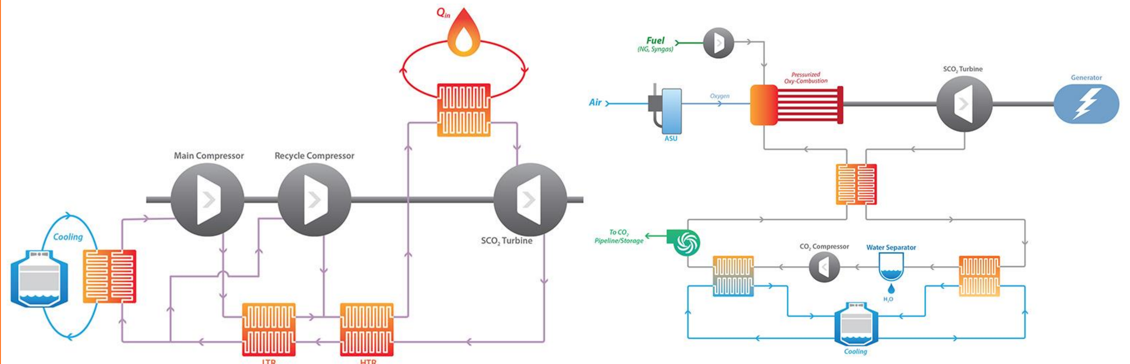
A Guideline for the Assessment of Uniaxial Creep and Creep-Fatigue Data and Models

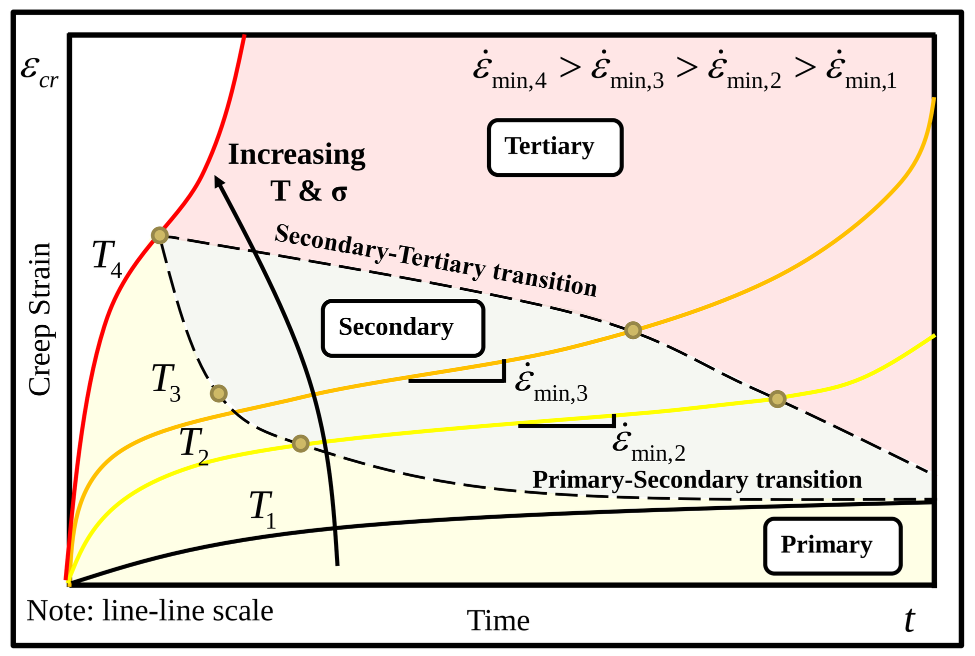
Mohammad Shafinul Haque, Christopher Ramirez, Jack F. Chessa, Calvin M. Stewart
Department of Mechanical, University of Texas El Paso, Texas, Tx 79902

1. Motivation

- Advance Ultrasonicsupercticical (A-USC) power plants steam pressure above 4000 psi and temperature exceeding 1400ºF;
- life extension for US coal-fired power plants where many plants will operate for up to 30 additional years of service.

