Journal of Material Science and Mechanical Engineering (JMSME)
Print ISSN: 2393-9095; Online ISSN: 2393-9109; Volume 2, Number 4; April-June, 2015 pp. 345-349
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http://www.krishisanskriti.org/jmsme.html

Evaluation of Various Properties of Ceramic Materials used in Ceramic Industries

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Abstract—*Ceramic materials are plays a vital role while designing a good interior for houses, apartments, and other construction places. These ceramic materials are mainly used for the manufacturing of interior materials, cups, sinks shining faces on tiles and good design idols and others. Silicon carbide, silicon nitride, sialon, zinc oxide and zirconia are the examples for ceramic materials used in present ceramic industries. The ceramic materials must have good mechanical properties, electrical properties, thermal properties and optical properties. So while manufacturing the ceramic products we must and should be evaluate all the properties of the ceramic materials. Ceramic materials are combined with the clay surfaces to get the shining. That is the main purpose of the ceramic materials in ceramic industry. Hence after manufacturing they may damage due reaction between the glazes and clay surfaces. So to check the reaction we should know the values of various properties of ceramic materials. This paper describes which properties we have to evaluate to check the reaction between ceramic materials and clay surfaces. And this paper particularly concentrated on at which condition we have to evaluate the thermal properties of ceramic materials in ceramic industries using some heating processes. It also describes how we can evaluate the thermal expansion coefficient of ceramic materials.*

1. INTRODUCTION

Ceramic materials are inorganic, non-metallic materials made from compounds of a metal and a non metal. Ceramic materials may be crystalline or partly crystalline. They are formed by the action of heat and subsequent cooling.[1] Clay was one of the earliest materials used to produce ceramics, as pottery, but many different ceramic materials are now used in domestic, industrial and building products. Ceramic materials tend to be strong, stiff, brittle, chemically inert, and non-conductors of heat and electricity, but their properties vary widely. For example, porcelain is widely used to make electrical insulators, but some ceramic compounds are superconductors.

Types of ceramic materials

A ceramic material may be defined as any inorganic crystalline material, compounded of a metal and a non-metal. It is solid and inert. Ceramic materials are brittle, hard, strong in compression, weak in shearing and tension. They withstand chemical erosion that occurs in an acidic or caustic environment. In many cases withstanding erosion from the acid and bases applied to it. Ceramics generally can withstand very high temperatures such as temperatures that range from 1,000 °C to 1,600 °C (1,800 °F to 3,000 °F). Exceptions include inorganic materials that do not have oxygen such as silicon carbide. Glass by definition is not a ceramic because it is an amorphous solid (non-crystalline). However, glass involves several steps of the ceramic process and its mechanical properties behave similarly to ceramic materials.

Traditional ceramic raw materials include clay minerals such as kaolinite, more recent materials include aluminum oxide, more commonly known as alumina. The modern ceramic materials, which are classified as advanced ceramics, include silicon carbide and tungsten carbide. Both are valued for their abrasion resistance, and hence find use in corrosive environments such as the wear plates of crushing equipment in mining operations where other ceramic materials would not be suitable. Advanced ceramics are also used in the medicine, electrical, and aerospace industries.[2]

Crystalline ceramics

Crystalline ceramic materials are not amenable to a great range of processing. Methods for dealing with them tend to fall into one of two categories - either makes the ceramic in the desired shape, by reaction in situ, or by "forming" powders into the desired shape, and then sintering to form a solid body. Ceramic forming techniques include shaping by hand (sometimes including a rotation process called "throwing"), slip casting, tape casting (used for making very thin ceramic capacitors, etc.), injection moulding, dry pressing, and other variations. (See also Ceramic forming techniques. Details of these processes are described in the two books listed below.)

Non – crystalline ceramics

Non-crystalline ceramics, being glasses, tend to be formed from melts. The glass is shaped when either fully molten, by casting, or when in a state of toffee-like viscosity, by methods such as blowing to a mold. If later heat-treatments cause this glass to become partly crystalline, the resulting material is known as a glass-ceramic.

