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TIME DEPENDENT SIMPLISTIC MODEL FOR TERTIARY CREEP DEFORMATION OF REACTOR GRADE ALUMINIUM USING MODIFIED GAROFALO-ROBINSON EQUATION

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ABSTRACT — This Aluminium and its alloy are widely used as in-core material in nuclear industries. Structural integrity of these materials throughout its intended design life and design loads is very important. Reactor environment induces many thermo-mechanical defects and alter its mechanical and high temperature behaviour in a significant way. Many researchers have extensively studied Aluminium and their alloys. However, the data at high temperature and modelling thereof is sparse and is not available in a coupled way. This paper attempts to bring all the data pertaining to creep behaviour of reactor grade boron free pure aluminium at various temperature and stress levels. Coupled expression has been developed using modified Garofalo equation of creep to model the secondary region, Robinson time weighted expression to model the tertiary region and modified LMP (Larson-Miller Parameter) to predict the rupture time.

Keywords — creep, pure aluminium, analytical modelling, material characterisation, modified Garofalo, Robinson, time weighted, LMP, rupture time, secondary, tertiary.

INTRODUCTION

The material under study is reactor grade boron free pure aluminium which is a very good candidate material for many in-core components of nuclear reactor. Analytical modelling of the material characteristics such as high temperature deformation under creep is an important parameter to be understood for design of nuclear reactors. The high temperature creep deformation of a material is often characterized by steady state secondary creep region [1], initiation of tertiary creep region and rupture time. Hyperbolic sine function used in Garofalo model has great potential to predict the steady state secondary creep region[3]. There are many damage based expressions to model the tertiary region, however, they are cumbersome and computationally expensive and may not be friendly for designers.[4] Hence, an attempt is made to bridge the simplistic model from secondary and tertiary region which could be handy designer's tool.

EXPERIMENTAL DATA AND DEVELOPMENT OF MODEL

Experiments were carried out on reactor grade boron free pure aluminium cylindrical specimens. The raw data acquired through experiments were processed and various parameters were plot. The analytical model was development based on the experimental data and tailored to the material under study.

Experimental conditions are tabulated in Table-1 below:

Table 1: Details of experimental conditions in creep test

Stress and Temperature in each case	
Case - 1	T = 300 ^oC σ = 15 MPa
Case - 2	T = 350 ^oC σ = 7.5 MPa
Case - 3	T = 400 ^oC σ = 3 MPa

The methodology adopted in modelling the creep behavior predicting secondary, tertiary and rupture time is by bridging Garofalo, Robinson and LMP models modified and tailored to reactor grade boron free pure aluminium material. The rupture time is predicted by modified LMP formulation [5], the tertiary region is captured through time weighted Robinson formulation [6] and secondary region is expressed through modified Garofalo equation.

$$d\varepsilon/dt = A.\sinh(\sigma/G)^n.\exp(-/RT).\sinh(t/tr) \qquad (1)$$

Where, ε – strain, A = 10727, σ = stress in MPa, G = Shear modulus in MPa, n – material constant, Q – Activation energy, R – Ideal gas constant, T – temperature in K, t – time, tr – estimated rupture time.

$$P = d \sinh(e+f.\sigma\ m)+g \qquad (2)$$

Where, P – parameter, d = -1359 K, e = -3.59, f = 1.34 MPa-1, m = 0.359, g = 11359 K, σ = stress in MPa

$$tr = 10P/T\text{-}C \qquad (3)$$

Where, tr – rupture time (s), P – parameter (K), T – temperature (K), C – constant

Plots comparing experimental data and estimation by proposed model are made and presented in the figures below:

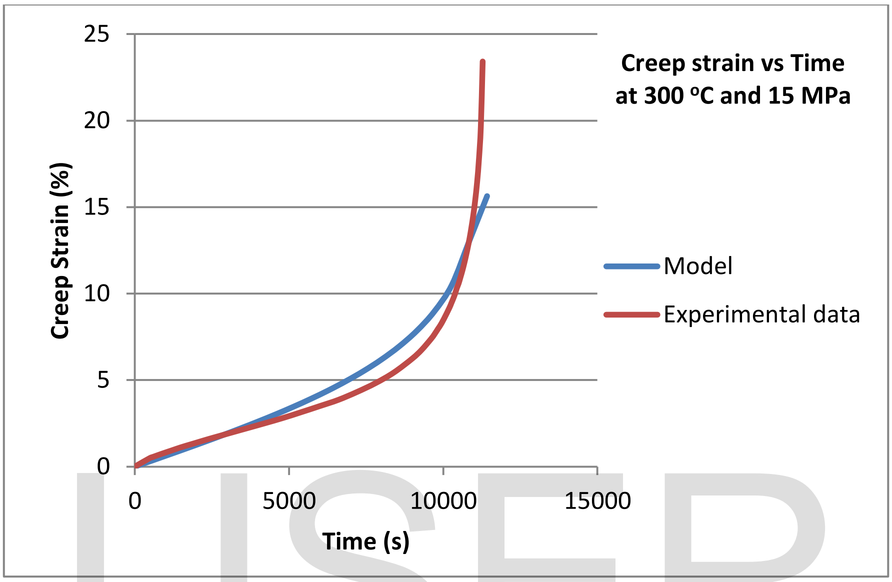

Figure 1: Comparison between experimental data and model at temperature of 300 ^{o}C and 15 MPa stress

