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A709 Code Case Design Parameters

Joint ART Materials/AMMT Program Review
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Acknowledgment

- Data from Argonne (Xuan Zhang), Idaho (Heramb Mahajan), and Oak Ridge (Yanli Wang)

RD-23IN040410, A709 Design Rules - INL

- **Scope**
  - Initiate efforts to develop design parameters such as allowable stresses, isochronous stress-strain curves, etc., using A709 data generated from the code case testing tasks
  - Support submittal of the first A709 Code Case to ASME by 2025

Structural Failure Modes for ASME Division 5 Class A Components

- **Class A design rules are based on design-by-analysis approach**
  - Sought to provide a reasonable assurance of adequate protection of structural integrity
  - Based on design against structural failure modes; four design evaluation checks

Time Independent Failure Mode	Category	Design Evaluation Procedure	Time Dependent Failure Mode	Category	Design Evaluation Procedure
Ductile rupture from short-term loading	Load-controlled	Primary load check	Creep rupture from long-term loading	Load-controlled	Primary load check
Gross distortion due to incremental collapse and ratcheting (low temperatures)	Deformation-controlled	Strain limits check	Creep ratcheting due to cyclic service	Deformation-controlled	Strain limits check
Loss of function due to excessive deformation	Deformation-controlled	Strain limits check	Creep-fatigue failure due to cyclic service	Deformation-controlled	Creep-fatigue check
Buckling due to short-term loading	Deformation-controlled	Buckling Check	Creep-buckling due to long-term loading	Deformation-controlled	Buckling Check

Design Parameters Required to Address Failure Modes for Class A Components

Design Parameters	Required Test Data
Allowable Stresses	
• S_m: based on yield and ultimate strengths at temperature	Tensile data at temperature (time-independent)
• S_t: based on time to 1% total strain, time to onset of tertiary creep, time to rupture • S_r: based on stress to rupture	Creep rupture data with full creep curves (time-dependent)
• S_{mt}: lesser of (S_m, S_t) • S_0: lesser of $(S, S_{mt}@300{,}000h)$	Derived design parameters
• R: Stress rupture factor - based on rupture strengths of base metal and weldment	Stress rupture data from base metal and weldment (time dependent)
Thermal aging factors on yield and ultimate	Tensile data of aged material (time-dependent)
Isochronous stress-strain curves constructed based on creep tests	Tensile stress-strain curves (time-independent), and creep strain data up to 3% (time-dependent)

Design Parameters	Required Test Data
Fatigue design curves	Strain-controlled continuous cycling tests
Creep-fatigue interaction diagram	Strain-controlled cyclic tests with hold times
EPP design parameters	Two-bar and SMT tests; cyclic stress-strain curves
Inelastic material model parameters	Test data for other design parameters; and strain rate change and thermomechanical cycling
Huddleston effective stress parameters	Multiaxial creep rupture data
External pressure charts	Tensile stress-strain curves (time-independent)
Time-temperature limits for external pressure charts	Isochronous strain-strain curves

Some design parameters are for setting design limits; some are for providing behavioral trends to support design evaluations

Ongoing A709 Code Case Testing

- **Being performed at Argonne, Idaho and Oak Ridge**
- **Base metal**
  - Tensile, creep, fatigue, creep-fatigue, SMT
- **Weldment (matching filler metal, GTA)**
  - Cross weld creep rupture
  - Tensile, fatigue and creep-fatigue (selective)