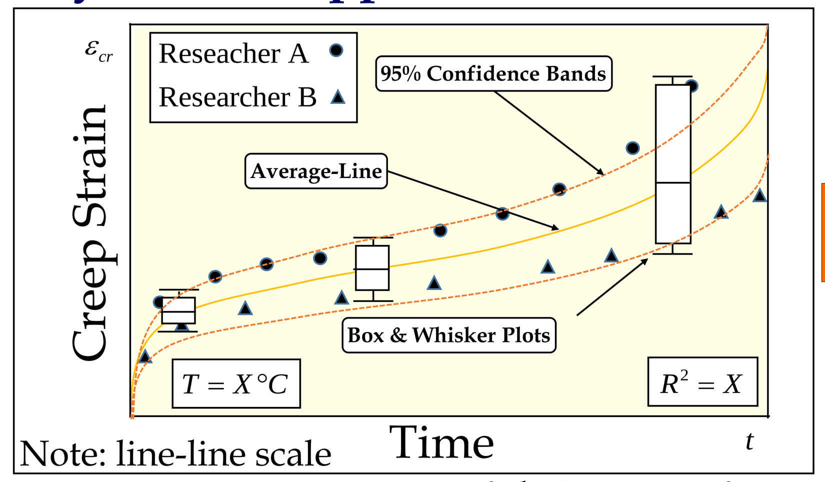


Indirect and directly fired supercritical CO_2 cycles



Characteristic curves for creep deformation

2. Systematic approach to assessment



Aggregate Datasets with Uncertainty

Analytical Fit

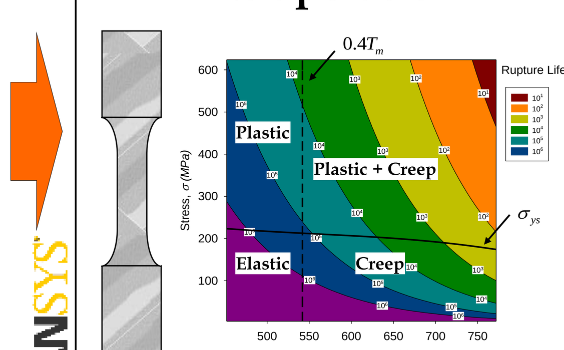
Global Optimization

MACHO

MAterial Constant Heuristic Optimization

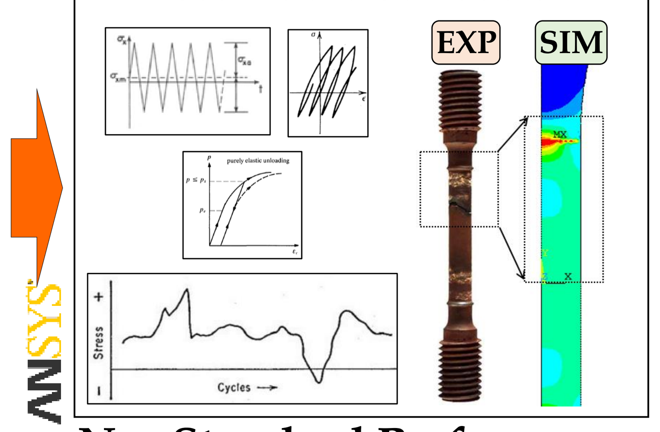
Model Fit to Datasets

Interpolation and Extrapolation



