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Review Paper

Ceramic materials: A companion of mankind

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Abstract

Mankind is always involved in the search for smart multifunctional material with superior physical and engineering properties compared to existing material for better performance in diverse fields. Due to a lack of researchers' interest, details of ceramics processing/fabrication, manufacturing were difficult. The properties of Ceramics depend on its microstructure obtained after its processing or fabrication so the control of fundamental microstructure has great importance for all ceramics behavior and its application. Understanding the manufacturing technology, processing science, and materials reaction to external spurs to cope with the desired shape, structure, and other traits helps to transfer the ceramics material into the value-added artifact. Thus strong and continuous effort is required for the continuous improvement of ceramics material in the field of Science and Engineering.

Keywords: Traditional ceramics, Clay, Silica, Lime, Abrasives.

Introduction

We are continuously being surrounded by materials. The progress of human society undoubtedly relies on our ability to explore, understanding, and exploitation of materials to fulfill our needs. Different era of human history has been entitled (stone age, Bronze age, Iron age, etc.) after the material that our ancestor mastered at that time[1,2].

Ancient human has access to naturally occurring materials such as stone, wood, clay minerals, wool, skin, and so on. Among these materials, clay is the most abundant, easily accessible material on the surface of the earth. Clay is a primary ingredient for traditional ceramic products. It is nearly impossible to know exactly about the inception of ceramics technology. However, it can be speculated that once the ancient humans notice the plasticity property of hydrated clay which made them realize that it could be molded into the desired shape and harden by drying and firing, it may have triggered the birth of ceramic[1,3-5].

The word "ceramics" originates from the Greek "keramos" which says "a potter's clay or a pottery" It is associated with a Sanskrit term meaning "burned earth'' as pottery is made by heating earth's clay. Ceramics is the oldest man-made material with outstanding characteristics such as resistance to corrosion, wear, and decay which made it lived the ravages of time better than other materials. It imparts archaeologists and historian clue to recreate and clarify the mystifying past shrouded in an impenetrable veil of time[6-9].

The oldest ceramic artifact known so far is the statuette of the woman named the Venus of Dolnivestonice found in the Czech Republic dating to about 26000BCE. Archeological evidence based on the fragments of pots from different parts of the world revealed that the pottery first appeared during the Paleolithic period in East Asia mainly china which subsequently spread to the Middle East and the Mediterranean basin during the Neolithic period. Whenever and wherever it was first invented, it is a ubiquitous invention found in many human settlements across Asia, Africa, Europe, and America, Pottery was crucial in the transformation of mankind from nomadic to the sedentary lifestyle around 10,000BCE. Eventually, it gave birth to agriculture and the formation of an agrarian society. It plays a pivotal role in the evolution of human civilization by providing the firm basis for the onset of trade and communication.

Glass is one of the oldest ceramics products with a history of more than 5000 years. It is believed that the manufacturing of glass had been started in ancient Phoenician and Egypt. Sand is the major ingredient in glass manufacturing[4,6,8,10].

Bricks are important structural ceramic products. Sumerians settlement in Mesopotamia is one of the early pieces of evidence of the use of mud brick (both dried and fired) for housing. In Lumbini (Nepal), archaeological excavation of the Mayadevi temple exposed numerous layers of pre Asokan brick structure which dates back to the third century BCE[10,11].

With the invention of the potter wheel around 3500 BCE and improvement in the kiln, pottery achieve both qualitative and quantitative enhancement. Even in the Bronze Age and Iron Age, pottery did not suffer devaluation and remains an important part of every household[10].

Plaster is another traditional ceramic, found in its earliest use in Turkey and Syria dating back around 8000BCE. It is a powder form of gypsum hemihydrate which turns into rigid solid ceramics on the addition of water at room temperature.

Another special ceramics is hydraulic cement introduced by Roman and Greeks around 2000 years ago. It is a mixture of powdered lime and volcanic ash which hardened with the addition of water. When mixed with sand and gravel, it forms concrete and is the most durable construction material. The Dome of the pantheon in Rome (constructed from concrete around 120 AD) is the living proof of the durability of concrete.

By around 600 AD, the noble ceramics product porcelain was developed in China. It was made by firing petuntse mixed with kaolin clay at a high-temperature kiln at about 1300C. The resultant product is white and translucent. This enthralling beauty of porcelain made the European potters longing to produce by them.

