A Guideline for the Assessment of Uniaxial Creep and Creep-Fatigue Data and Models

Calvin M. Stewart and Jack Chessa

NETL Kick-Off Meeting

October 6, 2016
Outline

- Motivation
- Research Objectives
- Team
- Systematic Approach to Assessment
  - Task 2: Locate, Digitize, Sort, Store Experimental Data
  - Task 3: Uncertainty and Integrity of Experimental Database
  - Task 4: Mathematical Analysis and FEA of the Models
  - Task 5: Calibration & Validation – Fit, Interpolation, Extrapolation of the Models
  - Task 6: Post-Audit Validation of the Models
  - Task 7: Uncertainty Analysis of the Models
- Gantt Chart
- Milestones
- Questions
Motivation

- Recent drives to increase the efficiency of existing fossil energy (FE) power plants and the development of **Advanced Ultrasupercritical (A-USC) power plants**, have led to designs with steam pressures **above 4000 psi** and temperatures **exceeding 1400°F**.
Motivation

- The existing FE fleet has an **average age of 40 years**.
- The Department of Energy has outlined a strategy of life extension for US coal-fired power plants where many plants will operate for **up to 30 additional years of service**.

In Service Hours....

- 30 Years = 262,974 hours
- 40 Years = 350,634 hours
- 70 Years = 613,607 hours

Creep-Rupture of 9Cr-1Mo Tube

- Uncertainty ↑
- Temperature ↑
- Stress ↓
• During Life Assessment, the integrity of components is assessed and the remaining service life estimated.

Deterioration of Component
- Creep
- Fatigue
- Creep-Fatigue
- Embrittlement & SCC
- Corrosion
- Erosion
- Wear
- Performance (HR, Output)

Change of Operating Circumstances
- Expected operation in future
- Decision support system
- Prolongation of overhaul interval
- Reduction of operating cost

Daily Operation Results
Overhaul Inspection Results
Life Assessment
Performance Assessment
Economical Assessment

Planning Modernization & Upgrading Program
- Repair
- Replacement
- Refurbishment
- Re-Powering
- Etc.

Based on Mitsubishi’s Life Extension Program
Motivation

• An immense number of models have been developed to predict the deformation, damage evolution, and rupture of structural alloys subjected to Creep and Creep-Fatigue.
• Of primary concern to FE practitioners is a determination of which constitutive models are the “best”, capable of reproducing the mechanisms expected in an intended design accurately; as well as what experimental datasets are proper or “best” to use for fitting the constitutive parameters needed for the model(s) of interest.

**RO1**

Development of Aggregated Experimental Databases of Creep and Creep-Fatigue Data

**RO2**

Computational Validation and Assessment of Creep and Creep-Fatigue Constitutive Models for Standard and Non-Standard Loading Conditions
Dr. Stewart is an Assistant Professor in the Department of Mechanical Engineering at the University of Texas at El Paso. He directs the Materials at Extremes Research Group (MERG). He has over 10 years of experience in the theoretical development and numerical implementation of constitutive models for creep, fatigue, oxidation, and creep-fatigue-oxidation interaction phenomenon.

Dr. Jack Chessa is currently an Associate Professor of Mechanical Engineering at the University of Texas at El Paso. His research interest has been focused on the development of novel numerical methods for solving several challenging areas such as fracture mechanics, durability of high temperature ceramics as well as oxidation are reactions of evolving interfaces.
Recent Work


Systematic Approach to Assessment

Example for Creep Deformation

- **Analytical Fit**
- **Global Optimization**
- **Interpolation & Extrapolation**
- **Post-Audit Validation**

**Aggregate Datasets with Uncertainty**

**Model Fit to Datasets**

**Standard Performance**

**NonStandard Performance**

**Performance**

- A
- B
- C
- D
- F

**Model Uncertainty**

- NSME, $Z_{CRMS}$
### DEF: Standard and NonStandard

<table>
<thead>
<tr>
<th>Standard</th>
<th>Nonstandard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creep / Stress Relaxation</td>
<td>Creep-Fatigue</td>
</tr>
<tr>
<td>Cyclic Hardening</td>
<td>Shakedown</td>
</tr>
<tr>
<td>Service-Like Conditions</td>
<td>Ratcheting</td>
</tr>
</tbody>
</table>

