Testing Methodologies and Effects Associated with Ceramic Materials

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Abstract: At present a huge number of industrial and scientific apps are using ceramics. In advance, such technology have great scope for use in a wide variety of applications as these are typically wear and corrosion resistant, lightweight, and thermodynamically stable. Additionally, such advanced ceramics have electrical properties. Such electrical properties make ceramics for use in electronic applications. For example electronic packaging. With the steadily increasing use of ceramics in industry, there exists an increasing demand to characterize and quantify the properties of ceramics. This leads to higher demand for improved testing techniques to yield more exact data used for activities such as design, safety analysis, quality control, and scientific understanding. This present study gives a brief overview of the major test methods currently being used, relative advantages and disadvantages to each other, and some common sources of error. In addition, a listing of standards that are both relevant and directly applicable to ceramics are given for various testing methods. This chapter considers the most common mechanical testing methods which are usually expected to be performed by students entering the first time into a lab. Tensile test-related parameters are evaluated. Very popular tests of ceramics are the various hardness tests (for example Vickers hardness test), which is not only a cost saving test, but also requires shorter times, since no specific specimen preparation, except of a smooth (often polished) surface is required. On small size specimens, Knoop hardness test is the general approach to obtain hardness data. Another accepted method of evaluating the mechanical properties of a ceramic is by a bending (flexural) test. The tests can be performed by three or four point bending tests. Compression tests are more popular than tension tests, since they tend to close pores, cracks and other flaws resulting in higher test results than by those obtained by tension, which tends to open rather than close cracks and microcracks. Toughness is an important criterion in ceramic properties (mechanical) evaluation. Because of the brittle nature of ceramics, special instrumented Charpy Impact Test machines were developed, primarily to evaluate the dynamic toughness of such materials. Creep and Fatigue tests are not included in this chapter and they will be evaluated in separate chapters. Because of the large scatter in the experimental results, Weibull statistical distribution is applied to obtain a mean value of the experimental results. In this manuscript, the descriptions of assorted testing methodologies associated with ceramics are presented.

***Keywords**: Ceramics Analytics, Ceramics Evaluation, Ceramics Testing*

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I. Introduction

Ceramics are composed of compounds of metals and non metals and may be crystalline or partly crystalline [1]. They are characterized as brittle, hard, strong in compression, and weak in shearing, tension and impact. These materials are also very resistant to both corrosion and very high temperatures and can be designed to either insulate against or selected to conduct electricity. Ceramics have a wide range of applications most notably in industries that require materials to withstand large compressive forces or intense heat exposure for extended periods of time [2].

Testing ceramics helps determine if they are suited for specific applications. Typically this involves a series of tests to measure the material’s mechanical properties. These properties include the yield strength, ultimate strength, tensile strength, compressive strength, flexural strength, fracture strength, hardness, fracture resistance and creep rate. With the knowledge of these values the behavior that is expected from the ceramic during the application can be predicted and it can be shown if it will succeed or fail.

Common Ceramics Test Methods

There are many different tests that can be performed upon ceramics but the most common and important are those that involve compression, tension, flexural, and fracture mechanics. Because of the way that ceramics are constructed they generally posses vary high compressive strengths and will most often fail due to tensile, flexural or fracture forces; therefore it is very important to test these properties. Each property may also be tested using conventional methods, creep mechanics or cyclic (fatigue) methods [3].

Material Testing Specimens

Depending on the method of testing a ceramic test sample can come in several different forms. For compression testing a ceramic sample is usually in the sample of a simple brick, cube or cylinder. Flexural and fracture testing require the sample to be smaller than compression testing but it is still rectangular in nature with the flexure sample generally as a thin rectangle and the sample for fracture ranging from a beam to a brick. A ceramic sample for tensile testing presents interesting obstacles as they are very brittle in nature and prone to fracturing when loaded improperly. The sample is generally the same as other tensile samples with the exception of the ends which are usually formed as button headed to fit into specially designed grips to avoid any incidental failure [4].