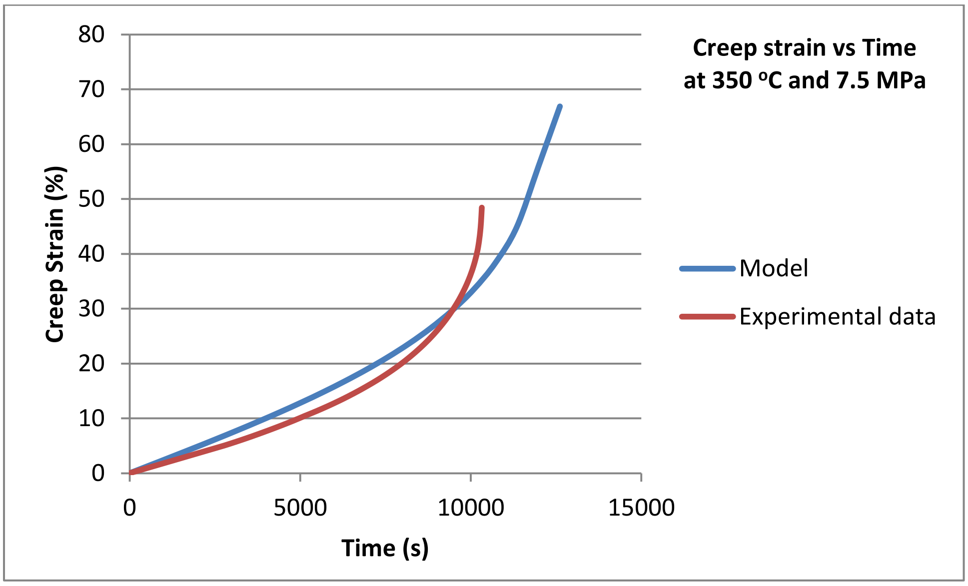

Figure 2: Comparison between experimental data and model at temperature of 350 °C and 7.5 MPa stress

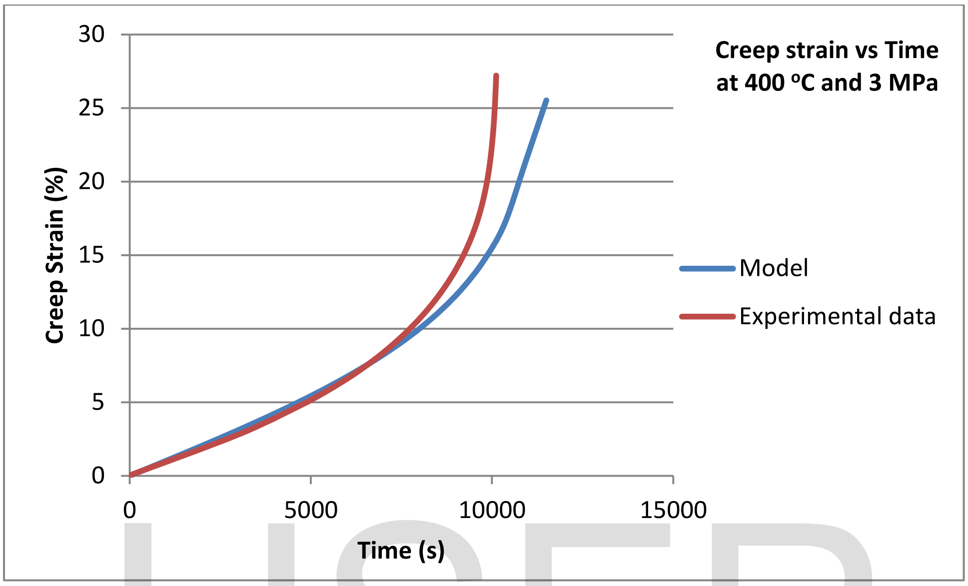

Figure 3: Comparison between experimental data and model at temperature of 400 °C and 3 MPa stress

The model is reasonably accurate and does capture various regions of the creep curve. It is able to represent secondary, secondary-tertiary transition and tertiary region within experimental uncertainties.

CONCLUSION

High temperature deformation under creep is an important parameter to be understood for the design of various in-core structure of a nuclear reactor. Through analytical modelling of material characteristic and benchmarking with experimental data could help reduce number of experiments and time involved. An analytical model has been developed incorporating LMP, modified Garofalo and Robinson methods. The rupture time is predicted by modified LMP formulation, the tertiary region is captured through time weighted Robinson formulation and secondary region is expressed through modified Garofalo equation. Hence, an attempt is made to bridge the simplistic model from secondary and tertiary region which could be handy designer’s tool. The model is being extensively implemented to estimate the rupture time, secondary-tertiary transition time to design various in-core components in nuclear reactors, without invoking cumbersome calculations involving estimation of several material constants to determine damage coupled creep expressions.

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