Numerical evaluation of combined branching and closure effects on fatigue crack growth

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The stress intensity factors (SIF) associated to branched fatigue cracks can be considerably smaller than that of a straight crack with the same projected length, causing crack growth retardation or even arrest [1]. This mechanism can quantitatively explain retardation effects even when plasticity induced crack closure cannot be applied, e.g. in high R-ratio fatigue problems. Analytical solutions have been obtained for the SIF of some branched cracks, however numerical methods are the only means to predict the subsequent curved propagation behavior [2].

In this work, a specialized FE program [3] is used to calculate the propagation path and associated SIF of bifurcated cracks, validated through experiments on 4340 steel ESE(T) specimens. A total of 6,250 FE calculations are used to fit empirical equations to the process zone size and crack retardation factor along the curved crack branches. The bifurcation simulations include several combinations of bifurcation angles, branch asymmetry ratios, crack growth exponents, and even considers interaction between crack branching and other retardation mechanisms such as crack closure, assuming the crack opening level is well known.

It is shown that very small differences between the lengths of the bifurcated branches are sufficient to cause the shorter one to eventually arrest as the longer branch returns to its pre-overload conditions. The process zone size is found to be smaller for lower bifurcation angles and for branches with greater asymmetry, in both cases due to the increased shielding effects on the shorter branch. Higher crack closure levels also result in smaller process zones, because the shorter branch is more easily arrested due to the reduction in its stress intensity range. However, a competition between smaller process zone sizes and lower growth rates of the longer branch takes place to determine the real effect of combined bifurcation and closure.

The proposed equations can be readily used to predict the propagation behavior of branched cracks in an arbitrary structure, as long as the process zone is small compared to the other characteristic dimensions. From these quantitative results, it is shown that crack bifurcation may provide a sound alternative mechanistic explanation for overload-induced fatigue crack retardation on structural components.

References

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