Reviewed Research on Application and Properties of Advanced Ceramics

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Abstract - Current research, sophisticated ceramic coating materials, and surface-coating processes are all summarized in this study that outlines technical advancements in ceramics. For the previous 15 years, new applications have evolved, and the research areas required to meet the present market need are also highlighted. Finally, the transition to SOFC applications provides additional prospects. When the name "ceramic" was first used, it solely applied to clay-based products. Although new ceramic material generations have greatly enlarged the range and quantity of viable applications, this is no longer the case. In our everyday lives and in society, many of these new materials have a significant influence The field of ceramics has come a long way from its humble origins as clay pots. Both the space shuttle and our kitchen flooring are tiled with ceramic. For anything from medical to pleasure, ceramic electronic gadgets allow for high-tech instrumentation. It's obvious that ceramics holds the key to the future.

Keywords - High Temperature Coatings, SOFC Applications, Wear Resistant Coatings, Advanced Ceramic Coatings.

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INTRODUCTION

Compounds of a metal and a nonmetal are used to create ceramic materials, which are inorganic, nonmetallic materials. All or portion of the material in ceramics is crystalline. Heat is used to create them, and then they are cooled to form them. The first ceramics were made from clay, but now a wide variety of ceramic materials are utilized in the manufacture of household, industrial, and construction goods. Many ceramic materials have a tendency to be hard and brittle, chemically inert, and non-conductors of heat and electricity, although these qualities may vary greatly. It's common to utilize porcelain as an electrical insulator, however certain ceramic compounds are really superconductors. [1]

Metal and non-metal alloys may be used to create ceramic materials. A solid block of inert matter. Brittle, hard, and strong in compression, ceramic materials are weak in shearing and tension. They are also fragile at high temperatures. Acidic or caustic environments do not degrade them chemically. In many circumstances, resisting the effects of acids and bases. Ceramics can often tolerate temperatures of up to 1,600 degrees Celsius without cracking. Inorganic compounds such as silicon carbide, which do not contain oxygen, are an exception. Ceramics, by definition, are solids made of crystalline materials (non-crystalline). While glass is a non-ceramic material, its mechanical characteristics are quite comparable to those of ceramics. [2]

Clay minerals like kaolinite and aluminum oxide, more generally known as alumina, are among the traditional ceramic basic ingredients. Silicon carbide and tungsten carbide are two recent ceramic materials designated as advanced ceramics. In mining operations, the wear plates of crushing equipment are made of both materials because of their high abrasion resistance. Additionally, advanced ceramics are found in the fields of medicine, electrical engineering, and consumer electronics. [3]

Since 1970, the ceramic coatings on metallic materials have made a big leap forward. Metals and metal alloys must now operate well under a variety of conditions as a result of ever-evolving technology. There have been adiabatic engine ceramic coatings since 1980. In this field, ceramic coatings were first used to gas turbine wings, and later to pistons, cylinder liners, valves, and piston crowns. Due to their superior qualities, ceramic coatings have been widely used in the surface modification industry for decades. [4]

The application of a thin ceramic layer to metal surfaces has long been an effective technique to improve their mechanical properties. Electrochemical and mechanical polishing, ultrasonic cleaning, acid dipping and laser surface melting are some of the most regularly used techniques of surface treatment. To protect base metals against hot corrosion and oxidation, as well as to minimize wear damage, ceramic coatings are most often utilized. In the case of thermal barrier coatings, ceramic coatings also serve to lower the temperature of the base metal. Advanced features of ceramic materials include heat resistance, corrosion resistance, wear resistance, electrical insulation, and many more. [5]

LITERATURE REVIEW

Wang, Hui. (2018) For structural connections, this article examines the procedure of creating a high strength ceramic layer on the surface. This research examines the coating flaws in conjunction with the coating deposition process by looking at the surface morphology and internal defects of the ceramic coating. XRD is used to examine the ceramic coating's pre- and post-spraying phase transitions as well as the toughness of the coating, its adherence to the reinforcing matrix, and its adhesion to concrete. It also examines its performance in conjunction with test research in this article Nanoceramic coating on structural connection shown to be effective, according to test data cited in this article. [6]

