Creep Life Assessment of Alloy 690 Steam Generator Tube using Larson-Miller Parameter

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Dec. 16 ~ 18, 2020

2020 KNS Autumn Meeting (Virtual Conference)

Korea Atomic Energy Research Institute(KAERI)

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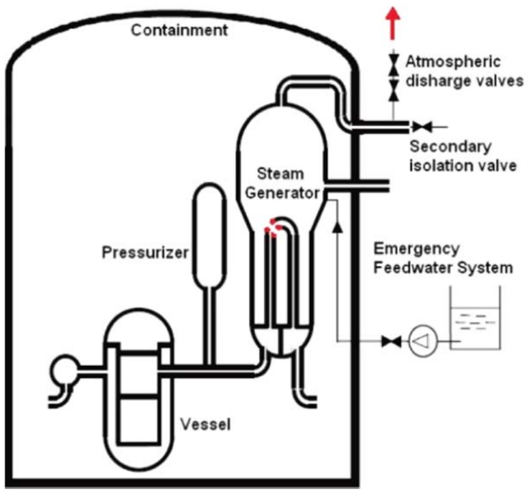
Introduction

TMLB' ?
T : Transient event
M : Failure of the secondary system relief valves and power conversion system
L : Failure of secondary system steam relief valves and auxiliary feedwater system
B' : Failure to recover onsite and offsite AC power

Evaluation of high Temperature Creep and Fracture Characteristics of SG tube

- SG Tube Creep Rupture (High Temperature)
  - A potential to fail due to creep rupture in a broad category of station blackout(SBO) severe accident scenarios represented by TMLB' sequence.→ The risk of containment bypass, large release of fission product
  - Normal operating temperature : 288~320°C (negligible)
  - Accident condition : ~830°C (creep effect)



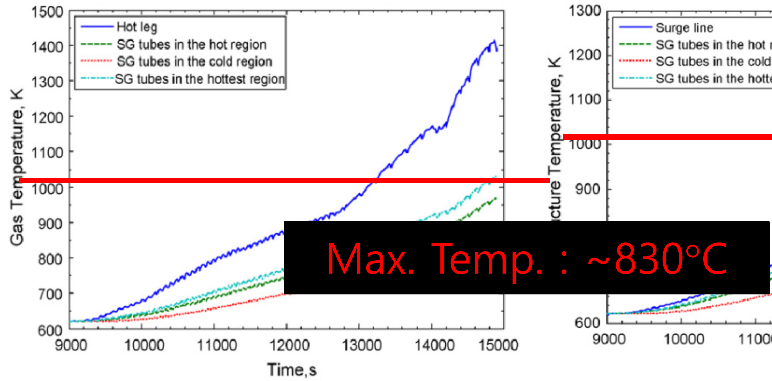


Fig. 7. Base case gas temperatures at the hot leg and SG entrance.

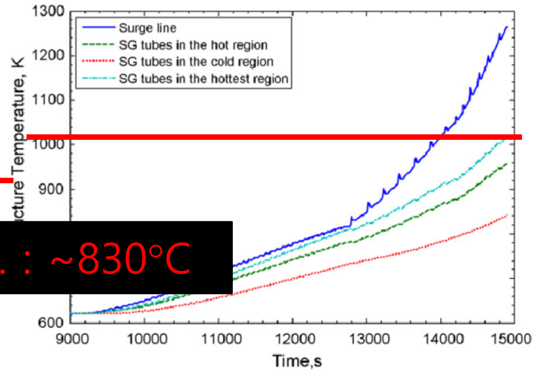


Fig. 8. Base case heat structure temperatures at the surge line and SG entrance.

Y Liao et al., "Potential steam generator tube rupture in the presence of severe accident thermal challenge and tube flaws due to foreign object wear", Nuclear Engineering and Design, 2009, V. 239, 1128-1135

