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Metallic materials — Principles and designs for multiaxial fatigue testing

Matériaux métalliques — Principes et conceptions associés aux essais de fatigue multiaxiale

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 4, *Fatigue, fracture and toughness testing*.

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Introduction

Structural components in industry are frequently subject to some form of multiaxial stressing. Fatigue cracks generally initiate from surface defects or discontinuities and are thus primarily influenced by the surface biaxial stress system. This can vary from equibiaxial, where surface principal stresses are equal in magnitude and sign (present under conditions of pressurization, rotation and thermal loading) to pure shear where surface stresses are equal in magnitude, opposite in sign (as in shafts and shear panels).

The majority of fatigue test data gathered worldwide have been and will continue to be under uniaxial conditions for reasons of simplicity and cost. A secondary goal of multiaxial testing is therefore to develop behavioural models which relate failure under specified multiaxial conditions to established uniaxial cases.

This document utilizes data gathered from the past 80 years spanning most multiaxial fatigue research. It can be of interest to new researchers in the field and form a basis for full International Standards as the need arises.

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Metallic materials — Principles and designs for multiaxial fatigue testing

1 Scope

This document discusses the general principles of multiaxial fatigue testing and the design recommendations for specific classes of multiaxial testing machines and test specimens.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
biaxial strain ratio
ϕ
ratio of the surface principal strains, smaller/larger

3.2
biaxial stress ratio
ψ
ratio of the surface principal stresses, smaller/larger

3.3
principal strains
$\varepsilon_1 > \varepsilon_2 > \varepsilon_3$
principal direct strains at a point in a multiaxial strain field

3.4
principal stresses
$\sigma_1 > \sigma_2 > \sigma_3$
principal direct stresses at a point in a multiaxial strain field

3.5
Poisson's ratio
ν
negative ratio of transverse to longitudinal strain under uniaxial tensile stressing

3.6
specimen diameter
d
diameter of a cylindrical tubular specimen

Note 1 to entry: The symbols d_0, d_i and d_m are used to express outside, inside and mean diameters, respectively.

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3.7
parallel length
l_p
parallel length of a cylindrical tubular specimen

3.8
fillet radius
r
fillet radius of a cylindrical tubular specimen

3.9
directional suffix
suffix identifying a direction in a cylindrical tubular specimen

Note 1 to entry: The suffixes z, r and θ are used to express axial, radial and circumferential directions, respectively.

3.10
strain component suffix
suffix identifying a strain component

Note 1 to entry: The suffixes e, p and t are used for elastic, plastic and total strain components, respectively.

3.11
internal pressure
P
internal pressure within a cylindrical tubular specimen

4 General principles

4.1 Methodology

Multi-axial fatigue testing sets out to simulate the dynamic stress-strain conditions at key locations on components, on test specimens of constant geometry for a given test series, and to determine the cyclic stress-strain history, crack initiation and propagation behaviour, fatigue life and failure mode.

Dependent on the level of geometric constraint in the real component, it can be more useful to test specimens under stress or strain control, e.g. a test specimen representative of a relatively unconstrained gas turbine blade can be tested in stress control whereas it can be more relevant to utilize strain control for a test specimen simulating part of a steam turbine disc subject to thermal straining during start-up.

Further, where stress amplitudes are sufficient to take test specimen materials well into the region of cyclic plasticity (LCF), it can be preferable to employ strain control in order to better control cyclic amplitude during the test and failure at end of test.

4.2 Historical development

Multiaxial fatigue has been addressed since the 1930s. Initially, testing machine and specimen designs were created to address specific biaxial stress conditions, e.g. torsion, bending + torsion, cantilever bending, anticlastic bending and plate pressurization. However, a criticism of much of the early research was that specimen design had to change in order to change the biaxial stress or strain ratio, leading to uncertainty in the interpretation of results.

The benefit of being able to test a single specimen design over a wide range of biaxiality led to the choice of two generic specimen types, tubular and cruciform, together with associated multi-axis testing machine designs.

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