Rząd, E., Dudziak, T., Polczyk, T. (2017) One hundred percent synthetic air and one percent H2S (vol. percent) were used in this work to assess ceramic coatings in a 50 mL/min sulfidation environment. The experiment was conducted for 336 hours at a temperature of 773.15 K (278.15 K/min). 16Mo3 low-alloyed was coated with chemically resistant glass enamels made of SiO2-B2O3-TiO2-Na2O. To study the degrading process of sulfurized coatings, the kinetic data was collected every 168 hours; macro- and micro-analyses using scanning electron microscopy, phase analyses using x-ray diffractometry (XRD), and chemical composition using EDS x-ray spectrometry were carried out. Ceramic coatings subjected to a severe environment at 773.15 K for 336 hours demonstrated significant levels of protection, according to the findings. [7]

Raghavendra Pratap Chaudhary (2018) Ceramic components with exceptional characteristics are in high demand across a wide range of sectors. Three-dimensional printing and additive manufacturing have the potential to produce ceramic components in a cost-effective manner. Although printing ceramics from powders is a difficult and time-consuming procedure, it can be done. An intriguing route toward AM of preceramic structures with heterogeneous topologies and the direct conversion to polymer-derived ceramics (PDC) – the equivalent materials – is provided by preceramic polymers. According to this analysis, current advances in additive manufacturing of PCPs and PDCs for various applications are summarized in detail. Various PCP synthesis methods and chemical formulations that may be used in AM techniques are explored in this paper. The article also examines standard PDC and AM methods that may be used with PCPs, as well as the accompanying advantages and disadvantages, in compared to powder-based ceramic 3D printing. The features and prospective uses of PDC structures with complex shapes are also examined. This research shows the AM capabilities of PCPs for the cost-effective manufacturing of improved ceramics with high resolution, higher performance, reduced environmental impact and novel functionality, in general. PCPs. [8]

Singh, Shiv & Kumar (2018) Interdisciplinary Uses of High-Tech Ceramics advances in ceramic synthesis and their application to catalysis, lithium-ion batteries, microbiological fuel cells and biomedical applications are discussed. This is a recent development. In addition, laser additive manufacturing methods and innovations in magnetic-based, doped, and piezoelectric ceramics and their applications are reviewed, as are advances in ceramic syntheses. Separator ceramics for microbiological fuel cells, lithium-ion battery lithium-polymer composite materials, and catalytic hybrid ceramic nanocomposites round out the list of topics covered in the book. There are several benefits to using metal and metal oxide nanostructures as antibacterial agents, ranging from simple manufacture to reduced risk of germs developing resistance. This is followed by a detailed discussion of biocompatible ceramic materials, including their mechanical and chemical characteristics as well as their use in various applications. Ceramics and their prospective applications will benefit from this book, which will be of service to new researchers, academicians, and postgraduate students. Advanced ceramic materials and their optical and electrochemical characteristics are examined. Myxines Synthesis, characterization, and a wide variety of applications, including energy and biomaterials, are covered. contributions from a variety of fields, including biotechnology and biomedical engineering; chemistry; physics; materials science; engineering; and medicine. [9]

Singh, Jitendra & Bansal (2018) Seven international symposia were conducted at the Palais des Conventions in Montreal, Quebec, Canada, during the Materials Science and Technology 2016 Conference (MS&TM3), which ran from October 27 to 31, 2016. Advances in Ceramic Matrix Composites; Advanced Materials for Harsh Environment; Advances in Dielectric Materials and Electronic Devices; Controlled Synthesis, Processing, and Applications of Structural and Functional Nanomaterials; Rustom Roy Memorial Symposium on Processing and Performance of Materials Using Microwaves, Electric, and Magnetic Fields; Solute; and Advanced Ceramic Matrix Composites. [10]

IMPORTANT PROPERTIES

As an excellent thermal insulator and a material that does not expand much when heated, ceramics can sustain very high temperatures. That means they may be used in anything from industrial furnaces to the space shuttle's outer shell, which protects it during reentry.

