EVALUATION OF THREE CONSTITUTIVE MODELS FOR THE PREDICTION OF HASTELLOY X ELEVATED TEMPERATURE CYCLIC RESPONSE

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An evaluation of material constitutive models for the prediction of elevated temperature cyclic stress and strain response is presented. This activity is being conducted under an ongoing NASA Contract (Ref. 1) to identify a procedure for predicting structural response (stress / strain) without the need for expensive and time consuming non-linear finite element analysis.

The approach for the method development assumes that, for a thermally loaded structure, the overall strain history can be defined by linear elastic analysis. The local stress history at a fatigue critical location is then determined from a one-dimensional material behavior model and the local strain and temperature conditions. Three material models are currently being evaluated to assess their ability to predict relevant high temperature cyclic material response characteristics. They are: (1) a time independent classical plasticity and creep representation, (2) a time dependent viscoplastic model capable of predicting combined creep and plasticity effects, and (3) an approximate elastic analysis approach that uses a series of stress-strain curves and a cyclic hardening model to determine reverse plasticity.

Previous structural analyses and life prediction activity conducted on a representative gas turbine high temperature component, i.e., combustor liner (Ref. 2), has indicated that the local stress-strain response reflects several high temperature material cyclic response characteristics. They include: (1) strain rate dependence, (2) creep-plasticity interaction and (3) the interaction of properties associated with variable temperature (thermomechanical) loading. In the current program, these characteristics are being systematically investigated to aid in the material model evaluation. Hastelloy X specimen constitutive test data developed in References 2 and 3, and under the present program, is being used to establish a cyclic response data base. Representative stress-strain data for continuous fully reversed cycling, fully reversed with creep and relaxation hold periods, and various thermomechanical loading histories comprise the data base.

Preliminary results comparing two of the material models with the data base are shown below. Figure 1 compares the predictions of the time-independent classical plasticity model and the viscoplastic model with 1600^{o}F continuous cycle testing. The classical plasticity model shows a slightly greater stress amplitude, due primarily to the differences in strain rates between the data used to generate the model and the test (.008 min^{-1} vs. .0024 min^{-1}). The prediction using the classical model also shows the characteristic square corners associated with a distinct single yield surface. The viscoplastic model predicts a more accurate stress amplitude for the test strain rate of .0024 min^{-1} and displays a smoother transition between elastic and plastic response. A comparison of the two models for the combustor louver lip thermo-mechanical loading cycle (Ref. 2) is shown in Figure 2. Simulation of the combustor lip with a uniaxial test specimen produced the stationary stress-strain response shown in the figure. Prediction with the classical plasticity and creep models resulted in a continuous ratchetting of the response in the positive stress direction. Shown is the 15th loading cycle. The prediction using the viscoplastic model does not display the same degree of stress ratchetting and more closely predicts the experimental data. Shown is the 2nd loading cycle.

References:

1. Development of a Simplified Analytical Method for Representing Material Cyclic Response, NAS3-22821.

2. Moreno, V.: Combustor Liner Durability Analysis. NASA CR 165250, 1981.

3. Walker, K.P.: Research and Development Program for Non-Linear Structural Modeling with Advanced Time-Temperature Dependent Constitutive Relationships, NASA CR 165533, 1981.

