Numerical Simulation of a Ni-Based Superalloy Under Fatigue Loading

The Center for Initiatives in STEM

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Abstract

Nickel/Chromium-based alloys are often employed in situations that are subject to aggressive operating environments. They demonstrate an excellent affinity for oxidation resistance, corrosion resistance, and strength retainment at a wide range of temperatures [2]. Though nickel-based alloys are known to operate well in these conditions, the material suffers from a lack of models exhibiting the effects of plastic deformation on the material. This is necessary to determine how many cycles the material should be expected to function properly (life-prediction modeling). Hence, a parametric simulation is being constructed to test the impact of fatigue on a cube composed of a Ni-based alloy. In addition to the conventional material-independent relationships used for finite element simulations (i.e. Hooke's Law, Ramberg-Osgood relationship), the Chaboche Viscoplastic model is used to incorporate material-dependent information relevant to the understanding of temperature dependence associated with the model [1]. The analysis will serve to increase the database associated with this relatively unexplored material.

Introduction

The primary objective of these efforts is to perform finite element analysis that incorporates plastic effects on a single element cube (***Figure 3***) composed of a nickel-based alloy. These alloys, in particular, are used for gas turbine blades, high-temperature fasteners, pressure vessels, and heat exchanger tubing. The purpose of this analysis is to correlate stress range, strain range, and mean stress with various loading conditions. An understanding of how these parameters are affected by loading conditions, will provide a much deeper knowledge of appropriate situations in which to employ the material.

