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Fine ceramics (advanced ceramics, advanced technical ceramics) — Mechanical properties of ceramic composites at ambient temperature in air atmospheric pressure — Determination of hoop tensile properties of tubes

Céramiques techniques (céramiques avancées, céramiques techniques avancées) — Propriétés mécaniques des céramiques composites à température ambiante et à pression atmosphérique — Détermination des propriétés en traction circonférentielle de tubes

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Foreword

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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 of 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 www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 206, *Fine ceramics*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Fine ceramics (advanced ceramics, advanced technical ceramics) — Mechanical properties of ceramic composites at ambient temperature in air atmospheric pressure — Determination of hoop tensile properties of tubes

1 Scope

This document specifies the conditions for the determination of hoop tensile properties of ceramic matrix composite (CMC) tubes with continuous fibre-reinforcement at ambient temperature in air atmospheric pressure. This document is specific to the tubular geometries since fibre architecture and specimen geometry factors in composite tubes are distinctly different from those in flat specimens.

This document provides information on the hoop tensile properties and stress-strain response, such as hoop tensile strength, hoop tensile strain at failure and elastic constants. The information can be used for material development, control of manufacturing (quality insurance), material comparison, characterization, reliability and design data generation for tubular components.

This document addresses, but is not restricted to, various suggested test piece fabrication methods. It applies primarily to ceramic and/or glass matrix composite tubes with a continuous fibrous-reinforcement: unidirectional (1D filament winding and tape lay-up), bi-directional (2D braid and weave) and tri-directional (*x*D, with $2 < x \leq 3$), subjected to an internal pressure.

Values expressed in this document are in accordance with the International System of Units (SI).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3611, *Geometrical product specifications (GPS) — Dimensional measuring equipment: Micrometers for external measurements — Design and metrological characteristics*

ISO 20507, *Fine ceramics (advanced ceramics, advanced technical ceramics) — Vocabulary*

ASTM E2208-02, *Standard Guide for Evaluating Non-Contacting Optical Strain Measurement Systems*

3 Terms and definitions

For the purpose of this document, the terms and definitions given in ISO 20507 and the following 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
calibrated length
l
part of the test specimen that has uniform and minimum *external diameter* (3.3)

3.2
gauge length
L_0
initial distance between reference points on the test specimen in the *calibrated length* (3.1)

3.3
external diameter
d_o
outer distance through the centre of the tube from one side to the other in the *gauge length* (3.2)

3.4
internal diameter
d_i
inner distance through the centre of the tube from one side to the other in the *gauge length* (3.2)

3.5
wall thickness
h
distance between the *internal* (3.4) and *external diameters* (3.3) in the *gauge length* (3.2)

3.6
hoop tensile strain
$\varepsilon_{\theta\theta}$
relative change in circumferential direction in the *gauge length* (3.2)

3.7
axial strain
ε_{zz}
relative change in the axial (or longitudinal) direction in the *gauge length* (3.2)

3.8
hoop tensile stress
$\sigma_{\theta\theta}$
stress supported by the test specimen in circumferential direction at any time in the test

3.9
burst pressure
P_F
highest recorded internal pressure undergone by the test specimen when tested to failure

3.10
hoop tensile strength
$\sigma_{\theta\theta,m}$
hoop tensile stress (3.8) calculated at the *burst pressure* (3.9)

3.11
proportionality ratio or pseudo-elastic modulus in the circumferential direction
$EP_{\theta\theta}$
slope of the initial linear section of the stress-strain curve

Note 1 to entry: Examination of the stress-strain curves for ceramic matrix composites allows definition in the following cases:

a) Material with an initial linear domain in the stress-strain curve.

The proportionality ratio or pseudo-elastic modulus is termed the elastic modulus in the circumferential direction, $E_{\theta\theta}$, in the single case where the linearity starts near the origin.

b) Material with no-linear section in the stress-strain curve.

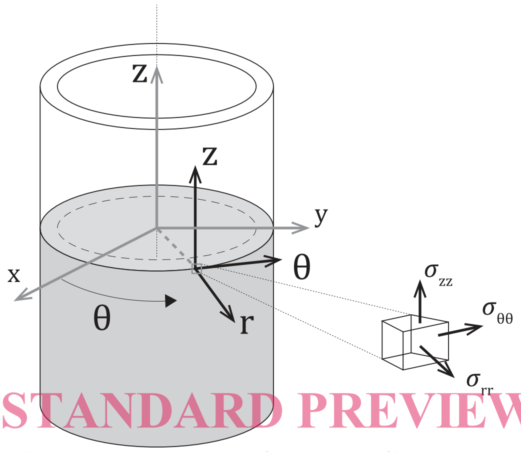
In this case only stress-strain couples can be fixed.

3.12
Poisson's ratio
$\nu_{\theta z}$
negative ratio of circumferential to *axial strain* (3.7)

3.13
coordinate system
system used to determine location in space

Note 1 to entry: Cylindrical coordinates are adopted in this document.

Note 2 to entry: The notations shown in Figure 1 apply for space representation.



Key

z axial

r radial

θ circumferential

Figure 1 — Cylindrical coordinate system used for the CMC tubes

4 Principle

A prepared tubular test specimen of specified dimensions is inserted into an appropriate test fixture assembly and subjected to monotonic loading via indirect internal pressure up to fracture. Uniform radial pressure is produced using hydraulic oil injection with a piston through an elastomeric bladder located inside the tubular test specimen. The elastomeric bladder mates to the inner diameter of the tubular test specimen, thus causing its expansion under pressure. The test is performed at constant piston displacement or constant strain (or constant loading rate). Both the applied pressure and resulting hoop tensile strain are measured and recorded simultaneously. The hoop tensile strength and corresponding strain are determined from the burst pressure while the various other hoop tensile properties are determined from the stress-strain response data.

