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Asynchronous multiaxial fatigue damage evaluation

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Abstract

One of the big challenges in fatigue characterization is to evaluate accumulated damage under asynchronous loading conditions. This multidisciplinary subject requires joining all multiaxial issues that are usually studied separately. Multiaxial fatigue models used in accumulated damage evaluation under random conditions are generally validated under loading blocks, which is a particular case of random loadings. In this work is evaluated the accumulated damage of asynchronous loading blocks using the stress scale factor (SSF) damage parameter, the virtual cycle counting, and a Palmgren–Miner type rule. Results show good agreement between the experimental data and the estimations.

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Keywords: Random loadings; asynchronous loadings; accumulated damage; variable amplitude loading; cycle counting.

1. Introduction

Equivalent stress models due to their straightforward applicability are very appreciated in mechanical design. However, they have some shortcomings to capture some multiaxial fatigue effects. For instance, non-proportional damage is quite different from the proportional one, but equivalent stresses are not capable to differentiate between these two types of damage mechanisms. This is so, because equivalent stress approaches are independent of the loading direction and depend only on the magnitude of the multiaxial loading components. Moreover, under multiaxial loading blocks conditions, fatigue damage is usually estimated by the maximum value of the equivalent stress computed within the loading block, ignoring the rest of the loading path, which in some cases leads to inacceptable estimates.

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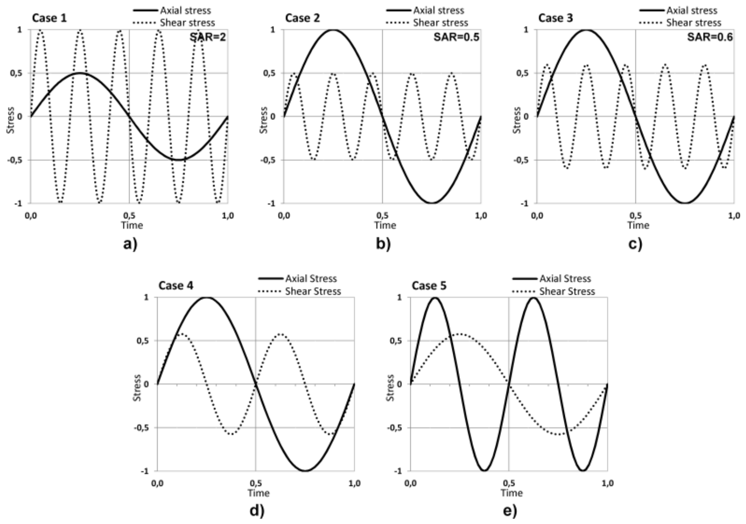
The loading path type has a huge influence in fatigue damage [1, 2], effects like, non-proportionality, proportionality, sequential, asynchronous, mean stresses, among others, causes different fatigue damages mechanisms [3–5]. Under asynchronous multiaxial loading conditions some of the aforementioned damage mechanisms are activated. Thus, to assess the corresponding fatigue damage it is necessary to have into account the damage of each loading type [6]. Furthermore, those effects may have different damage levels and may vary from material to material. In some conditions, the loading path effect can be more damaging in one material than in other one. Due to that, in cases of major importance, it is advised to have a damage map for the material, which could be obtained by specific experimental tests [7]. Moreover, it is well known, that the loading path effect on fatigue damage is strongly influenced by micro-notches and cyclic plasticity, especially under variable amplitude loading conditions [8–12]. Therefore entering with local cyclic plasticity it is very important to cyclically update the local stress states. In this paper is studied the SSF criterion's performance under asynchronous loadings. This criterion contains several features such as non-proportionality sensitivity or the virtual cycle counting among others. This criterion was successfully validated under loading blocks with several loading effects such as sequential, proportional and non-proportional [1,2,6,7]. Therefore, here it is inspected the SSF criterion reliability to capture the asynchronous multiaxial fatigue damage. Results show good agreement between experimental data and the estimated results.

2. Materials and methods

The 42CrMo4 quenched and tempered high strength steel was the material used in this work. The specimen´s geometric shape was a solid hourglass with a 6.35 mm diameter at middle length, with a total length of 101 mm [2]. The specimens were inspected and polished. Fatigue tests were carried out through a multiaxial servo-hydraulic machine; specimens were tested using 5 different loading paths under axial and torsion combined loadings, as shown in Figure 1. The failure condition was the total separation of the test sample. Loading cases 1, 2, and 3 (see Fig. 1a), b), and c)) are asynchronous loading blocks where the relation between the number of axial and shear reversals is maintained in the three loading blocks, the difference between them is the stress amplitude ratio (SAR) of each loading block, i.e. SAR=2.0, SAR=0.5 and SAR=0.6, respectively. The SAR allows identifying how much the fatigue damage is dominated by the axial or shear damage mechanism. In Case 4 (see, Fig. 1d)), the asynchronous loading block have two axial reversal against four in shear, and in Case 5 (see, Fig. 1e)), the opposite occurs, i.e. four reversal in axial against two in shear.



a) b) c)

d) e)