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Investigation of ceramic Materials their Property andDifferent Industrials Applications.

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Abstract:-A ceramic material possess crystalline or partly crystalline structure. They are either formed from a molten mass that solidifies on cooling, formed and matured by the action of heat, or chemically synthesized at low temperatures.The different character of ceramic materials springs rise to many solicitations in mechanical engineering, materials engineering, electrical engineering and chemical engineering. As ceramics are heat resistant, they can be used for many tasks for which materials like metal and polymer are unsuitable. Ceramic materials are used in a wide range of industries, including mining, aerospace, medicine, refinery, food and chemical industries, packaging science, electronics, industrial and transmission electricity, and guided light wave transmission.

The overarching objective of this work was the evaluation of current ceramic materials (both monolithic and composite) for use in various industrial places likewise heat exchangers whether macro or micro type, evaporators, condensers, heat pump systems, gas coolers, tube banks and matrix surfaces, glass industry, aerospace, military etc. their characteristic study and potential examination over wide range of application.

Keywords: Ceramics, Ceramic matrix composites, Energy, Strength.

1) Introduction :-

A ceramic is an inorganic, non-metallic solid material comprising metal, non metal or metalloid atoms primarily held in ionicand covalent bonds. The crystal of ceramic materials ranges from highly oriented to semi-crystalline, and often completely amorphous (e.g., glasses). Varying crystal and electron consumption in the ionic and covalent bonds cause most ceramic materials to be good thermal and electrical insulators and extensively researched in ceramic engineering,With such a large range of possible options for the composition/structure of a ceramic.

The American Society for Testing and Materials (ASTM) defines a ceramic material as “an article [whose] body is produced from essentially inorganic, non-metallic substances and either is formed from a molten mass which solidifies on cooling, or is formed and simultaneously or subsequently matured by the action of the heat.” Most ceramic materials are hard, porous and brittle so the use of ceramics in application often requires methods for mitigating the problems associated with these characteristics. Ceramic materials are usually ionic or covalently bonded and may be crystalline or amorphous in structure. Because of this type of electronic bonding, ceramics tend to fracture before undergoing plastic deformation often resulting in fairly low tensile strength and generally poor material toughness. Moreover, because these materials tend to be porous, the microscopic

pores can act as stress concentrators further decreasing the toughness and strength of ceramics. These factors can combine, leading to a catastrophic failure of the material instead of the normally more gentle modes of failure associated with metals. Although often neglected, ceramics do exhibit plastic deformation. In crystalline materials, this deformation process occurs very slowly due to the rigid structure of the ceramic and the lack of slip systems for dislocations to move. For non-crystalline
ceramic materials, viscous flow is the dominant source of plastic deformation and is also very slow.

1.1 Types of Ceramics Materials:-

they are usually classified as two main types namely Crystalline ceramics and Non-crystalline ceramics e.g. Barium Titanate, Boron Nitride, EarthenwareLead, Zirconate Titanate, Porcelain, Silicon Carbide, Silicon Nitride, Zirconium Dioxide

1.1.1 Crystallineceramics: -Crystalline ceramic materials are not acquiescent to a great range of dispensation. 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 slip casting, tape casting,injection moulding ,dry pressing, and other variations. A few methods use a hybrid between the two approaches.

1.1.2 Non-crystalline ceramics: - Non-crystalline ceramics, being glass, 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 into a mould. If later heat treatments cause this glass to become partly crystalline, the resulting material is known as a glass-ceramic, widely used as cook-top and also as a glass composite material for nuclear waste disposal.

2) Property of ceramic materials:-

General properties such as high melting temperature, high hardness, poor conductivity, high moduli of elasticity, chemical resistance and low ductility are the norm,with known exceptions to each of these rules (e.g. piezoelectric ceramics, glass transition temperature, superconductive ceramics, etc.).

2.1Mechanical 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 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 defects 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 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 poortoughness 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.

These materials do show plastic deformation. However, due to the rigid structure of the crystalline materials, there are very few available slip systems for dislocations to move, and so they deform very slowly. With the non-crystalline (glassy) materials, viscous flow is the dominant source of plastic deformation, and is also very slow. It is therefore neglected in many applications of ceramic materials.

2.2 Electrical properties:-

2.2.1 Semiconductors**: -**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 boundaryeffects.

One of the most widely used of these is the varistor. These are devices that exhibit the property that resistance drops sharply at a certain threshold voltage.

This makes them ideal for surge-protection applications; as there is control over the threshold voltage and energy tolerance, they find use in all sorts of applications. The best demonstration of their ability can be found in electrical substations, where they are employed to protect the infrastructure from lightning strikes.

Semiconducting ceramics are also employed as gas sensors. When various gases are passed over a polycrystalline ceramic, its electrical resistance changes. With tuning to the possible gas mixtures, very inexpensive devices can be produced.

2.2.2 Superconductivity

The Meissen demonstrated by levitating a magnet above a cuprate superconductor, which is cooled byliquid nitrogen

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.