Generally, the test is carried out under conditions of ambient temperature and environment.

NOTE 1 The resulting force from internal pressure loading is applied in the radial direction. Monotonic refers to a continuous non-stop test rate with no reversals from test initiation to final fracture.

NOTE 2 The method described in this document does not cover the possibility of applying pressurization via a dense rubber material in compressive without fluid.

5 Apparatus

5.1 Pressurizing system

The pressurizing system shall be able to apply a continuously increasing and uniform internal pressure to the tubular test specimen.

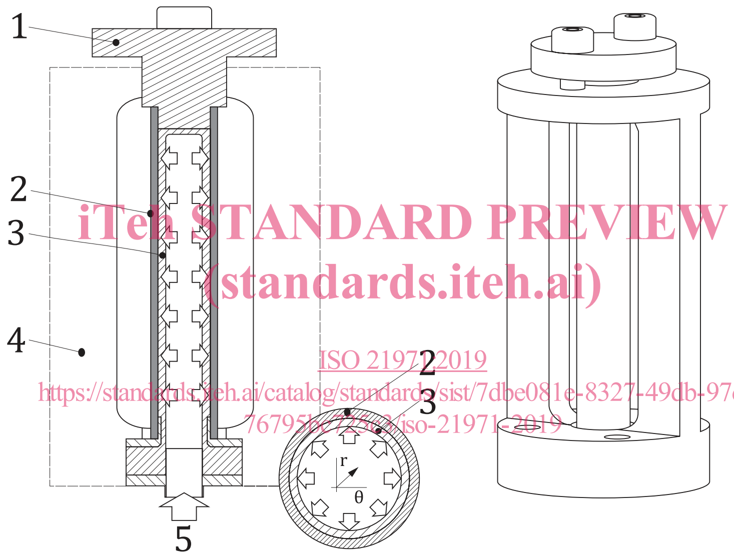
The following equipment is recommended for this test:

a) an oil (or other fluid) bath maintained at uniform temperature;

b) an annular and leak-tight elastomeric bladder surrounding the inner periphery of the tubular test specimen able to transmit a uniform pressure loading by its elasticity expansion;

c) a test machine (or a press) capable of applying a determined compressive force on a piston free to move vertically to increase oil pressure in the elastomeric bladder.

Figure 2 shows a schematic example to illustrate the principle of a satisfactory pressurizing system.



Key

1 cover plate

2 tubular test specimen

3 elastomeric bladder

4 space flange

5 oil inlet for pressurization (P)

Figure 2 — Example of hydrostatic pressurizing system for CMC tubular test specimen

5.2 Test specimen gripping and end closure

The gripping device shall be able to maintain the tubular test specimen in position to withstand internal pressure induced by the expansion of the elastomeric bladder while allowing it to move radially. An example of construction detail is shown in Figure 2 for which the tubular test specimen is mounted on a spacer flange. A cover plate is clamped on the flange with two screws to obtain a correct alignment.

The brittle nature of the CMCs requires particular attention to minimize crack initiation and fracture. Therefore, it is recommended that the attachment screws are released and then the adjustment screw adjusted to push the mating flanges back slightly until they come into contact with the tube, but without applying any axial force to it.

Specimen end closure shall be able to withstand the maximum test pressure. Closure shall be designed so that it does not cause failure of the specimen.

5.3 Strain measurement

5.3.1 General

Strain should be locally measured in order to avoid having to take into account the compliance of the machine. This may be by means of suitable bonded resistance strain gauges or digital image correlation (DIC). If Poisson's ratio is to be determined, the tubular test specimen shall be instrumented to measure strain in both longitudinal and circumferential directions.

5.3.2 Strain gauges

5.3.2.1 Strain gauge selection

The strain gauges, the surface preparation of the tubular test specimen and the bonding agents should be chosen to provide adequate performance on the tested materials.

Some guidelines on the use of strain gauges on CMC tubes are as follows.

Unless it can be shown that strain gauge readings are not unduly influenced by localized strain events such as fibre crossovers, strain gauges should have an active gauge length greater than three characteristic unit cells (repeating units) of the reinforcement in both longitudinal and circumferential directions. This averages the localized strain effects of the fibre crossovers.

Under internal pressure loading, a single-grid gauge pattern would normally be used with the gauge axe aligned to coincide with the circumferential direction of the tubular test specimen.

NOTE Poisson's ratio can be determined with biaxial two-element (0-90) strain gauge rosettes, which measure the strain in both the circumferential and longitudinal directions.

5.3.2.2 Surface preparation

The relatively rough surface of composites usually requires some preparation prior to strain gauge bonding. The basic steps shall include solvent degreasing, abrading or filling and cleaning.

Matrix-rich surfaces can usually be abraded with 320-grit silicon carbide paper (SCP-2) to produce a satisfactory matte finish. However, unless their surfaces have been machined or have received a smoothing treatment, tubular test specimens of poor matrix content composites or those with textured surface requires alternative techniques.

NOTE A typical method is to apply an epoxy precoat to fill the surface irregularities and finish by polishing.

Reinforcing fibres should not be exposed or damaged during the surface preparation process. In particular, abrasion shall be kept to a minimum to avoid possible damage to fibres in the outer surface of the composite.

5.3.3 Digital image correlation

5.3.3.1 General

The DIC method can also be used to determine local strain of CMC tubular test specimens loaded under internal pressure from the displacement field measurement. The general procedure to be followed for estimating the strain shall be in accordance with ASTM E2208-02.

Some guidelines on the use of the DIC method on CMC tubes are as follows.