#### Data Models
- **Data**
  - High Availability
- **Models**
  - Often Calibrated

#### Limited Availability
- Rarely Calibrated
Systematic Approach to Assessment

Task 1: Maintain Project Management Plan

Task 2: Locate, Digitize, Sort, Store Experimental Data

Task 3: Uncertainty and Integrity of Experimental Database

Task 4: Mathematical Analysis and FEA of the Models

Task 5: Calibration & Validation – Fit, Interpolation, Extrapolation of the Models

Task 6: Post-Audit Validation of the Models

Task 7: Uncertainty Analysis of the Models
Creep Data
- Creep-rupture
- Minimum creep strain rate
- Time to creep strain
- Creep deformation
- Stress relaxation

Fatigue Data
- Strain-Life
- Cyclic Hysteresis loops
- Stress Amplitude per Cycle

Creep-Fatigue Data
- Tensile Hold Tests

Established Data Sources
- NIMS
- NASA
- Oak Ridge National Laboratory
- KAERI
- ASM International
- Vallourec
- PSM
- Siemens

Need to Establish Connections
Locate, Digitize, Sort, and Store Data

- Established Databases
- Materials Handbooks
- Government Technical Reports (OSTI, NASA STI)
- Dissertations
- Journal Article
- Etc.

Decreasing Priority

Increasing Quantity of Data
## Current & High Priority Data Sources

<table>
<thead>
<tr>
<th>Organization</th>
<th>Database(s)</th>
<th>Access</th>
<th>Available Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Institute of Materials Science</td>
<td>MatNavi</td>
<td>Granted</td>
<td>Material properties, monotonic, creep rupture</td>
</tr>
<tr>
<td>(NIMS)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Materials and Processes Technical</td>
<td>NASA Databases, ASM International</td>
<td>Granted</td>
<td>Material properties, monotonic, creep deformation &amp; rupture,</td>
</tr>
<tr>
<td>Information System (MAPTIS)</td>
<td>Databases, Commercial Data</td>
<td></td>
<td>fatigue curves</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oak Ridge National Laboratory (ORNL)</td>
<td>Gen IV Materials Handbook</td>
<td>Pending</td>
<td>Material properties, monotonic, creep, statistical properties</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Creep Rupture Data (NIMS Database)

P91 Creep Rupture
- P91 550C
- P91 600C
- P91 650C
- P91 700C

Data points: 272

316SS Creep Rupture
- 316SS 550C
- 316SS 600C
- 316SS 650C
- 316SS 700C
- 316SS 750C
- 316SS 800C
- 316SS 850C

Data points: 696
Locate, Digitize, Sort, and Store Data

- **MetaData** – A set of data that describes the characteristic of a dataset.
- MetaData can be used to identify **sources of uncertainty** in our data.
<?xml version="1.0" encoding="US-ASCII"?>
<!-- Possible XML format for various test data -->
<database>
<!-- here is a possible creep test data. Go to http://xmlgrid.net/ to validate the data -->
<experiment material="inconel 718" country="USA" laboratory="ORNL" reference="the big creep database" type="creep deformation" name="stewart101">
<data name="chemical composition" format="ascii" dtype="float" units="hours" rank="1"> 52.50 1.00 19.00 3.05 17.00 0.35 0.35 0.08 0.60 0.90 0.30 0.015 0.006 0.015 5.125</data>
<data name="time" format="ascii" dtype="float" units="hours" rank="1"> 0.0 1.0 2.0 3.0 4.0 5.0 </data>
<data name="strain" format="ascii" dtype="float" units="mm/mm" rank="1"> .000 .001 .002 .005 .010 .020 </data>
<data name="description" dtype="string"> "This is a basic creep test conducted by Dr. Calvin Stewart" </data>
<data name="stress" dtype="float" units="MPa" rank="0"> 2000.0 </data><data name="tbd"/></experiment>
</database>
Uncertainty and Integrity of Experimental Data

• Integrity Check
  • average line
  • upper and low bounds
  • standard deviations
  • coefficient of variation
  • box and whisker plots
  • factor of 2 bands
  • confidence intervals
  • coefficient of determination