2.2.3Ferroelectricity and supersets

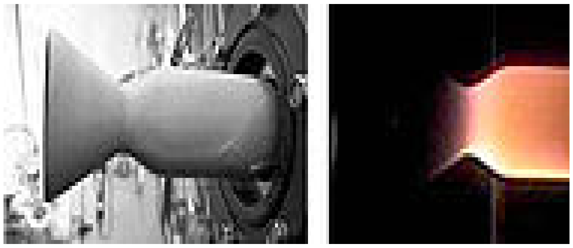
Piezoelectricity, a link between electrical and mechanical response, is exhibited by a large number of ceramic materials, including the quartz used to measure time in watches and other electronics. Such devices use both properties of piezoelectrics, using electricity to produce a mechanical motion (powering 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.

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.

The most common such materials are lead zirconatetitanate and barium titanate.

2.2.4 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.



Silicon nitride rocket thruster. Left: Mounted in test stand. Right: Being tested with H_2/O_2 propellants

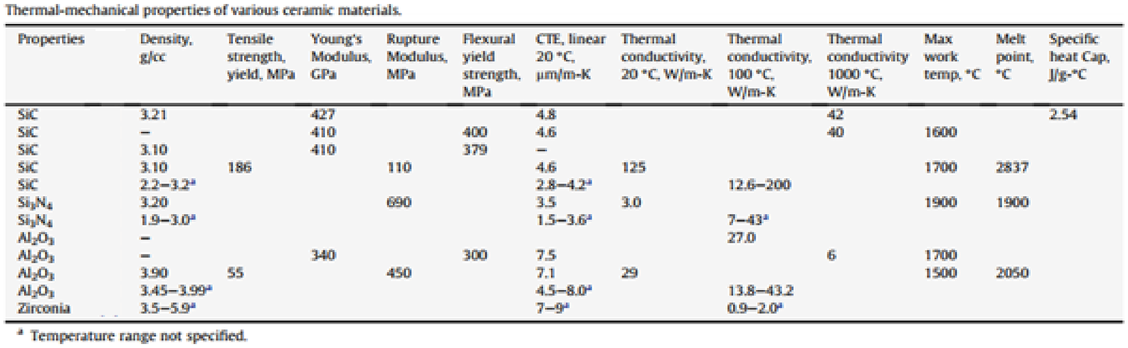
2.3 Optical properties

Optically transparent materials focus on the response of a material to incoming lightwaves 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 lightwave transmission via frequency selective waveguides involves the emerging field of fiber optics and the ability of certain glassy compositions as atransmission 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.

Cermax xenon arc lamp with synthetic sapphire output window

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.

Table 1. :- Thermo electric property of ceramic materials



Thermal-mechanical properties of various ceramic materials.

Properties	Density, g/cc	Tensile strength, yield, MPa	Young's Modulus, GPa	Rupture Modulus, MPa	Flexural yield strength, MPa	CTE, linear 20 °C, μm/m-K	Thermal conductivity, 20 °C, W/m-K	Thermal conductivity, 100 °C, W/m-K	Thermal conductivity 1000 °C, W/m-K	Max work temp, °C	Melt point, °C	Specific heat Cap, J/g-°C
SiC	3.21		427			4.8			42			2.54
SiC	–		410		400	4.6			40	1600		
SiC	3.10		410		379	–						
SiC	3.10	186		110		4.6	125			1700	2837	
SiC	2.2–3.2ᵃ					2.8–4.2ᵃ		12.6–200				
Si_3N_4	3.20			690		3.5	3.0			1900	1900	
Si_3N_4	1.9–3.0ᵃ					1.5–3.6ᵃ		7–43ᵃ				
Al_2O_3	–							27.0				
Al_2O_3	–		340		300	7.5			6	1700		
Al_2O_3	3.90	55		450		7.1	29			1500	2050	
Al_2O_3	3.45–3.99ᵃ					4.5–8.0ᵃ		13.8–43.2				
Zirconia	3.5–5.9ᵃ					7–9ᵃ		0.9–2.0ᵃ				

[a] Temperature range not specified.

3 Strength of ceramic:-

A material's strength is dependent on its microstructure. The engineering processes to which a material is subjected can alter this

$$\sigma_y = \sigma_0 + \frac{k_y}{\sqrt{d}}$$

microstructure. The varieties of strengthening mechanisms that alter the strength of a material include the mechanism of grain boundary strengthening. Thus, although yield strength is maximized with decreasing grain size, ultimately, very small grain sizes make the material brittle. Considered in tandem with the fact that the yield strength is the parameter that predicts plastic deformation in the material, one can make informed decisions on how to increase the strength of a material depending on its microstructural properties and the desired end effect.The relation between yield stress and grain size is described mathematically by the Hall-Petch equation which iswhere k_y is the strengthening coefficient (a constant unique to each material), σ_o is a materials constant for the starting stress for dislocation movement (or the resistance of the lattice to dislocation motion), d is the grain diameter, and σ_y is the yield stress.