Introduction

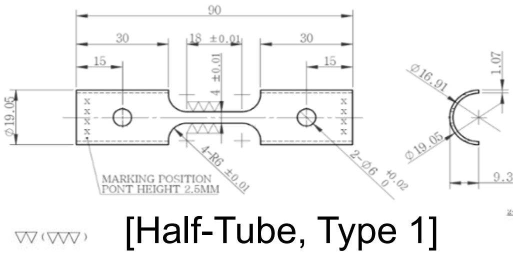
- **Evaluation of high Temperature Creep and Fracture Characteristics of SG tube**
  - Creep Rupture model
    - Flow stress model, creep rupture model (ANL, BCL, PNNL, INEL)
    - NUREG-1570, NUREG-2195
  - Replacement of SG Tube Material
    - Alloy 600(Cr:16wt%) → Alloy 690(Cr:30wt%) : high corrosion resistant in high temperature
    - The mechanical properties and creep test data in the as-manufactured material conditions for alloy 690
  - Researches on Alloy 690 Tube
    - Alloy 600 : SCC, Creep failure

구 분	고리1, 한울1,2	고리2,3,4 한빛1,2	한빛3~6	한울3~6 신고리1,2 신월성1,2	신고리3,4 신한울1,2	월성1~4
설계 제작	WH Doosan	WH	CE Doosan	CE Dossan	CE Dossan	F.W/B.W Doosan
튜브 재질	Alloy 690TT	Alloy 600TT	Alloy 600HTMA	Alloy 690TT	Alloy 690TT	Alloy 800

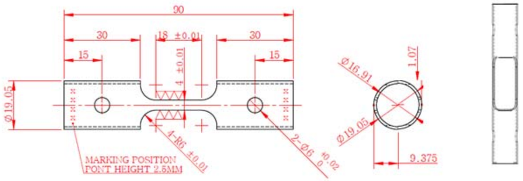
Material and Specimen

▪ Material and tensile/creep specimen

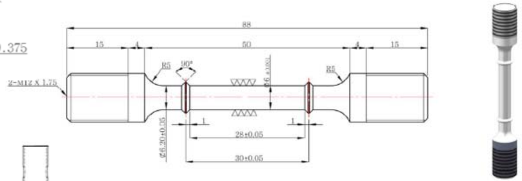
- Alloy 690 SG tube used in APR-1400 NPPs



[Half-Tube, Type 1]



[Tube, Type 2]



[Rod]

[GEOMETRY OF SPECIMENS]

[CHEMICAL COMPOSITION OF ALLOY 690 SG TUBE]

C	Mn	Si	S	P	Ni	Cr	Mo
0.020	0.493	0.265	0.0006	0.005	59.16	29.27	0.028
Cu	**Co**	**Al**	**Ti**	**Nb**	**N2**	**B**	**Fe**
0.012	<0.010	0.165	0.245	<0.010	0.020	<0.0005	10.3

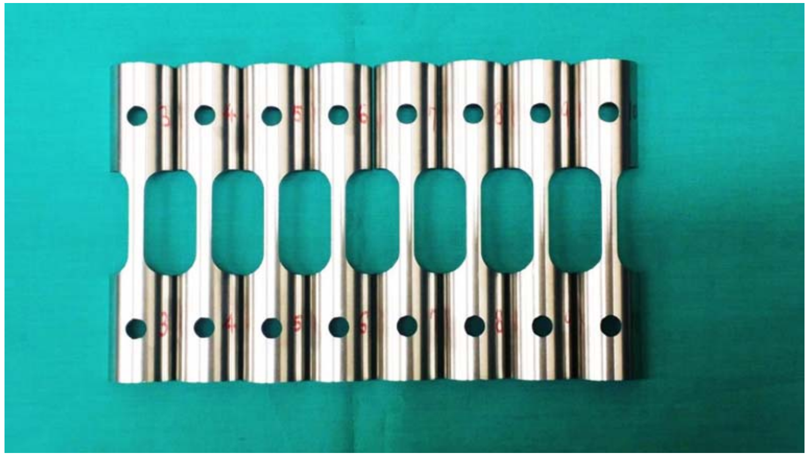
[TENSILE PROPERTIES OF ALLOY690 SG TUBE]

Temp. (°C)	Temp. (°K)	YS (MPa)	TS (MPa)	Uni. El. (%)
25	298	356	794	45
200	473	294	689	42
300	573	283	671	43
400	673	280	664	45
500	773	269	635	41
600	873	247	574	35
700	973	236	436	17
800	1073	217	239	8
900	1173	117	132	10

Test Method and Procedures

Test Method

- Insight 50 static machine
- Tube and rod type creep specimens(50)
- Temperature : 650~850°C
- Stress : 30~360 MPa
- Data : Rupture time
  Steady-state creep rate(SSCR)