• A parametric evaluation of the full database and individual datasets with regards to metadata will be performed to quantify the impact of experimental uncertainty on the material response.
Mathematical Analysis and FEA of the Models

1. Generate Model Database
2. Taxonomy of Models
3. Material Constant Determination
Model Database

- Model Name (Year)
- Authors
- Primary Source
- Taxonomy
- Equations
  - Count
  - Functional form
- Material Constants
  - Count
  - Physical representation
  - Functional form
- Notes
  - Advantages
  - Disadvantages
  - Special remarks
- Analytical form of the Material Jacobian matrix (pseudo-Jacobian if necessary)
  \[
  C_{TOT} = \frac{\partial \sigma_i}{\partial \varepsilon_j}
  \]
- USER MATerial (USERMAT) subroutine
### Unification of Master Curve Models

\[
P_{\text{unified}} = \frac{\log(t_r) - \alpha_0 - \alpha_1 T^\nu}{(T' - \alpha_1')^\nu}
\]

<table>
<thead>
<tr>
<th>Model</th>
<th>Year</th>
<th>Parametric equation</th>
<th>Condition</th>
<th>Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Larson-Miller</td>
<td>1952</td>
<td>[P_{\text{LMP}} = T \left(\log(t_r) + t_a\right)]</td>
<td>(r = -1, q = 1), (\alpha_0 = \alpha_1 = 0)</td>
<td>Linear</td>
</tr>
<tr>
<td>Manson-Haferd</td>
<td>1953</td>
<td>[P_{\text{MH}} = \frac{\log(t_r) - \log(t_a)}{T - T_a}]</td>
<td>(r = q = 1), (\alpha_3 = 0)</td>
<td>Linear</td>
</tr>
<tr>
<td>Manson-Succop</td>
<td>1953</td>
<td>[P_{\text{MS}} = \log(t_r) - BT]</td>
<td>(r = 1, q = 0), (\alpha_0 = 0)</td>
<td>Linear</td>
</tr>
<tr>
<td>Orr-Sherby-Dorn</td>
<td>1954</td>
<td>[P_{\text{OSD}} = \log(t_r) - Q / RT]</td>
<td>(r = -1, q = 0)</td>
<td>Linear</td>
</tr>
<tr>
<td>Goldhoff-Sherby</td>
<td>1968</td>
<td>[P_{\text{GS}} = \frac{\log(t_r) - \log(t_a)}{1 / T - 1 / T_a}]</td>
<td>(r = -1, q = 1), (\alpha_0 = 0, \alpha_3 = 0)</td>
<td>Linear</td>
</tr>
<tr>
<td>Modified Manson-Haferd</td>
<td>2016</td>
<td>[P_{\text{MMH}} = \frac{\log(t_r) - \log(t_a)}{T}]</td>
<td>(r = 1, q = 1), (\alpha_3 = \alpha_4 = 0)</td>
<td>Linear</td>
</tr>
<tr>
<td>Manson-Brown</td>
<td>1953</td>
<td>[P_{\text{MB}} = \frac{\log(t_r) - \log(t_a)}{(T - T_a)^\nu}]</td>
<td>(r = 1, \alpha_0 = 0)</td>
<td>Non-Linear</td>
</tr>
<tr>
<td>Graham-Walles</td>
<td>1955</td>
<td>[P_{\text{GW}} = \frac{\log(t_r)}{T - T_a}]</td>
<td>(r = q = 1), (\alpha_0 = \alpha_3 = 0)</td>
<td>Linear</td>
</tr>
<tr>
<td>Chitty-Duval</td>
<td>1963</td>
<td>[L_{\text{CD}} = T - m \log(tr)]</td>
<td>(r = q = 1), (\alpha_0 = 0), (T = \alpha_2 - \alpha_3)</td>
<td>Linear</td>
</tr>
<tr>
<td>White le may</td>
<td>1978</td>
<td>[P_{\text{WM}} = \frac{1 / T - 1 / T_a}{\log(t_r) - \log(t_a)}]</td>
<td>Inverse of Goldhoff-Sherby</td>
<td>Linear</td>
</tr>
<tr>
<td>Mendelson-Roberts-Manson</td>
<td>1965</td>
<td>[P_{\text{MRM}} = \frac{\log(t_r) / \sigma^\nu - \log(t_a)}{(T - T_a)^\nu}]</td>
<td>Special Manson-Brown</td>
<td>Non-Linear</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name: Larson-Miller</th>
<th>Authors: Larson and Miller</th>
<th>Year: 1952</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model Equations:</td>
<td>Attribute:</td>
<td></td>
</tr>
<tr>
<td>(P_{\text{LMP}} = T \left(\log(t_r) + t_a\right))</td>
<td>Creep-Rupture</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Master curve</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time-Temperature Parameter</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Linear iso-stress line</td>
<td></td>
</tr>
<tr>
<td>Number of constants:</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Constant terms, definition, unit:</td>
<td>Larson-Miller parameter, Point of convergence respectively, both are unitless</td>
<td></td>
</tr>
<tr>
<td>Sample plot:</td>
<td><img src="image" alt="Sample Plot" /></td>
<td></td>
</tr>
<tr>
<td>Note: (advantages/limitations/special remarks)</td>
<td>Linear iso-stress line. For wide range of data exhibits inflection point.</td>
<td></td>
</tr>
</tbody>
</table>

