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Theoretical and experimental investigations of fracture mechanical graded materials

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Abstract

With the focus on innovative manufacturing and application-oriented products considering lightweight construction functional graded materials become more and more interesting. Due to the application matched functional gradation different local demands such as absorbability, abrasion and fatigue of structures are met. However the gradation has a remarkable influence on the crack propagation behaviour. According to the different fracture mechanical graded materials the area of stable crack growth is more or less distinct and the crack velocity changes. In addition the crack propagation direction can be influenced by the gradation. Within this contribution the influence of a fracture mechanical gradation on the crack growth rate, the area of stable fatigue crack growth and the crack propagation direction is investigated. For the prediction of the crack growth behaviour in fracture mechanical graded materials considering different loading situations (Mode I, Mixed Mode) a new concept was developed. This TSSR-concept can be applied to sharp as well as smooth material gradations. In addition results of experimental investigations of crack growth considering fracture mechanical graded materials are discussed.

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Keywords: fracture mechanical gradation; crack growth; theoretical concepts; experimental investigations; Mixed Mode

1. Introduction

Functional graded materials are generally characterized by local different properties. Thereby they meet requirements placed upon a component and enable a very large variety of applications. Various kinds of gradation

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can be adjusted according to materials and manufacturing processes. Components and structures which are characterized by different elastic properties (e.g. Young's modulus E, Poisson ratio ν) show an elastic material gradation, while fracture mechanical graded materials possess different fracture mechanical specific values (e.g. Threshold value $\Delta K_{I,th}$, fracture toughness K_{IC}, crack velocity da/dN). Furthermore the combination of the mentioned material gradations is imaginable.

Components consisting of the fracture mechanically different materials M1 and M2 with the principle crack velocity curves in Figure 1 show a totally different crack propagation behavior than homogeneous and isotropic materials. The crack velocity curves are characterized by remarkable differences in the crack velocity da/dN as well as in the area of stable fatigue crack growth. A change in the crack velocity and in the occurrence of unstable crack growth is connected with crack propagation from a material area in a fracture mechanically different area (Schramm and Richard (2012)). In Figure 1 (a) the begin of crack growth occurs only in dependency of the loading situation because these curves show the same Threshold value $\Delta K_{I,th}$. Different Threshold values are used in Figure 1 (b) leading to the possibility that the crack propagation takes place in the direction which has the smaller resistance against crack propagation and hence the smaller fracture mechanical material value. In summary, crack growth can not only be influenced by the loading situation but also additional by the fracture mechanical material gradation.

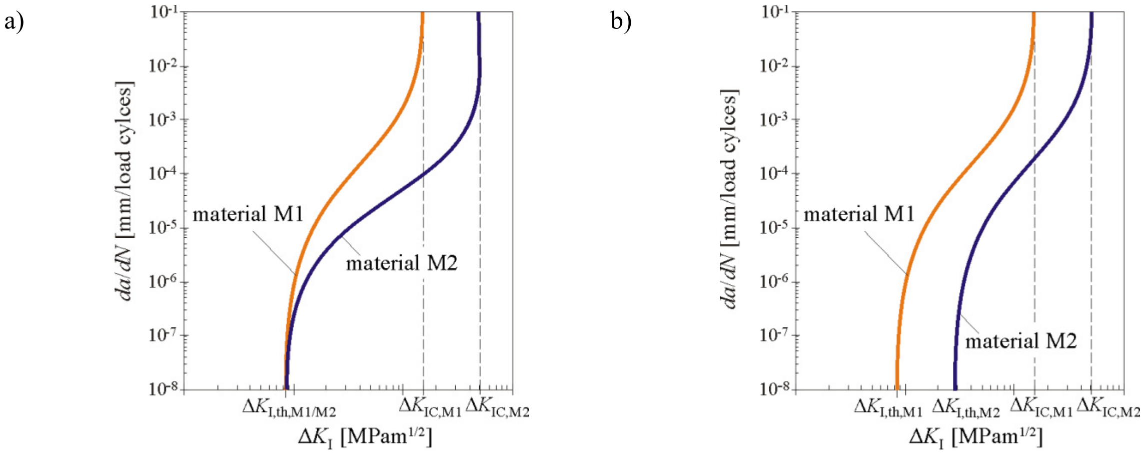

Figure 1: Principal illustration of the crack velocity curves of the materials M1 and M2
(a) same Threshold values $\Delta K_{I,th,M1/M2}$, (b) different Threshold values $\Delta K_{I,th,M1}$ and $\Delta K_{I,th,M2}$

This contribution deals with the prediction of crack propagation in fracture mechanically graded materials. In this context the TSSR-concept is presented which can be applied to various loading situations. In addition, experimental investigations of crack propagation in consideration of appropriate material gradations are presented.

2. Crack growth in fracture mechanical graded materials

Figure 2 shows a structure with different fracture mechanical materials M1 and M2. In Figure 2 (a) the initial crack is situated in certain distance of the material gradation. Hence there is only homogenous and isotropic material behavior around the crack tip. Accordingly the crack growth occurs in dependency of the present loading situation (Mode I, Mode II or Mixed Mode). In this case the crack propagation concepts for homogenous and isotropic materials, such as the MTS-concept of Erdogan and Sih (1963), can be applied. The crack tip in Figure 2 (b) is within the material transition and sees two fracture mechanical different microstructures. The assumption of crack propagation along the path of least resistance leads to two potential kinking angles: the stress induced kinking angle $\varphi_{0,MTS}$ and the gradation angle φ_M (respectively $\varphi_M \pm 180°$) itself.

In the following the TSSR-concept is presented which enables the determination of the crack propagation, meaning the ability to propagate and the direction of crack growth, considering the stress situation and the fracture mechanical material gradation.