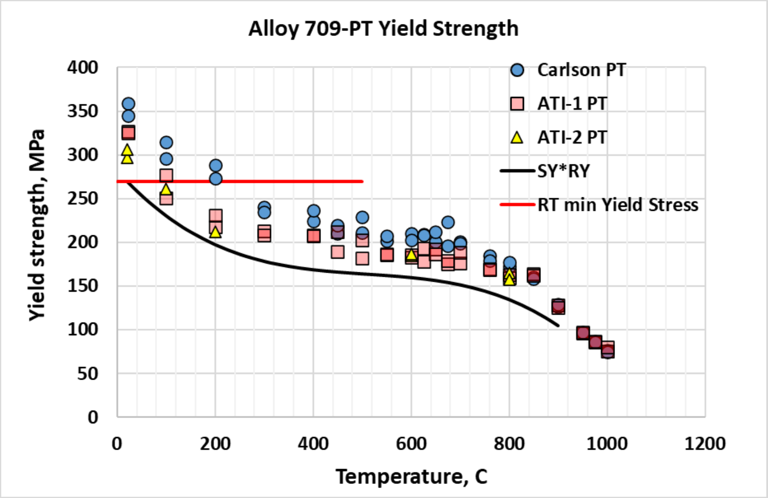
Code Yield and Tensile Strengths

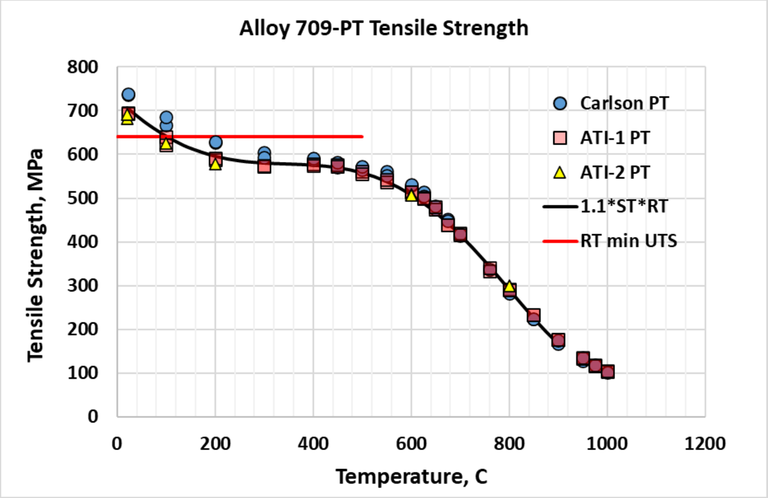
- **The ASME, Section II procedure to develop the Code yield and tensile strengths at temperature is somewhat convoluted**
  - Yield stresses at temperature are normalized by the room temperature value from the same heat
  - The normalized yield stress data are used to establish a “trend curve” (R_Y) using polynomial fit
  - The trend curve is then multiplied by the room temperature specification minimum yield strength (S_Y) to determine the Code yield stress at temperature, $S_Y R_Y$
  - Procedure for UTS is similar, except that an additional factor of 1.1 is used to determine the Code tensile strength at temperature, $1.1 S_T R_T$

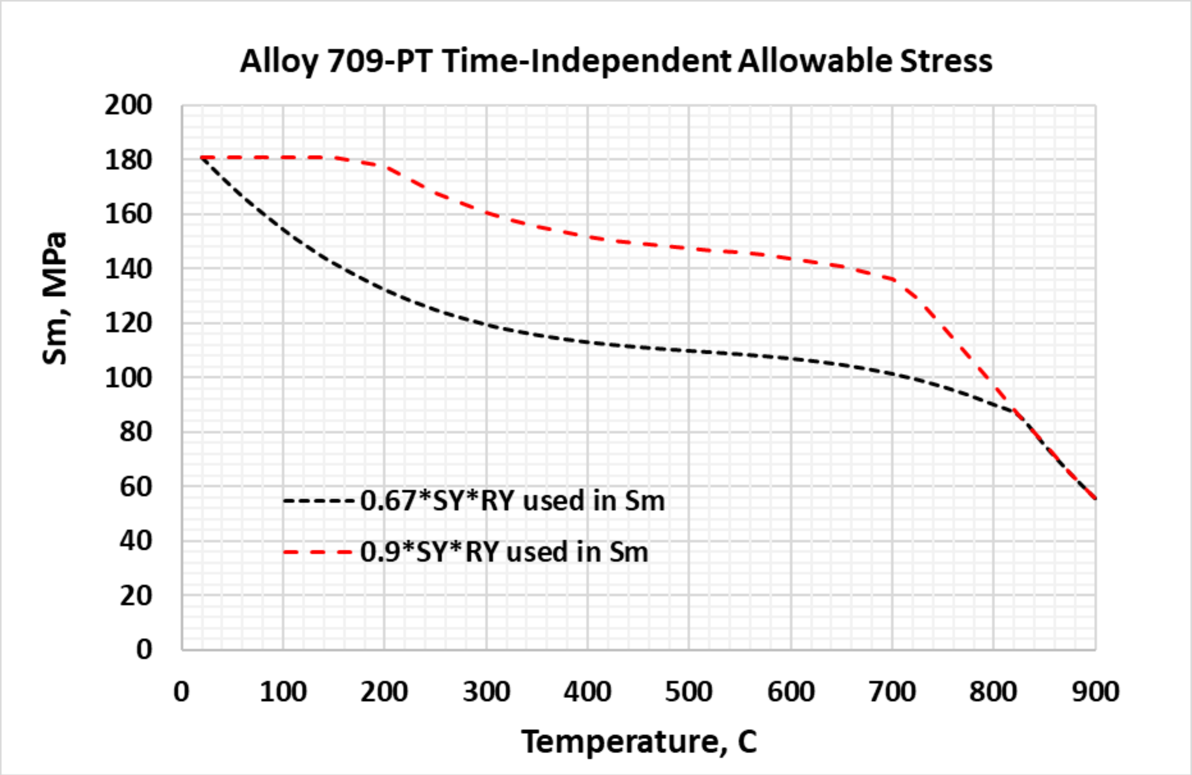
Time-Independent Allowable Stress Criteria