References:
Taxonomy of Models

**KINGDOM:** Phenomenological, Mechanistic, Multiscale

**CLASS:**

- Deformation
  - ORDER: Minimum creep strain rate
  - FAMILY: Originating Model/Author
    - Primary creep
    - Secondary creep
    - Tertiary creep
    - Mixed
    - Creep Viscoplasticity
    - Viscoplasticity
    - Unified Viscoplasticity
    - Zero-Yield Unified Viscoplasticity

**Damage & Rupture**

- ORDER
  - Classic damage mechanics / Ratios
  - Continuum damage mechanics
  - Microstructural damage mechanics

**Family**

- Originating Model/Author

**Order**

- Development Timeline
  - 1910
  - 1920
  - 1930
  - 1940
  - 1950
  - 1960
  - 1970
  - 1980
  - 1990
  - 2000
  - 2010
Material Constant Determination

- Analytical Optimization for Simple Models
- Numerical Optimization for Complex Models (# of Matl Constants >> Variables)

**MACHO**

MAterial Constant Heuristic Optimization

**Features**

- Global Optimization Routine (uphill and downhill moves)
- Suitable for a high number of variables (tens of thousands)
- Internal FEM Code
- 64-bit, multi-core, multi-CPU
- Scalable memory allocation
Calibration and Validation

- The calibrated models will be parametrically simulated across a full range of temperature, stress, and time to testing for fit, interpolation, and extrapolation ability of the models.
- Evaluate the credibility of characteristic curves produced by the models.
- Ideally, the best models will be able to predict extreme conditions and pass physical realism requirements.

Parametrically explore the

Time-Temperature-σ/ε Map

and

Time-Temperature-Δσ/Δε Map
# Extreme Conditions for Creep

<table>
<thead>
<tr>
<th>Condition</th>
<th>Creep Rupture</th>
<th>Deformation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma &lt; 0$</td>
<td>$t_r \approx \infty$</td>
<td>$\dot{\varepsilon}_{cr} \approx 0$</td>
</tr>
<tr>
<td>$\sigma = 0$</td>
<td>$t_r = \infty$</td>
<td>$\dot{\varepsilon}_{cr} = 0$</td>
</tr>
<tr>
<td>$0 &lt; \sigma &lt; UTS$</td>
<td>$t_r \propto f(\sigma, T)$</td>
<td>$\dot{\varepsilon}_{cr} \propto f(\sigma, T)$</td>
</tr>
<tr>
<td>$\sigma = UTS$</td>
<td>$t_r \approx 0$</td>
<td>$\dot{\varepsilon}_{cr} \gg 1$</td>
</tr>
<tr>
<td>$T \Rightarrow T_{D-to-B}$</td>
<td>$t_r \approx \infty$</td>
<td>$\varepsilon_{cr} \approx 0$</td>
</tr>
<tr>
<td>$0.3T_m &lt; T &lt; T_m$</td>
<td>$t_r \propto f(\sigma, T)$</td>
<td>$\dot{\varepsilon}_{cr} \propto f(\sigma, T)$</td>
</tr>
<tr>
<td>$T_m$</td>
<td>$t_r = 0$</td>
<td>$\dot{\varepsilon}_{cr} \gg 1$</td>
</tr>
</tbody>
</table>