Amorphous ceramics that are utilized in windows, lenses, and many other common applications are known as glasses. Some ceramics exhibit photoconductivity, a phenomenon in which light causes an electrical reaction. Because fiber optic cable can transmit data over greater distances with less interference and signal loss than copper wire, it is quickly becoming the preferred method of transmitting data in the communications industry.

Ceramics are robust, hard, and long-lasting. Due to their favorable structural properties, they are appealing candidates for use in construction. The only real negative is that they are fragile, however new materials like composites are being developed to alleviate this issue.

Ceramics may range from good insulators to superconductors in terms of electrical characteristics. So, they're put to good use in a broad variety of contexts. Some are electrolytic capacitors, while others are semiconductors. Using piezoelectric materials, sensors can detect changes in pressure and turn them into an electrical output. The discovery of novel high Tc superconductors and the development of their probable uses is presently the focus of a large research effort.

Clay items have been made in the same way for millennia, and crystalline ceramics are no exception. Sintering takes place at high temperatures once the materials are chosen, processed, and shaped into the required form. A molten state is used to pour the glass, shape it while it is still hot, then cool it down. Sol-gel processing and chemical vapor deposition techniques are currently being researched and improved upon.

RECENT WIDER USE OF ADVANCED CERAMIC MATERIALS

Due to their improved qualities as compared to ordinary ceramics, advanced ceramic materials are rapidly becoming the appropriate materials for a broad variety of technical applications, such as cutting tools, engines, turbines, space vehicles, and biomedical applications. The manufacturing, composition, and microstructure of advanced ceramics vary greatly from those of standard ceramic materials. For this reason, substantial study into the microstructural, mechanical, electrical, optical, and biological aspects of advanced ceramic materials must be conducted in order to better understand and further develop them for specific technical applications.

A. Advanced Ceramics for Nuclear Applications

Fission and fusion reactors are important to nuclear applications. The fission nuclear fuel cycle relies on a wide range of ceramic materials, from nuclear fuels through high-level nuclear waste containment. The fusion nuclear fuel cycle is sustained in fusion reactors by a variety of ceramic materials. Basic neutron-material interactions, such as transmutation reactions resulting in gaseous products and crystalline flaws generated by high-energy neutrons, are critical at first. Bubbles formed by gaseous atoms in crystals or at grain boundaries cause considerable swelling and mechanical strength reduction, which eventually leads to material failure. Defects like as voids, interstitial atoms, dislocation loops, and vacancies are all possible. Thermal diffusivity, chemical stability, and electrical conductivity may all be affected by the formation of crystalline flaws in these materials.

Ceramics made of Al2O3 and AlN have a greater tendency to swell than those made of SiC or Si3N4. The mechanical integrity of these materials deteriorates rapidly when linear swelling exceeds 1%, indicating the production of microcracks or void swelling. When compared to compounds with more ionic bonding nature, covalently-bonded SiC and Si3N4 demonstrate superior tolerance. Neutron irradiation of SiC results in dimensional changes that may be divided into three distinct regimes. Amorphization of crystalline SiC may occur with neutron irradiation of more than a few dpa at low irradiation temperatures. At temperatures between 100°C and 1050°C, swelling is saturable to a pressure of less than 1 dpa. Increases in irradiation temperature reduce the saturated swelling quantity. Interstitials and voids may migrate and produce defective clusters such as voids at temperatures as high as 1050-1500o C. At moderate and high temperatures, interstitial atom clusters occur in -SiC. An increase in fluence and temperature encourages the growth of long-term fault clusters. Dislocation loops are densely produced after a high dosage of neutron irradiation on Si3N4 and are generally parallel to the [0001] axis. Alumina's prismatic and basal planes both produce interstitial dislocation loops. As the irradiation temperature rose, so did the anisotropy. It is generated in the grains at a high radiation temperature when gaps are aligned along the c-axis. The length of the a-axis and caxis are swollen from isotropic to anisotropic in the instance of AlN, which has around 5x1024 n/m2. Loops of interstitial dislocation may be seen on the basal plane of ani tropically altered specimens. When anisotropic swelling causes stress, microcracks begin to form at the grain boundary. For high-temperature gas-cooled reactors, graphite is employed as a structural and moderator material as well as a fuel cladding material. Nuclear waste immobilization and containment may be possible with certain types of sophisticated ceramic materials. Synthetic diamonds, carbon-carbon composites, and synthetic silica are all employed in the construction of fusion reactor structures.