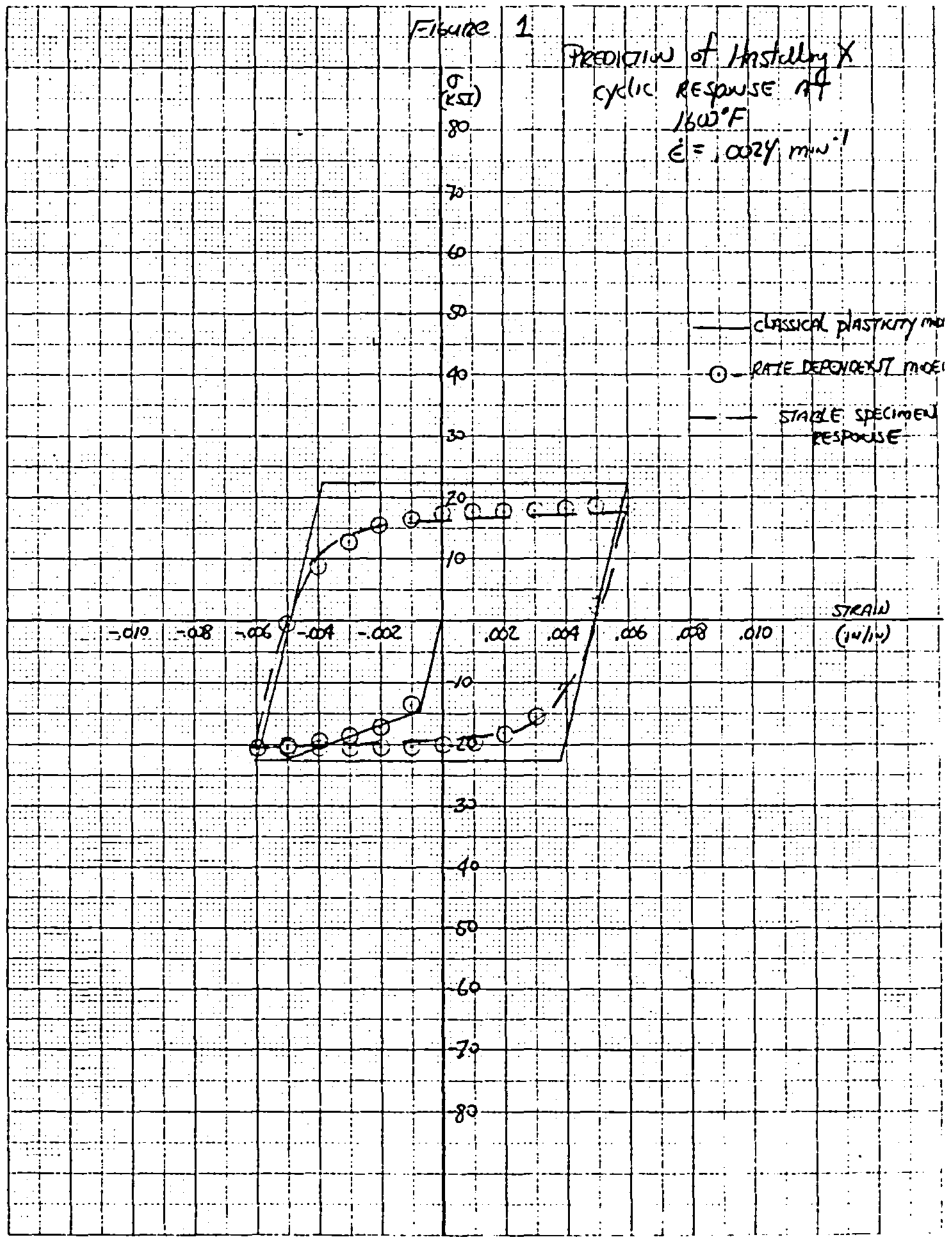

Figure 1
Prediction of Hastelloy X cyclic response at 1600°F
$\dot{\epsilon}$ = .0024 min⁻¹
σ (KSI)
80
70
60
50
40
30
20
10
-10
-20
-30
-40
-50
-60
-70
-80
-.010
-.008
-.006
-.004
-.002
.002
.004
.006
.008
.010
STRAIN (in/in)
classical plasticity model
rate dependent model
stable specimen response