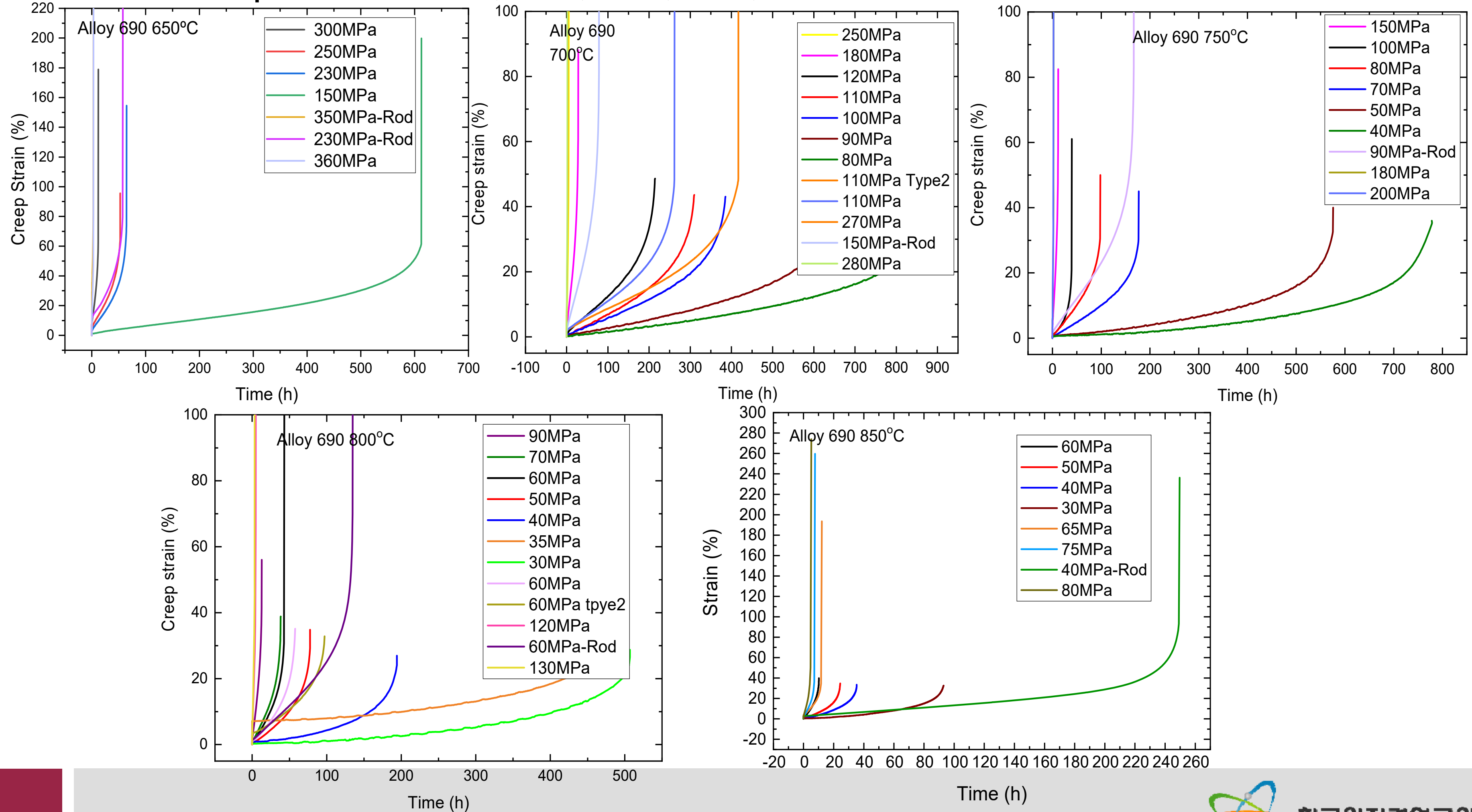


[PIN-TYPE CREEP SPECIMENS]

[TEST SET-UP FOR CREEP TESTS]