However, Europeans only succeeded to produce porcelain in about 1710 on their own. During the 18th century, Meissen in Germany, severs in France, and Staffordshire in England emerged as hubs for ceramic production[4,6,10].

The industrial revolution parallel with advancement in science had a rippling effect on the transformation of ceramic technology. The invention of electricity, automobiles, and progress made in chemistry regarding understanding the composition, properties (interaction of constituent) of materials in the 19th century was a turning point in ceramic technology. This gave us new ceramics known as advanced or fine or technical ceramics.

Unlike traditional ceramics, advanced ceramics are prepared from processed and purified raw materials. Even chemically synthesize raw materials are used without solely relying on the natural form of materials. They are based on oxides, carbides, nitrides, and borides of Al, Mg, Mn, Si, Zr, and other metal ions. Typical examples are Alumina (Al_2O_3), Magnesia (MgO), Silicon carbide (SiC), etc[10,12,13].

Their outstanding mechanical, thermal, electro-optical, dielectric, magnetic properties open a wide domain of applications. Indeed, it spans several areas such as electronics, communication, transportation, manufacturing, energy and environment, medicine, defense, and even space exploration[3,10,14].

With this background, it may arise: Is ceramics just pottery or something else? In common parlance, ceramics means sanitary ware (white wares), bricks, tiles, and decorative stuff which generally refers to traditional ceramics. Ceramics is at the crossroads of various scientific and engineering disciplines. It is an arduous task to have its very precise and unanimous definition. The majority of modern ceramists follow the definition put forward by David Kingery who is also known as the father of modern ceramics[3,4,15].

According to W. David Kingery, *Ceramics* is the "*art and science of making and using solid articles which have as their essential component, and are composed in large part of, inorganic nonmetallic materials."* It means ceramic is anything that is not an organic material or a metal. It is considered an exhaustive definition that incorporates both traditional and advanced ceramics[3,15].

Types of Ceramics

There are four types of material in the realm of material science and Engineering viz metal and alloys, ceramics, polymers, and Composites. Unlike traditional ceramics, novel materials with exceptional characteristics comprise metallic and ceramic on chemical root has been developing as required. Based on development and uses, ceramic materials are categorized into traditional and advanced ceramics without distinct contours between them. Ceramics pottery is taken as the oldest traditional ceramics materials invented in the world. "Advanced ceramics" is in the sense of being progress of state-of-art materials with their bizarre aptitude varies from ignition to storage system[16-18].

This article is mainly focused on one aspect of ceramics that is traditional ceramics. The research trends and efforts on the traditional ceramics fabrication, components formulation, and applications are presented.

Relatively, the terms "Tradition" signifies something unadventurous and "ceramics" involved to construction material (cement, bricks, floor, or wall covering) and things such as coffee mugs, glazed pottery, floor tile, or bathroom-toilets, etc in past times but it is not obsolete technology that we are used. It is largely unknown to the public, or even many scientific communities, that the use of ceramic materials and their derivatives goes far beyond these products. Traditional ceramics is an endless field for novelties and improvements in technology for a researcher.

Most of the artifacts and trades of ceramics (from pottery to electrical spark plugs) of ceramic companies are generally in the form of traditional ceramics and their market has been growing continuously with the rate of ~8.5%/yr. However, emission of CO_2 take place during manufacturing process of traditional ceramics products operated at high temperature ~950^0 C. This insinuates that ceramic companies need more effective and efficient technology to preserve low-priced goods with desired quality and to sustain in this competitive global market[19-22].

The chart below presents a grouping of several traditional ceramics materials based on the material's compositions, characteristics, technology, and application over time in brief[1,23].