Figure 1: *Turbine Blade composed of a Ni-Based Alloy*

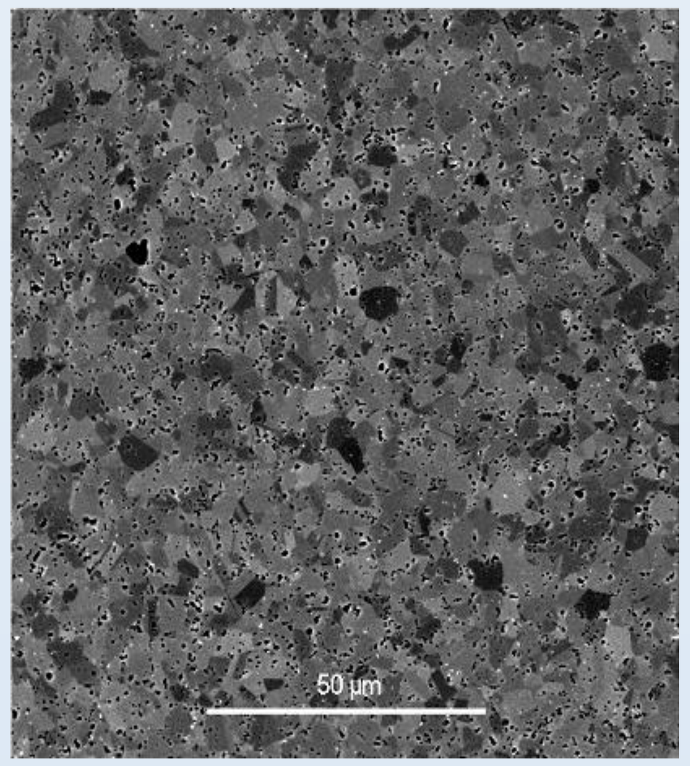

Figure 2: *Microstructure of a Ni-Based Alloy*

Methods

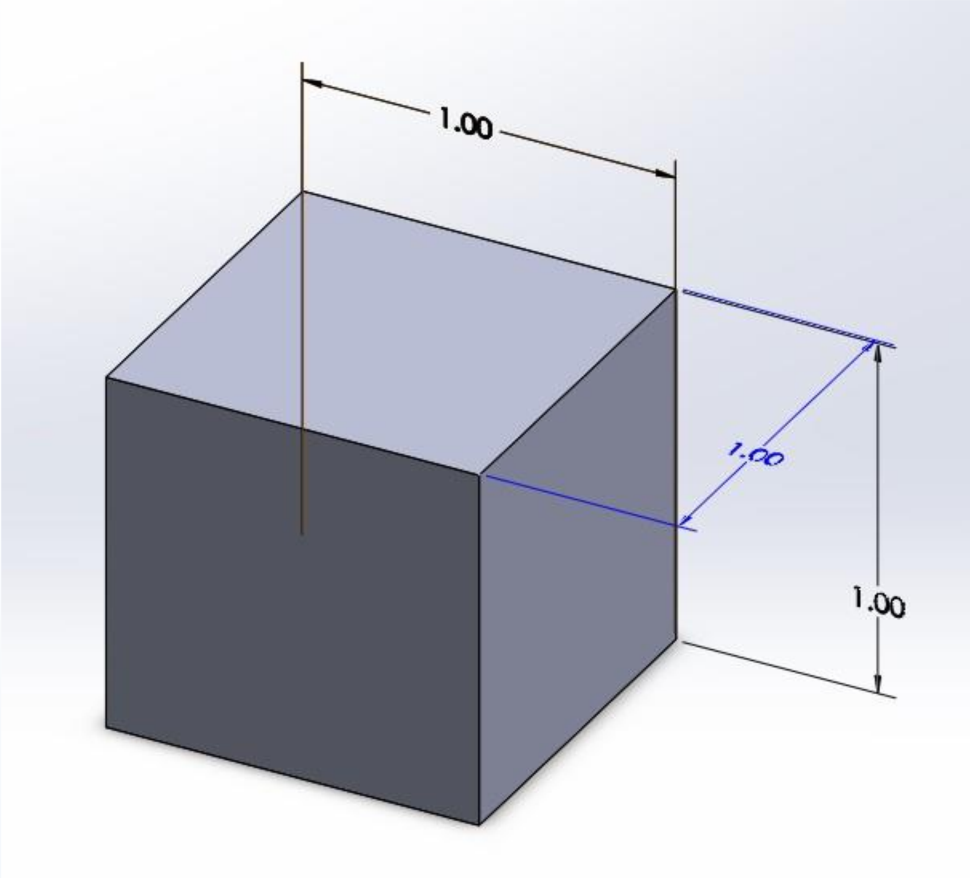

Figure 3:*Cube Used in Simulations (Dimensions Listed in inches)*

Numerical simulations are created to verify that a constitutive model is performing properly. ANSYS Workbench 18.2 is used for the finite element analysis on the geometries in the study. In order to perform these analyses, the main components of user input are: meshing, boundary conditions/restraints, loading conditions, and user programmable features (UPFs). Proper mesh is a necessity for an accurate finite element analysis. Shape, size, and quantity must all be considered when trying to create the best mesh to model a material. UPFs allow for users to add more advanced material properties than are offered in the ANSYS default settings (i.e. kinematic hardening terms).

Results

Analysis of the stress-strain relationship gives useful insight into the behavior of a material. Young's (Elastic) Modulus, Yield Strength, Ultimate Tensile Strength are just a few important values that are captured when examining these hysteresis loops. Where they are most beneficial are in showing how the incorporation of mean stress, plastic strain range, and stress range affects the functional life of the material.

