DRAFT INTERNATIONAL STANDARD
ISO/DIS 18610

ISO/TC **206** Secretariat: **JISC**

Voting begins on:
2015-07-08

Voting terminates on:
2015-10-08

Fine ceramics (advanced ceramics, advanced technical ceramics) — Mechanical properties of ceramic composites at room temperature — Determination of elastic properties by an ultrasonic technique

Céramiques techniques — Propriétés mécaniques des céramiques composites à température ambiante — Détermination des propriétés élastiques par une méthode ultrasonore

ICS: 81.060.30

Reference number
ISO/DIS 18610:2015(E)

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Foreword

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The committee responsible for this document is ISO/TC 206, *Fine ceramics (advanced ceramics, advanced technical ceramics)*.

Fine ceramics (advanced ceramics, advanced technical ceramics) — Mechanical properties of ceramic composites at room temperature — Determination of elastic properties by an ultrasonic technique

1 Scope

This International Standard specifies an ultrasonic method to determine the components of the elasticity tensor of ceramic matrix composite materials at room temperature. Young's moduli shear moduli and Poisson coefficients, can be determined from the components of the elasticity tensor.

This International Standard applies to ceramic matrix composites with a continuous fibre reinforcement: unidirectional (1D), bidirectional (2D), and tridirectional (× D, with $2 < \times \leq 3$) which have at least orthotropic symmetry, and whose material symmetry axes are known.

This method is applicable only when the ultrasonic wavelength used is larger than the thickness of the representative elementary volume, thus imposing an upper limit to the frequency range of the transducers used.

NOTE Properties obtained by this method might not be comparable with moduli obtained by EN 658–1, EN 658–2 and EN 12289. (Check for ISO EQUIVALENT)

2 Normative references

The following referenced documents are indispensable for the application 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.

EN 1389, *Advanced technical ceramics — Ceramic composites — Physical properties — Determination of density and apparent porosity*

ISO/AWI 19634, *Fine ceramics (advanced ceramics, advanced technical ceramics) — Notations and symbols of ceramic composites*

ISO/IEC 17025:2005, *General requirements for the competence of testing and calibration laboratories*

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

EN 12668-1, *Non-destructive testing — Characterization and verification of ultrasonic examination equipment — Part 1: Instruments*

EN 12668-2, *Non-destructive testing — Characterization and verification of ultrasonic examination equipment — Part 2: Probes*

EN 12668-3, *Non-destructive testing — Characterization and verification of ultrasonic examination equipment — Part 3: Combined equipment*

3 Terms definitions and symbols

For the purposes of this document, the terms and definitions given in CEN/TR 13233:2007 and the following apply.

3.1
stress-strain relations for orthotropic material

elastic anisotropic behaviour of a solid homogeneous body described by the elasticity tensor of fourth order C_{ijkl}, represented in the contracted notation by a symmetrical square matrix (6 × 6)

Note 1 to entry: If the material has at least orthotropic symmetry, its elastic behaviour is fully characterized by nine independent stiffness components C_{ij}, of the stiffness matrix (C_{ij}), which relates stresses to strains, or equivalently by nine independent compliance components S_{ij} of the compliance matrix (S_{ij}), which relates strains to stresses. The stiffness and compliance matrices are the inverse of each other.

If the reference coordinate system is chosen along the axes of symmetry, the stiffness matrix C_{ij} and the compliance matrix S_{ij} can be written as follows:

$$\begin{bmatrix}\sigma_1\\ \sigma_2\\ \sigma_3\\ \sigma_4\\ \sigma_5\\ \sigma_6\end{bmatrix}=\begin{bmatrix}C_{11} & C_{12} & C_{13} & 0 & 0 & 0\\ C_{12} & C_{22} & C_{23} & 0 & 0 & 0\\ C_{13} & C_{23} & C_{33} & 0 & 0 & 0\\ 0 & 0 & 0 & C_{44} & 0 & 0\\ 0 & 0 & 0 & 0 & C_{55} & 0\\ 0 & 0 & 0 & 0 & 0 & C_{66}\end{bmatrix}\begin{bmatrix}\varepsilon_1\\ \varepsilon_2\\ \varepsilon_3\\ \varepsilon_4\\ \varepsilon_5\\ \varepsilon_6\end{bmatrix}$$

