INTERNATIONAL STANDARDS FOR PROPERTIES AND PERFORMANCE OF ADVANCED CERAMICS

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ABSTRACT
Mechanical and physical properties and performance of brittle bodies, including advanced ceramics and glasses, can be difficult to measure correctly unless the proper techniques are used. ASTM Committee C28 on Advanced Ceramics has developed numerous full-consensus standards (e.g., test methods, practices, guides, terminology) to measure various properties and performance of a monolithic and composite ceramics and coatings that, in some cases, may be applicable to glasses. These standards give the "what, how, how not, why, why not, etc." for many mechanical, physical, and thermal properties and performance of advanced ceramics. Use of these standards provides accurate, reliable, repeatable and complete data. Involvement in ASTM Committee C28 has included users, producers, researchers, designers, academicians, etc. who write and continually update, as well as validate through round robin test programmes, more than 45 standards since the committee's inception in 1986. Included in this poster is a pictogram of the ASTM Committee C28 standards and how to obtain them either as i) individual copies with full details or ii) a complete collection in one volume. A listing of other ASTM committees that might be of interest is included. In addition, some examples of the tangible benefits of standards for advanced ceramics are employed to demonstrate their practical application.

KEYWORDS – ceramics, composites, coatings, standards, characterizations, properties, measurements.

INTRODUCTION

Demand for more efficient, environmentally-friendly heat engines, including gas turbines; unlubricated, wear-resistant bearings; long-lived, ever-sharp cutting implements, insulating, high-strength electronic packages, to name a few applications, have fueled extensive worldwide investigations of the mechanical, physical, and thermal behavior (and its subsequent characterization) of structural ceramics (SCs) and ceramic matrix composites (CMCs). From an engineering perspective, determination of the properties and performance (e.g., mechanical, thermal, thermo-mechanical, physical, environmental, etc.) of SCs and CMCs is required for a number of reasons: 1) to provide basic characterization for purposes of materials development, quality control and comparative studies; 2) to provide a research tool for revealing the underlying mechanisms of properties and performance; and 3) to provide performance-prediction data for engineering applications and components design [1]. As SC and CMC prototypes and products reach the marketplace in greater numbers, the paucity of standards (i.e., test methods, classification systems, unified terminology, and reference materials) for these materials and the lack of applicable design codes and their related data bases are limiting factors for their commercial diffusion and industrial acceptance [2].

The term "standards" has multiple meanings for multiple users. In the research and technical communities, standards may be fundamental test methodologies and units of measure. For manufacturers or end-product users standards may be materials specifications and tests to meet requirements. Commercial standards are the rules and terms of information transfer among designers, manufacturers and product users [2]. Fundamental differences exist between levels of standards: company (internal use with only internal consensus); industry (trade/project use with limited organizational consensus); government (wide usage and varying levels of consensus); full-consensus (broadest usage and greatest consensus).

As of the middle of the second decade of the 21st century, there are still relatively few national or international full-consensus standards [3-6] for testing both SCs and CMCs. Continued material development may be impaired by this limited ability to test on a common-denominator basis [2]. The lack of standards for SCs and CMCs may in part be due to the novelty of these advanced engineering materials. For example, initial speculative and actual applications of SCs and CMCs in gas turbines may be dated to Word War II in the mid 1940's along with follow on work in 1950's [7], major efforts in Europe, Japan and the United States [8] to process, to characterize and to design with SCs and CMCs seem to have emerged from the 1970's push for more efficient heat engines. Indeed, while many different test methods and test results were being reported in the 1970s an oft-noted item on any list of hindrances to acceptance of SCs and CMCs in engineering applications was lack of standard test methods, design codes and data bases [9]. In 1981, the Japan Industrial Standards Committee (JISC) introduced a number of partial consensus standards for SCs including one for the flexural strength [10]. In due course other national standards bodies followed with their own standards for SCs and CMCs including American Society for Testing and Materials (ASTM) with the establishment of Committee C28 on Advanced Ceramics in 1986 [10]. Eventually this national effort led to the establishment of the Technical Committee TC206 on Fine Ceramics within the International Organization on Standards (ISO) in 1993 [4].