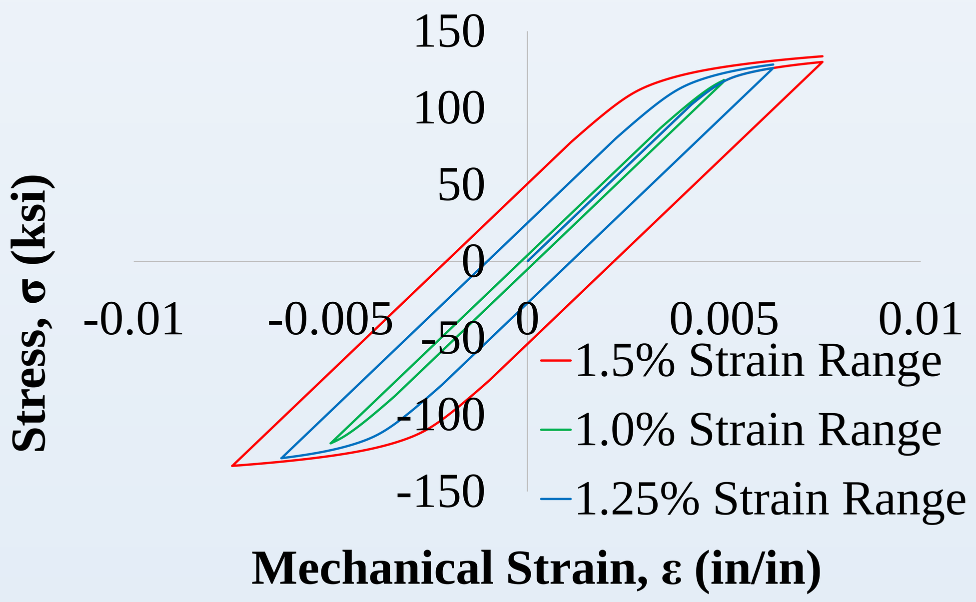

Figure 4: *Three strain ranges for cube single element at **70°F***

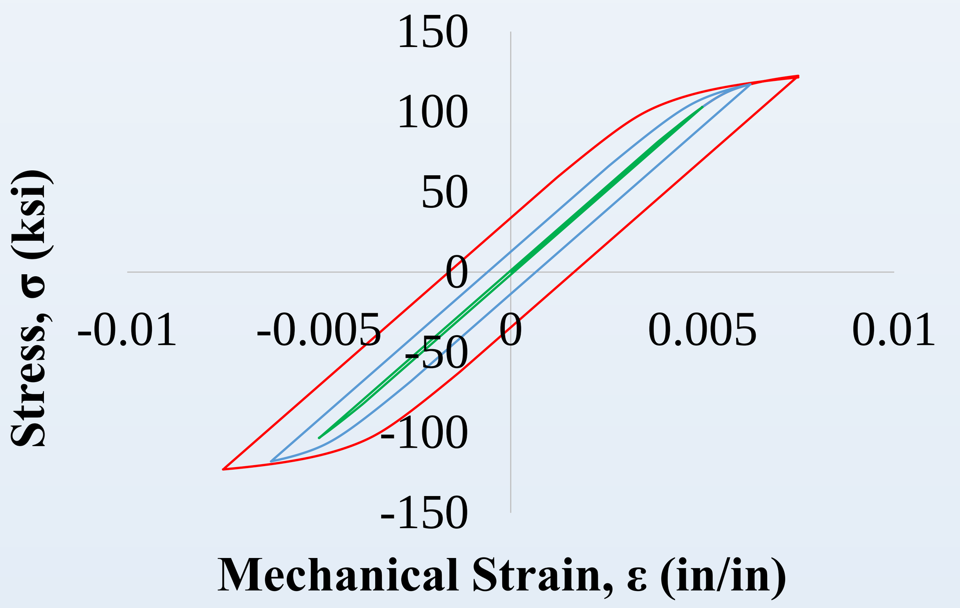

Figure 5: *Three strain ranges for cube single element at **1200°F***

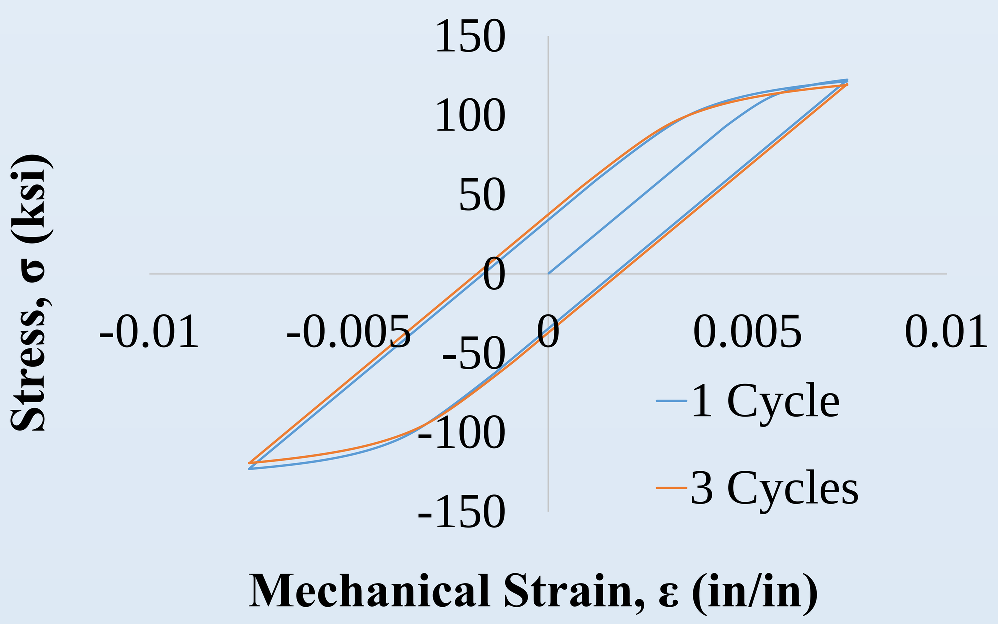

Figure 6: *Comparison of one and three fully reversed cycle at 1.5% strain range and 70°F*

