vary linearly with the temperature gradient, which strongly affects the permeability as a function of depth in the mushy zone. At a finite point in time, as observed in the reconstruction, the connectivity of one body of interdendritic liquid during solidification can contain in the range of ninety percent of the total interdendritic liquid and reach down into nearly half of the entire mushy zone height. Lastly, permeability within these structures can be anisotropic based upon the direction of fluid flow within the same volume.

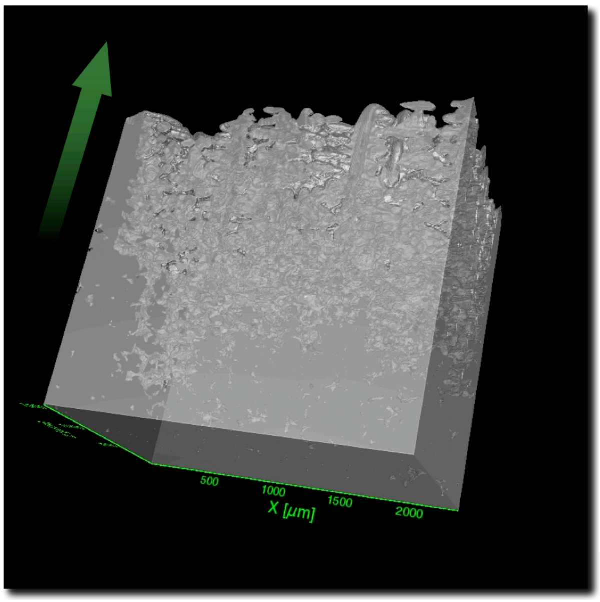

Figure 1 – 2300 x 2300 x 1500 μm reconstructed volume in a nickel-base superalloy. Arrow denotes the solidification direction

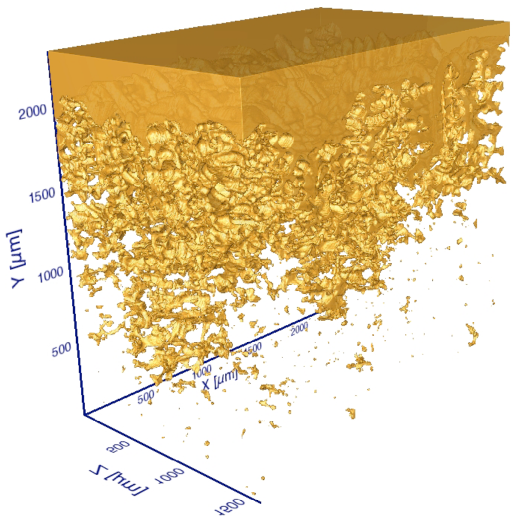

Figure 2 – Reconstructed interdendritic liquid

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