In this paper, first an overview of ASTM as well as Committee C28 is provided. Details of each subcommittee of Committee C28 along with their respective standards are given in the following sections. Finally, some examples of the tangible benefits of standards for advanced ceramics are employed to demonstrate their practical application.

ASTM AND COMMITTEE C28 ADVANCED CERAMICS

ASTM The American Society for Testing Materials (ASTM) is the primary standards writing establishment in the United States for testing of materials, and is a private, nonprofit corporation for the development of full voluntary consensus standards on characteristics and performance of materials, products, systems, and services, and for the promotion of related knowledge. This is accomplished through the work of various ASTM committees consisting of volunteer experts, who following previously established regulations, generate a product (standard) that is widely recognized, accepted, and used.

Committee C28 ASTM Committee C28 on Advanced Ceramics was organized in 1986 when it became apparent that ceramics were being considered for many new high technology applications in the aerospace, biomedical, military, and automotive areas. These applications were viewed as being particularly demanding in terms of behavior requirements. Hence, it was important that standards be written for the production, inspection, testing, data analysis, and probabilistic design of advanced structural ceramics. An advanced ceramic can be defined as "a highly engineered, high performance, predominantly non-metallic, inorganic ceramic material having specific functional attributes," and includes both monolithic and composite ceramic materials. Accordingly, Committee C28 was organized with various subcommittees as shown in Fig. 1 with task groups addressing specific technical topics under each subcommittee and writing appropriate standards. These standards may take the form of nomenclature, guides, practices, or test methods. Committee members from industry, government laboratories, and academia serve on these various subcommittees. Additional participation and membership are always encouraged, especially as new technical issues are defined and additional expertise required. Listings of completed standards are given under each subcommittee. The standard designation number gives the year the standard was approved or reapproved. A pictograph illustration of selected standards under the jurisdiction of Committee C28 is shown in Figure 2.

Scope of Committee C28 The scope of Committee C28 includes the promotion of knowledge, stimulation of research and development of standards (classifications, specifications, nomenclature, test methods, guides, and practices) relating to processing, properties, characterization, and performance of advanced ceramic materials.

This committee works in concert with other technical committees (e.g., D30 "Composite Materials," E07 "Non Destructive Testing," E08 "Fatigue and Fracture," E28 "Mechanical Testing," F04 "Medical and Surgical Materials and Devices", and G02 "Wear and Erosion") and other national and international organizations having mutual or related interests.

Work of Committee C28 Committee C28 develops and maintains standards for monolithic and composite advanced ceramics. An advanced ceramic is a highly-engineered, high-performance predominately non-metallic, inorganic, ceramic material having specific functional attributes. The C28 standards cover methods for testing bulk and constituent (powders, fibres, etc.) properties, thermal and physical properties, strengths and strength distributions, and performance under varying environmental, thermal, and mechanical conditions. The scope of application of the methods ranges from quality control through design data generation.

The Committee's primary objective is the development of technically rigorous standards which are accessible to the general industrial laboratory and consequently are widely accepted and used in the design, production, and utilization of advanced ceramics.

While the committee's roots are in energy-related industries and programs, C28 supports the needs of automotive, aerospace, electronic, medical and other industries requiring advanced ceramics. Some specific applications include nano-ceramics, bio-ceramics, coatings, electronics, sensors/actuators, porous substrates and fuel cells. C28 actively pursues standards development to support these emerging applications.

