A new approach of multiaxiality for tension-torsion fatigue testing of elastomers

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Abstract

The unique mechanical properties of elastomers explain their use in most industrial sectors. In particular, they can withstand very large strain without breaking, before returning to their initial state almost instantaneously. These large strains are associated with complex mechanical responses that are sometimes difficult to characterize. To consider their multiaxial behavior, elastomers are generally characterized by a combination of uniaxial tensile/compression tests, plane tensile tests, and equibiaxial tensile tests (1). Taking account of this multiaxial character under fatigue loading is more complex, and tensile-torsion tests carried out on diabolo type specimens are generally considered. It turns out that in these studies, the authors adopt various definitions of multiaxiality but none of them has been used to construct mechanical tests(2,3).
Here, we propose a new definition of multiaxiality based on invariants of the logarithmic strain tensor (Hencky or true strain tensor). Three physically motivated invariants, K1, K2, and K3, were proposed in the early 2000s (4). They describe respectively the volume change, the intensity of deformation, and the mode of deformation. As they are derived from continuum mechanics, they are defined at any material point. Thanks to these invariants, and to avoid any confusion with existing terms, we introduce the notion of modality with the following two definitions:

1. A test is 'uni-modal' at a given point if, during the test, the value of the invariant K3 is constant;

2. A test is 'multi-modal' at a given point if the value of the K3 invariant changes during the trial.

To exploit these definitions in the context of fatigue tension-torsion testing, we numerically simulate a loading cycle by the finite element method to relate the loading conditions (U, α) where U is the vertical displacement and the angular displacement applied by the testing machine to a local mechanical state characterized by (K2, K3). By scanning a wide range of loading conditions (U, α), it is thus possible to identify loading paths that keep the K3 invariant constant; in other words, it is possible to construct tension-torsion tests that ensure a uni-modal deformation state in the crack initiation zone in a diabolo specimen.

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In practical terms, we study in detail the mechanical state of the crack initiation zone during a uni-modal cycle, i.e. iso-K3, for two very different diabolo geometries: AE2 and AE42. We then show that the loading path depends on the geometry of the sample, but that the mechanical states in the samples are virtually identical: they admit the same principal stretch ratios and stresses. This demonstrates that it is possible to construct tension-torsion fatigue tests on elastomers that are comparable in terms of mechanical states despite very different geometries. This is a first step towards rationalizing multiaxial fatigue tests for soft materials.

Bibliography

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