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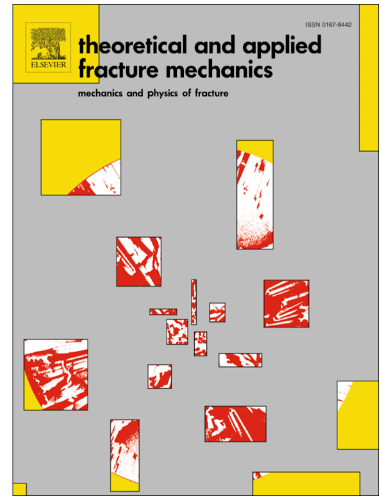

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A temperature-dependent model for predicting the fracture toughness of superalloys at elevated temperature

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Abstract: The plane-strain fracture toughness of tensile mode K_{IC} of superalloys at elevated temperature plays an imperative role in damage tolerance design and structure integrity assessment. In this paper, a novel temperature-dependent model is proposed to predict K_{IC} values of superalloys at elevated temperatures, which is based on stress-strain curves and linear expansion coefficients α of superalloys. Firstly, relation between K_{IC} and strain-hardening exponent n, Young's modulus E is introduced based on Krafft's model. Then, relation between n and temperature is established by a semi-empirical method, and relation between E and temperature is derived based on physical meanings. To validate the model, K_{IC} measurement tests on standard specimens made from turbine disc Nickel-based superalloy GH4720Li are conducted under temperatures of 25℃, 300℃, 550℃, 600℃, and 650℃, respectively. Tested results of GH4720Li show that the maximum error between the predicted values of K_{IC} and tested ones is within 10% under all temperatures. Tested K_{IC} results of another superalloy GH4169 (Ref. [1]) also agree well with the predicted ones of the model. The model can be used to design high temperature components based on damage tolerance design concept.

Keywords: Fracture toughness; Nickel-based superalloy GH4720Li; Elevated temperature; Young's modulus; Strain-hardening exponent

1. Introduction

The plane-strain fracture toughness of tensile mode K_{IC}, which is used as a critical value to judge whether a crack of a certain material reaches unstable level [2], plays an imperative role in damage tolerance design and structure integrity assessment [3]. For components working at elevated temperature, such as gas turbine disc, shaft etc., they usually have a temperature distribution with large gradient, therefore K_{IC} measured at room temperature is far from enough to meet design requirements at practical engineering design [4]. Models that describe the relation between K_{IC} and temperature with accepted accuracy is urgently needed for design of superalloy components working at elevated temperature.

The direct way to obtain relation between K_{IC} and temperature is to conduct K_{IC} measurement tests of standard specimen at different elevated temperatures [5-9], and then fit these data with empirical models [10, 11]. The limitation of this empirical modelling is that the data-fitting model lacks of wide scope of applicability and can only be used for the investigated material specifically. Furthermore, to improve accuracy of the model, more data at elevated temperatures are needed, which will cause considerable expenses of time and money.

To overcome limitations of above empirical data-fitting method, Master Curve method, which is derived based on physical meanings, has been put forward to predict K_{IC} values at different temperatures for ferritic steels [12-14]. The method assumes that K_{IC} is a joint function of the temperature T and reference temperature T_0, in which T_0 can be obtained based on experimental results of small-sized specimen [15-17]. Once T_0 of the material is obtained, K_{IC}

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