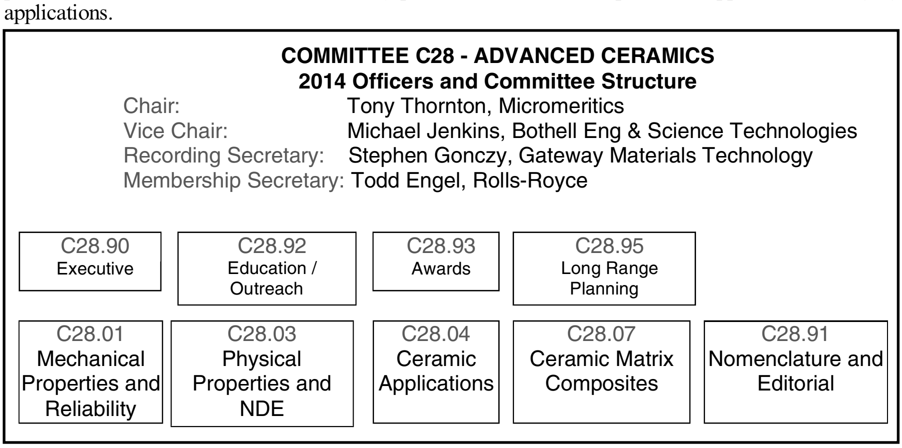

Figure 1 Committee Structure of ASTM Committee C28 on Advanced Ceramics

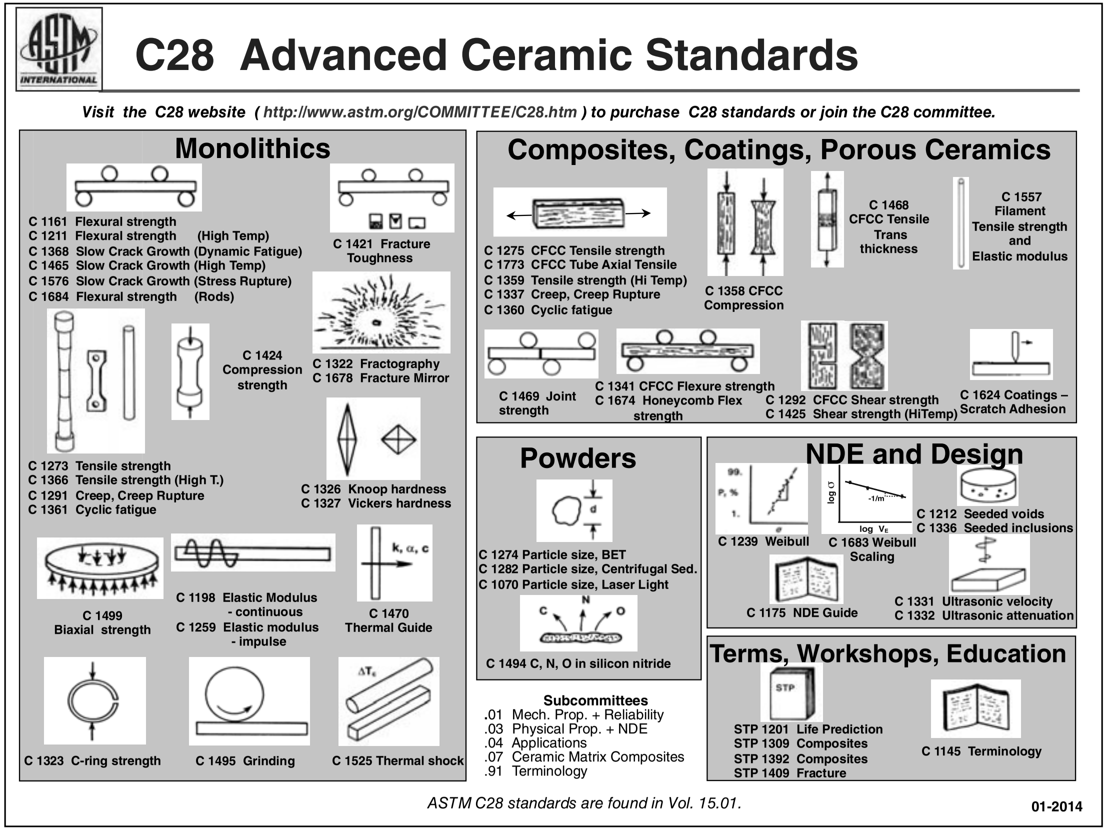

Figure 2 Pictograph of selected ASTM standards under the jurisdiction of Committee C28

Committee C28 coordinates its work with other organizations with mutual interests in advanced ceramics. The membership represents an international group of people interested in furthering advanced ceramic technology.

