

CRACK INITIATION AND PROPAGATION AS A CONSEQUENCE OF THERMAL SHOCK

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SUMMARY

An analysis is given of the initiation and subsequent propagation of a surface crack in a stainless steel section subjected to high frequency thermal shocks. This situation is of practical importance in fast reactors where mixing of sodium flows at two different temperatures may induce cracking in immediately adjacent metal sections.

Estimates of the maximum sustained temperature range allowable to avoid crack nucleation in the surface layers have been made using fatigue endurance data from the limited life region for 316 steel. The thermal shock induces equibiaxial surface strains and values have been calculated for a variety of temperature changes by invoking a constant plastic volume relationship. Using these methods it is apparent that a metal temperature difference of 50 °C is sustainable when considered against the desired minimum fatigue endurance line. Factors which affect this assessment are discussed; these include the pessimism incurred by the use of a minimum fatigue endurance line as recognition of the errors associated with possible attenuation in the sodium temperature and the use of an infinite heat transfer coefficient in calculating metal temperatures.

The subsequent growth of any initiated cracks has been analysed by use of linear elastic fracture mechanics methods. Whereas in fatigue under a uniform stress, the stress intensity factor K is derived by inserting the corresponding value of stress, the non-uniform nature of the induced (thermal shock) stress distribution is such as to necessitate the use of a suitably weighted average. In this context the expression

$$K = 2 \sqrt{\frac{a}{\pi}} \int_0^a \frac{\sigma_{app} dx}{\sqrt{a^2 - x^2}}$$

has been used in integrated forms to provide stress intensity solutions for various important practical cases. In the above equation, a is the current crack length, and σ_{app} the applied stress.

The solutions have been applied to calculate the extent of crack propagation expected under typical thermal shock situations. Additionally a comparison is given of the effects of inclusion of multiple cracking into such solutions. This treatment leads to a reduction in the peak stress intensity factor value and results in reduced penetration into the section thickness as a consequence of a fraction of the surface expansion or contraction being taken up by actual crack opening, thereby reducing the surface strain.

A discussion is given of the predictions and two factors of prime importance emerge. Firstly, the extent of bending stress present in any section determines whether arrest or full section penetration of the crack occurs. Secondly, the frequency of application of the thermal shock determines the areas of applicability of the present analysis.