TECHNICAL REPORT

ISO/TR 12112

First edition
2018-04

Metallic materials — Principles and designs for multiaxial fatigue testing

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

iTeh Standards
(https://standards.iteh.ai)
Document Preview

ISO/TR 12112:2018
https://standards.iteh.ai/catalog/standards/iso/11dcd60b-3a6b-4757-bf1a-d61cce02d534/iso-tr-12112-2018

Reference number
ISO/TR 12112:2018(E)

© ISO 2018

iTeh Standards
(https://standards.iteh.ai)
Document Preview

ISO/TR 12112:2018
https://standards.iteh.ai/catalog/standards/iso/11dcd60b-3a6b-4757-bf1a-d61cce02d534/iso-tr-12112-2018

COPYRIGHT PROTECTED DOCUMENT

© ISO 2018

All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

 © ISO 2018 – All rights reserved

Contents

Page

Foreword ..... **v**

Introduction ..... **vi**

1 Scope **1**

2 Normative references **1**

3 Terms and definitions **1**

4 General principles **2**
4.1 Methodology 2
4.2 Historical development 2
4.3 Specific multiaxial test methods 6
4.3.1 Bending + torsion[6] 6
4.3.2 Axial + torsion[7] 6
4.3.3 Axial + internal pressure[8] 6
4.3.4 Axial + internal + external pressure[9] 6
4.3.5 Axial + internal + external pressure + torsion[10] 6
4.3.6 Cruciform — LCF[11] 6
4.3.7 Cruciform — Crack growth[12] 7
4.4 Multiaxial fatigue analysis 7
4.4.1 Computer aided design 7
4.4.2 Fatigue life prediction 7
4.5 Multiaxial fatigue failure criteria 8

5 Axial + torsion testing systems and specimen design **9**
5.1 Historical development 9
5.2 Specimen design 11
5.2.1 Design considerations 11
5.2.2 Design recommendations 11
5.2.3 Comparison with ASTM E2207[4] 11
5.3 Machine design 12
5.3.1 Frame 12
5.3.2 Loadcells 12
5.3.3 Strain measurement 12
5.3.4 Control 12
5.3.5 Data acquisition 12
5.3.6 Software 12

6 Cruciform testing systems and specimen design **13**
6.1 Historical development 13
6.2 Specimen design 13
6.3 Machine design 14
6.3.1 Frame 14
6.3.2 Loadcells 14
6.3.3 Strain measurement 15
6.3.4 Crack growth monitoring 15
6.3.5 Control 15
6.3.6 Data acquisition 15
6.3.7 Software 15

7 Axial + differential pressure systems and specimen design **16**
7.1 Historical development 16
7.2 Specimen design 19
7.2.1 Design considerations 19
7.2.2 Design recommendations 19
7.2.3 Axial stress due to pressure 20
7.3 Machine design 20
7.3.1 Frame 20

iTeh Standards
(https://standards.iteh.ai)
Document Preview
ISO/TR 12112:2018
https://standards.iteh.ai/catalog/standards/iso/11dedf60b-3a6b-4757-bfba-d61ee902d534/iso-tr-12112-2018

© ISO 2018 – All rights reserved

7.3.2 Pressure containment 20
7.3.3 Differential pressure 20
7.3.4 Force measurement 20
7.3.5 Pressure measurement 20
7.3.6 Strain measurement 20
7.3.7 Control 20
7.3.8 Data acquisition 20
7.3.9 Software 21
Annex A Historical analysis of specimen geometry 22
Bibliography 29

iTeh Standards
(https://standards.iteh.ai)
Document Preview

ISO/TR 12112:2018
https://standards.iteh.ai/catalog/standards/iso/11dcd60b-3a6b-4757-bf1a-d61cce02d534/iso-tr-12112-2018

 © ISO 2018 – All rights reserved

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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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*.

iTeh Standards
(https://standards.iteh.ai)
Document Preview
ISO/TR 12112:2018
https://standards.iteh.ai/catalog/standards/iso/11dcd60b-3a6b-4757-bf1a-d61cce02d534/iso-tr-12112-2018

© ISO 2018 – All rights reserved

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.

iTeh Standards
(https://standards.iteh.ai)
Document Preview

ISO/TR 12112:2018
https://standards.iteh.ai/catalog/standards/iso/11dcd60b-3a6b-4757-bf1a-d61cce02d534/iso-tr-12112-2018

 © ISO 2018 – All rights reserved

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/

iTeh Standards
(https://standards.iteh.ai)
Document Preview

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

ISO/TR 12112:2018
https://standards.iteh.ai/catalog/standards/iso/11dcd60b-3a6b-4757-bf1a-d61cce02d534/iso-tr-12112-2018

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.