In addition to standards development, C28 sponsors symposia providing a forum for the timely transfer of technical information relevant to the design, analysis, processing, fabrication, and characterization of monolithic and composite advanced ceramics. Special workshops and technical presentations are often held to identify specific industrial needs and support the technical development of new standards.

The Committee meets twice a year in with an on-site meeting and a Web-teleconference. The Committee is self-regulated by committee-approved by-laws under the auspices of ASTM International

SUBCOMMITTEES OF ASTM COMMITTEE C28

C28.01 Mechanical Properties & Reliability This subcommittee develops standards for mechanical properties and reliability (short term and long term) of monolithic advanced ceramics in a number of areas including flexural strength, tensile strength, compressive strength, cyclic fatigue, creep and creep rupture, hardness, and fracture toughness. Standards under the jurisdiction of Subcommittee C28.01 include the following.

C28.01 Standards:

C1161-13 Test Method for Flexural Strength of Advanced Ceramics at Ambient Temperature

C1198-13 Test Method for Dynamic Young's Modulus, Shear Modulus, and Poisson's Ratio for Advanced Ceramics by Sonic Resonance

C1211-13 Test Method for Flexural Strength of Advanced Ceramics at Elevated Temperature

C1239-13 Practice for Reporting Uniaxial Strength Data and Estimating Weibull Distribution Parameters for Advanced Ceramics

C1259-14 Test Method for Dynamic Young's Modulus, Shear Modulus, and Poisson's Ratio for Advanced Ceramics by Impulse Excitation of Vibration

C1273-10 Test Method for Tensile Strength of Monolithic Advanced Ceramics at Ambient Temperatures

C1291-10 Test Method for Elevated Temperature Tensile Creep Strain, Creep Strain Rate, and Creep Time-to-Failure for Advanced Monolithic Ceramics

C1322-10 Practice for Fractography and Characterization of Fracture Origins in Advanced Ceramics

C1326-13 Test Method for Knoop Indentation Hardness of Advanced Ceramics

C1327-14 Test Method for Vickers Indentation Hardness of Advanced Ceramics

C1361-10 Practice for Constant-Amplitude, Axial, Tension-Tension Cyclic Fatigue of Advanced Ceramics at Ambient Temperatures

C1366-13 Test Method for Tensile Strength of Monolithic Advanced Ceramics at Elevated Temperatures

C1368-10 Test Method for Determination of Slow Crack Growth Parameters of Advanced Ceramics by Constant Stress-Rate Flexural Testing at Ambient Temperature

C1421-10 Test Methods for the Determination of Fracture Toughness of Advanced Ceramics

C1424-10 Test Method for Compressive Strength of Monolithic Advanced Ceramics at Ambient Temperatures

C1465-13 Test Method for Determination of Slow Crack Growth Parameters of Advanced Ceramics by Constant Stress-Rate Flexural Testing at Elevated Temperature

C1495-12 Test Method for Effect of Surface Grinding on Flexure Strength of Advanced Ceramics

C1499-13 Test Method for Monotonic Equibiaxial Flexural Strength Testing of Advanced Ceramics at Ambient Temperature

C1525-13 Test Method for Determination of Thermal Shock Resistance for Advanced Ceramics by Water Quenching

C1576-13 Test Method for Determination of Slow Crack Growth Parameters of Advanced Ceramics by Constant Stress Flexural Testing (Stress Rupture) at Ambient Temperature

C1683-10 Standard Practice for Size Scaling of Tensile Strengths Using Weibull Statistics for Advanced Ceramics

C1684-13 Standard Test Method for Flexural Strength of Advanced Ceramics at Ambient Temperature -Cylindrical Rods

C28.03 Physical Properties & NDE This subcommittee develops standards for physical, chemical, micro-structural, and non-destructive characterization of powder and bulk advanced ceramics. Standards under the jurisdiction of Subcommittee C28.03 include the following.

