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## Comparison of the Variance in the R-Value Calculated Using the Power Law in IF Steel to Experimental Measurements

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As advances in engineering and technology increasingly require engineers and scientists to work in smaller length scales, they must have a greater understanding about how materials and their properties behave at these scales. This is true particularly in the field of mechanical engineering with the development of MicroElectroMechanical Systems or MEMS. These are tiny mechanical systems that are only measured in micrometers and that can only be seen with the aid of high powered microscopes. In order to build MEMS that are reliable and perform as they should, engineers not only must have an understanding of the material properties of the components but be confident that any part made out of a given material will perform as predicted.

Most materials used to make such components are polycrystalline. The material properties of any given polycrystalline material vary greatly depending on the size and orientation of the individual crystals that make up the whole material. These crystals are typically called grains. A material's characteristic atomic makeup including the grains, their size and their orientation is typically called the microstructure of a material.

Typical grain sizes in materials range from a few microns to several millimeters. A sample of material that is large in size compared with the average size of its individual grains will typically have a random representation of grains throughout the material. Such a large sampling will have predictable properties no matter what sampling of the material is tested as long as the grain size is much smaller than size of any given sampling.

It can be observed, however, that as the size of a sample of material reaches the actual grain size of that material, the variance in the properties of that sampling will vary much greater from sampling to sampling. This is because the microstructure of the sample is no longer averaged over many grains, but it is dependent only on one to only a few grains. The variance in material properties at smaller scales will make it much harder for engineers to guarantee part quality or function unless this variance is understood and quantified.

The scope of this project was to first develop an appropriate mathematical model that would predict the variance in material properties in any given material depending on the size of application, and second to test these models against data collected experimentally.

Statistically based mathematical models have been used extensively to obtain estimates of properties in polycrystalline materials<sup>1</sup>. We have taken these existing models and developed a way to consider the variance of a material property as a function of the size of an observation window in which the microstructure is described. This observation window is determined by the size of the application that is needed. For example, if one is making a part that is 100 microns at its greatest dimension they will want to know the variance in material properties for an

observation window of 100 microns. This will help the engineer to plan for any variation in the material properties at this length scale in their design.

In order to determine the variance in any given material property a statistical representation of the microstructure must be obtained. At Brigham Young University a method has been developed to measure the grain size and grain orientation of any given polycrystalline material using a scanning electron microscope (SEM). We have devised that an acceptable representation of the microstructure can be obtained by performing several scans on the SEM at different angles to insure that a complete statistical representation of the microstructure is obtained.

Never has such a statistical representation of the microstructure of a material been obtained in this way. In order to do this, I have worked to determine a scheme that would require 12 different scans on the SEM to make such a representation. I have helped develop a program using the C++ programming language that will take the data from the scans done on the SEM and calculate the statistical representation of the microstructure. The bulk of this part of the project was completed over the summer of 2003. It is planned that a complete description of this work will be submitted for publication in a research journal by summer 2004<sup>2</sup>.

The mathematical model of properties variance will initially be testing by determining the variance in the R-value, the ratio of thickness-to-width stains in a material. The R-value will be determined using two different observation windows in order to examine the variance depending on the length scale. The strains used to calculate the R-value can be estimated using a power relation which relates the strain-rate and stress<sup>3</sup>.

The R-value will be measured in IF steel. Experimentally the R-value is measured by pulling tensile samples on a tensile testing machine that have had grids etched into them with mild acid. The R-value is determined from the measured difference in the length of the grids after they have been strained. Initial testing has been done which has determined R-values, but the program that will predict the R-values and variance has not yet been completed.

I have worked throughout this last semester, Winter Semester 2003, to program the variance relationship for the R-value. This program currently calculates the R-value of a material. Currently it is done to the point of finding the R-value for any given point in the material, but must be integrated with the complete statistical representation of the microstructure to find a complete R-value for a given observation window. This will then be integrated with the rest of the variance relationship to determine the overall variance in the R-value for any given observation window.

It is anticipated that the program which predicts the R-value given an observation window and the experiments which will test the mathematical model will be done by the end of January 2004. These findings will then be submitted to an engineering journal for publication and presented in June 2004 at NUMIFORM, a materials conference at Ohio State University.

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<sup>1</sup> S. Torquato, Random Heterogeneous Materials, 2002, New York.

<sup>2</sup> Gao, et al. "2-Point Microstructure Representation," Planned to be submitted by Summer 2004.

<sup>3</sup> J. Hutchinson, "Bounds and Self-Consistent Estimates for Creep of Polycrystalline Materials," 30 June 1975.