Creep Test Results

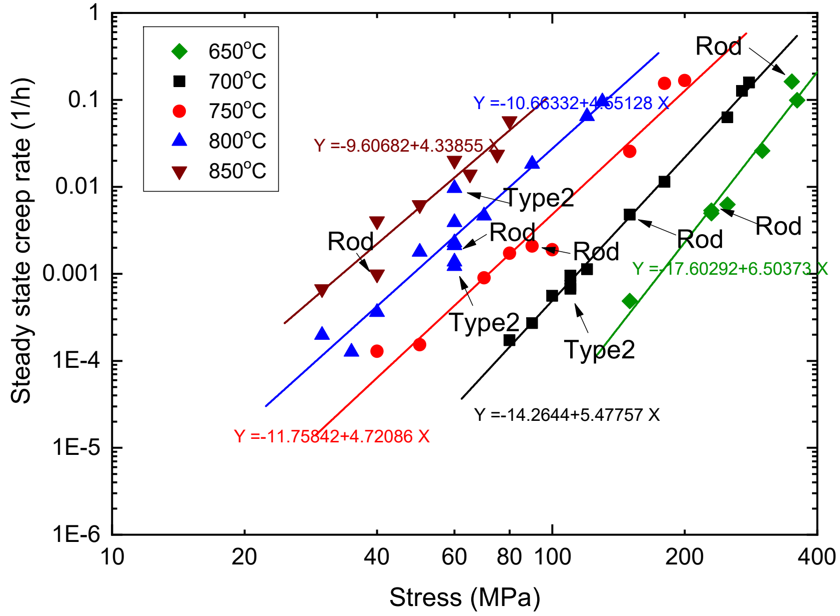
- **Creep curve**
  - Temperature : 650, 700, 750, 800, 850°C



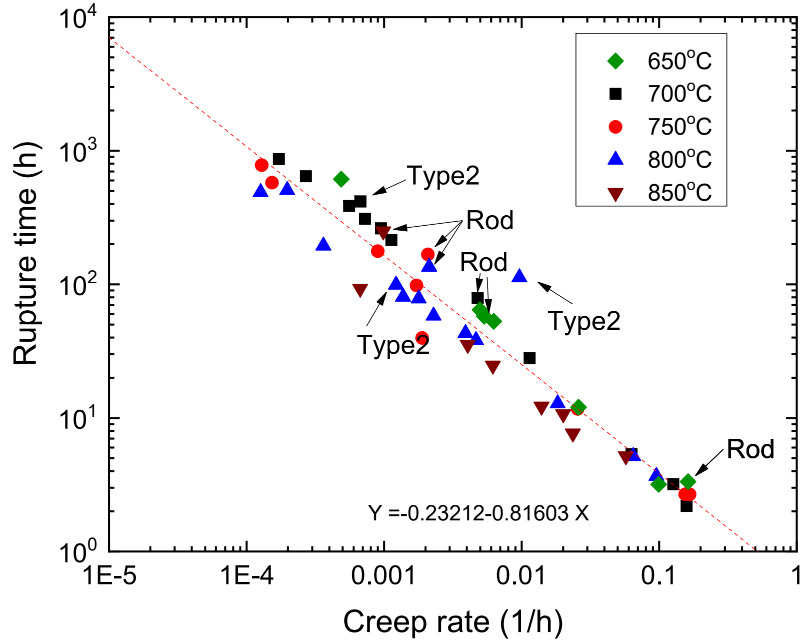
[CREEP CURVES OF ALLOY 690 TESTED AT 650-850°C]

Creep Test Results

- **Creep data : KAERI(50)**
- **Monkman-Grant(M-G) Relationship** $\log t_r + m \log \dot{\varepsilon}_s = K$
  - SSCR vs. Stress
  - Rupture time vs. SSCR (secondary creep strain range)



[PLOT OF LOG SSCR VERSUS LOG STRESS]



[PLOT OF M-G RELATIONSHIP FOR ALLOY 690]

Creep Life Prediction

Creep Life Prediction Models

- LMP(Larson-Miller Parameter)
  - Rate process theory
  - C : 13.8 (Unit : K, MPa, hr) Alloy600 : C=15
  - C_1=-3973.7, C_2=48627.9, C_3=11.26339 (Unit : K, Pa, sec) for Bi-linear
- 3rd polynomial

$$P_{LM}(\sigma) = (18.471836 + 1.915234(\log\sigma) - 1.777063(\log\sigma)^2 + 0.093028(\log\sigma)^3) \times 10^3$$