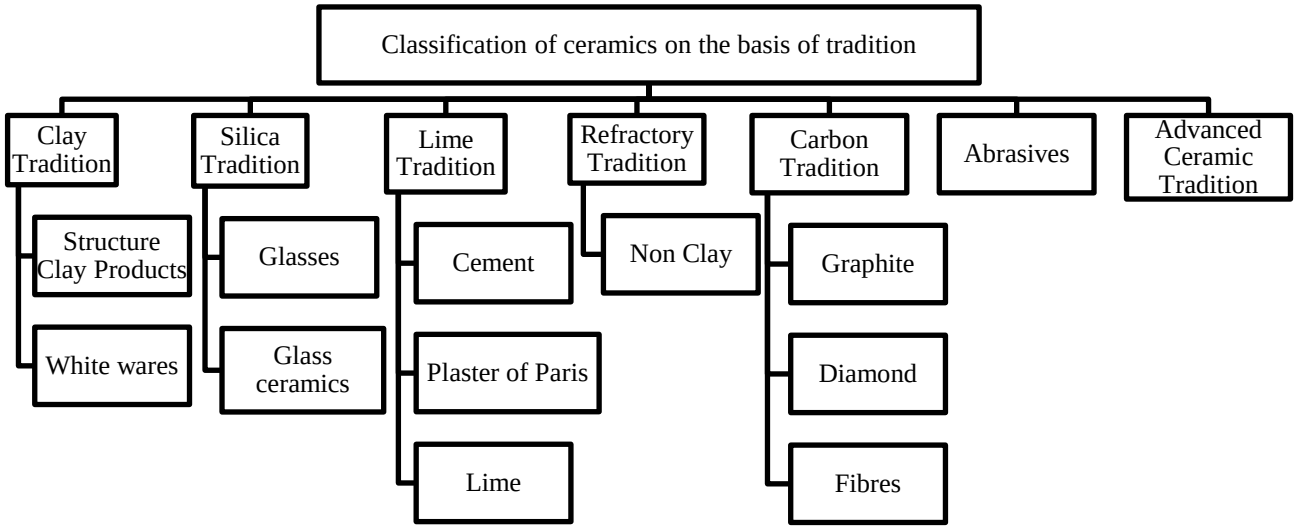

Figure-1: Grouping of traditional ceramics.

Clay Tradition: Sedimentary rock with clay minerals having a phyllosilicate structure (e.g. Kaolinite $Al_4(Si_4O_{10})$ $(OH)_8$– Triclinic) is the primary ingredient of this tradition. The main characteristic of clay is its plasticity (streaks, laminations) in mixing with water in a proper that makes itself shape the products in various designs. Microstructural properties of clay depend on the embedded moisture in the clay sources, its grain size and mixing method. Most of the clay-based ceramics are produced using at least 20wt % minerals in the raw batch.

On heating (~800^0C), clay green ceramics emits the viscous fluid (mixture of SiO_2 and Al_2O_3) which enhances the mechanical strength by increasing packing density and cohesion along with the removal of moisture contents. This environmental friendly clay product is of two types: Structural clay products (bricks, tiles, sewer pipes, toilet basins, etc) require structural integrity whereas white wares (pottery, porcelain tableware, sanitary wares, and electrical insulators) requires structural integrity as well as good surface finish. For instance, practicable innovative ceramic tiles made from industrial remainders can be use in place of marble, granite as well as concrete by lowering the environmental impact of the mining natural minerals from mines[1,4,5,23-26].

Silica Tradition: Silica ($Si+O_2$) exists in two forms i.e. amorphous (opal, pebbles) or crystallized form (Quartz) in nature, which is the chief raw material in this tradition. Feldspars and quartz are the most abundant silicates. It converts into a glassy form from a liquid state on cooling although most ceramics crystallizes on solidification. All glass products contain around 70% silica of the total volume and the remaining are metal oxide (Na_2O, CaO, etc). There are two types of ceramic products in this tradition viz Glass and Glass-ceramics.

Glass is the monocrystalline structure of an inorganic nonmetallic solid material that results in providing insufficient cooling time in a liquid state to rigid form without crystallizing. Windowpane, ordinary mirrors, vessels, lighting fixtures, etc., are some traditional use of glass.

On proceeding with the controlled crystallization of parent glass, a polycrystalline material called Glass ceramics is obtained which contains casually aligned crystals and some residual glass (~2-5 %) without voids. The crystalline structure appears on heat treatment which nucleated and grows the crystalline phase during the formation of a glassy state (Tempered glass). Its optical transparency to visible spectrum depends on the nucleation and growth of crystal phase inside the glass. Due to its unique characteristics, such as scratch resistance, shatters into small evenly pieces, high toughness, and strength glass-ceramics product has been commercially successful. It is mainly used in vehicles, entrance doors, shower and tub enclosures, patio furniture, microwave oven, skylights, for thermal insulation and composites[5,27-29].