Standard Performance

Post-Audit Validation



NonStandard Performance

Model Uncertainty

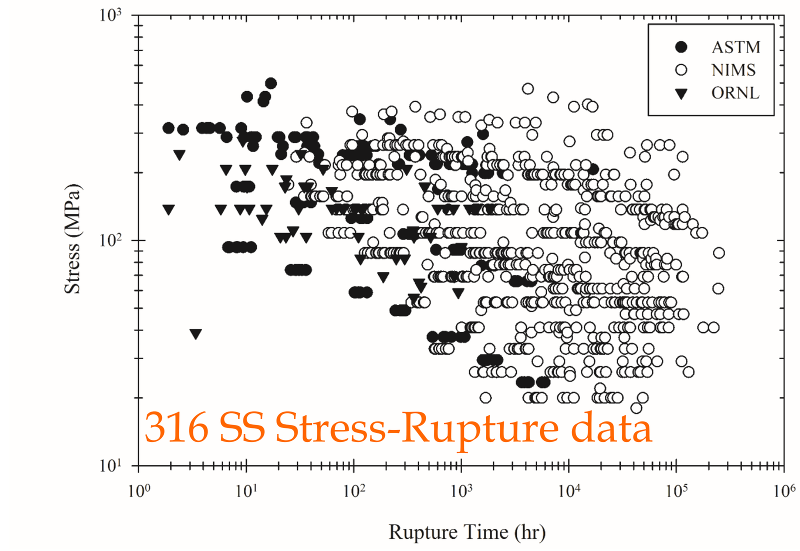
$NSME, Z_{CRMS}$

Performance

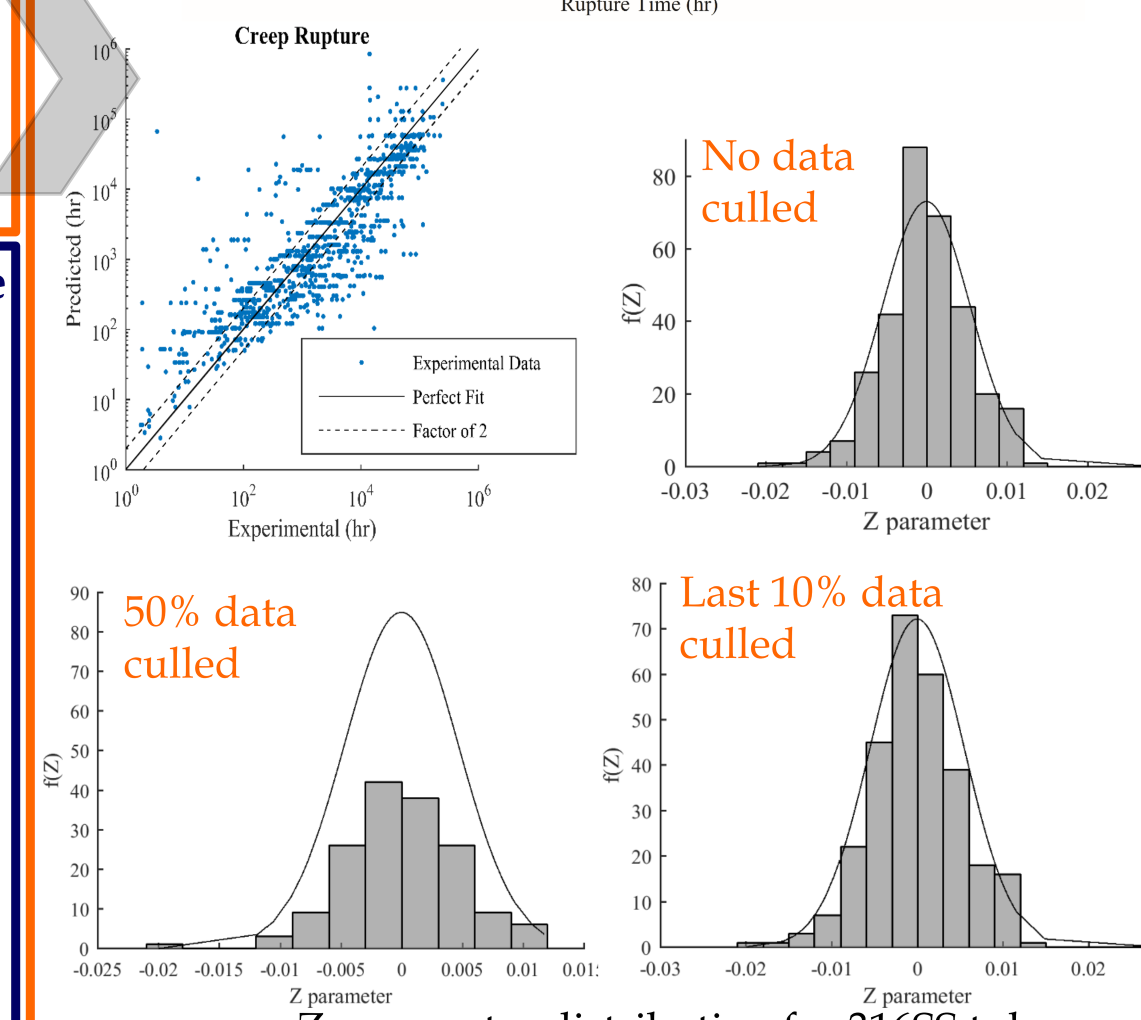
A B C D F

3. Data mining and processing

Alloy Name	Material Code	Country Code	Laboratory Code	Material Spec / Grade
Chemical Composition	Thermomechanical Processing	Form	Test Type	Test Standard
	Specimen Geometry	Test Equipment	Environment	