Properties of ceramics

The physical properties of any ceramic substance are a direct result of its crystalline structure and chemical composition. Solid state chemistry reveals the fundamental connection between microstructure and properties such as localized density variations, grain size distribution, type of porosity and second-phase content, which can all be correlated with ceramic properties such as mechanical strength σ by the Hall-Petch equation, hardness, toughness, dielectric constant, and the optical properties exhibited by transparent..

Ceramography is the art and science of preparation, examination and evaluation of ceramic microstructures. Evaluation and characterization of ceramic microstructures is often implemented on similar spatial scales to that used commonly in the emerging field of nanotechnology: from tens of angstroms (A) to tens of micrometers (µm). This is typically somewhere between the minimum wavelength of visible light and the resolution limit of the naked eye.

The microstructure includes most grains, secondary phases, grain boundaries, pores, micro-cracks, structural defects and hardness micro indentions. Most bulk mechanical, optical, thermal, electrical and magnetic properties are significantly affected by the observed microstructure. The fabrication method and process conditions are generally indicated by the microstructure. The root cause of many ceramic failures is evident in the cleaved and polished microstructure. Physical properties which constitute the field of materials science and engineering include the following:

Mechanical properties

Mechanical properties are important in structural and building materials as well as textile fabrics. They include the many properties used to describe the strength of materials such as: elasticity / plasticity, tensile strength, compressive strength, shear strength, fracture toughness & ductility (low in brittle materials), and indentation hardness.

In modern materials science, fracture mechanics is an important tool in improving the mechanical performance of materials and components. It applies the physics of stress and strain, in particular the theories of elasticity and plasticity, to the microscopic crystallographic found in real materials in order to predict the macroscopic mechanical failure of bodies. Fractography is widely used with fracture mechanics to understand the causes of failures and also verify the theoretical failure predictions with real life failures.

Ceramic materials are usually ionic or covalent bonded materials, and can be crystalline or amorphous. A material held together by either type of bond will tend to fracture before any plastic deformation takes place, which results in poor toughness in these materials. Additionally, because these materials tend to be porous, the pores and other microscopic imperfections act as stress concentrators, decreasing the toughness further, and reducing the tensile strength. These combine to give catastrophic failures, as opposed to the normally much more gentle failure modes of metals.

To overcome the brittle behavior, ceramic material development has introduced the class of ceramic matrix composite materials, in which ceramic fibers are embedded and with specific coatings are forming fiber bridges across any crack. This mechanism substantially increases the fracture toughness of such ceramics. The ceramic disc brakes are, for example using a ceramic matrix composite material manufactured with a specific process.

Electrical properties

Semi conductors

Some ceramics are semiconductors. Most of these are transition metal oxides that are II-VI semiconductors, such as zinc oxide.

While there are prospects of mass-producing blue LEDs from zinc oxide, ceramicists are most interested in the electrical properties that show grain boundary effects.

Super conductivity

Under some conditions, such as extremely low temperature, some ceramics exhibit high temperature superconductivity. The exact reason for this is not known, but there are two major families of superconducting ceramics.

Ferro electricity and super sets

Piezoelectricity, a link between electrical and mechanical response, is exhibited by a large number of ceramic materials, including the quartz used to measure time in watches and other electronics. Such devices use both properties of piezoelectrics, using electricity to produce a mechanical motion (powering the device) and then using this mechanical motion to produce electricity (generating a signal). The unit of time measured is the natural interval required for electricity to be converted into mechanical energy and back again.

The piezoelectric effect is generally stronger in materials that also exhibit pyroelectricity, and all pyroelectric materials are also piezoelectric. These materials can be used to inter convert between thermal, mechanical, or electrical energy; for instance, after synthesis in a furnace, a pyroelectric crystal allowed to cool under no applied stress generally builds up a static charge of thousands of volts. Such materials are used in motion sensors, where the tiny rise in temperature from a warm body entering the room is enough to produce a measurable voltage in the crystal.