Applicable Standards

- ASTM C1161 Flexural Bend Ceramics Test Equipment
- ASTM C1211 Flexural Testing for Ceramics
- ASTM C1273 Tensile Ceramic Test Equipment
- ASTM C1291 Tensile High Temperature Ceramics Test Machine
- ASTM C133 Crush Modulus Rupture Refractories Test Equipment
- ASTM C1361 Tension Tension Fatigue Ceramics Test Machine
- ASTM C1399 Residual Strength Fiber-Reinforced Concrete Test Equipment
- ASTM C1421 Fracture Toughness Ceramics Test Machine
- ASTM C1424 Compression Ceramics Test Machine
- ASTM C1499 Equibiaxial Flexural Ceramics Test Equipment
- ASTM C1550 Flexural Toughness Testing of Fiber Reinforced Concrete
- ASTM C1557 Tensile Fibers Test Equipment
- ASTM C158 Flexural Bend Testing for Glass
- ASTM C1674 Ceramic Flexural Strength Test Equipment
- ISO 14125 Plastic Composites Flexure Bend Test Machine
- ISO 14126 Compression Fiber-Reinforced Plastic Composites Test Machine
- ISO 14130 Flexure Short Beam Plastic Composites Test Equipment
- ISO 22214 Fine Ceramics Cyclic Bending Fatigue Testing

Glasses or Ceramics are used for the construction and furnishing, decoration, medical equipment, beakers in laboratories and for various other purposes. With the wide usage of glass products for different applications, it is necessary to test the properties of the glasses such as impact resistance strength, breaking strength, transparency, translucency or opaqueness and many more. Out of the mentioned properties, determining the impact resistance strength of different types of glasses is quite important. Measuring the impact strength of glasses and glass panels where the glasses usually come into direct contact especially at the time of moving to avoid breakage and fatal accidents [5].

To ensure the quality of the glasses and ceramics, various types of ceramics and glass testing equipment are used that helps to ensure the integrity of the products. The testing instruments are designed in strict accordance with the standards that are introduced by various standardization authorities such as ASTM, BIS, ISO, etc.

Type of Impact Tests

The impact test can be performed on the glasses by using different test methods such as:

Pendulum Impact Test – Pendulum Impact test is also known as Izod /Charpy impact test. The widely used test method to measure the strength and quality of the glasses and ceramics is Pendulum Impact test. The test involves that the glass panel resists specific amount of impact load which is applied to the material by a swinging pendulum which is attached to a pre-determined load according to the specification of the glasses as per the requirements of the test. After the impact is applied to the sample, the sample is examined for any sort of damage or fracture [6].

Dart Impact tester – It is also a type of impact test which is widely used to test the impact resistance strength of plastic packaging films that are used in different production verticals for the purpose of packaging. The testing instrument is designed as per the standards that are introduced by standardization authorities to measure the impact resistance strength of plastics [7].

Standards for Glass & Ceramics Testing

ASTM standardization authorities have introduced the standards for glass and ceramics to evaluate the mechanical, physical and chemical properties of these materials. These materials are used for flooring and tiles, white wares, art and craft, and other industrial applications. The ASTM standards for glass and ceramics are testing help the material science experts in different laboratories to analyze the quality of the products easily to produce high-quality products only.

Advanced Ceramics Testing

Advanced ceramics consist of metallic oxides, carbides, and nitrides that provide excellent hardness and resistance to high temperatures, wear, and corrosion. They are usually made by mixing powdered minerals with certain chemicals, followed by shaping and heating to form the part. They function as components in electronics, armor, cutting tools, jet engines, medical devices, heat exchangers, and many other products.

Most ceramic materials are metallic oxides, such as aluminum oxide and zirconium oxide. **Aluminum oxide** is called alumina, its mineral is called corundum, and as a gemstone it is known as sapphire or ruby, second only to diamond in hardness. Synthetic aluminum oxide is equally hard, and is very resistant to abrasion and wear. One of its primary applications is the transparent window for bar code readers in supermarkets.

Zirconium oxide combines strength and toughness with biocompatibility and high resistance to wear. These properties make it suitable for medical implants, particularly in the femoral head of hip implants, and in implants for knees, shoulders, and spines.

Some of the most important ceramics are metallic carbides, such as silicon carbide and tungsten carbide. Silicon carbide applications include heating elements for industrial furnaces, wear-resistant parts for pumps and rocket engines, and semiconductor substrates. Combining silicon carbide with boron carbide and other materials produces lightweight armor that protects people as well as airplanes and helicopters. Tungsten carbide provides superior hardness and strength, making it the material of choice for cutting tools.

Another group of ceramics is composed of nitrides, including silicon nitride and aluminum nitride. Silicon nitride's excellent high temperature strength and fracture toughness make it ideal for aerospace applications such as bearings, bushings, and similar components. Aluminum nitride's unusual combination of excellent thermal conductivity and high electrical resistivity make it uniquely valuable in semiconductor and other electronics applications.