316 SS Stress-Rupture data



Z-parameter distribution for 316SS tube

4. Creep model collection and classification

Life Prediction

Creep-Rupture

- Larson-Miller (1952); Manson-Haferd (1953); Sherby-Dorn (1954); Monkman-Grant (1956); Omega (1995); Theta (1992); Kachanov-Rabotnov (1967-69); Wilshire (2006); Sinh (2013); etc.

Fatigue Rupture

- Palmgren-Miner (1924,1945); Robinson (1938); Lieberman (1962); Coffin-Manson (1953-54); Morrow-Halford (1965-66); Chaboche (1988); Scott-Emuakpor (2011); etc.

Creep-Fatigue Rupture

- Manson (1971), British R5; Chaboche (1980), ASME B&PV III, French RCC; etc.

Constitutive Laws

Creep Viscoplasticity (Zero Yield Surface)

- Primary: Andrade (1910); Bailey (1935); McVetty (1943); Garofalo (1965); etc.
- Secondary: Norton (1929); Soderberg (1936); McVetty (1943); Dorn (1955); Johnson-Henderson-Kahn (1963); Garofalo (1965); etc.
- Mixed: McVetty (1943); Graham and Walles (1955); Garofalo (1965); Kachanov-Rabotnov (1967-69); Theta (1984); RCC-MR (1985); Omega (1995); Liu-Murakami (1998); Dyson-McLean (1998); Sinh (2013); etc.

Cyclic Viscoplasticity (Yield Surface)

- Bodner (1975); Hart (1976); Chaboche (1977); Robinson (1978); Krempl (1980);etc.

Creep-Fatigue Viscoplasticity (Equilibrium Surface)

- Miller (1976); Walker (1981); Sinh (2013); etc.

Taxonomy Chart

Type:
- Phenomenological
- Mechanistic
- Multiscale

Capability:
- Deformation
- Damage
- Rupture

Deformation
- Minimum creep strain rate
- Primary creep
- Secondary creep
- Tertiary creep
- Viscoplasticity

Damage
- Continuum Damage Mechanics
- Microstructural damage mechanics
- Ratio (stress, strain, energy, time) damage mechanics

Rupture
- Time-Temperature Model
- Time-Stress Model
- Time-Temperature-Stress Model

Taxonomy example

Kachanov-Rabotnov

Originating Model: Self
Type: Phenomenological
Capability:
Deformation - Secondary and Tertiary
Damage - Continuum Damage Mechanics
Rupture - Time-Stress Model (or Time-Temperature Stress if Arrhenius Function employed [ref])