In turn, pyroelectricity is seen most strongly in materials which also display the ferroelectric effect, in which a stable electric dipole can be oriented or reversed by applying an electrostatic field. Pyroelectricity is also a necessary consequence of ferroelectricity. This can be used to store information in ferroelectric capacitors, elements of ferroelectric RAM.

Most common such materials are lead zirconate titanate and barium titanate. Aside from the uses mentioned above, their strong piezoelectric response is exploited in the design of high-frequency loudspeakers, transducers for sonar, and actuators for atomic force and scanning tunneling microscopes.

Positive thermal coefficient

Increases in temperature can cause grain boundaries to suddenly become insulating in some semiconducting ceramic materials, mostly mixtures of heavy metal titanates. The critical transition temperature can be adjusted over a wide range by variations in chemistry. In such materials, current will pass through the material until joule heating brings it to the transition temperature, at which point the circuit will be broken and current flow will cease. Such ceramics are used as self-controlled heating elements in, for example, the rear-window defrosts circuits of automobiles.

At the transition temperature, the material's dielectric response becomes theoretically infinite. While a lack of temperature control would rule out any practical use of the material near its critical temperature, the dielectric effect remains exceptionally strong even at much higher temperatures. Titanates with critical temperatures far below room temperature have become synonymous with "ceramic" in the context of ceramic capacitors for just this reason.

Optical properties

Optically transparent materials focus on the response of a material to incoming light waves of a range of wavelengths. Frequency selective optical filters can be utilized to alter or enhance the brightness and contrast of a digital image. Guided light wave transmission via frequency selective waveguides involves the emerging field of fiber optics and the ability of certain glassy compositions as a transmission medium for a range of frequencies simultaneously (multi-mode optical fiber) with little or no interference between competing wavelengths or frequencies. This resonant mode of energy and data transmission via electromagnetic (light) wave propagation, though low powered, is virtually lossless. Optical waveguides are used as components in integrated optical circuits (e.g. light-emitting diodes, LEDs) or as the transmission medium in local and long haul optical communication systems. Also of value to the emerging materials scientist is the sensitivity of materials to radiation in the thermal infrared (IR) portion of the electromagnetic spectrum. This heat-seeking ability is responsible for such diverse optical phenomena as Night-vision and IR luminescence.

Thus, there is an increasing need in the military sector for high-strength, robust materials which have the capability to transmit light (electromagnetic waves) in the visible (0.4 – 0.7 micrometers) and mid-infrared (1 – 5 micrometers) regions of the spectrum. These materials are needed for applications requiring transparent armor, including next-generation high-speed missiles and pods, as well as protection against improvised explosive devices (IED).

In the 1960s, scientists at General Electric (GE) discovered that under the right manufacturing conditions, some ceramics, especially aluminum oxide (alumina), could be made translucent. These translucent materials were transparent enough to be used for containing the electrical plasma generated in high-pressure sodium street lamps. During the past two decades, additional types of transparent ceramics have been developed for applications such as nose cones for heat-seeking missiles, windows for fighter aircraft, and scintillation counters for computed tomography scanners.

In the early 1970s, Thomas Soules pioneered computer modeling of light transmission through translucent ceramic alumina. His model showed that microscopic pores in ceramic, mainly trapped at the junctions of microcrystalline grains, caused light to scatter and prevented true transparency. The volume fraction of these microscopic pores had to be less than 1% for high-quality optical transmission.

This is basically a particle size effect. Opacity results from the incoherent scattering of light at surfaces and interfaces. In addition to pores, most of the interfaces in a typical metal or ceramic object are in the form of grain boundaries which separate tiny regions of crystalline order. When the size of the scattering center (or grain boundary) is reduced below the size of the wavelength of the light being scattered, the scattering no longer occurs to any significant extent.

In the formation of polycrystalline materials (metals and **ceramics**) the size of the crystalline grains is determined largely by the size of the crystalline particles present in the raw material during formation (or pressing) of the object. Moreover, the size of the grain boundaries scales directly with particle size. Thus a reduction of the original particle size below the wavelength of visible light (~0.5micrometers for shortwave violet) eliminates any light scattering, resulting in a transparent material.

