SLOVENSKI STANDARD
SIST ENV 820-3:2000

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Advanced technical ceramics - Monolithic ceramics - Thermomechanical properties - Part 3: Determination of resistance to thermal shock by water quenching

Advanced technical ceramics - Monolithic ceramics - Thermomechanical properties - Part 3: Determination of resistance to thermal shock by water quenching

Hochleistungskeramik - Monolithische Keramik - Thermomechanische Eigenschaften - Teil 3: Bestimmung der Thermoschockbeständigkeit mit dem Wasserabschreckversuch

Céramiques techniques avancées - Céramiques monolithiques - Propriétés thermomécaniques - Partie 3: Détermination de la résistance au choc thermique par la méthode de trempe a l'eau

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CEN

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Foreword

This European Prestandard has been prepared by Technical Committee CEN/TC 184 'Advanced Technical Ceramics, of which the secretariat is held by BSI.

ENV 820 consists of three Parts:

Part 1 : Determination of flexural strength at elevated temperatures
Part 2 : Determination of self-loaded deformation
Part 3 : Determination of resistance to thermal shock by water quenching

CEN/TC 184 approved this European prestandard by Resolution 2 during its sixth meeting, held in Alkmaar on 1992-09-30.

In accordance with the CEN/CENELEC Internal Regulations, the following countries are bound to announce the existence of this European prestandard:

Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

1 Scope

This Part of ENV 820 describes the principles of thermal shock testing, and provides a general method for conducting thermal shock tests for both test pieces and components by quenching into water.

2 Normative references

This European Prestandard incorporates, by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European prestandard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

EN 623-1	Advanced technical ceramics - Monolithic ceramics - General and textural properties - Part 1 : Determination of the presence of defects by dye penetration tests[1]
EN 843-1	Advanced technical ceramics - Monolithic ceramics - Mechanical properties of monolithic ceramics at room temperature - Part 1 : Determination of flexural strength[1]
EN 45001	General criteria for the operation of testing laboratories
HD 426.2 S1	Specification for ceramic and glass insulating materials - Part 2 : Methods of test
HD 446.1 S1	Thermocouples - Part 1 : Reference tables
HD 446.2 S2	Thermocouples - Part 2 : Tolerances

3 Introduction to thermal shock behaviour

3.1 Causes of thermal stress failure

Because ceramics are rigid, elastic bodies, thermal stresses derived from temperature gradients through the thickness of a test piece or component cannot be readily relaxed, as for example in ductile metals. If the tensile or shear thermal stress level exceeds the strength of the material, then cracks can develop which degrade the strength of the material, or in extreme circumstances can cause complete fragmentation.

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[1] In preparation

The factors that influence the ability of a ceramic component to withstand degradation of its functional properties by thermal stress are several:

a) the geometry of the component, especially the wall thickness and the radii of curvature of exposed corners and faces, which control the rate of heat transfer to the component;

b) the thermal conductivity and/or thermal diffusivity of the material comprising the component, which controls the thermal gradients which are set up by the transfer of heat to or from the component;

c) the thermal expansion characteristics, which control the levels of thermal strain developed under the temperature gradients established in the component;

d) the elastic properties, which control the levels of stress developed by thermal strains;

e) the strength of the material at the locations where the tensile or shear thermal stresses develop to high levels, and the density of the defects which are present as crack initiating sites;

f) the fracture toughness of the material, which controls the resistance to the propagation of cracks once fracture is initiated;

g) the amount and distribution of porosity, which controls the resistance to thermal shock damage through reducing the elastic moduli.

These factors combine to control the survivability of a component in any given environment in which temperature changes rapidly.

3.2 Mechanisms of failure

Creating a thermal gradient in a ceramic body introduces a distribution of thermal strains which cannot exceed the failure strain of the component material at any point if the component is to survive undamaged. If the failure strain is exceeded, then cracks may develop and grow to relieve the strain, and these will tend to initiate and propagate in regions where the thermal strains are in greatest tension or in shear. Thermal gradients may arise in practice due to steady localized application of heat to a component, or to the sudden immersion of a component into a hotter or cooler environment.

A hot ceramic component subject to sudden chilling of its surface by immersion in a cooler medium has its surface layer subjected to a high tensile stress which is transient in nature. If this stress is sufficiently high, tensile, opening mode cracks can develop from surface defects or other fracture initiating sites. Typically, excessive rates of cooling lead to the crazing of the surface by a network of meandering cracks. In a material with a low level of toughness, the cracks may run sufficiently to cause complete fragmentation of the component. In a material with a moderate level of toughness, the cracks may halt, and result in a weaker, but still intact component. In a coarse-grained or porous weak material, the cracking may be minor, and lead to very little overall degradation. Figure 1 illustrates typical behaviour.

A cold ceramic component subjected to sudden heating by immersion in a hotter medium has a thermal stress distribution which is compressive on its surface, but tensile internally. Generally speaking, the tensile stress levels are lower than in the equivalent cooling situation, and thus components tend to be able to survive greater upward thermal shocks than downward ones. Another mode of failure is in shear, close to the surface under high compressive stress, and this results in the production of spalls or flakes which come away from the surface. Similarly, a cold ceramic subjected to localized heating, for example by a gas flame or a laser, will suffer tensile stresses on the opposite side and around the periphery of the heated zone, with similar results.

Repeated thermal shock cycling can result in the progressive accumulation of mechanical damage if the shock is sufficiently severe.

3.3 Thermal shock parameters

3.3.1 The extent of damage is controlled by a number of physical parameters summarized in 3.1, but especially the thermal expansion coefficient, the toughness and the strength. Resistance to propagation of damage in repeated cycling is controlled principally by the density of cracking and the toughness. To describe the relative performance of different ceramic materials, it is common to find thermal shock parameters being employed. The following have been devised from models of downward thermal shock of brittle elastic solids and are given in 3.3.2 to 3.3.5 as examples to illustrate the roles played by various mechanical and thermal properties of the material.

3.3.2 For very rapid thermal shock (instantaneous change of surface temperature):

$$R = \frac{\sigma(f)\ (1 - \nu)}{E\alpha}$$

where:

R thermal shock parameter of first type;
$\sigma(f)$ fracture strength (typically biaxial strength);
ν Poisson's ratio (typically 0,25);
E Young's modulus;
α thermal expansion coefficient.

3.3.3 For constant rate of heat transfer from the component to the medium:

$$R^{1} = \frac{\sigma(f)\ (1 - \nu)\lambda}{E\alpha}$$

where:

R^{1} thermal shock parameter of second type;
λ thermal conductivity.

3.3.4 For constant rate of change of surface temperature:

$$R^{11} = \frac{\sigma(f)\ (1 - \nu)D}{E\alpha}$$

where:

R^{11} thermal shock parameter of third type;
D thermal diffusivity.

3.3.5 For resistance to loss of strength on thermal cracking:

$$R^{1111} = \frac{EY(f)}{\sigma(f)^2\ (1 - \nu)}$$

where:

R^{1111} thermal shock parameter of fifth type;
$Y(f)$ fracture energy.

NOTE: Further information on thermal shock parameters may be found in annex A.