5. Metamodeling

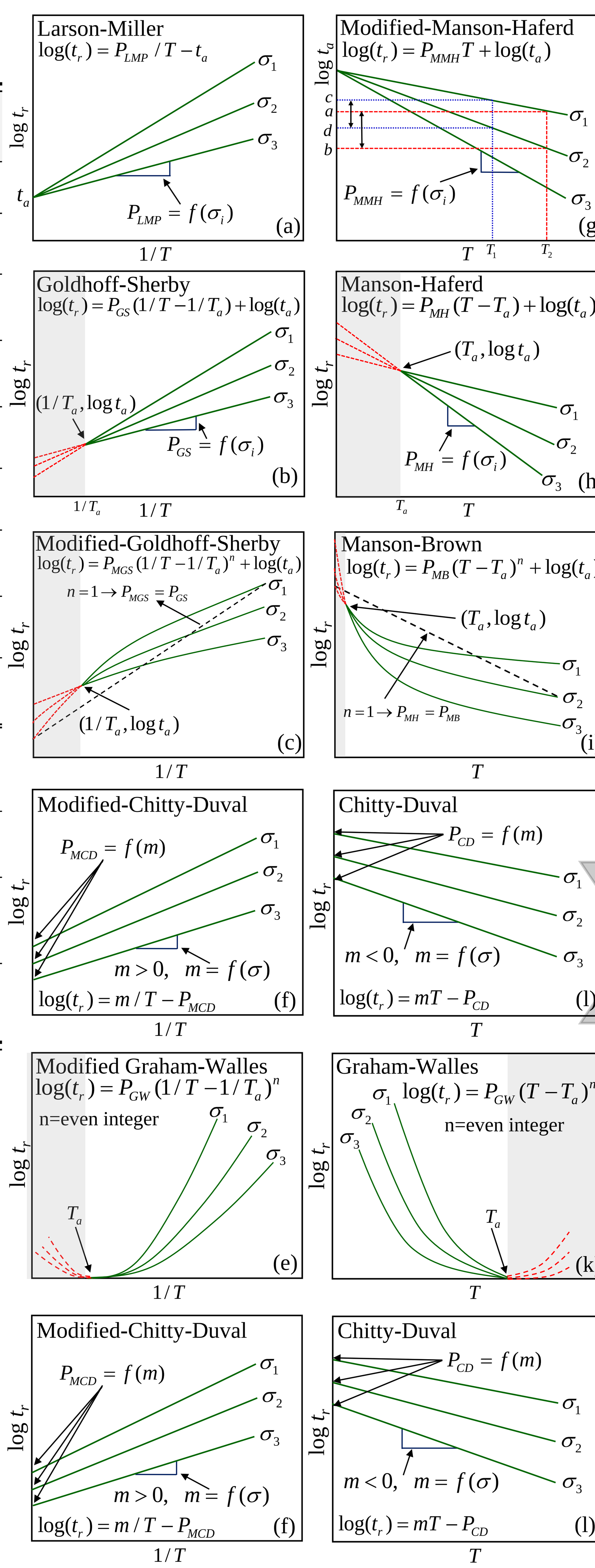
Summary of the time-temperature parameter creep rupture models

$$P_{HS}=\frac{\log(t_r)-\alpha_0-\alpha_1 T^r}{(T^r-\alpha_2^r)^q}$$

Model	Parameter equation	Metamodel condition
Larson-Miller	$P_{LMP}=T(\log(t_r)+t_a)$	$\alpha_2=\alpha_1=0$, $r=-1, q=1$
Manson-Haferd	$P_{MH}=\frac{\log(t_r)-\log(t_a)}{T-T_a}$	$\alpha_1=0$, $r=q=1$
Manson-Brown	$P_{MB}=\frac{\log(t_r)-\log(t_a)}{(T-T_a)^n}$	$\alpha_1=0, r=1$, $q=n$
Orr-Sherby-Dorn	$P_{OSD}=\log(t_r)-Q/RT$	$\alpha_0=0$, $r=-1, q=0$
Manson-Succop	$P_{MS}=\log(t_r)-BT$	$\alpha_0=\alpha_2=0$, $r=1, q=0$
Graham-Walles	$P_{GW}=\frac{\log(t_r)}{(T-T_a)^n}$	$\alpha_0=\alpha_1=0$, $r=1,\ q=n$
Chitty-Duval	$P_{CD}=mT-\log(t_r)$	$\alpha_0=\alpha_2=0$, $r=1,\ q=0$
Goldhoff-Sherby	$P_{GS}=\frac{\log(t_r)-\log(t_a)}{1/T-1/T_a}$	$\alpha_1=0$, $r=-1, q=1$
Modified-Manson-Haferd	$P_{MMH}=\frac{\log(t_r)-\log(t_a)}{T}$	$\alpha_2=\alpha_1=0$, $r=1, q=1$
Modified-Graham-Walles	$P_{MGW}=\frac{\log(t_r)}{(1/T-1/T_a)^n}$	$\alpha_0=\alpha_1=0$, $r=-1, q=n$
Modified Chitty-Duval	$P_{CD}=\frac{m}{T}-\log(t_r)$	$r=-1$, $q=0$, $\alpha_0=\alpha_2=0$
Modified-Goldhoff-Sherby	$P_{GS}=\frac{\log(t_r)-\log(t_a)}{(1/T-1/T_a)^n}$	$r=-1, q=n$, $\alpha_1=0$

