Probability Analysis in Predicting Creep Life of Power Plant Material Using High Power Ultrasound

Minati Ku. Sahu[1], A Ghosh[1],, J. Kumar[2], S. N. Singh[2] and S. Palit Sagar[1]

1: CSIR-National Metallurgical Laboratory, Jamshedpur-831007, India; 2: National Institute of Technology, Jamshedpur-831014, India

E-mail id: minati.sahu@rediffmail.com

DOI: https://doi.org/10.1007/s11665-023-08113-y

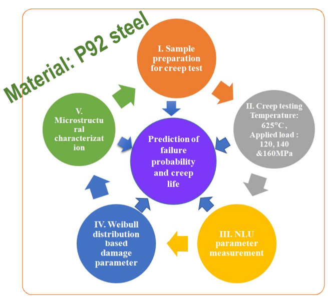
Abstract

For the non-destructive evaluation of power plant materials for various types of damage, including creep damage characterization, nonlinear ultrasonic (NLU) has been proven to be an effective method. To anticipate the failure probability or creep life of any power plant component, however, the information available from NLU measurement is insufficient. Through a two-parameter Weibull analysis of NLU data, a method has been developed to calculate the likelihood of failure relative to creep life of power plant components. With three distinct applied loads of 120 MPa, 140 MPa, and 160 MPa, P92 steel was subjected to creep testing at 625 °C for the inquiry. The level of damage was then calculated using Weibull distribution analysis utilising the NLU parameter, which was measured in the same specimen at various interruptions. Inconsistencies in the Cumulative Distribution Function (CDF) and the damage accumulation rate plots were looked at in relation to damage levels. Additionally, the behaviour of the predicted NLU parameter produced using the inverse CDF was assessed in relation to the measured value. Significant microstructural alterations, such as the creation and coalescence of microcracks, the growth and coarsening of precipitates, and damage buildup during creep deformation have all been used to support this theory. Weibull distribution-based analysis demonstrated its potential as a substitute technique for extrapolating from NLU measurements the failure probability and life of power plant components subject to creep deformation.

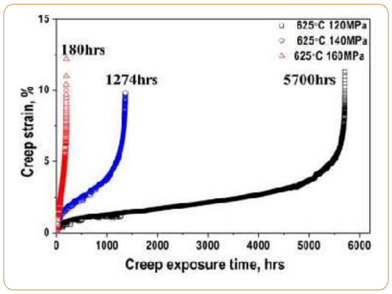
Background

- ❑ Nondestructive assessment of damage in components during service plays a major role in residual life estimation of in-service components.
- ❑ Conventional methods using ultrasonic characteristics in the linear elastic region are only sensitive to gross defects
- ❑ Creep is time-dependent plastic deformation which occurs when a material is subjected to a constant load and temperature for an extended period
- ❑ Nonlinear ultrasonic (NLU) parameter is more sensitive to micro damages.
- ❑ It can be applicable for remaining life assessment of plant materials to avoid unscheduled shutdown/catastrophic failure.
- ❑ *A remaining life predictive model can be developed from the existing NLU parameter data and can be validated on any other crept specimen of same material exposed to any other test condition.*

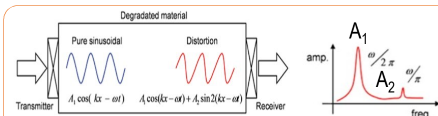
Objective & Methodology



Creep Characteristics

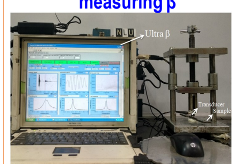


Non-linear Ultrasonic

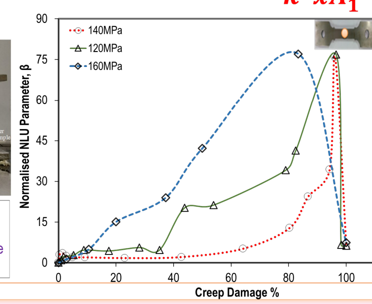


$$\beta = \frac{8A_2}{k^2 x A_1^2}$$

Portable Instrument for measuring β

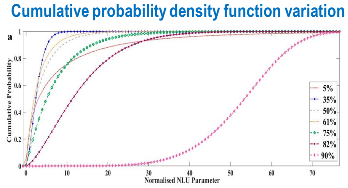


x : Propagation distance,
A_1: Fundamental wave amplitude
A_2: Second harmonic wave amplitude
β : Nonlinear ultrasonic parameter



