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A numerical investigation of creep-fatigue life prediction utilizing hysteresis energy as a damage parameter

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ABSTRACT

This paper explores the hypothesis that there exists an intrinsic material property, hysteresis damage energy at failure, which could be used as a creep-fatigue life prediction parameter. The connection between hysteresis energy and fatigue damage was introduced in the 1920's by Inglis, but the use of hysteresis energy as a measure of damage was first presented by Morrow and Halford. Hysteresis energy shows promise in bridging the gaps associated with life prediction when the combination of both creep and fatigue scenarios are present. Numerical simulations which replicate experimental test configurations with 9Cr–1Mo steel were performed from which the hysteresis energy failure density (HEFD) could be calculated for each experiment. Taking the average of the HEFD values calculated for all of the experimental data as the parameter for failure ($E_{Intrinsic}$), creep-fatigue life predictions were made using a simplistic hysteresis energy based method as well as the time fraction/cycle fraction method endorsed by ASME Code and compared to experimental results. A good correlation with experimental results was obtained for life predictions using hysteresis energy density as a damage parameter. An investigation of the interaction between creep damage and fatigue damage based on the hysteresis energy method was also performed and compared with the damage interaction diagram utilized by the ASME and RCC-MR design codes. The hysteresis energy based method proved easy to implement and gave improved accuracy over the time fraction/cycle fraction method for low cycle creep-fatigue loading.

1. Introduction

1.1. Background and motivation

Utilizing the energy associated with a material's hysteresis loop response as a damage parameter seems promising in bridging the gaps associated with creep-fatigue interaction and life prediction [1,2]. Using hysteresis energy as a measurement of material damage captures both creep and fatigue effects for a loading history as each can be viewed as components that make up the total hysteresis response. A diverse array of industries offer products for use in high temperature applications and would benefit from improved creep-fatigue life assessment. The fossil fuel and nuclear power industry are areas in particular in which there is great demand for improved creep-fatigue life prediction methods and design guidelines. Since the thermal efficiency of a power plant increases with higher temperature operation, a strong impetus for research in the domain of high temperature design where creep-fatigue effects dominate is formed. The fact that the commonly used design codes, ASME, and RCC-MR [3,4] to name a few, currently incorporate factors of safety for life on the order of 20 or greater make for designs that are much less than optimum [5–7]. As future power plants are desired to run at very high temperatures (up to 1000 °C), the application of current design codes to future plant development may lead overdesigned and even impossible designs to implement. With future power plants desired to be operational for up to 60 years [8], the components of these plants will experience many loading cycles during their lifetime, giving a great demand for accurate creep-fatigue life prediction methods and more optimal design methodologies to ensure the success of very high temperature design and implementation.

1.2. Hysteresis energy method background

Dating back to the 1920's when Inglis presented observations of a connection between hysteresis energy and fatigue life [9], hysteresis energy has been studied as a candidate damage parameter for use in component life assessment and prediction. Morrow

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