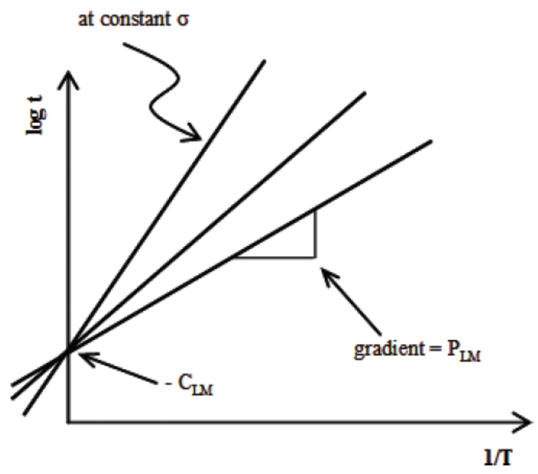
- SINH Function

$$P_{LM}(\sigma) = P_1 + P_2 \sinh(P_3 \log\sigma) + P_4 \log\sigma$$
$$= 22805.28227 - 0.0909 \sinh(3.90877 \log\sigma) - 3381.16252 \log\sigma$$

- Bi-linear

$$P_{LM}(\sigma) = C_1 \log\sigma + C_2$$
$$= -3501.2\log\sigma + 23059 \quad \text{for } \log\sigma < 2$$
$$= -4399.7\log\sigma + 24909 \quad \text{for } \log\sigma > 2$$

$$\mathrm{LMP} = \mathrm{T}(\log t_r + C)$$

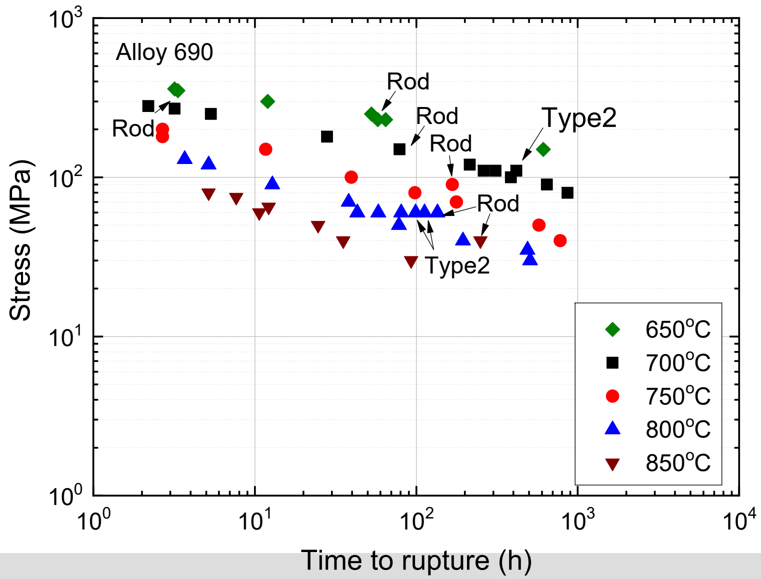


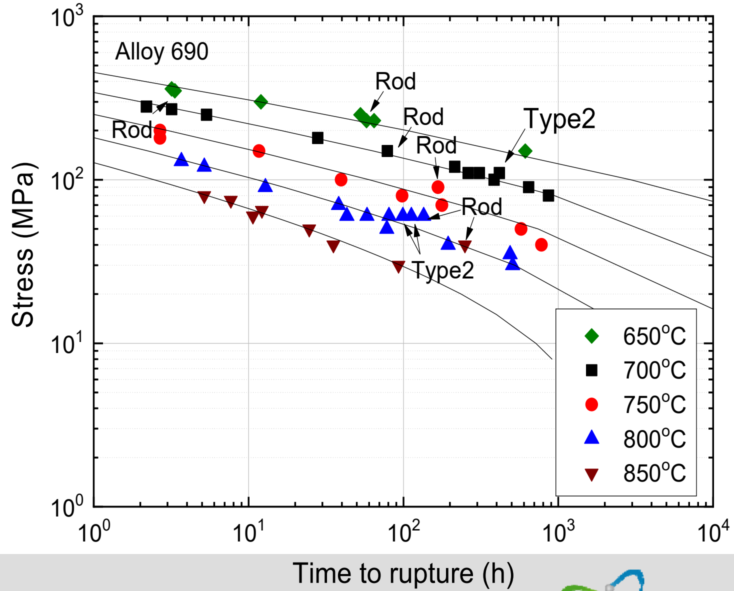
[DETERMINATION OF LMP (C)]