B. Advanced Ceramics for Turbine Applications

The use of advanced ceramic materials in turbines might offer a number of benefits. However, a totally dense ceramic turbine engine is not practicable, thus metal-ceramic bonds must be designed and manufactured. Thermal expansion coefficient (CTE) mismatch between ceramics and metals is a key impediment to their usage in turbine applications. Thermal cycling might induce catastrophic breakdown of the ceramic by causing excessive strain at the metal/ceramic contact in service. Ceramic materials such as silicon nitride must be joined to high temperature metal alloys like nickel nitrides using different ways. A mechanically flexible metal interlayer between the metal and ceramic has been created and optimized for use in a successful joint design and vacuum brazing operation. Because of the variation in CTE, the joint is put under stress. An active metal braze alloy or a surface wetting agent was used to overcome the problem of wetting the ceramic. Design information on component life expectancy was generated using Finite Element Analysis (FEA) for joint component design.

C. Thermal and Environmental Barrier Coatings

By increasing the working temperature of gas turbines with modern ceramic components, efficiency is improved while environmental effect is minimized. However, in the presence of hot corrosive gases and water vapor at high velocities, these silicon-based ceramics are prone to hot-corrosion and recession. EBCs are required to protect ceramic substrates from damaging gas-phase components, as well as to protect the EBCs from the strong combustion atmospheres that they are built into. Increasing the working temperature requires the use of thermal barrier coatings (TBCs) that are poor thermal conductors, allowing the substrate to run at lower temperatures than that of the combustion temperature. The CTE mismatch was determined by taking into account the deposition, structure, and properties of EBCs on Si-based ceramics, as well as EBC/TBC coating systems, as well as the lack of harmful chemical interactions at the interfaces, effective thermal conductivity of the TBC, and hot-corrosion and recession resistance of the EBC.

RECENT USE OF SURFACE COATINGS

Sports technology, aeronautics, transportation, chemical, and petroleum sectors are among the industries that benefit from surface coatings. The use of surface coatings in several specialized sectors has been rising in recent years. Sport (horses' hooves and clothes), biomedical/orthopedic (e.g.,hydroxyapatite), dental, cancer treatment, and the arts (such as glass coloring and enameling) are just a few examples of where thermal sprayed coatings may be used. It is possible to alter the qualities of components by applying surface coatings. Metals and alloys, nitrides, carbides, diamond-like carbon (DLC), ornamental coatings and thermal barrier coatings are some of the most common types of finishes. A thin, durable coating is required for modern cutting applications if the tools are to be protected from damage. Among the applications are high-speed cutting, hard machining of high-hardness materials, dry cutting, and cutting of materials such as Titanium, AlSi alloy, and other non-ferrous abrasive materials that are difficult to cut the coatings that are applied to the tool's surface are typically a few microns thick. They improve the cutting edge's wear resistance and minimize friction and diffusion. The transportation sector greatly benefits from surface engineering. Coating technologies account for around 6% of the total cost of making engines and gearboxes. Power units, vehicle components, and permanent structures are all examples of uses for surface coatings in the transportation business. Power generating equipment, such as diesel engines and power transmission systems, may benefit from engineering coatings. The power units are protected from deterioration and wear by surface coatings. Thermally sprayed coatings are used to increase the wear resistance of several automotive components, such as the suspension and brakes. Wheel arches and bumpers are coated with epoxy-based polymer coatings. They may also be applied to the outside of certain automobiles in order to improve their abrasion and corrosion resistant properties. Additionally, polymer coatings serve to dampen noise. A third use of surface coatings is to prevent seawater corrosion on stationary constructions like bridges and oil rigs.