Note: $\sigma$ is equivalent stress
### Physical Realism Requirements

<table>
<thead>
<tr>
<th>Creep Rupture Requirements</th>
<th>Creep Deformation Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>• The isotherms do not cross-over, come-together, or turn back;</td>
<td>• Minimum creep strain rate isotherms</td>
</tr>
<tr>
<td>• The extrapolated isotherms produce a sigmoidal behavior if a sigmoidal response is expected in material;</td>
<td>o do not cross-over, come-together, or turn back;</td>
</tr>
<tr>
<td>• Both mechanism transition stresses decrease with temperature;</td>
<td>o transitions from power-law creep to breakdown;</td>
</tr>
<tr>
<td>• $T_{D_{to-B}} &lt; T &lt; 0.3T_m$, the isotherms for creep-rupture are tightly bunched together;</td>
<td>• Creep deformation</td>
</tr>
<tr>
<td>• $0.3T_m &lt; T &lt; T_m$, the isotherms become more dispersed.</td>
<td>o growths with $\sigma$ and $T$; isostress lines do not cross-over, come-together, or turn back;</td>
</tr>
<tr>
<td></td>
<td>o regime dominance (primary at low stress and temperature, secondary at intermediate stress and temperature, tertiary at high stress and temperature) depends $\sigma$ and $T$;</td>
</tr>
<tr>
<td></td>
<td>o Increasing $\sigma$ and $T$ coincidences with increased rupture strain as the creep deformation mechanisms change.</td>
</tr>
</tbody>
</table>
Calibration and Validation

Note: log-log scale

\[
\frac{\sigma}{\sigma_{UTS}}
\]

Normalized Stress

Rupture Time

\( t_r \to 0 \quad m_3 \to 0 \quad \sigma \to 0 \quad t_r \to \infty \)

- Short-Term
- Intermediate
- Long Term

Controlled by Obstacle Plasticity
Controlled by Microstructural Stability
Controlled by Grain Boundary Strength and Aging

Near Elastic Limit
Sigmoidal Behavior
Mechanism Transition
Mechanism Transition
Calibration and Validation

Minimum Creep Strain Rate

Note: log-log scale

Power-Law

Diffusional Flow

Mechanism Transition

Increasing Temperature

Breakdown

T_1 T_2 T_3 T_4

n_1 n_2 n_3

Calibration and Validation

Diffusional Flow / Harper Dorn
Controversy
Kassner, Kumar, and Blum 2007
Blum and Maier 1999
Calibration and Validation

Note: line-line scale

Increasing $T$ & $\sigma$

Primary-Secondary transition

Secondary-Tertiary transition

$\dot{\varepsilon}_{\text{min},4} > \dot{\varepsilon}_{\text{min},3} > \dot{\varepsilon}_{\text{min},2} > \dot{\varepsilon}_{\text{min},1}$

$\varepsilon_{cr}$

Creep Strain

Time

$T_1$

$T_2$

$T_3$

$T_4$
• Post-audit validation will provide insight into the ability of the constitutive models to reproduce various non-standard test responses.

**POST-AUDIT VALIDATION**

**Calibrated Model Simulations**

- NonStandard Test Data
- Literature and/or Experiments
- Shakedown
- Ratcheting
- Stepped Isostress
- Stepped Isothermal
- Variable Amplitude Loading
- Etcetera...

**NonStandard Performance**

- 50kN · 1200°C
- Gas Port
- Quartz View Port
Experimental Capabilities

Challenger-Columbia Structures and Materials Research Facility
This 5,500 ft² facility houses state of the art materials synthesis, processing, and testing equipment for developing advanced materials research for next generation energy and aerospace systems. Dr. Stewart’s Materials at Extreme Research Group (MERGe) is housed in this facility and he maintains the equipment above.