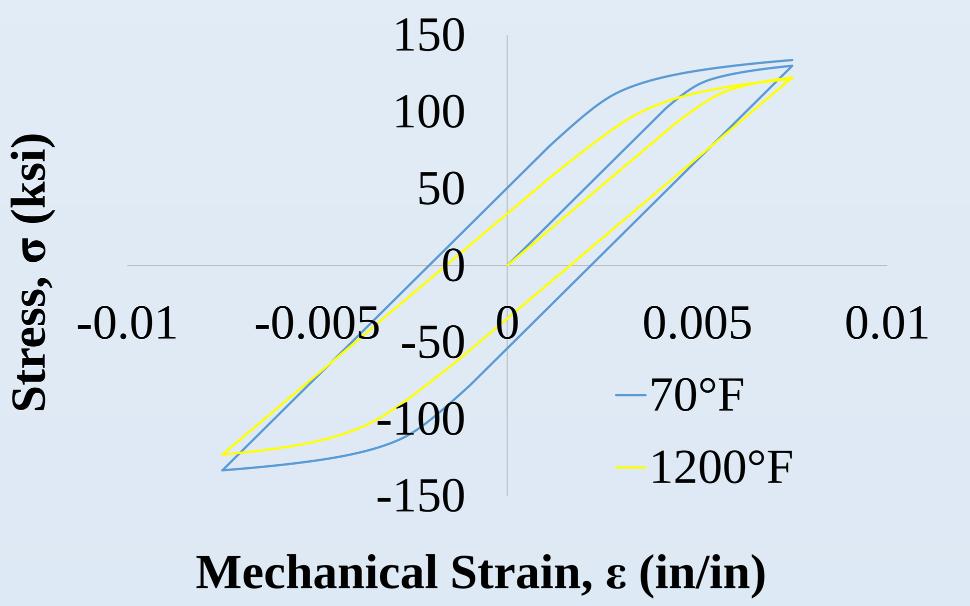

Figure 7: *Comparison of hysteresis for 70°F and 1200°F with 1.5% Strain Range*

Future Direction

Going forward the model will continue to be subjected to geometries of increasing complexity. This includes a rectangular prism specimen, smooth coupon specimen, and notched coupon specimen. Due to low element quantity and high aspect ratio of some elements, the results for the smooth and notched coupon specimen are not yet reliable enough to be included in this paper. In addition to running the fatigue simulations included here, creep fatigue (***Figure 10***), thermomechanical fatigue (TMF; ***Figure 8: In-Phase TMF***, ***Figure 9: Out-of-Phase TMF***), and creep TMF are modes of fatigue that will be examined.