Recently, Japanese scientists have developed techniques to produce ceramic parts that rival the transparency of traditional crystals (grown from a single seed) and exceed the fracture toughness of a single crystal.[citation needed] In particular, scientists at the Japanese firm Konoshima Ltd., a producer of ceramic construction materials and industrial chemicals, have been looking for markets for their transparent ceramics.

Livermore researchers realized that these ceramics might greatly benefit high-powered lasers used in the National Ignition Facility (NIF) Programs Directorate. In particular, a Livermore research team began to acquire advanced transparent ceramics from Konoshima to determine if they could meet the optical requirements needed for Livermore's Solid-State Heat Capacity Laser (SSHCL). Livermore researchers have also been testing applications of these materials for applications such as advanced drivers for laser-driven fusion power plants.

Examples of ceramic materials

Until the 1950s, the most important ceramic materials were (1) pottery, bricks and tiles, (2) cements and (3) glass. A composite material of ceramic and metal is known as cermet.

- Barium titanate (often mixed with strontium titanate) displays ferroelectricity, meaning that its mechanical, electrical, and thermal responses are coupled to one another and also history-dependent. It is widely used in electromechanical transducers, ceramic capacitors, and data storage elements. Grain boundary conditions can create PTC effects in heating elements.
- Bismuth strontium calcium copper oxide, a high-temperature superconductor
- Boron nitride is structurally isoelectronic to carbon and takes on similar physical forms: a graphite-like one used as a lubricant, and a diamond-like one used as an abrasive.
- Earthenware used for domestic ware such as plates and mugs.
- Ferrite is used in the magnetic cores of electrical transformers and magnetic core memory.
- Lead zirconate titanate (PZT) was developed at the United States National Bureau of Standards in 1954. PZT is used as an ultrasonic transducer, as its piezoelectric properties greatly exceed those of Rochelle salt.[3].
- Porcelain is used for a wide range of household and industrial products.
- Sialon (Silicon Aluminium Oxynitride) has high strength; resistance to thermal shock, chemical and wear resistance, and low density. These ceramics are used in non-ferrous molten metal handling, weld pins and the chemical industry.
- Silicon carbide (SiC) is used as a susceptor in microwave furnaces, a commonly used abrasive, and as a refractory material.
- Silicon nitride (Si_3N_4) is used as an abrasive powder.
- Steatite (magnesium silicates) is used as an electrical insulator.
- Titanium carbide Used in space shuttle re-entry shields and scratchproof watches.
- Uranium oxide (UO_2), used as fuel in nuclear reactors..
- Zinc oxide (ZnO), which is a semiconductor, and used in the construction of varistors.

Zirconium dioxide (zirconia), which in pure form undergoes many phase changes between room temperature and practical sintering temperatures, can be chemically "stabilized" in several different forms. Its high oxygen ion conductivity recommends it for use in fuel cells and automotive oxygen sensors. In another variant, metastable structures can impart transformation toughening for mechanical applications; most ceramic knife blades are made of this material.