$$\begin{bmatrix}\varepsilon_1\\ \varepsilon_2\\ \varepsilon_3\\ \varepsilon_4\\ \varepsilon_5\\ \varepsilon_6\end{bmatrix}=\begin{bmatrix}S_{11} & S_{12} & S_{13} & 0 & 0 & 0\\ S_{12} & S_{22} & S_{23} & 0 & 0 & 0\\ S_{13} & S_{23} & S_{33} & 0 & 0 & 0\\ 0 & 0 & 0 & S_{44} & 0 & 0\\ 0 & 0 & 0 & 0 & S_{55} & 0\\ 0 & 0 & 0 & 0 & 0 & S_{66}\end{bmatrix}\begin{bmatrix}\sigma_1\\ \sigma_2\\ \sigma_3\\ \sigma_4\\ \sigma_5\\ \sigma_6\end{bmatrix}$$

Note 2 to entry: For symmetries of higher level than the orthotropic symmetry, the C_{ij} and S_{ij} matrices have the same form as here above. Only the number of independent components reduces.

3.2
engineering constants

compliance matrix components of an orthotropic material which are in terms of engineering constants:

$$\left[S_{ij}\right]=\begin{bmatrix}{}^{1}\!/_{E_{11}} & {}^{-\nu_{21}}\!/_{E_{22}} & {}^{-\nu_{31}}\!/_{E_{33}} & 0 & 0 & 0\\ {}^{-\nu_{12}}\!/_{E_{11}} & {}^{1}\!/_{E_{22}} & {}^{-\nu_{32}}\!/_{E_{33}} & 0 & 0 & 0\\ {}^{-\nu_{13}}\!/_{E_{11}} & {}^{-\nu_{23}}\!/_{E_{22}} & {}^{1}\!/_{E_{33}} & 0 & 0 & 0\\ 0 & 0 & 0 & {}^{1}\!/_{G_{23}} & 0 & 0\\ 0 & 0 & 0 & 0 & {}^{1}\!/_{G_{13}} & 0\\ 0 & 0 & 0 & 0 & 0 & {}^{1}\!/_{G_{12}}\end{bmatrix}$$

where

E_{11}, E_{22} and E_{33}	are the elastic moduli in directions 1, 2 and 3 respectively;
G_{12}, G_{13} and G_{23}	are the shear moduli in the corresponding planes;
ν_{12}, ν_{13}, ν_{23}	are the respective Poisson coefficients

3.3
angle of incidence

θ_i

angle between the direction 3 normal to the test specimen front face and the direction n_i of the incident wave (see Figure 1 and Figure 2)

3.4
refracted angle

θ_r

angle between the direction 3 normal to the test specimen front face and the direction n of propagation of the wave inside the test specimen (see Figure 1 and Figure 2)

3.5
azimuthal angle

ψ

angle between the plane of incidence $(3, n_i)$ and plane $(2, 3)$ where n_i corresponds to the vector oriented along the incident plane wave and direction 2 corresponds to one of the axes of symmetry of the material (see Figure 1)