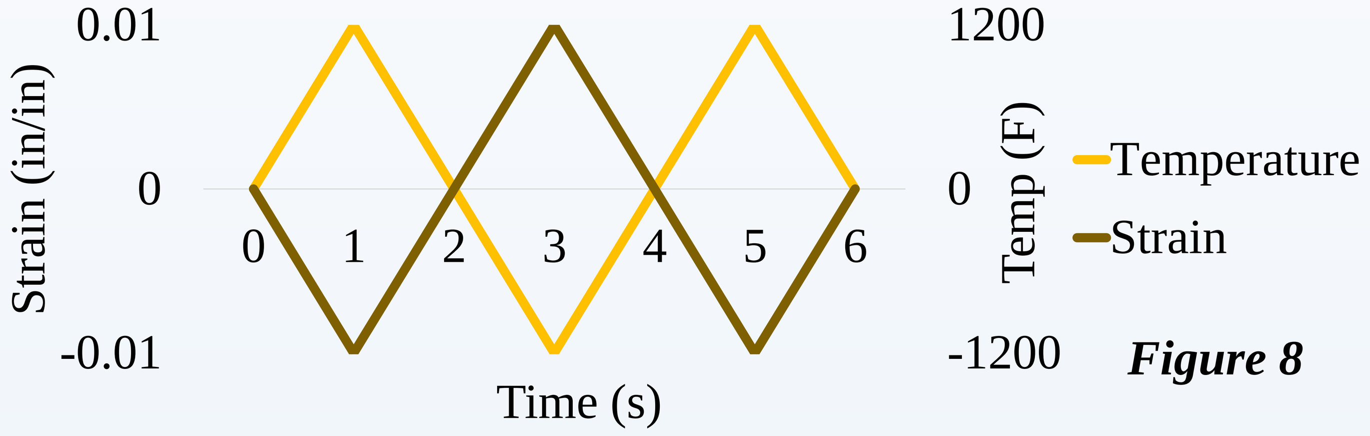

Figure 8

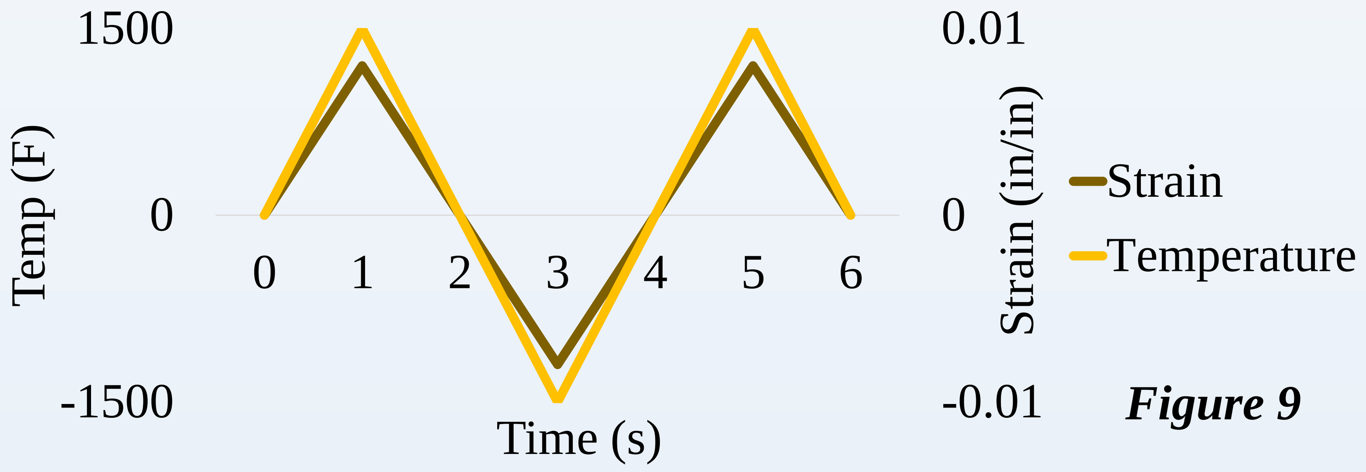

Figure 9

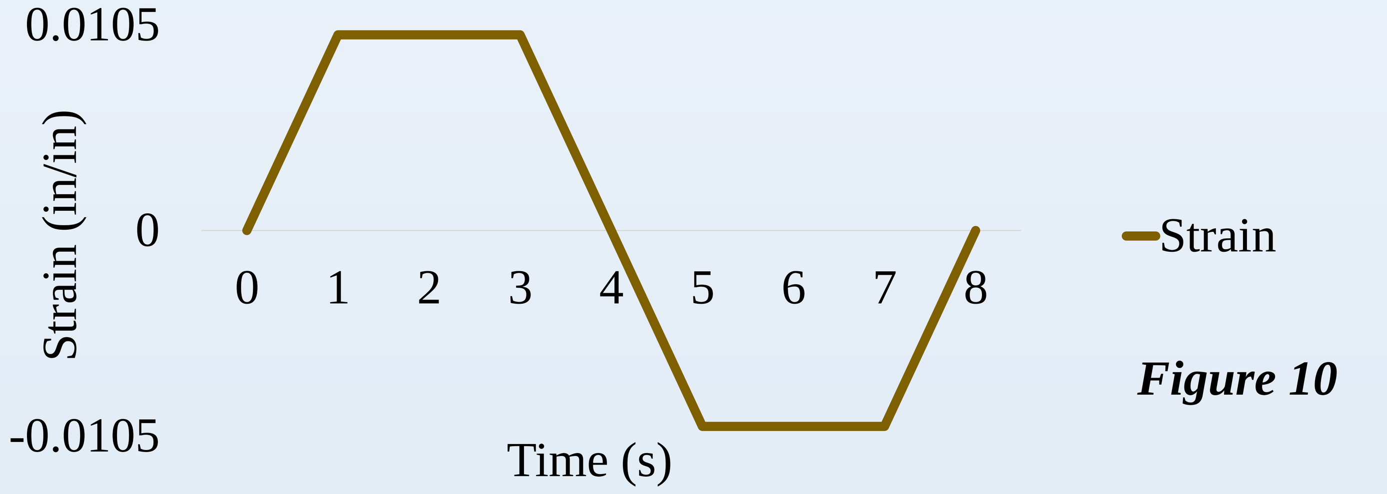

Figure 10

References

[1] N. O'Nora, T. Bouchenot, G. Geiger and A.P. Gordon, "Constituitive Modeling of TMF annd Creep-Fatigue on a Ni -Base Alloy" Proceedings of ASME TurboExpo 2019: *Turbomachinery Technical Conference and Exposition* (2019)

[2] F. Irmak and A.P. Gordon, "A Framework For Life Prediction of 2.25Cr-1Mo Under Creep and Thermomechanical Fatigue" *Proceedings of the 2018 Turbomachinery Technical Conference & Exposition* (2018)

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