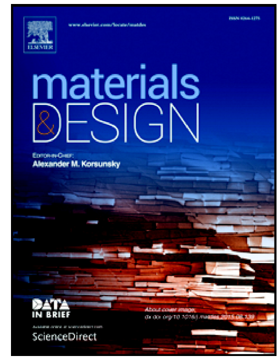

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PII: S0264-1275(18)30078-9
DOI: https://doi.org/10.1016/j.matdes.2018.01.064
Reference: JMADE 3667

To appear in: *Materials & Design*

Received date: 14 December 2017
Revised date: 15 January 2018
Accepted date: 30 January 2018

The effects of residual stress on elastic-plastic fracture propagation and stability

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Abstract
Residual stresses in materials affect their resistance to the initiation of fracture and to subsequent crack growth. Using full-field strain measurements and finite element analysis we demonstrate that the effect of residual stress on a material's crack growth resistance curve can be understood using elastic-plastic fracture mechanics. It is shown that Lei's modified J-integral formulation (J_{mod}) is a good predictor of the load vs crack extension behaviour of an elastic-plastic material containing residual stresses.

Keywords: Residual stress; fracture; neutron diffraction; digital image correlation; finite element analysis.

Introduction
Residual stresses in structural materials can affect the initiation of fracture at pre-existing cracks by modifying the intensity of the crack tip stress field [1]. When stresses due to externally-applied loading occur together with residual stresses, their effects on the crack tip stress field superimpose. Therefore, depending on whether they favour crack opening or crack closure, residual stresses can either promote or inhibit the initiation of fracture. In a linearly-elastic material, the effects of residual and applied stresses on the Mode I stress intensity factor K_I superimpose perfectly. K_I is then simply the sum the stress intensities imposed individually by residual stress and applied loads [2]:

$$K_I = K_I^A + K_I^R \tag{1}$$

where K_I^R and K_I^A are Mode I stress intensity factors resulting from residual and applied components of the stress field respectively. For a brittle material that exhibits almost perfect linear elasticity up to the point of fracture initiation, this leads to the following fracture initiation criterion:

$$K_{Ic} \leq K_I^A(a_0) + K_I^R(a_0) \tag{2}$$

where K_{Ic} is the material's Mode I initiation fracture toughness and a_0 is the initial crack length.

In materials that exhibit non-linear load-elongation behaviour prior to fracture initiation the contributions of residual and applied loading to the crack driving force combine non-linearly [2], and consequently Equation 2 is not an accurate criterion for fracture initiation. The presence of residual stress affects the crack tip stress field and distribution of plastic strain that develops around the crack tip as it is loaded [3]. Consequently, the effect of residual stress on the strain energy release rate is not simply additive with the effect of applied loading [2], [4]. In a finite element model of an elastic-plastic object, it is possible to impose a residual stress field explicitly and then calculate the Rice J contour integral that occurs at a crack tip in the object as it is loaded [5]. The J-integral does