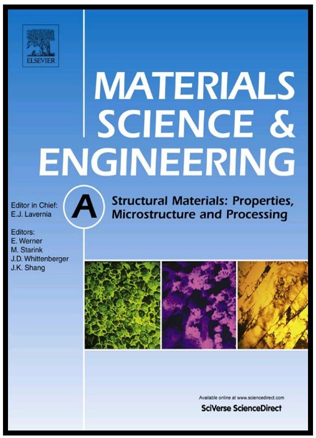

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A physically-based high temperature yield strength model for 9Cr steels

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Abstract:

The strength of 9Cr steels, which is controlled by chemical composition and microstructure, evolves significantly under high temperature loading. This paper presents a temperature-independent, physically-based model for evolving yield strength, including the interdependent effects of dislocations, solutes, precipitates and grain boundaries. The key roles of solute and precipitate strengthening in 9Cr steels are successfully predicted. The measured significant beneficial effect of up to 3 wt.% tungsten on solute strengthening, and hence, yield strength are successfully predicted. The new model demonstrates that the reported strength reduction in 9Cr-3W alloys under thermal aging can be primarily attributed to Laves phase formation and associated depletion of tungsten solutes, consistent with microstructural observations.

Keywords: 9Cr steels; Solid solution strengthening; Laves phase; Martensitic laths; Precipitate hardening

1. Introduction

The worldwide goal of cleaner and more sustainable energy production has led to (i) highly flexible operation of conventional power plants, to supplement unpredictable renewable energy sources, and (ii) higher plant operating temperatures and pressures, to improve efficiency. The net result is an increase in thermal cycling of existing power plant with greater thermal gradients, and hence, susceptibility of critical plant components to thermo-mechanical fatigue (TMF), as well as accelerated creep, corrosion and oxidation. Thus, the range of mechanisms of microstructural degradation is expanding due to the interactions of creep, fatigue and oxidation, with the determination of continually evolving fundamental mechanical properties such as yield strength becoming much more difficult.

9Cr steels are widely considered the optimum material for heavy wall power plant components due to their relatively low coefficient of thermal expansion and cost and excellent high temperature properties. The high strength of 9Cr steels is attributed to the complex precipitate and solute-strengthened hierarchical microstructure. This hierarchical microstructure consists of prior austenite grains, packets and blocks, demarcated by high angle grain boundaries (HAGBs), as illustrated schematically in Figure 1. It has been shown that this HAGB microstructure exhibits a Hall-Petch type effect on yield strength in Fe-0.2C martensitic alloys at room temperature, which is controlled by the mean block size [1]. The martensitic transformation during heat treatment also leads to a high dislocation density (1×10^{14} to 1×10^{15} m^{-2}) and the formation of a low-angle boundary (LAB) dislocation