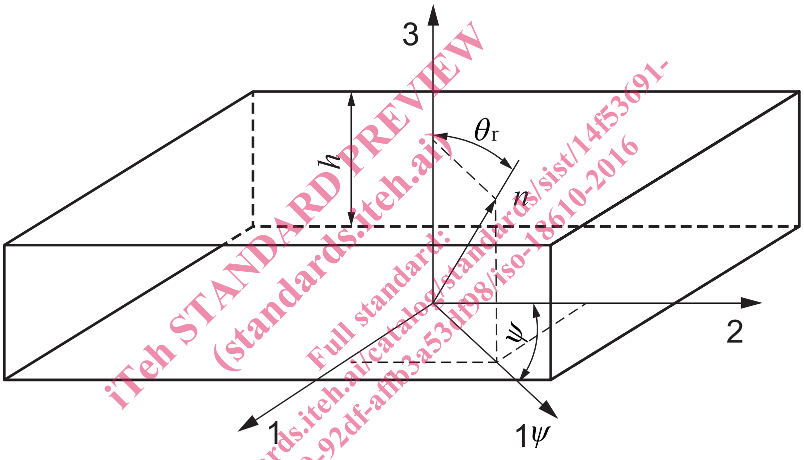


Figure 1 — Definition of the angles

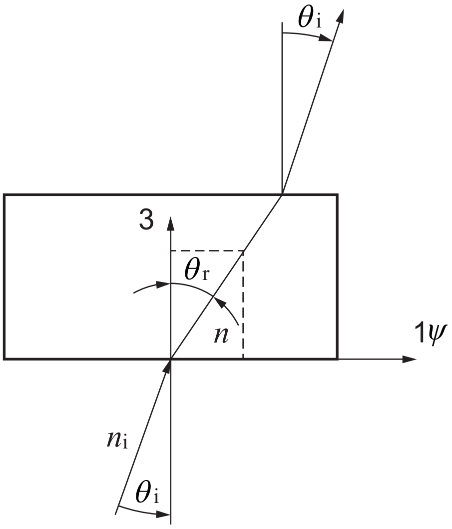


Figure 2 — Propagation in the plane of incidence

3.6

first critical angle

θ_c

angle of incidence θ_{i} that provides an angle of refraction of 90-degrees of the quasi longitudinal wave angle

3.7

unit vector

n

unit vector oriented along the propagation direction of the incident plane wave inside the specimen, with its components n_{k} (k = 1, 2, 3) (see Figure 1 and Figure 2):$n_1 = \sin\theta_{\mathrm{r}}\ \sin\psi n_2 = \sin\theta_{\mathrm{r}}\ \cos\psi n_3 = \cos\theta_{\mathrm{r}}$

3.8

propagation velocity

$V(n)$

phase velocity of a plane wave inside the specimen in dependence on unit vector n (i.e. in dependence on ψ and θ_r)

Note 1 to entry: Vo is the propagation velocity in the coupling fluid.

3.9

delay

$\delta t(n)$

difference between the flight time of the wave when the test specimen is in place and the flight time of the wave in the coupling fluid with the test specimen removed under the same configuration of the transducers in dependence on unit vector n

3.10

bulk density

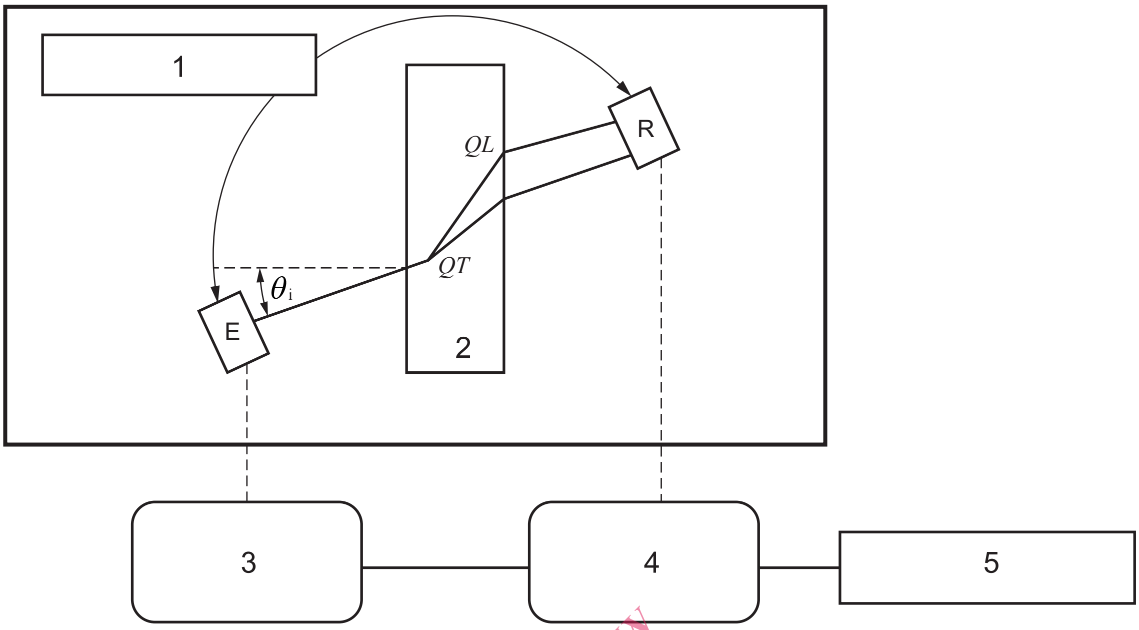
ρ

bulk density of the specimen without porosity

4 Principle

The determination of the elastic properties consists of calculating the coefficients of the propagation equation of an elastic plane wave, from a set of properly chosen velocity measurements along known directions.