Surface coatings on engine components have been used in the aerospace industry for more than 50 years. Special qualities such as high temperature strength, corrosion resistance, and load bearing capabilities may be achieved using surface-coated gas turbine engines. Polymer coatings are sprayed on the pieces to protect them from the elements. PVD magnetron sputtering may also coat gears and ball bearings with MoS_2 for use in spacecraft. As a result, the transmission's internal temperature is kept at a more manageable level, which in turn preserves the gears. A component's performance may be improved by modifying its surface. As an example, the slat track, a landing gear component made of maraging, has to have its surface modified in order to increase its wear resistance. Conventional hard chromium plating may cause difficulties in the machining process. A plasma nitriding surface modification has recently been used for this purpose. Contrary to chromium plating, it does not diminish fatigue life and does not need any post-machining operations.

DEVELOPMENT OF ADVANCED CERAMIC COATING APPLICATIONS OVER THE LAST 15 YEARS

Metal components like Ni super alloys, Ti alloys, and Co-Cr alloys were mostly protected with ceramic coating prior to the 1990s (Table 2). There has been a proliferation of new applications over the last 15 years and the following section outlines some of the most recent ones.

A. Heat resistant Ceramic Coatings for Gas Turbines

To achieve high-efficiency power generation facilities, the operating temperature of gas turbines in the 1990s and after has been significantly high. The development of heat-resistant superalloys used to make turbine hot sections, as well as advancements in heat-resistant coating and cooling technologies, have allowed for such high working temperatures. Single-crystal Ni-based superalloy blades and ceramic heat barrier coatings are essential for gas turbines operating above 15000 C, and steam-cooled technologies should also be used. An essential aspect of the process is the use of thermal barrier coatings (TBC).

B. High temperature Corrosion Resistant Ceramic Coatings for Waste to Energy Boilers

The treatment of garbage must now promote high levels of waste recycling and reduce environmental loads like CO2 and dioxins across the globe. Thermal recycling is centered on the idea of more efficient waste-to-energy (WTE) facilities. A high level of total cost performance is essential for factories in the eye of a storm, such as the globalization of the economy. It's only lately that WTE boilers with steam temperatures above 400°C/3.9 MPa have made headway. Industrial wastes such as biomass, RDF, RPF, and other industrial wastes have also been burned in fluidized bed boilers operating between 450 to 540°C and 5.9 to 9.8 MPa, as well. HCl, Sox, and low-melting point ashes containing highly concentrated chlorides are deposited on the high-temperature components of the boiler in WTE boilers, which are more corrosive than fossil fuel boilers because of the higher temperature and composition fluctuations of WTE combustion gas. In order to improve power generating efficiency while also lowering maintenance costs, corrosion-resistant materials and coatings are essential. As a result, the use of very durable ceramics with acceptable overall cost and suitable incorporation of metals and plant engineering is necessary. Engineers have used sophisticated refractory and metallic materials including ceramic tile for boiler water walls, metal spray coatings, and a weld overlay of nickel-based alloys for long-term stability. As a result, synthetic raw materials including high-purity silicon carbides (SiC) and alumina (Al2O3) have been employed in refractory materials. High-Sic refractories have been widely used to protect furnace walls against high-temperature damage and ash sludging. For a water-cooled furnace, the SiC tile system has shown to be effective in protecting the furnace, as well as simple to maintain.