© ISO 2018 – All rights reserved

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

iTeh Standards
(https://standards.iteh.ai)
Document Preview

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.

© ISO 2018 – All rights reserved

Table 1[5] summarizes the attributes of the different test methods applicable to tubular and plate specimens.

Biaxiality is shown in terms of the range of surface strains with ε_1 held constant. Only cruciforms and systems employing axial force plus internal and external pressure are capable of applying fully reversed fatigue cycles over the full range of biaxiality ($-1 \leq \phi \leq +1$) to test specimens.

Buckling is a key concern in the design of effective LCF specimens.

A reasonable gauge area of essentially constant strain is beneficial.

Ideally, strain should be constant through the thickness.

If all the applied forces are carried by the gauge area, then all stresses and strains can be determined; otherwise, only total (not plastic) strains can be measured.

The ability to visually observe the specimen is useful especially for surface crack monitoring.

Some designs are suitable for high temperature and thermo-mechanical fatigue (TMF) testing.

Systems involving torsion cause the principal axes to rotate up to 45°.

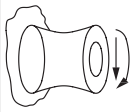
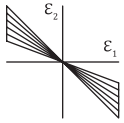
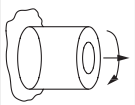
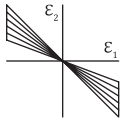
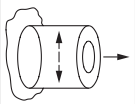
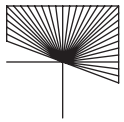
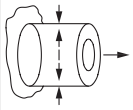
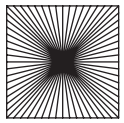
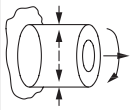
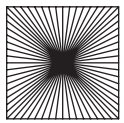
System cost can be scaled by the number of actuators, and therefore closed servo-loops, in the design.

iTeh Standards
(https://standards.iteh.ai)
Document Preview

ISO/TR 12112:2018
https://standards.iteh.ai/catalog/standards/iso/11dcd60b-3a6b-4757-bf1a-d61cce02d534/iso-tr-12112-2018

© ISO 2018 – All rights reserved

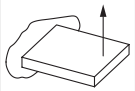
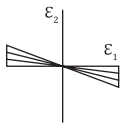
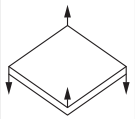
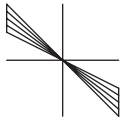
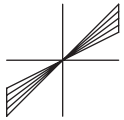
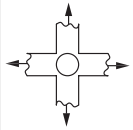
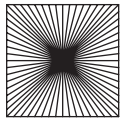
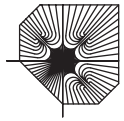
Table 1 — Multiaxial test methods for tubular and plate specimens

	Biaxial specimen schematics and modes of loading	Range of surface principal strains	Single geometry	Immune to buckling	Invariant σ and ε on gauge area	Min. ε-gradient through thickness	Monitoring biaxial σ and ε_P	Specimen observation	Crack growth studies	High temperature capability	TMF studies	Rotation of principal stresses	No. of actuators proportional to cost
Bending + torsion			√	√		√		√				√	1
Axial + torsion			√		√	√	√	√	√	√	√	√	2
Axial + P_{int}			√		√	√	√	√		√			2
Axial + P_{int} + constant + P_{ext}			√		√	√	√			√			2
Axial + P_{int} + P_{ext} + torsion			√		√	√	√					√	4

iTeh Standards
(https://standards.iteh.ai)
Document Preview
ISO/TR 12112:2018
https://standards.iteh.ai/catalog/standards/iso/11dcd60b-3a6b-4757-bf1a-d61cce02d534/iso-tr-12112-2018