A thin specimen with plane parallel faces is immersed in an acoustically coupling fluid (e.g. water): see Figure 3. The specimen is placed between an emitter (E) and a receiver (R), which are rigidly connected to each other and have two rotational degrees of freedom. Using appropriate signal processing, the propagation velocities of each wave in the specimen are calculated.



Key

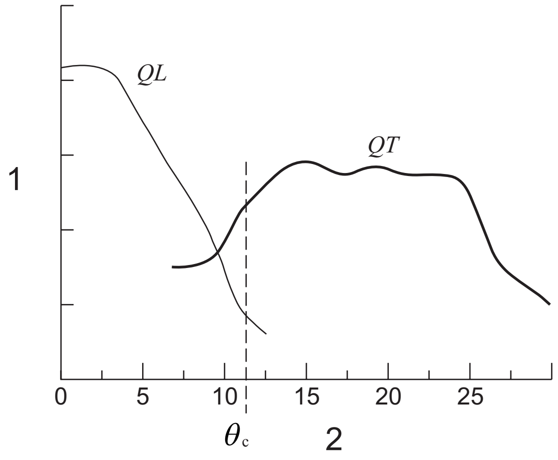
1	rotation drive
2	test specimen
3	pulse generator
4	digital oscilloscope
5	micro-computer

Figure 3 — Ultrasonic test assembly

Depending on the angle of incidence, the wave created by the pulse sent by the emitter E is refracted within the material in one (a quasi longitudinal wave *QL*, or a quasi transverse wave *QT)*, two (*QL*+ *QT or* two quasi transverse waves QT_1, QT_2) or three bulk waves ($QL+ QT_1+QT_2$) that propagate in the solid at different velocities and in different directions.

The receiver R collects one, two or three pulses, corresponding to each of these waves.

The difference between the propagation time of each of the waves and the propagation time of the emitted pulse in the coupling fluid without the specimen is measured. The evaluation procedure is based on the measurement of the time of flight of the quasi-longitudinal and one or both quasi-transverse waves, and is only valid when the *QL* and the *QT* waves are appropriately separated (see Figure 4).

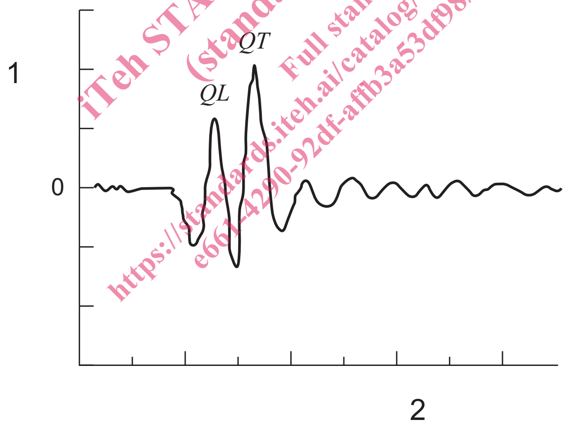


Key

1 amplitude

2 incidence angle

a) Amplitude of the *QL* and *QT* waves as a function of the incidence angle with overlapping in the region of θ_c



Key

1 amplitude

2 time

b) Temporal waveform of the *QL* and *QT* waves at an incidence angle θ_i close to the critical angle θ_c. Both *QL* and *QT* waves are present and can be distinguished in the positive domain but are slightly overlapping in the negative domain

Figure 4 — Example of partial Overlapping of *QL* and *QT* waves at an incidence angle θ_i

From the propagation velocities the components of the elasticity tensor are obtained through a least square regression analysis which minimises the residuals of the wave propagation equations.

Young's moduli, shear moduli and Poisson coefficients are determined from these components.