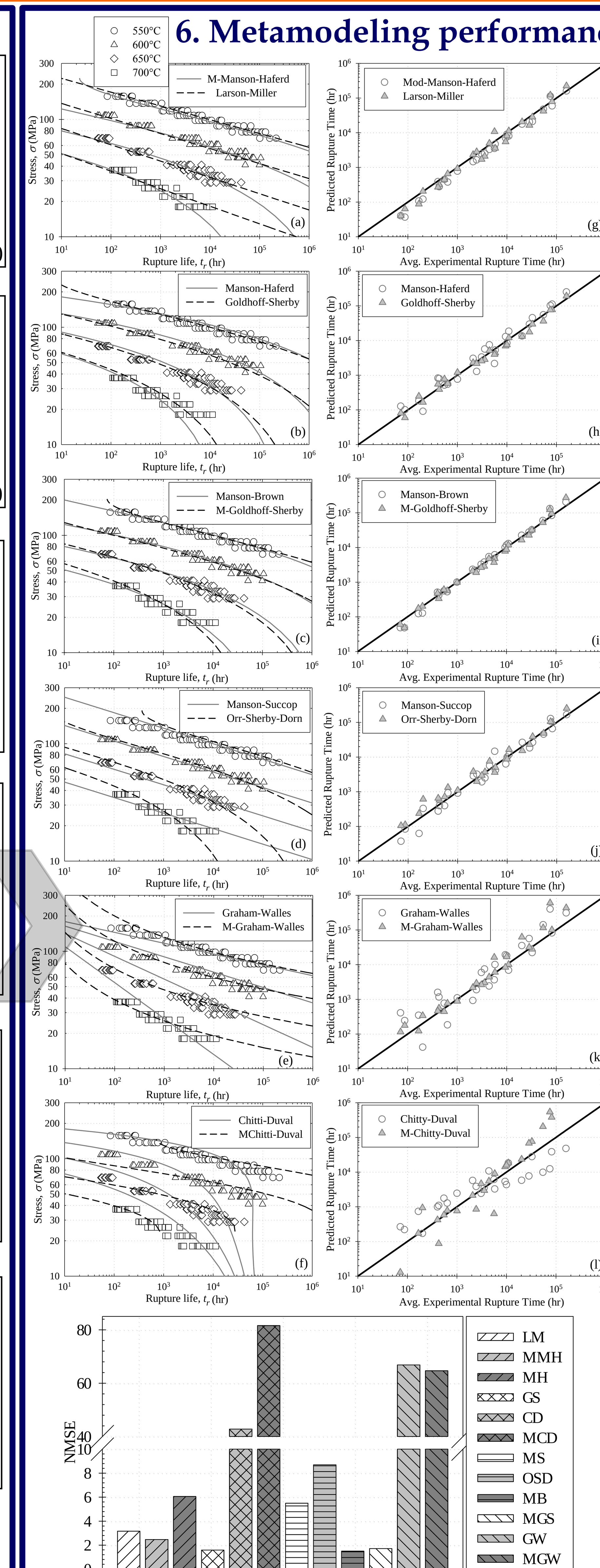
Flow chart – Metamodeling process

	Conventional approach	Proposed approach
1	Metamodeling using predefined stress-parameter function.	Metamodeling in parameter form.
2	Regression analysis to optimize material constants.	Simultaneous regression analysis to optimize material constants and stress-parameter function.
3	Sub models are forced fit to the predefined function.	Most suitable mathematical function is determined for each sub models.
4	Analysis may be biased. Risk of rejecting a potential model.	Each model is evaluated using most suitable stress-parameter function. More flexible.