Testing and Ceramics Characterization

Ceramics vary widely in chemistry, function, and shape, so at NSL our tests and characterization methods are tailored for each component.

Common advanced ceramics currently analyzed at NSL include:

- Alumina (Al_2O_3)
- Boron Carbide (B_4C)
- Boron Nitride (BN)
- Chrome Oxide (Cr_2O_3)
- Magnesium Oxide (MgO)
- Silica (SiO_2)
- Titanium Dioxide (TiO_2)
- Zinc Oxide (ZnO)
- Zirconia (ZrO_2)
- Mixtures (eg. Silica/alumina or silica/alumina/zirconia)

Examples of analyses include:

- Bulk Analysis (%): SiO_2, Al_2O_3, ZrO_2, CaO, K_2O, Na_2O, MgO, MnO, Fe_2O_3, P_2O_5, ZnO, Cr_2O_3, TiO_2, HfO_2
- Trace Analysis (ppm): Na, Mg, Al, Si, K, Ca, Ti, Fe, Zn, Se, Zr , Ag, Sn, Sb, Pb, Bi

CERAMICS TESTING METHODS

Chemical Composition

Heavy Metals Analysis (ASTM F1088)
ICP Chemical Analysis
Identification of Unknown Powders
Particle Size
Sieve Analysis
RoHS Testing
XRF Analysis

X-Ray Diffraction Analysis

Ca:P Ratio of Hydroxyapatite
Compound Morphology
Crystal Structure
Phase Identification
Powder Diffraction

Mechanical Testing

Abrasion Testing
Bend Strength
Density
Dynamic Mechanical Analysis (DMA)
Fatigue Testing
Indentation Toughness
Modulus of Rupture (MOR)
Single-Edged Notched Beams (SENB)
Wear Testing

Materialography

Failure Analysis
Fractographic Analysis
Grain Size
Microhardness (Knoop, Vickers)
Microstructure
Porosity (via Image Analysis)

Biomedical Ceramics Testing

The medical device industry is finding new, effective ways to utilize ceramics to improve device durability and biocompatibility, which in turn help with patient longevity and quality of life. Due to the fact these materials are implanted in the human body, ceramic testing is critical to ensure patient safety.

Ceramic coatings on medical devices extend the life of orthopedic implants and also allow them to be more easily integrated into the body with coatings such as Hydroxyapatite.

We offer testing on a wide range of ceramic coatings for production control, to support R&D efforts or overflow testing for your internal lab.

Ceramics Analysis for Energy Industry

Ceramic materials are key to more efficient energy systems. Power generation components require the ability to withstand harsh environments while providing superior electrical, physical and thermal properties.

IMR Test Labs provides ceramic testing services to many major energy industry suppliers. Our experts have worked with thermal barrier coatings such as plasma and EB-PVD as well as ceramic matrix composites, raw powders and much more.

We provide analytical services that include fatigue, composition, physical properties, metallurgical evaluation and failure analysis.

Aerospace Coatings Analysis

The environment inside modern engines requires a high-performance material, impervious to high-heat conditions. Ceramics have long been used in the aerospace industry due to their durability.

IMR is well known for our ability to analyze thermal barrier and other ceramic coatings. We can also provide ceramics testing services on materials from raw powders and parts that span from particle size to failure analysis.

Ceramics Testing for Electronics Manufacturers

High-quality ceramics improve performance and reliability of electronic devices. Ceramic parts also allow for smaller and more compact devices.

IMR has extensive experience with electronic packaging testing, including RoHS, metallurgical evaluation, failure analysis and raw materials analysis.

We have performed ceramics testing on chips, capacitors, resistors and more. We can look at individual components as well as the assembled package, from characterization of multilayer capacitors to solder joints and investigation of shorts and opens.

Ceramics Testing in Dental Industry

Dental ceramics are constantly evolving to provide superior strength, wear resistance and durability.

IMR has extensive experience working with these materials and providing routine production control, support for R&D and failure analysis services to numerous dental ceramic manufacturers.

We have tested raw formulations as well as finished materials for a wide range of properties. From basic composition to failure analysis, IMR's labs can provide the answers you need on your dental materials.

II. Conclusion

Ceramic materials are engineered to be lightweight, wear, chemical and heat resistant. This makes them ideal for parts subjected to harsh environments where traditional metals and polymers would not endure, including aerospace components, implantable medical devices, electronics and power generation/transmission equipment.

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