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Simplified Inelastic Analysis Methods for Bounding Fatigue and Creep Rupture Damage

Bounds on inelastic strain ranges and maximum residual stresses introduced by transient operating conditions are obtained. These strain ranges and maximum residual stresses can be used to determine fatigue damage and creep rupture damage. Methods for integrating creep rupture damage during relaxation of surface stresses are also included. The solutions are based on uniaxial models.

Introduction

The initial elastic state of stress in structural components in elevated temperature service is redistributed due to creep. For constant loading the stress field tends asymptotically to a stationary state when the stress rates become zero. Of course, each histogram of loading also includes transient conditions. If the interim stresses caused by transient conditions remain elastic, the stresses after the transient return to the previous steady distribution and the time dependent response of the creeping structure remains unaffected by such short term loading cycles. Cycles intensive enough to cause plastic yielding, even if only local yielding, change the response of the structure in subsequent operating periods. The generated residual stresses interact with the stress field caused by the primary loads.

The term "steady cyclic state" is used to describe repetitive loading resulting in cyclic changes in the stress field which also become repetitive [1]. An analysis of the associated steady stress cycles makes it possible to bound strain ranges and maximum stresses for convenient groupings of such cycles. The bounds are derived herein for the uniaxial model described in [2]. These bounds can be used for loading histories including nonuniform cycles.

Bounds on inelastic strain ranges are needed for fatigue evaluations. Since the fatigue design curves in the Code [3] are based on the total strain ranges, the bounded inelastic strain ranges must be added to the corresponding elastic ranges before entering the curves. The more liberal fatigue design curves for inelastic analysis may be used, since the total inelastic strain ranges are obtained from the solutions derived herein. The maximum range of local inelastic strain including the contribution of both plastic and creep strain is bounded.

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Bounds on maximum stresses are required to evaluate creep rupture damage. The damaging effect can be approximated using the linear time fraction Robinson's rule [4] or alternate damage hypotheses with the stress to rupture curves given in the Code. The solutions given herein bound the maximum local stress time history. The damage can be conservatively calculated using the maximum values of stress that occur during each time period. More accurate evaluations can be obtained by including the relaxation of the maximum stresses within the operating periods. The solutions include methods for conservative evaluation of stresses which are relaxing in time. A stepwise approximation of the relaxation stress curve can be used with the creep rupture curves or the damage can be integrated along both curves. The method given herein uses a conservative approximation of the Code creep rupture curves by power relations due to Kachanov [5]. For known relations defining relaxation of stresses, damage within any operating period can be obtained by integration.

The rules for summation of creep fatigue and rupture damage are given in the Code.

Model and Stress Profiles

A complete description of a uniaxial model used to bound the accumulated strains in the presence of creep is given in [2]. The concept of an elastic core stress near the midwall was used to obtain bounding solutions. This model was subsequently extended in [6] to include temperature-dependent yield properties and arbitrary strain and cyclic hardening properties of the material. The applicability of the solutions was also extended therein to include severe loading conditions resulting in plastic ratcheting.

The generalized curves given in [6] defining the dimensionless loading regimes resulting in elastic response, *E*, shakedown, *S*, plastic captive cycling, *P*, and plastic ratcheting, *R*, are shown in Fig. 1 herein. This graph shows the isostrains σ_c in regimes S_1, S_2 and *P* and the lines of constant