Deformation Response and Life of Metallic Composites

Final Performance Report

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Introduction

The project was initially funded for one year (for $100,764) to investigate the potential of particulate reinforced metals for aeropropulsion applications and to generate fatigue results that quantify the mean stress effect for a titanium alloy matrix material (TIMETAL 21S). The project was continued for a second year (for $85,000) to more closely investigate cyclic deformation, especially ratcheting, of the titanium alloy matrix at elevated temperature. Equipment was purchased (for $19,000) to make the experimental program feasible; this equipment included an extensometer calibrator and a multi-channel signal conditioning amplifier. The project was continued for a third year ($50,000) to conduct cyclic relaxation experiments aimed at validating the elastic-viscoelastic-viscoplastic model that NASA GRC had developed for the titanium alloy. Finally, a one-year no cost extension was granted to enable continued analysis of the experimental results and model comparisons.

Accomplishments

- A detailed literature review of particulate reinforced metals including constituents, processing, properties, applications, improvements, and a cryogenic application was compiled and presented as a powerpoint presentation [1]. In addition, a particle reinforced aluminum for a cryogenic application was investigated, but material was not procured.

- For stress-controlled fatigue tests on TIMETAL 21S the S-N curve was found to be well represented by a power law having a temperature-dependent coefficient and a temperature independent exponent. A tensile mean stress caused strain ratcheting that does not shake down. The Goodman approach was found to be reasonably successful in correlating mean stress to low cycle fatigue life given the limited amount of data [2].

- The effect that gripping a sample with water-cooled wedge grips at different locations has on the temperature distribution throughout the specimen was quantified. This enabled better control of the temperature distribution and eased the test setup process [3].

- A labview control and data acquisition program was developed for conducting cyclic tests in three different control modes: strain control with strain limits, stress control with stress limits, and strain control with stress limits [3].

- Experimental results for TIMETAL 21S confirmed and quantified the strain rate effect at 650 °C as well as quantified the associated effects that different control modes have on the shape of hysteresis loops and ratcheting behavior. The accumulated strain (ratchet strain) for cyclic loading with stress limits plotted as a function of time resembles a classic creep curve having three distinct regions. [3-5]

- One-of-a-kind cyclic experiments were conducted on TIMETAL 21S to validate the GVIPS model of Saleeb and Arnold [6]. Each cycle was interrupted with numerous strain-holds to initiate stress relaxation. These hold times were designed to take place in all four quadrants of the stress-strain plane to enable assessment of the functional form of the potentials used in the GVIPS model. A very clear path-dependence was reported [4-5].

- All test data on TIMETAL 21S were analyzed with CES software and the results were supplied to NASA GRC for inclusion in their database. We also provided raw test data for NASA GRC to use for characterizing the GVIPS model with the COMPARE optimization code. [7]

- Flow surfaces for fibrous SiC/TIMETAL 21S laminates were predicted using GMC and HFGMC micromechanical models. Flow surfaces at the laminate, ply, and matrix subcell level were predicted using GMC for $[0/90]_s$, $[\pm45]_s$, $[\pm30]_s$, $[0/\pm45/90]_s$, $[0/\pm60]_s$, and [0] laminates in the axial-transverse and axial-shear stress planes. GMC and HFGMC predictions for unidirectional composites were compared, which showed that HFGMC admits a shear-normal coupling that is unable to occur in GMC. The significance of this is that it reiterates that fine microstructural discretization with HFGMC is meaningful, while it is not for GMC. [8]

- The MAC/GMC micromechanics based computer code was also used to identify load paths in the axial-shear stress plane that will provide the most meaningful characterization results for an alumina fiber reinforced aluminum composite. This analytical study was undertaken to guide an experimental program on thin-walled composite tubes. [9]

- Time-dependent strength differential effect experiments were conducted on Inconel 718 at 650 °C. These experiments demonstrate that the tension-compression asymmetry is significant. It could be especially important for metal forming operations where the accuracy of elastic springback predictions is critical. [10]

References

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Future Work Suggestions

The experimental investigation of TIMETAL 21S was undertaken in support of constitutive modeling of the titanium alloy for use as the matrix in a composite. The next step is to conduct a micromechanical modeling study of a composite material with the objective of identifying load paths that will provide a rigorous test of the constitutive model. The experiments themselves and the results will be very interesting because the elastic fibers will provide constraint to the time-dependent deformation of the matrix. Uniaxial tests on unidirectional specimens having different orientations should be conducted first, followed by nonproportional axial-torsion tests to assess the multiaxial capabilities of the constitutive model (which go back to the functional form of the dissipation and free energy potentials) to predict strain ratcheting.

This project reports strain ratcheting during high temperature tests that resembles a creep curve. The GVIPS unified viscoplasticity model is capable of simulating these ratchet strains. There are many applications at moderate or room temperature where strain ratcheting occurs from a mechanism that is not creep related. Is the GVIPS model accurate for these applications? It should be, because in the quasistatic limit viscoplastic response approaches time-independent plastic response. Since the structure of strain ratcheting-capable plasticity models is quite different than the GVIPS structure it would be interesting to determine GVIPS capability in this area. In the literature there are ratcheting databases for materials such as 1070 steel. We could characterize the GVIPS model for one of these materials and then compare model predictions with ratcheting data in the literature.

While the COMPARE program optimizes the fit of material parameters to the characterization data, there is still the nagging question of what data should be used for characterization. This is a major question that limits usage of sophisticated constitutive models because of the relatively large number of material parameters required for the model to accurately represent deformation mechanisms active over short and long time scales, multiaxial loading, and a wide range of temperatures. There are two major 'data content' questions: (1) what type of data is optimal and (2) how much data is necessary? The 'type of data' question refers to simple experiments such as relaxation, creep, monotonic tests at different strain rates, stepped relaxation, stepped creep, or more complex experiments that activate a variety of mechanisms and therefore require less specimens. The 'how much data' question refers to specimen-to-specimen variation, the number of stress levels for creep testing, relaxation hold times, etc., and most importantly, the time, loading rate, and strain range domains of interest. Answering these questions is critical to the widespread use of this class of constitutive models.

Participating Students

Patricia Solimine, Master of Science in Engineering Mechanics awarded 5/2002.

Devaraj Doraiswamy, Master of Science in Engineering Mechanics, awarded 12/2003.

Lulin Shen, Master of Science in Engineering Mechanics, awarded 12/2003.

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Kara Lencoski, Bachelor of Science in Engineering Science, awarded 5/2003.

Jeremy Thoryk, Bachelor of Science in Engineering Science awarded 5/2004.

Publications

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C.J. Lissenden, D. Doraiswamy, and S.M. Arnold, "Experimental investigation of cyclic and time-dependent deformation of titanium alloy at elevated temperature," to be submitted to *Int. J. Plasticity.*

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