© ISO 2018 – All rights reserved

Table 1 *(continued)*

	Biaxial specimen schematics and modes of loading	Range of surface principal strains	Single geometry	Immune to buckling	Invariant σ and ε on gauge area	Min. ε-gradient through thickness	Monitoring biaxial σ and ε_P	Specimen observation	Crack growth studies	High temperature capability	TMF studies	Rotation of principal stresses	No. of actuators proportional to cost
Cantilever bend				√	√			√		√			1
Anticlastic bend				√	√			√	√	√			1
Plate pressurization				√	√								1
Cruciform LCF			√			√		√		√	√		4
Cruciform crack growth			√		√	√	√	√	√	√	√		4

iTeh Standards
(https://standards.iteh.ai)
Document Preview
ISO/TR 12112:2018
https://standards.iteh.ai/catalog/standards/iso/1dcd60b-3a6b-4757-bf1a-d61eee02d534/iso-tr-12112-2018

© ISO 2018 – All rights reserved

4.3 Specific multiaxial test methods

4.3.1 Bending + torsion[6]

This was the first technique used to apply combined stresses in high cycle fatigue (HCF) at room temperature. Oscillating vertical forces were applied to a horizontally clamped cylindrical specimen which could be rotated by up to 90° in the horizontal plane so as to introduce bending, bending + torsion, or torsion in the waisted centre section. Specimens were either solid or hollow. A number of these electro-mechanical testing machines were built between 1930 and 1950 to investigate fatigue of aero-engine steels, especially for crankshaft applications.

4.3.2 Axial + torsion[7]

This popular technique employs a single tubular specimen design with a gauge length over which stress and strain are substantially invariant and access for strain measurement and crack monitoring. The principal stress and strain directions progressively rotate through 45° as the test moves from uniaxial to torsion. Elevated temperature testing and thermo-mechanical fatigue (TMF) are achievable with relevant accessories and control software. Despite a limited range of strain biaxiality ($-\nu \geq \phi \geq -1$), this approach is widespread and standard testing machines with dual servo-hydraulic actuators are available from commercial manufacturers.

4.3.3 Axial + internal pressure[8]

This approach permits a single tubular specimen design with essentially invariant stress and strain over the gauge length. Crack studies are difficult as maximum stress occurs at the bore, so cracks can only be visible after penetration of the wall shortly prior to failure. In addition, cyclic plasticity results in strain ratchetting as external radial compression cannot be applied to fully reverse the stress — strain cycle. Hence this approach is essentially restricted to elastic HCF studies. The testing machine typically utilizes a dual actuator servo-hydraulic design.

iTeh Standards
(https://standards.iteh.ai)
Document Preview
ISO/TR 12112:2018
https://standards.iteh.ai/catalog/standards/iso/dcd60b-3a6b-4757-bf1a-d61cce02d534/iso-tr-12112-2018

4.3.4 Axial + internal + external pressure[9]

This design enables fully reversed cycling without ratchetting because radial compression can be applied. Axial and circumferential stresses and strains are measurable, enabling LCF hysteresis loops on both surface axes, which makes the approach suitable for fundamental behavioural studies. Because a pressure vessel is located around the specimen, visual observations are difficult. Also elevated temperature testing above about 200 °C requires gas pressurization which presents safety issues. By employing variable internal pressure and fixed external pressure, a design with just 2 servo-hydraulic actuators is achievable.

4.3.5 Axial + internal + external pressure + torsion[10]

The addition of torsion introduces rotation of principal stress or strain axes which allows, in principle, material anisotropy and the effects of the different symmetries (in the axial and circumferential directions) to be investigated. The mechanical design is complex with 4 servo-hydraulic actuators, but has been successfully achieved.

NOTE Multiaxial testing machines featuring axial force and differential pressure are typically used for academic research or specific R&D applications, and are usually designed and manufactured to order.

4.3.6 Cruciform — LCF[11]

Four orthogonal loading arms apply biaxial strain to a central circular gauge area on the specimen. This area is usually spherically recessed on both sides in order to resist buckling and ensure that cracks initiate near the centre. In consequence, the gauge area does not support all the applied forces, i.e. some of the force is shunted around the outside. As a result, stresses and plastic strains are not readily

 © ISO 2018 – All rights reserved