C28.03 Standards:

C1070-14 Test Method for Determining Particle Size Distribution of Alumina or Quartz by Laser Light Scattering

C1175-10 Guide to Test Methods for Nondestructive Testing of Advanced Ceramics

C1212-10 Practice for Fabricating Ceramic Reference Specimens Containing Seeded Voids

C1274-12 Test Method for Advanced Ceramic Specific Surface Area by Physical Adsorption

C1331-12 Practice for Measuring Ultrasonic Velocity in Advanced Ceramics with the Broadband Pulse-Echo Cross-Correlation Method

C1332-13 Test Method for Measurement of Ultrasonic Attenuation Coefficients of Advanced Ceramics by the Pulse Echo Contact Technique

C1336-14 Practice for Fabricating Non-Oxide Ceramic Reference Specimens Containing Seeded Inclusions

C1470-13 Guide for Testing the Thermal Properties of Advanced Ceramics

C1494-13 Test Method for Determination of Mass Fraction of Carbon, Nitrogen, and Oxygen in Silicon Nitride Powder

C1678-10 Standard Practice for Fractographic Analysis of Fracture Mirror Sizes in Ceramics and Glasses

C28.04 Applications This subcommittee develops standards (including guides, specifications, practices, test methods) for various engineering applications of advanced ceramics, such as nanoceramics, coatings, electrodes, porous ceramics, fuel cells, armor, sensors/actuators, and thermal systems. Standards under the jurisdiction of Subcommittee C28.04 include the following.

C28.04 Standards:

C1323-10 Test Method for Ultimate Strength of Advanced Ceramics with Diametrally Compressed C-Ring Specimens at Ambient Temperature

C1624-10 Test Method for Adhesion Strength and Mechanical Failure Modes of Ceramic Coatings by Quantitative Single Point Scratch Testing

C1674-11 Standard Test Method for Flexural Strength of Advanced Ceramics with Engineered Porosity (Honeycomb Cellular Channels) at Ambient Temperatures

C28.07 Ceramic Matrix Composites This subcommittee develops standards for determination of the thermo-mechanical properties and performance of ceramic matrix composites including tension, compression, shear, flexure, cyclic fatigue, creep/creep rupture, ceramic fibers, interfacial properties, thermo-mechanical fatigue, environmental effects, and structural/component testing. Standards under the jurisdiction of Subcommittee C28.07 include the following.

C28.07 Standards:

C1275-10 Test Method for Monotonic Tensile Behavior of Continuous Fiber-Reinforced Advanced Ceramics with Solid Rectangular Cross-Section at Ambient Temperatures

C1292-10 Test Method for Shear Strength of Continuous Fiber-Reinforced Advanced Ceramics at Ambient Temperatures

C1337-10 Test Method for Creep and Creep Rupture of Continuous Fiber-Reinforced Ceramic Composites under Tensile Loading at Elevated Temperature

C1341-13 Test Method for Flexural Properties of Continuous Fiber-Reinforced Advanced Ceramic Composites

C1358-13 Test Method for Monotonic Compressive Strength Testing of Continuous Fiber- Reinforced Advanced Ceramics with Solid Rectangular Cross-Section Specimens at Ambient Temperatures

C1359-13 Test Method for Monotonic Tensile Strength Testing of Continuous Fiber-Reinforced Advanced Ceramics with Solid Rectangular Cross-Section Specimens at Elevated Temperatures

C1360-10 Practice for Constant-Amplitude, Axial, Tension-Tension Cyclic Fatigue of Continuous Fiber-Reinforced Advanced Ceramics at Ambient Temperatures