In commercial facilities running at 500°C/9.8 MPa steam temperatures, cermet and ceramic spray coatings have been employed to extend the useful life of boiler super heaters in severe erosion–corrosion environments induced by soot blowers. The TiO2 625 alloy cermet coating using HVOF spray technique, as well as Cr3C2NiCr alloy cermet and ZrO2(YSZ, Yttria stabilized zirconia)/Ni base alloys dual layer coatings using plasma jet spray process, were subjected in super heaters at metal temperatures of 432 to 500 °C for a maximum 1.3 to 2 years. Metal spray coatings' three-year durability limit was exceeded by the TiO2 625 cermet, 625/YSZ, and Necrosis/YSZ coatings tested as part of the lifespan study. Corrosive gases (HCl, SOx, etc.) penetrating the base material/coating contact validated coating degradation processes. Corrosion at the interface and "swelling" of the coating layer develop as the adhesive strength decreases, and eventually the layer breaks away. As a result, a thick coating is critical to extending product life. Corrosion resistance, coating porosity, base material adhesive strength, thermal characteristics, and other elements all play a role in durability. Corrosive gas components cannot pass through the top-coated YSZ layer in dual ceramic Ni-base alloys/YSZ coatings.

C. Wear-Resistant Ceramic Coatings for Bio implants

In light of the rising life expectancy and greater performance expectations from the increasing number of younger patients for whom the procedure is recommended, joint replacement bearing surfaces need to be optimized. While maintaining their toughness and fracture resistance, ceramic surface coatings hold considerable promise for improving the tribological performance and lifetime of artificial joints. In theory, the coating–substrate combination is straightforward, but in practice it has proved difficult. In alternative technology, it's crucial that the coating adheres to the substrate. If the ceramic layer fails to adhere, it will release hard third-body particles that might exacerbate the abrasive wear of bearing surfaces. The most thoroughly investigated hard coatings for orthopedic applications are those made from titanium nitride (TiN) and diamond-like carbon (DLC), as well as zirconium oxide (ZrO2), which is made by controlled oxidation of a zirconium alloy substrate.

D. High temperature protective ceramic coatings

Ceramic coatings used to defend against high temperatures must have excellent adhesion to the substrate. As the alloys are heated to temperatures exceeding 12000 C in an oxidizing environment for a few hours during the hot rolling process of stainless CERAMICS, an oxide coating forms on top of the free surfaces. Metal loss of up to 2% of the crude stainless CERAMICS might be caused by thick multilayer oxide scale, which would significantly affect the surface quality of downstream goods. Because of this, avoiding or slowing the high temperature oxidation process as much as possible is very motivating. Metals are well-protected against oxidation at high temperatures by ceramic coating. After the slab reheating process, the coating should be readily removed since any remaining coating may significantly harm the CERAMICS surface quality.

CONCLUSIONS

The present research state of advanced ceramic coatings on stainless CERAMICS is summarized in this study, which also examines the advanced ceramic materials, different surface coating processes, application during the previous 15 years, and future potential. As a result, the following may be concluded:

Stainless CERAMICS's beauty, strength, ductility, and formability make it an ideal material for high-temperature and SOFC applications. Due to its high price, it supports the need for continual study to maximize its potential.

Surface qualities such as roughness, hardness, wear resistance, corrosion resistance, and oxidation resistance have all been improved in advanced ceramic coatings.

For a broad variety of thermal barrier coatings, the Air plasma spraying process, which has superior surface qualities and thermal properties, is employed.

Because of its great wear resistance and low heat conductivity, advanced ceramic materials surface coatings and surface modification methods are often employed.

Yttrian stabilized zirconia, an advanced ceramic substance, is widely used to coat gas turbines and diesel engines, aviation engines, and other heat-generating devices.

In nuclear power generating areas, advanced ceramic materials have lowered the amount of heat that is transferred from the components' walls.

For high temperature gradient areas, mullite is a suitable substitute for zirconia and may serve as a thermal barrier layer.

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