

Article

# Recent Advances in Creep Modelling Using the $\theta$ Projection Method

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**Abstract:** The theta projection method has been used to predict uniaxial creep curve shapes for a wide range of materials. However, one of the criticisms of the existing method is that the multilinear approach, commonly used to correlate theta parameters to applied test conditions, does not extrapolate well over a full range of creep conditions, due to not accounting for changes in creep mechanisms. This is particularly important for evaluating the creep behaviour of structural engineering components that operate in an environment in which a wide range of stress and/or temperatures exist during their service life. This study uses the theta projection method to evaluate creep curves for the nickel-based superalloy, Waspaloy, over a range of test conditions, considering changes in observed dominant creep mechanisms. A clear break in the trend of  $\theta_3$  and  $\theta_4$  with respect to stress is observed, indicating that a change in mechanism is important for tertiary creep. Using a power law approach along with optimisation algorithms, the residual error between predicted and experimentally observed creep curves is reduced. With more accurate prediction of creep curves, creep rates throughout the duration of creep can be more accurately calculated, providing the basis of more accurate computational creep models.

**Keywords:** creep; superalloys; theta projection method



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## 1. Introduction

Engineering components that operate at high temperatures for extended periods of time, such as those in high-temperature plant applications or aeroengines, must be designed to withstand the effects of creep deformation and rupture. Single-point prediction methods can provide useful estimations of stress rupture lives, but for many applications, characterising the evolution of creep rate over time is important. This is the case for applications where stress relaxation occurs around stress concentration features. Full creep curve methods such as the theta ( $\theta$ ) projection method [1] and the Omega method [2] describe the evolution of creep rate from primary creep through the minimum creep rate to tertiary creep. Other methods include a true stress model by Wu [3] which has a similar formulation to the  $\theta$  method but includes terms for micromechanical deformation, and an extension to the Wilshire method [4,5].

The  $\theta$  projection method correlates creep strain,  $\epsilon_t$ , to time,  $t$ , using

$$\epsilon_t = \theta_1 (1 - e^{-\theta_2 t}) + \theta_3 (e^{\theta_4 t} - 1) \quad (1)$$

where  $\theta_{1-4}$  are the  $\theta$  coefficients.  $\theta$  parameters are obtained from experimental observations by minimising the error between Equation (1) and constant stress creep data.  $\theta_1$  and  $\theta_2$  characterise primary creep, whereas  $\theta_3$  and  $\theta_4$  characterise tertiary creep. These parameters can be correlated with applied stress and temperature to predict creep curves for any applied conditions. This is commonly achieved through use of the following multilinear expression [6]:

$$\ln(\theta_k)_j = a_k + b_k \sigma_j + c_k T_j + d_k \sigma_j T_j \quad j = 1, \dots, n, \quad k = 1, \dots, 4 \quad (2)$$

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