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Fatigue life estimation methods: Basic assumptions, advantages, limitations and potential improvements

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Abstract

There are three fatigue life estimation methods most often used currently in engineering practice, i.e. the nominal stress method (S-N), the local notch tip stress-strain method (ε-N) and the fracture mechanics-based method (da/dN-ΔK). The first two methods are based on the stress index as the basic parameter accounting for the load and geometry effects. The fracture mechanics-based fatigue life evaluations require using the stress intensity factor K which accounts for the load history effects, overall geometry of analysed object and specific geometry and location of the fatigue crack.

The S-N method uses so called nominal stress history S as the principal load parameter which determines fatigue lives of engineering objects subjected to cyclic loading histories. Unfortunately, the definition of the nominal stress is not unique and this fact reults in possible errors and mis-application of the nominal S-N method. Therefore, the unique and nonarbitrary definition of the nominal stress is proposed which removes the ambiguity concerning the location and magnitude of the nominal stress. The proposed nominal stress definition is particularly useful while using Finite Element method for the determination of stresses in real engineering components and structures. The S-N method is unfortunately insensitive to the loading sequence, i.e. the actual loading history and there is no general agreement on how the residual stress effect should be accounted for when using the smooth specimen material properties. Nevertheless, the S-N method is frequently used in engineering practice as a design tool.

The local notch tip stress-strain method (ε-N) uses the actual elastic and elastic-plastic strains and stresses at the notch tip or critical stress concentrator. It requires applying methods enabling determination of elastic-plastic notch tip strains and stresses accounting for the material stress-strain nonlinearity around the notch tip. This method enables to rationally account for the effect of residual stresses and the effect of the loading sequence, i.e. the loading history effect. However, the definition of the predicted fatigue life, according to the (ε-N) method, is not consistent because it might be sometimes close to the total life of the analysed object but it may also coincide with the number of loading cycles necessary to generate a crack of certain size. Advantages of the local notch tip stress-strain method lie in the fact that it is capable of accounting for the material memory effects and, in the subsequence, it is capable of accounting for the loading sequence effect and residual stresses. The notch tip stress analysis requires finding all components of the stress and strain tensor therefore the method has the potential of being used for the multiaxial fatigue analyses. The predicted fatigue lives are understood as lives coinciding with the creation of fatigue cracks of

certain size but the method itself does not provide how small or large those cracks might be and how much fatigue live remains to the final failure.

The fracture mechanics-based method deals with the estimation of fatigue lives based on the analysis of fatigue crack growth and requires determination of the stress intensity factor composed of the reference stress, coinciding often with nominal stress, but it also accounts for the stress distribution in the prospective crack plane. The fracture mechanic-based fatigue live estimation method accounts for the remaining post crack initiation part of the fatigue life involving the macroscopic growth of a leading fatigue crack. The method enables to assess the load history effects, the geometry of the analysed object and the specific geometry of the crack and the residual stress effects. The fatigue live, according to fracture mechanics approach depends also on the fluctuating stress distribution in the critical cracked cross section. Therefore, this approach accounts not only for the stress magnitude at one specific point in the analysed body but it actually accounts for the entire stress distribution in the prospective crack plane. It is believed that the main disadvantage of the fracture mechanics-based methodology lies in the fact that it is related to the remaining part of the fatigue life of an engineering object, i.e. to the fatigue crack propagation stage.
However, recent studies indicate that the fracture mechanics approach might be capable of providing good estimation of the total fatigue life of a component or structure if appropriate non-arbitrary initial crack is used for the analysis of fatigue lives. Such an approach enables estimation of the entire fatigue life of smooth, notched and cracked engineering components without the necessity of defining arbitrary stages of fatigue crack initiation and growth.