Theoretically, a material could be made infinitely strong if the grains are made infinitely small. This is, unfortunately, impossible because the lower limit of grain size is a single unit cell of the material. Even then, if the grains of a material are the size of a single unit cell, then the material is in fact amorphous, not crystalline, since there is no long range order, and dislocations can not be defined in an amorphous material. It has been observed experimentally that the microstructure with the highest yield strength is a grain size of about 10 nanometres, because grains smaller than this undergo another yielding mechanism, grain boundary sliding.Producing engineering materials with this ideal grain size is difficult because of the limitations of initial particle sizes inherent to nanomaterials and nanotechnology.

4Applications: -

4.1 Military:-

There is an increasing need in the military sector for high-strength, robust materials which have the capability to transmit light around the visible (0.4–0.7 micro meters) and mid-infrared (1–5 micro meters) regions of the spectrum. These materials are needed for applications requiring transparent armour. Transparent armor is a material or system of materials designed to be optically transparent, yet protect from fragmentation or ballistic impacts. The primary requirement for a transparent armour system is to not only defeat the designated threat but also provide a multi-hit capability with minimized distortion of surrounding areas. Transparent armour windows must also be compatible with night vision equipment. New materials that are thinner, lightweight, and offer better ballistic performance are being sought.[3] Such solid-state components have found widespread use for various applications in the electro-optical field including: optical fibres for guided lightwave transmission, optical switches, laser amplifiers andlenses, hosts for solid-state lasers and optical window materials for gas lasers, and infrared (IR) heat seeking devices for missile guidance systems and IR night vision. Ceramics such as alumina and boron carbide have been used in ballistic armored vests to repel large-caliber rifle fire. Such plates are known commonly assmall arms protective inserts, or SAPIs. Similar material is used to protect the cockpits of some military airplanes, because of the low weight of the material.

4.2 In Microwave Technique :-

The heating technique and the method of heating recovery are a fundamental issue from the furnace design point of view of and economic effectiveness of the process. In these processes the problem constitutes the lack of the appropriate ceramic materials that would meet the requirements. In this work the standard ceramic materials were examined and verified. The possibilities of application of microwave techniques were evaluated. In addition the requirements regarding the parameters of new ceramic materials applied for microwave technologies were determined.

4.3 heat transfer systems :-

The principal objective used in heat exchangers is to exchange heat between medium and for this appropriate materials of heat exchanger should be chosen that is cheap in cost ,this work was the evaluation of current ceramic materials (both monolithic and composite) for use in heat exchangers, and the assessment of their potential benefits and feasibility for application in heat transfer systems. One of the major goals was to identify the most promising concepts of heat exchanger design using ceramics based on the available information from industry, patents, and the technical literature. In doing so, industries and applications where these materials are currently used were identified. The types of heat exchangers that wereconsideredincluded evaporators, condensers, heat pump systems, gas coolers, tube banks and matrix surfaces

4.4 Automotive industry :-

Carbon-ceramic brake disks for vehicles are resistant to brake fade at high temperatures.Advanced composite ceramic and metal matrices have been designed for most modern armoured fighting vehicles because they offer superior penetrating resistance against shaped charges (such as HEAT rounds) and kinetic energy penetrators**.** In the early 1980s, Toyota researched production of an adiabatic engine using ceramic components in the hot gas area. The ceramics would have allowed temperatures of over 3000 °F (1650 °C). The expected advantages would have been lighter materials and a smaller cooling system (or no need for one at all), leading to a major weight reduction. The expected increase of fuel efficiency of the engine (caused by the higher temperature, as shown by Carnot's theorem) could not be verified experimentally; it was found that the heat transfer on the hot ceramic cylinder walls was higher than the transfer to a cooler metal wall as the cooler gas film on the metal surface works as a thermal insulator. Thus, despite all of these desirable properties, such engines have not succeeded in production because of costs for the ceramic components and the limited advantages. (Small imperfections in the ceramic material with its low fracture toughnesslead to cracks, which can lead to potentially dangerous equipment failure.) Such engines are possible in laboratory settings, but mass production is not feasible with current technology

4.5 Aerospace

Engines; shielding a hot running aircraft engine from damaging other components.

Airframes; Used as a high-stress, high-temp and lightweight bearing and structural component.

Missile nose-cones; Shielding the missile internals from heat.

Space Shuttle tiles

Space-debris ballistic shields – ceramic fibre woven shields offer better protection to hypervelocity (~7 km/s) particles than aluminium shields of equal weight [14]

Rocket nozzles, withstands and focuses the exhaust of the rocket booster.

4.6 Biomedical

Artificial bone; Dentistry applications, teeth.

Biodegradable splints; Reinforcing bones recovering from osteoporosisImplant material

4.7 Electronics&Optical

- Capacitors,Integrated circuit packages, Transducers, Insulators
- Optical fibres, guided lightwave transmission, Switches, Laser amplifiers, Lenses, Infrared heat-seeking devices

Apart from this ceramics also use in household application like knives, gas turbines etc.

5 Conclusion :-

The vast varieties of ceramics are widely used in various sectors including biomedical to military and automobiles. Its application put a way to innovate its applicability as well enhance its strength, it can be done by proper crystalline structure of maintaining mixed contain property.

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