<table>
<thead>
<tr>
<th>Team MERGe</th>
<th>100 kN</th>
<th>50 kN</th>
<th>50 kN</th>
<th>5 kN</th>
<th>200 N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BioReactor Liquid/Gas</td>
</tr>
<tr>
<td></td>
<td>-150 to</td>
<td>Rm to</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gas Env.</td>
<td>Gas Env.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The model performance will be evaluated with respect to experiment uncertainty.

The repeatability and stability of extrapolations using the models will be tested across boundary conditions regimes (short term creep, long term creep, low cycle fatigue, high cycle low frequency fatigue, creep-fatigue interaction, etc.) and when the database is culled by 50% overall and 10% in the long term creep and creep-fatigue interaction regime.

By breaking the data and model performance into categories and executing this uncertainty matrix, the bias in the experimental data can be separated from model performance.
Uncertainty Analysis of the Models

### Predicted / Experimental Comparison

- **Conservative**
- **Non-Conservative**

**Best Model(s)**

**Factor of 2**

**Note:** log-log scale

### Experimental / Predicted Comparison

- **Conservative**
- **Non-Conservative**

**Best Model(s)**

**Factor of 2**

**Note:** line-log scale

- **Long term**
- **Intermediate**
- **Short Term**

**Symbols:**
- $X_{sim}$
- $X_{exp}$
- $0.3T_m$
- $0.8T_m$
- $T_m$
- $0.2\sigma_{YS}$
- $\sigma_{YS}$
- $\sigma_{UTS}$
Cumulative Measures of Goodness

<table>
<thead>
<tr>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_1$</td>
<td>$T_2$</td>
<td>OBJ, CRMS</td>
</tr>
</tbody>
</table>

Do Not Consider

Consider

Best Model(s)

Uncertainty Analysis of the Models

Creep Deformation / Hysteresis Loops

$$NMSE = \frac{1}{n} \sum_{i=1}^{n} \left[ \left( \frac{X_{\text{sim},i} - X_i}{X_{\text{max}}} \right)^2 \right]$$

$$OBJ = \sum_i NMSE_i;$$

Rupture and/or Cycles to Failure

$$Z_{CRMS} = 10^{2.5CRMS}, \quad CRMS = \sqrt{\frac{\sum [\log(t_r) - \log(t_{r,\text{sim}})]^2}{n-1}};$$
The results of the mathematical/FEA, standard, nonstandard, and uncertainty analysis will be used to assign performance letter grades (A, B, C, D, or F) to each model for each loading condition, phenomena, and regime of interest.
Gantt Chart