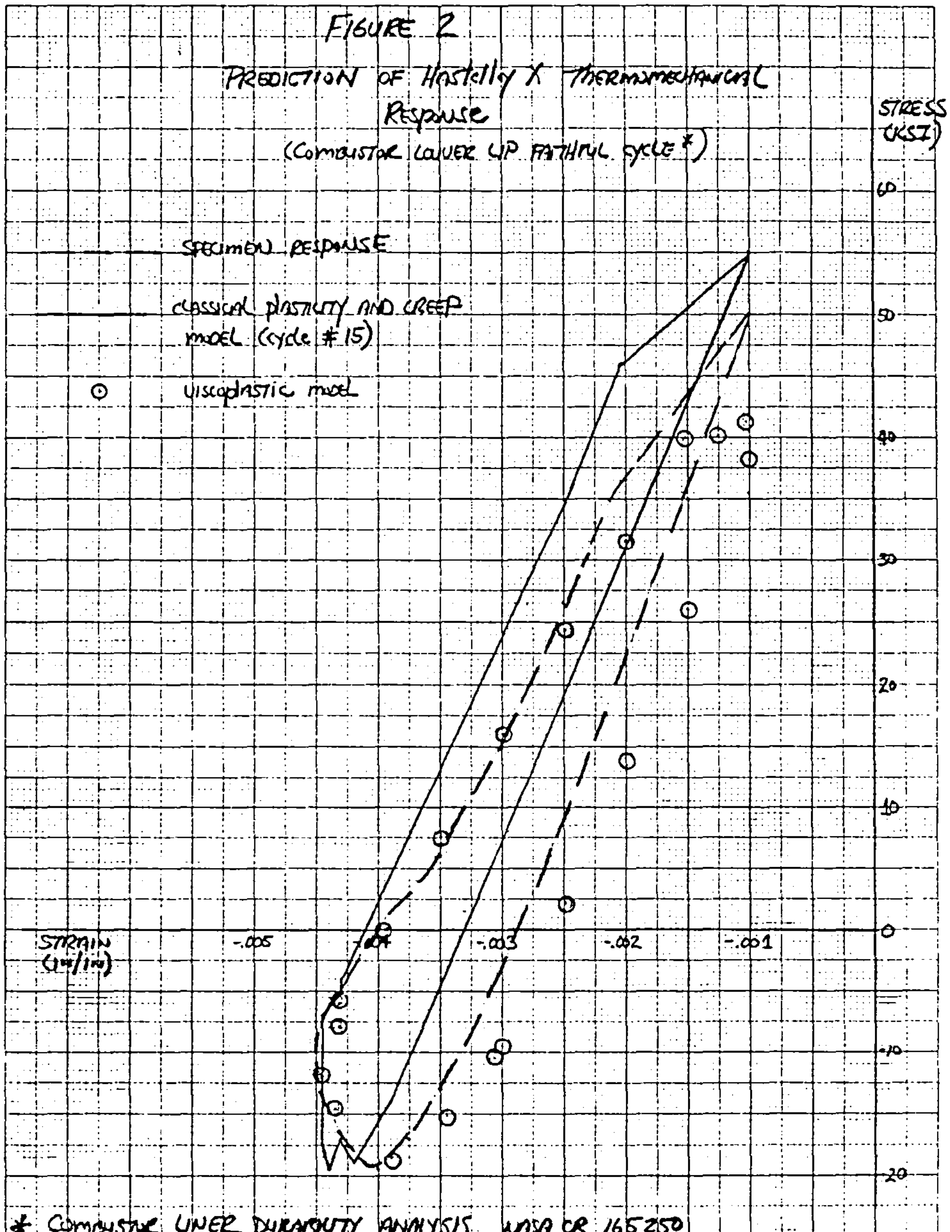

FIGURE 2
PREDICTION OF Hastelloy X THERMOMECHANICAL Response
(COMBUSTOR LOUVER LIP FAITHFUL CYCLE *)
SPECIMEN RESPONSE
CLASSICAL PLASTICITY AND CREEP model (cycle # 15)
VISCOPLASTIC model
STRESS (KSI)
60
50
40
30
20
10
0
-10
-20
STRAIN (in/in)
-.005
-.004
-.003
-.002
-.001
* COMBUSTOR LINER DURABILITY ANALYSIS NASA CR 165250