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Abstract

This paper addresses the important issue of the description of short fatigue crack behaviour. It is typical for these cracks that they propagate under large scale yielding conditions at the crack tip, which means that the non-linear fracture mechanics has to be applied. This paper presents results of experiments designed to measure the short crack growth rates in five different materials – 316L steel, Eurofer 97 steel, ODS Eurofer steel, Duplex 2205 steel and Al 6082 alloy. The crack growth rates of these materials are described using different fracture mechanics parameters – the stress intensity factor, the J-integral and the plastic part of the J-integral. These approaches are evaluated and compared. The comparison revealed that the plastic part of the J-integral is the parameter governing the short crack growth rate in large scale yielding conditions. Moreover, crack growth rate data from all the tested materials measured at various loading levels lies on a unique curve. This remarkable observation suggests that the crack growth rate is determined by the extent of energy spent to plastic deformation, irrespective of the other materials properties.

1 Introduction

The ability to predict fatigue crack propagation in the structural component is an important aspect for assessment of the fatigue lifetime or maintenance intervals [1]. Usually, crack tip stress field is described by stress intensity factor and fatigue crack growth rate is calculated simply using famous Paris-Erdogan law. In the case of short cracks, it is usually difficult to satisfy conditions of applicability of linear elastic fracture mechanics [2-6]. As defined in [6], "the short crack effect" occurs when the crack size is comparable with microstructural size scales, the extent of local inelasticity or the extent of crack tip shielding. In these cases, short fatigue crack usually propagates faster than predicted by data measured on long cracks, thus the traditional concept using stress intensity factor can result in large overestimation of the residual lifetime of a structure. Therefore, accurate description of the short crack behaviour is still an important task for fatigue community. Although the behaviour of short cracks is well documented, see e.g. [2-8], prediction power of suggested models is usually restricted.

Crack propagation in the case of small fatigue cracks under Large Scale Yielding (LSY) conditions has been addressed by several groups since the seventies [3-21]. According to the literature, fatigue crack growth rate for high strain fatigue loading can be expressed by relation [7]:

$$\frac{\mathrm{d}a}{\mathrm{d}N} = f(\varepsilon_p, a) \tag{1}$$

where a is crack length and ε_p is plastic strain range. This type of equation was proposed by Tomkins [9], Skelton [7,8] or Polák [4,5]. These equations describe fatigue crack growth rate as a function of the crack length and nominal plastic strain range (which defines external loading level). The advantage of this concept is the simplicity of description of experimental data (usually measured on simple cylindrical specimens). Its limitation is the applicability on very short cracks only [3] and complicated transferability from experimental specimens to structural component.