2. EXPERIMENTAL PROCEDURE

In the research work, the coefficient of thermal expansion is determined using NETZSCH Dilatometer 420 PC. Fig 2.1 shows a typical NETZSCH Dilatometer 420 PC. Thermal expansion is the tendency of matter to change in volume in response to change in temperature. The degree of expansion to the change in temperature is called the material's coefficient of thermal expansion and generally varies with temperature. Coefficient of Thermal Expansion is one of the most important properties of ceramic materials. Since nearly all ceramic materials are used in various temperature ranges, measurement of CTE as a function of temperature is necessary in order to know the behavior of the material. Several different systems for measurement of CTE can be used depending on the temperature conditions. One of the most common systems used is a Dilatometer. A Dilatometer measures the length or the volume changes of the sample, when the sample follows a temperature program and submits a small force. In a push rod dilatometer, the change in length of the sample is detected by an inductive displacement transducer. Calibration and corrections of measurements are done by using various standards and comparison with materials of known expansion. The measurement of the coefficient of thermal expansion (CTE) can be carried out in the temperature range from approximately – 150°C to 1500°C. NETZSCH Dilatometer 420 PC comprises of Thyristor controlled unit, Linear Variable Differential Transformer (LVDT), automatic pressure control unit, variety of sample holders RCS (Rate Controlled Sintering) software and TMA (Thermo Mechanical Analyzer). The coefficient of thermal expansion (CTE) can be controlled by two parameters simultaneously namely wall thickness and volume fraction comprehensively. The CTE values have a stronger dependence on particle volume fraction than the wall thickness in the range of temperatures explored. The thermal expansion results with the variation of temperature for the composites and the matrix are shown for different percentage composition. It is obvious that the CTE of the composites and matrix increases with increase in temperature. The pushrod dilatometer method for measuring thermal expansion is experimentally simple, reliable and easy to automate. In this method, the relative expansion of the specimen is transmitted referring to cooled or heated zone to a measuring device (an extensometer) by means of tubes and/or rods of a stable reference material. In this technique, the specimen is placed at the end of a tube and a smaller rod is placed in the tube in contact with the specimen. An extensometer has the capability to detect the difference in expansion between the specimen and an equal length of the tube. The most widely used extensometer is the LVDT (Linear Variable Differential Transformer).

Fig. 2.1: NETZSCH Dilatometer 420PC

3. RESULTS & DISCUSSION

For the determination of Coefficient of Thermal Expansion, the size of the cylindrical sample diameter is less than 6mm and length in between 32-60 mm for NETZSCH Dilatometer 420PC. The specimen was tested from room temperature to 500^{0}c. This temperature range was selected by giving the heat treatment above the half of its melting point. If the specimen does not oxidize at that temperature then experiment was conducted beyond that temperature. That specimen was tested after that insert in to dilatometer. That Dilatometer consists of aluminum knob. The melting point of aluminum was 660^{o}c. so the experiment was conducted below that temperature.

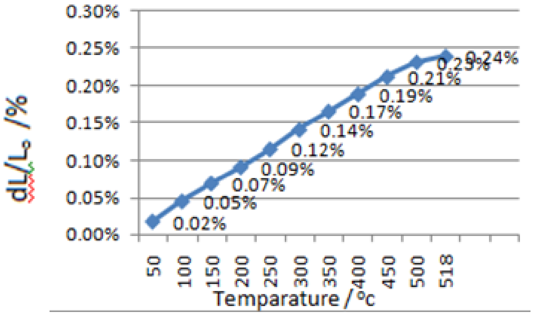

Fig. 3.1: Variation CTE with temperature

Fig. 3.1 shows variation of CTE and temperatures for Zirconium oxide. It was noticed that the coefficient of thermal expansion was increased with the increase of temperatures. There is consistency in the increase of CTE for different temperatures recorded at regular intervals. During the testing of different samples, the elongation was observed to be low.

Table 3.1: Variation of elongation , CTE with temperatures

S. NO	Temperature range oC	Dl/lo%	CTE
1	30.5-50	0.02	53.58E-07
2	30.5-100	0.05	54.24E-07
3	30.5-150	0.07	51.37E-07
4	30.5-200	0.09	49.50E-07
5	30.5-250	0.12	49.30E-07
6	30.5-300	0.14	49.50E-07
7	30.5-350	0.17	49.58E-07
8	30.5-400	0.19	49.28E-07
9	30.5-450	0.21	48.76E-07
10	30.5-500	0.23	47.92E-07
11	30.5-518	0.24	47.73E-07

4. CONCLUSIONS

The following conclusions are drawn based on the results obtained:

1. It is noticed that, the CTE of the ceramic materials increase with the increase in temperature. There is consistency in the increase of CTE for different temperatures recorded at regular intervals.
2. During the testing of different samples, the elongation was observed to be low, as such the increase in the values of CTE of all compositions were in endurable limits.
3. The theoretical and experimental values of density of ceramics can compared and it can proved to have negligible porosity.

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