Creep Life Prediction

- **Creep Life Prediction**
  - Analysis of test results
    - Short-term creep test : simulation of severe accident condition
    - Cross-sectional area : Type1<Type2<Rod
    - Rupture time : Type1<Type2<Rod
    - More creep test for type 2 and rod specimens are required to analyze the effect of cross-sectional area and geometries of specimens

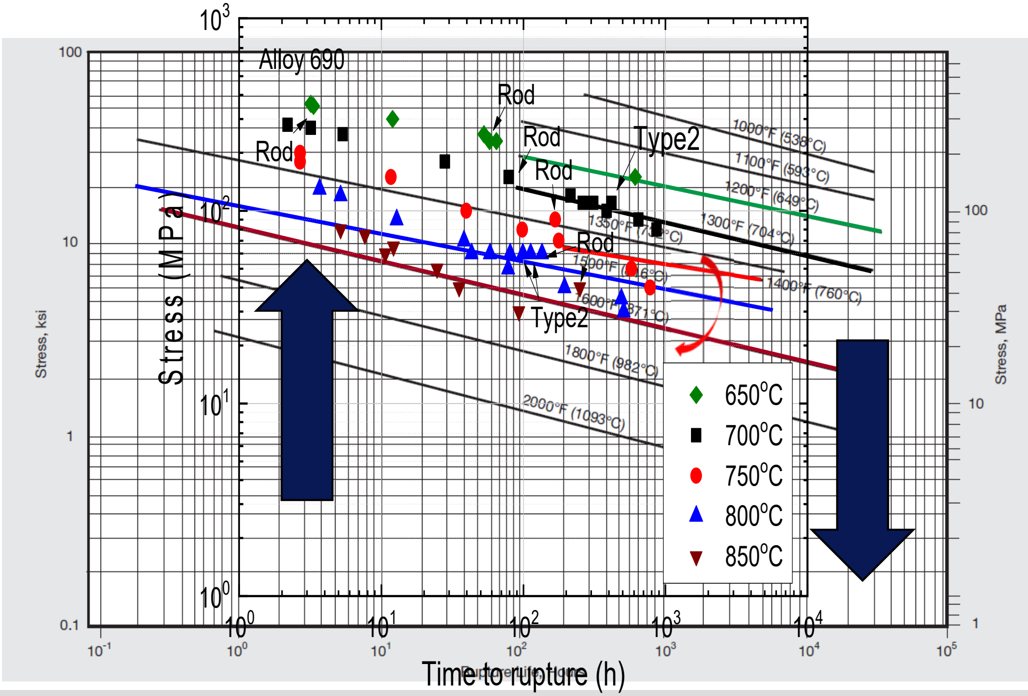
$$P_{LM}(\sigma) = (18.471836 + 1.915234(\log\sigma) - 1.777063(\log\sigma)^2 + 0.093028(\log\sigma)^3) \times 10^3$$





Creep Life Prediction

- **Comparison of Creep Rupture Data**
  - INCONEL 690 data : plate in the as-hot-rolled condition
  - Manufacturer vs. KAERI
    - Creep Strength : Short-term (KAERI>Manufacturer)
      Long-term (Manufacturer>KAERI)
  - Severe accident condition : Short-term



Concluding Remarks

- The creep test was performed to predict the creep life of Alloy 690 material.
- Using creep data, creep life was evaluated for alloy 690 SG tubing material using the Larson-Miller Parameter (LMP) method.
- An optimum material specific constant, C_1-C_3, in the master curve of LM method was investigated to be C_1=-3973.7, C_2=48627.9 and C_3=11.26339 which were calculated in units of Kelvin (Temperature), Pa (Stress), and second (t_r) in linear function. Coefficient of determination (COD), R^2 was 0.99 for optimal constant C_3=11.26339.
- Rupture time was increased as increase of cross-section area of specimens, which is considered geometry effect. More creep test for type 2 and rod specimens are required to analyze the effect of cross-sectional area and geometries.
- Comparison results of creep data between manufacturer and KEARI were reviewed, creep strength of KAERI results were higher than those of manufacturer results, but this trend reversed as the rupture time increased.

Thank you for your attention