Weibull Probability Plot for Creep Damage Estimation

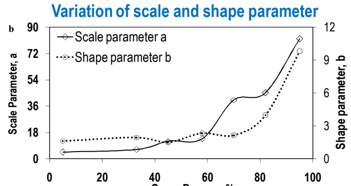
Cumulative probability density function variation



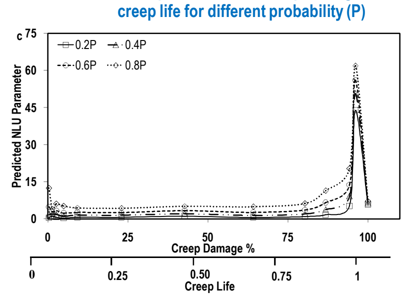
$$p(\beta) = \frac{b}{a}\left(\frac{\beta}{a}\right)^{b-1} e^{-\left(\frac{\beta}{a}\right)^{b}}$$

p (β) : Probability density function

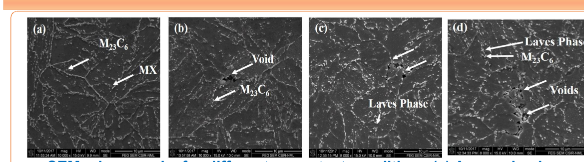
Variation of scale and shape parameter



Predicted NLU parameter with creep damage % as well creep life for different probability (P)

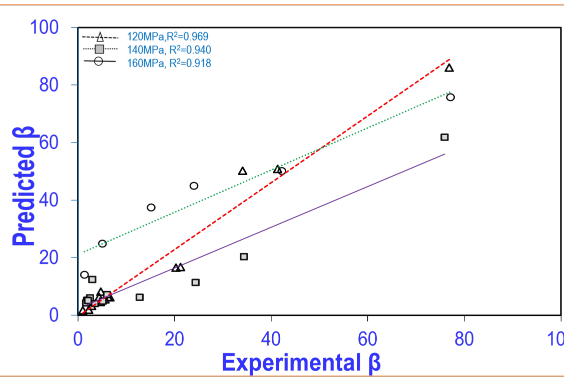


Microstructural Variation



SEM micrographs for different creep test conditions (a) As-received (b)625°C,120MPa,(c)625°C, 140MPa,(d)625°C,160MPa

Experimental β vs. Predicted β



Summary

- ❖ The creep-rupture behaviour of P92 steel was investigated in this study for a test temperature of 625°C and loads of 120MPa, 140MPa, and 160MPa. A two-parameter Weibull cumulative distribution-based prediction technique was developed for assessing creep damage based on the NLU parameter, β .
- ❖ Inclination of CDF curves with an increase in creep damage % gave an indication that the component was approaching failure. Therefore, the onset of specimen failure can be predicted from the behaviour of Weibull scale and shape parameters, which define CDF curves.
- ❖ Increase with applied stress owing to increase in the area fraction of precipitates and voids, as confirmed from P92 steel microstructure.
- ❖ The NLU parameter predicted from the Weibull inverse CDF with a probability of 0.8 demonstrated a strong correlation with the experimentally acquired NLU data.

References

1. Matlack, K.H., Kim, J.Y., Jacobs, L.J. and Qu, J., 2015. Review of second harmonic generation measurement techniques for material state determination in metals. Journal of Nondestructive Evaluation, 34(1), pp.1-23.
2. Kalbfleisch, J.D. and Prentice, R.L., 2011. The statistical analysis of failure time data. John Wiley & Sons.
3. Dieter, G.E., 1986. Mechanical Metallurgy, Mc Graw Hill Book. New York (1988).

Peeref International Poster Challenge