- **Time-independent allowable stress, S_m, is determined as the lesser of**
  - one-third of S_T, the room temperature specification minimum tensile strength
  - one-third of $1.1 S_T R_T$, the Code tensile strength at temperature
  - two-thirds of S_Y , the room temperature specification minimum yield strength
  - two-thirds of $S_Y R_Y$, the Code yield strength at temperature
    - For austenitic stainless steels, nickel alloys, copper alloys, and cobalt alloys having an S_Y/S_T ratio less than 0.625, the two-thirds factor on the Code yield strength at temperature can be increased to 0.9, if the additional deformation does not impact the functions of the component
    - For A709, $S_Y/S_T = 0.42$

Preliminary A709 Time-Independent Allowable Stresses







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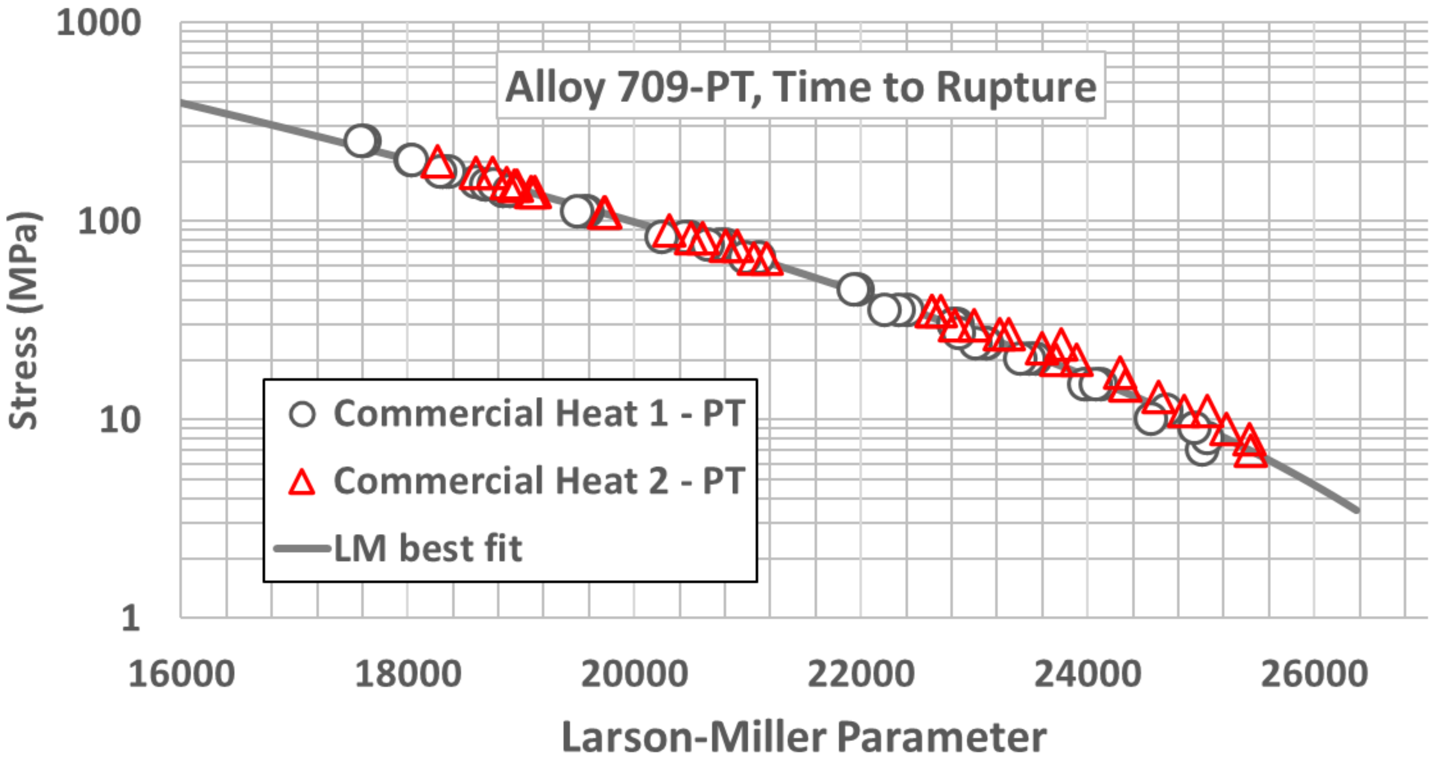
Code Creep Rupture Stress

- **The Larson-Miller correlation for rupture stress and time is** $log_{10} t_r = \left(\frac{1}{T_a}\sum_{p=0}^{n} a_p (log_{10}\sigma)^p\right) - C$, with a_p and C the regression parameters
- **Data variability is accounted for by the lower bound equation**

$$log_{10} t_r = \left(\frac{1}{T_a}\sum_{p=0}^{n} a_p (log_{10}\sigma)^p\right) - C - h \times SEE, \qquad h = 1.645$$