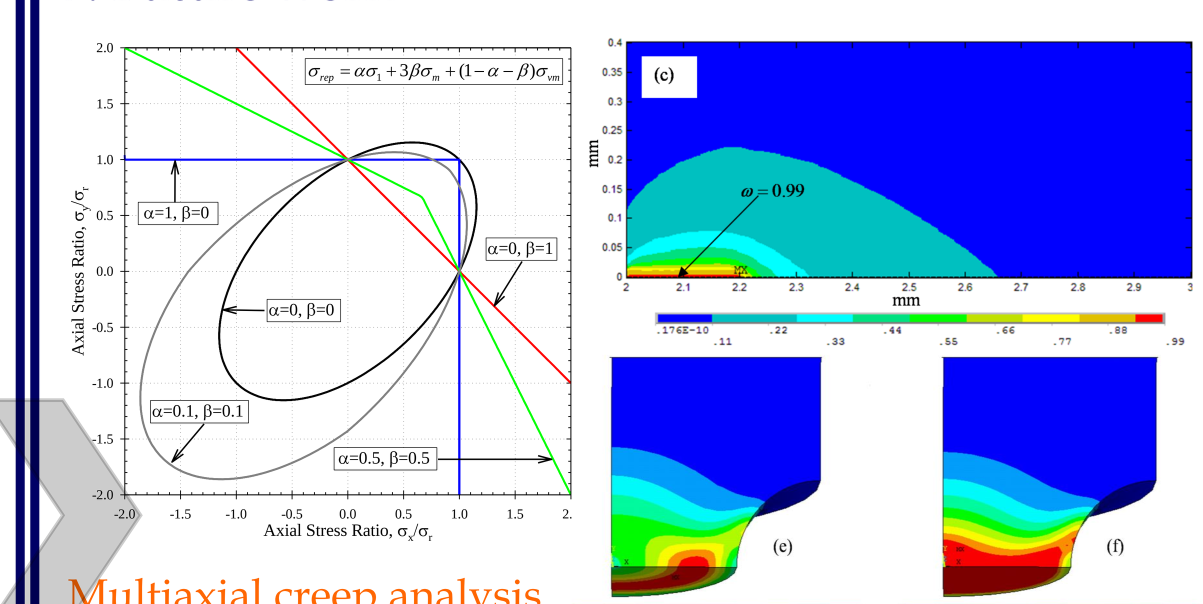
Schematic of the isostress lines observed in twelve time-temperature parameter models

6. Metamodeling performance

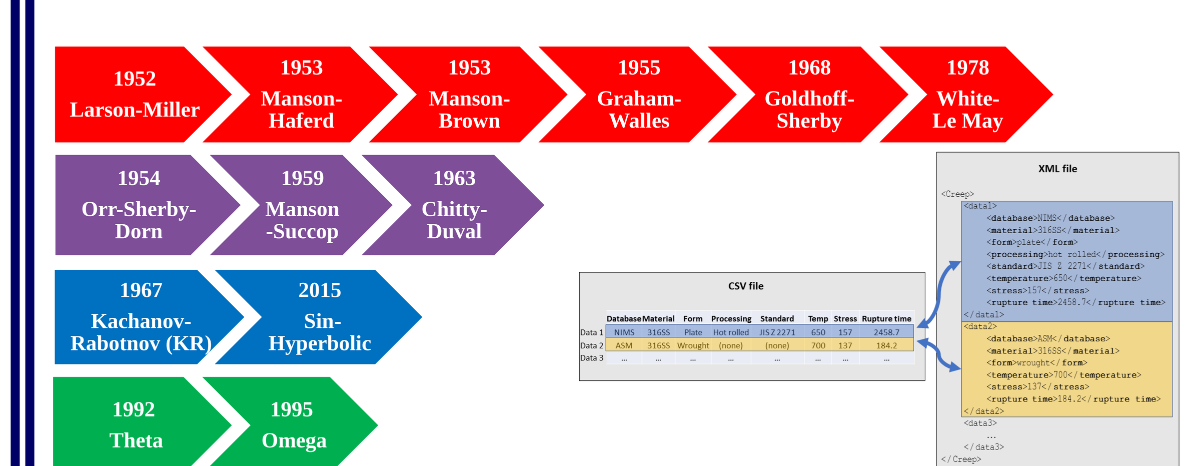


Model performance analysis

7. Future work



Multiaxial creep analysis



Website: Online database and Creep design tool

Acknowledgement

Department of Energy
National Energy Technology Laboratory
Award number: DE-FE0027581