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Crack growth: Does microstructure play a role?

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ABSTRACT

The experimental data presented in this paper reveals that even if the growth of long cracks in two materials, with different microstructures, have different da/dN versus ΔK curves the corresponding small crack curves can be similar. We also see that long cracks in a large range of steels with different microstructures, chemical compositions, and yield stresses can have similar crack growth rates. The materials science community is challenged to explain these observations. The experimental data also suggests that the threshold term ΔK_{thr} in the Hartman-Schijve variant of the NASGRO crack growth equation appears to have the potential to quantify the way in which small cracks interact with the local microstructure. In this context it is also noted that the variability in the life of operational aircraft is controlled by the probability distribution associated with the size and nature of the material discontinuities in the airframe rather than the probability distribution associated with the scatter in the growth of small cracks with a fixed initial size.

Contents

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1. Introduction

Classical metallurgical engineering literature is laden with the science and technology of microstructural design of alloys and metals to enhance their strength and to achieve effective resistance to growth of an existing crack. Metallurgical engineers have been improving the strength of various engineering alloys by thermo-mechanical treatments to bring about the required changes in microstructures, such as by the refinement of grain size, by mechanical working for developing strained crystal structure or by developing suitable precipitates in the alloy microstructure. The classical metallurgy text book examples showing the profound role of microstructure in strengthening include: martensitic microstructure of steels that have extremely high hardness; precipitation hardening of aluminium through alloying with copper that caused sufficient specific strengthening and enabled the first ever flight by Wright brothers in early 1900s; and anisotropy of microstructure of an extruded aluminium alloy that causes considerable differences in strength along the extrusion and perpendicular directions. The very title of an article whether microstructure plays a role in crack growth may sound absurd to a metallurgical researcher or engineer: whilst the role of microstructure in the growth of long cracks is clearly undeniable it is shown [1] that da/dN versus ΔK curves can provide a pragmatic and reliable method of assessment. In particular, [1] revealed that the da/dN versus ΔK data associated with the growth of long cracks in five different bridge steels, lay on a single "master curve". These steels had a range of different chemical compositions and yield stresses that varied from between approximately 250 MPa up to approximately 800 MPa Furthermore, this bridge steel da/dN versus ΔK "master curve" coincided with that seen for the high strength aerospace steel 4340 which has a yield of approximately 1500 MPa, see Fig. 1. The bridges steels shown in Fig. 1 are:

(i) A36, where the crack growth data was taken from [2,3], which is common in older bridges.
(ii) HPS 485W a high performance bridge steel used in North American bridges [4].
(iii) HPS 350WT a high performance bridge steel with an improved low temperature performance [4].
(iv) A588-80A [4], a weathering steel that is widely used in bridges. This steel has little R ratio dependency, see [5].
(v) The Chinese bridge steel 14MnNbq [6].

The 4340 steel crack growth da/dN versus ΔK data is from [7].

Ali et al. [1] also revealed that the da/dN versus ΔK curves for the five cast steels 0030, 0050A, 8630 and a C-Mn and a Mn-Mo steel were also very similar to the master curve, which is labelled B-D, shown in Fig. 1 for the bridge steels and the aerospace steel 4340, see Fig. 2. Details on the heat treatments and chemical composition of these different steels are given in [8]. The yield stress associated with these five cast steels varied from approximately 300 MPa for 0300 steel to approximately 1000 MPa for the 8630 steel.

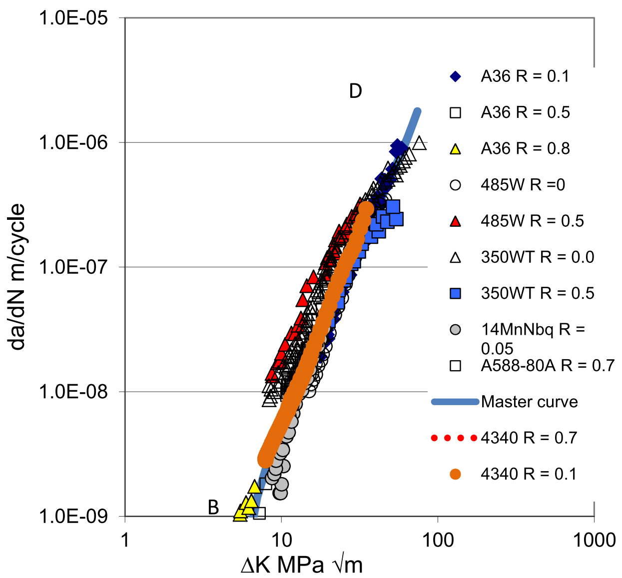

Fig. 1. Representation of the growth of long cracks in a range of bridge steels, from [1].