C1425-13 Test Method for Interlaminar Shear Strength of 1-D and 2-D CFCCs at Elevated Temperatures

C1468-13 Test Method for Transthickness Tensile Strength of Continuous Fiber- Reinforced Advanced Ceramics at Ambient Temperatures

C1469-10 Test Method for Shear Strength of Joints of Advanced Ceramics at Ambient Temperature

C1557-08 Test Method for Tensile Strength and Young's Modulus Fibers

C28.90 Executive This subcommittee manages administrative matters of main Committee C28 through its membership comprised of the committee and subcommittee officers of C28.

C28.91 Nomenclature and Editorial This subcommittee compiles nomenclature and terminology used in the various standards of Committee C28. Standards under the jurisdiction of Subcommittee C28.91 include the following.

C28.91 Standards:

C1145-06 Terminology on Advanced Ceramics

C1286-94 Withdrawn 2001 Classification Advanced Ceramics

C28.92 Education and Outreach This subcommittee develops and supports efforts for education and outreach for the C28 committee.

C28.93 Awards This subcommittee accepts/acts on nominations for various awards

C28.95 Long Range Planning This subcommittee proposes, facilitates and promotes long range planning activities consistent with the mission, goals and objectives of the Committee and its subcommittees.

COLLABORATION

Committee C28 Advanced Ceramics collaborates with other ASTM committees through membership of its members on other committees, liaison activities, advisory ballots, and joint workshops/symposia. Some collaborating ASTM committee include C08 Refractories; C21 Ceramic Whitewares and Related Products; C26 Nuclear Fuel Cycle; D30 Composite Materials; E07 Nondestructive Testing; E08 Fatigue and Fracture; E10 Nuclear Technology and Applications; E28 Mechanical Testing; F04 Medical and Surgical Materials and Devices; F34 Rolling Element Bearings; and G02 Wear and Erosion

Committee C28 also collaborates with other standards writing organizations (SWOs) through, liaison activities and joint workshops/symposia. Collaborating international organizations include **ISO** TC206 Fine/Technical/Advanced Ceramics and CEN TC184 Technical Ceramics

EXAMPLES OF TANGIBLE BENEFITS

Although many examples of tangible benefits of ASTM C28 standards could be cited only two are given here in the interests of brevity.

F 1973: Standard Specification for High Purity Dense Yttria Tetragonal Zirconium Oxide Polycrystal (Y-TZP) for Surgical Implant Applications ASTM Committee F04 on Surgical and Medical Devices and the U.S. Food and Drug Administration used generic standards from Committee C28 for their new standard specification, F 1973. Specifically:

- "The average flexural strength shall be 800 MPa or greater by 4 point bending in accordance with Test Method C 1161"
- "The minimum elastic modulus shall be 200 GPa in accordance with Test Methods C 1198 or C 1259"
- "If Weibull modulus is tested, it shall be tested in accordance with Test Method C 1239"

Transparent Armor Ceramics as Spacecraft Windows Standards from Committee C28 allowed comparisons among authors and helped to interpret data. In particular:

- Standardized fracture toughness tests using Test Method C1421 ensured correct comparisons of different authors' results
- Standard-sized circular disks could be used to determine Poisson's ratio and Young's modulus via Test Method C1259 and biaxial strength via Test Method C1499 as well as the slow crack growth parameters, n and A, via Test Method C1368. This allowed efficient understanding of the behavior of the material.

CONCLUSIONS

Demand for advanced ceramics and ceramic matrix composites in the market place is expected to grow as these materials improve in consistency and reliability, and reduced cost. Standardized test methods are expected to accelerate use of these materials as they become available and are used nationally and internationally. ASTM Committee C28 on Advanced Ceramics has produced, as of this writing, forty high-quality, technically-rigorous consensus standards for processing, characterization, design, and evaluation of this class of materials. These activities have accelerated in recent years and many more standards are expected to be completed in the near future.

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