Lime Tradition: Naturally occurring limestone is the base material for this tradition. Reactive quicklime (CaO) obtain from limestone is used in construction works to bond the blocks by making a slurry with water. Calcium-Oxide (Ca-O) group shows high reactive properties with water and carbon dioxide as a result of calcium oxide compounds such as gypsum ($CaSO_4.2H_2O$), quicklime (CaO), or Calcium Silicate are used

to form Portland cement clinker in construction work. At ambient temperature cement forms a hard, bonded mass through hydration reaction. The four main compounds in cement are Tri-calcium silicate, Di-calcium silicate, Tri-calcium aluminate, and Tetra-calcium aluminoferrite. Later the use of gypsum, mortar, sand-mortar, and concrete, etc. are used in construction and bonding blocks themselves[23,27].

Refractory Tradition: The original refractory materials were produced during the nineteenth century and the first work was done on the development of Al_2O_3 and ZrO_2 around 1920. There are many types of modified clay (plastic clays, refractory plastic clays, refractory clays, and red clays) and they do not reflect the same properties and behavior on heating. Among them, Refractory clay derived from Kaolin is suitable for high-temperature processes as it is being rich in alumina, silica along with other oxides (MgO, Fe_2O_3, TiO_2, etc) and contains porosity typically >10% by volume. Refractory materials are used as thermal insulation in high-temperature furnaces such as steelmaking, metal foundry operations. They contain resistive power to degrade by corrosive gases, liquids, or solids at elevated temperatures[4,27].

Carbon Tradition: Fairly, Carbon-based material does not fall into metals, ceramics, or polymers classes, but graphite form of carbon can be considered as ceramics which is in a crystalline structure. Graphite can adsorb gases so it is essentially used in biomaterials such as the formation of pyrolytic carbon. Carbon fiber is another form of carbon, i.e. polymer carbon, and is sometimes called graphite fiber which is made from graphite crystals oriented linearly just like flattened ribbons which make carbon fiber strong lengthwise. The amount of carbon contains (>92%) and the orientation of the layered carbon ribbon determines the physical properties of carbon fiber. Carbon fiber is five times stronger than steel and twice as stiff and lighter than steel as well. That's why carbon fiber is favored by engineers and designers for manufacturing.

For example, Silicon carbide (SiC) is a carbon-fiber ceramic composite, formed from heating the mixture of SiO_2 and carbon. On heating with oxygen at elevated temperatures, a silicon dioxide protective layer is formed on the surface of SiC which makes it good anti-chemical property. The core component of SiC governs the hardness of the composite. Carbon fiber enhances the mechanical strength and rupture toughness of the material. Mainly silicon carbide ceramic is used in four areas viz functional ceramics, advanced refractory materials, abrasives, and metallurgical raw materials[30-33].

Abrasives

The grinding efficiency of all kinds of grinding tools purely depends on the performance of abrasives. Abrasive are generally made from ceramic bonded silicon carbide (SiC) which shows good thermal conductivity and hardness. Silicon carbide abrasives are commonly used in the grinding of a range of materials, such as cemented carbide, cast iron, to ceramics as well. Unfortunately, due to their high fragility and chemical wear, SiC abrasives are inappropriate for grinding steel-like parts. Diamond abrasive products are assumed to be supreme abrasive for hard materials, but diamond produces serious chemical wear while working with iron metal at high temperatures and also reduces the grinding mechanism of the grinding tool.

Super hard abrasives are better than traditional abrasives for application but they have costly in both manufacture and utilization. Around 0.05% of the world's production abrasives are super hard abrasives. The development of new abrasives and crushing apparatus is one of the main reasons for the continuous development of modern grinding techniques. Although machining quality depends on many factors, enhancement of the performance of special abrasives is the chief one[34].

Conclusion

Ceramics is one of the most influential materials developed by mankind which has been constantly accompanying human civilization. It is not only the oldest but also the newest and the sophisticated material which is ushering the civilization to a new level. Special attention is required for all fabrication processes to achieve the ceramics material with appropriate microstructure for desired functional and structural properties The amazing properties of ceramics are behind the inexorable progress in various fields like electronics, communication, and medicine. Ceramics is magical and there is still more of its magic to reveal. Thus strong and continuous effort is required for the continuous improvement of ceramics material in a linear pattern: Take – Make - Use - Dispose for the sustainability in the field of Material Science and Engineering.

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