Larson-Miller Fit for A709 Creep Rupture Data To-date



Quadratic Stress Polynomial Used

Comparison of Lower Bound Rupture Stress of A709 with 316H

Temperature, C	Ratio of lower bound rupture stress of A709 to 316H		
	65,000 h	100,000 h	300,000 h
550	1.52	1.53	1.55
600	1.61	1.61	1.64
650	1.71	1.72	1.75
700	1.84	1.86	1.91
750	2.01	2.04	2.12
800	2.26	2.31	2.44
850	2.65	2.73	3.00
900	3.35	3.54	4.25

Evaluation of Constant Strain Range Creep-Fatigue Test Data

- **Creep Damage**

$$\sum_{k=1}^{q}\left(\int_{0}^{t_k}\frac{dt}{T_d}\right), \qquad q = \#\ of\ CF\ cycles\ to\ failure, T_d = average\ rupture\ time$$

$$t_k = hold\ time\ at\ the\ k^{th} cycle$$

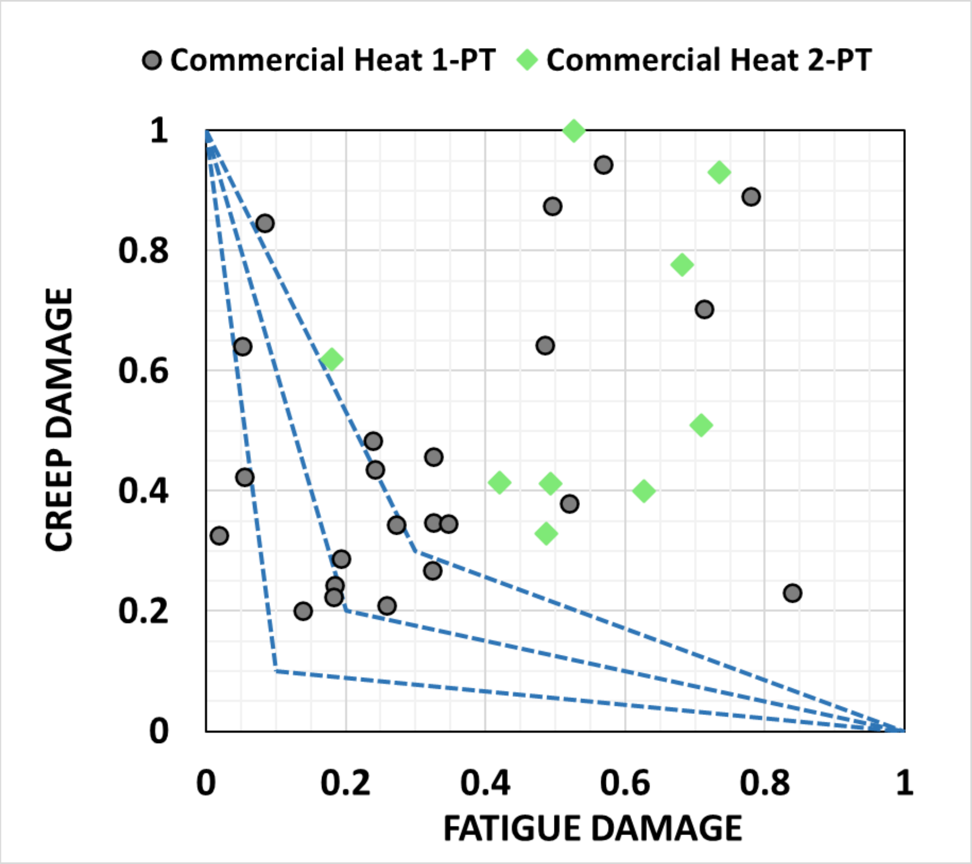
  - Creep damage integral during hold time computed cycle by cycle till failure

- **Fatigue Damage**

$$\frac{n}{N_d}, \qquad n = \#\ of\ cycles\ to\ failure\ in\ CF\ test$$

$$N_d = average\ \#\ of\ cycles\ to\ failure\ from\ separate\ fatigue\ tests\ under\ the\ same\ strain\ range\ and\ temperature\ as\ the\ CF\ test$$

Preliminary Creep-Fatigue Interaction Diagram



(0.1,0.1) or (0.2,0.2) are both reasonable intersection points

Summary

- Efforts have been initiated to develop design parameters from test data
- Thus far, most of the data evaluated were from the first two commercial heats
- Data from these commercial heats continue to support the creep strength advantage of A709 over 316H
- Design parameters will be refined as more data are available
- Work on the development of other design parameters will begin as data become available

Thank you

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