- Creep
- Creep-Fatigue
<table>
<thead>
<tr>
<th>Milestone</th>
<th>Title</th>
<th>Description</th>
<th>Success Metrics</th>
<th>Reporting</th>
<th>Quarter</th>
<th>Date</th>
<th>Done?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phase 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M1</td>
<td>P91 and 316SS Database Compiled</td>
<td>An exhaustive database of high integrity data.</td>
<td>Sorted excel workbooks</td>
<td>Summarized in Quarterly Report</td>
<td>Y1-Q4</td>
<td>9/1/2017</td>
<td>NO</td>
</tr>
<tr>
<td>M2</td>
<td>Uncertainty Analysis of Databases</td>
<td>The databases are analyzed according to material and equipment/test related uncertainties.</td>
<td>Separation of systematic and random variables</td>
<td>Summarize results in Quarterly Report</td>
<td>Y2-Q2</td>
<td>3/1/2018</td>
<td>NO</td>
</tr>
<tr>
<td>M3</td>
<td>Topical Report</td>
<td>“A Guideline for the Assessment of Creep and Creep-Fatigue Data”</td>
<td>Submission</td>
<td>Emailed to Program Manager</td>
<td>Y2-Q2</td>
<td>3/1/2018</td>
<td>NO</td>
</tr>
<tr>
<td><strong>Phase 2</strong></td>
<td></td>
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<tr>
<td>M4</td>
<td>Mathematical Analysis Report</td>
<td>Document describing the mathematical form and material constant determination procedure of all models.</td>
<td>Completed Document</td>
<td>Summarize results in Quarterly Report</td>
<td>Y1-Q4</td>
<td>9/1/2017</td>
<td>NO</td>
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<tr>
<td>M5</td>
<td>Calibration and Validation</td>
<td>Fit, Interpolation, and Extrapolation of Models</td>
<td>Material constants and characteristic creep curves</td>
<td>Summarize results in Quarterly Report</td>
<td>Y2-Q4</td>
<td>9/1/2018</td>
<td>NO</td>
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<tr>
<td>M6</td>
<td>Post-Audit Validation</td>
<td>Simulations and Experiments under complex loading conditions</td>
<td>Blind Simulations compared to the experimental data</td>
<td>Summarize results in Quarterly Report</td>
<td>Y2-Q4</td>
<td>9/1/2018</td>
<td>NO</td>
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<tr>
<td>M7</td>
<td>Model Uncertainty</td>
<td>Parametric exercise of models against creep data uncertainty</td>
<td>Characteristic creep curves for different datasets</td>
<td>Summarize results in Quarterly Report</td>
<td>Y3-Q2</td>
<td>3/1/2019</td>
<td>NO</td>
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<tr>
<td>M8</td>
<td>Final Assessment</td>
<td>Letter Grade score of models for mathematical/FEA, calibration validation, and post-audit validation</td>
<td>A table listing the performance of each model under different boundary conditions and regimes of interest</td>
<td>Summarize results in Quarterly Report</td>
<td>Y3-Q4</td>
<td>9/1/2019</td>
<td>NO</td>
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<tr>
<td>M9</td>
<td>Topical Report</td>
<td>“A Guideline for the Assessment of Creep and Creep-Fatigue Models” &amp; “Recommendations for Improved Creep-Fatigue Models”</td>
<td>Submission</td>
<td>Emailed to Program Manager</td>
<td>Y3-Q4</td>
<td>9/1/2019</td>
<td>NO</td>
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<td><strong>Outside Budget Periods</strong></td>
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<td>M10</td>
<td>Final Report</td>
<td>Summary of experimentation, findings and data</td>
<td>Final Report</td>
<td>Y4-Q1</td>
<td>12/31/2019</td>
<td>NO</td>
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In Preparation. The Next 6 months...

• ASME PVP 2017
  • Time-Stress Parameters in Continuum Damage Mechanics
  • A Guideline to Representative Stress Model Selection for Multiaxial Creep
  • Development of a Stepped Iso-Stress Method Accelerated Creep Test for Metallics

• Nuclear Material Design
  • Model Transformations of Theta Projection, MPC Omega, and Sin-Hyperbolic Creep Deformation, Damage, and Life Prediction Models

• ASME Journal of Pressure Vessel Technology (Special Issue)
  • A Review of Master Curve Models for Creep-Rupture
Questions?

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Modern Materials
- Structural Alloys
- Composites
- Polymers

Advanced Materials
- Additively Manufactured Materials
- Biomaterials
- Nano-Composites
- Thin Engineered Materials

Extreme Conditions
- Temperature (Cryogenic to Melting)
- High Pressure
- Strain Rate / Impact / Ballistics
- Chemistry (Oxidation, Corrosion)
- Frequency

Physiologically-Relevant Cell Culture
The goals of MERG are to:

- Expand the UTEP’s capability to conduct experimental research that replicate the extreme boundary conditions experienced by modern and advanced materials.

- Develop theoretical models that capture the key phenomena (at appropriate time- and length-scales) that enable the prediction of constitutive response, damage evolution, and component life at a high fidelity.

- Design numerical tools to facilitate the rapid implementation of theory into academia, government, and industry.
From Materials to Models

Experimental Methods
- Subjecting small samples to mechanical test conditions bearing similarity to larger structures

Theory Development
- Applying of theories of elasticity, plasticity, viscoplasticity, etc.
- Developing constitutive models and life prediction equations from the experimentally observed behavior

Numerical Modeling
- Using appropriate continuum and/or non-continuum mechanics based numerical codes to simulate the materials response

Post-Audit Validation
- Evaluate the physical-realism of simulations through parametric simulations compared to blind experimental data.

Design
Outcomes

• Experimental Database of Standard and NonStandard Data
• Library of Validated Creep and Creep-Fatigue Models
• Topical Report – A guideline to the assessment of creep and creep-fatigue data
• Topical Report – A guideline to the assessment of creep and creep-fatigue models
• Final Report
• Conference papers
• Journal articles