Colloidal processing of ceramics

Business, Industries

Colloidal processing principles have over the years been used to form ceramic materials that exhibit homogenous properties. Through their application, it has been possible to control microstructure properties of materials. Moreover, the formation of porous ceramics has been achieved through novel techniques. Archaeological pottery artifacts indicate that ceramic components date back to early civilization period. For the last two centuries, however, advances have been made in ceramic component production. Consequently, the use of these materials has vastly been expanded in contemporary life. One such area is electronic where they help in energy regulation, storage, and transmission. This paper will analyze in detail the fabrication process of ceramics, an industrial process that involves the formation of colloids. It is evident that there are several methods of fabricating ceramics, some of which originated from the ancient civilization. The method of fabrication is defined by the physical state of the starting material. The three different phases are the gaseous, liquid, and solid phase. In the colloidal processing of ceramics, the starting materials are in liquid phase. To control the microstructure and properties of the final product, multiple cationic elements are added to these electronic ceramic materials. Throughout all the steps involved in colloidal processing, the focus has to be given to the stability of the material to form components with the desired properties. The paper will cover the chemical process involved, the design elements of reactors involved in colloidal processing, preparation of the colloid, product separation and purification, limitations of the process, and analysis of its cost-effectiveness.

Introduction

The manufacture of ceramic components dates back to the ancient times as indicated by various archaeological pottery artifacts (Rahaman, 2003). Consequently, ceramics involve a variety of materials that can generally be grouped into two: advanced and traditional ceramics. The traditional ceramics refer to those materials that were manufactured from the earliest civilizations. They include pottery and clay-based refractories. Additionally, glasses, concretes, structural clay products, and cement fall under this group. Although these traditional ceramics still form a significant proportion of the present-day ceramic industry, focus has, over the years, been shifted to advanced ceramics. They are formed through colloidal processes and systems and made from materials that exhibit high levels of purity. Moreover, strictly-controlled conditions are required when manufacturing these advanced ceramics, unlike the traditional ones. The end product bears the specifically tailored microscopic or macroscopic attributes that are vital if the component being made is to function as desired.

The Chemical Process

The sol-gel fabrication of ceramics involves the conversion of fine particles of metal compounds into gel, a highly viscous mass. According to Rahaman (2003), the processes involved can be distinguished based on whether a solution or a sol is used. For the case of sol, the material is made up of colloidal particles that form a network as a result of being joined together through surface forces. In the second case, a solution consisting of metal oxides is used.

Metal alkoxide solutions form the primary starting material in the sol-gel route. Their general formula is M(OR)x. Consequently, they can be viewed as an alcohol ROH where R stands for an alkyl group. They can also be taken as a derivative. In the cases of an alcohol, a metal hydroxide derivative M(OH)x or a metal M takes the place of the hydroxyl proton. Water is usually added to this mixture. It can be in pure state or having been diluted using more alcohol. The mixture is then stirred and the temperatures maintained in the range of 50 o C to 90 o C. When the solution’s PH and reactants are maintained at the appropriate reactants, hydrolysis and condensation occur. The two processes yield polymer chains.

Hydrolysis:

For the condensation process, the chemical reaction that takes place is:

The process by which metal-organic polymeric compounds are broken down to form ceramics is known as polymer pyrolysis. The polymers broken down following this procedure are known as preceramic polymers given that they are ceramic precursors. While the conventional organic polymers are formed by a long chain of carbon atoms, the preceramic polymers are made up of atoms of other elements such as silicon, nitrogen, and boron. Additionally, they may contain carbon atoms. The ceramic produced following the polymer pyrolysis may comprise elements that initially formed the chain. Polymer pyrolysis is closely connected to sol-gel process in which synthesis of metal-organic polymer takes place, followed by its conversion to form an oxide.

The nature of the ceramic formed through the process of polymer pyrolysis is influenced by the polymer itself, especially its composition and structure. In turn, the polymer structure and condition are determined by polymerization reaction in addition to the chemical process involved in the synthesis of the monomers. Moreover, the characteristic of the end product is influenced by pyrolysis conditions.

Mechanical Design Elements

When processing ceramics, the colloidal particle properties must be tailored and optimized into the final product that exhibits the required microstructure that matches the desired performance. The final properties that a given ceramic component exhibit are influenced by the various aspects of preparing and processing the ceramic. The instruments used during these activities have been designed based on the scientific knowledge currently available regarding the process of synthesizing materials. One of the main instruments used in the colloidal processing of ceramics is spark plasma sintering.

Figure: The schematics of Spark Plasma Sintering

The system uses spark plasma, which provided the required thermal energy to carry out solid state sintering. The function of the pulse DC Unit is to supply high electrical current that is necessary for field assisted sintering. The system has the benefit of providing rapid heating as well as cooling of the material as desired. Additionally, it provides shorter sintering time and can achieve higher densification rate compared to conventional methods of solid state sintering. The ceramics processed using this method exhibit exceptional strength when compared to other techniques. According to the schematic, the lower and upper punches are used to supply the current to the system. The graphite die is designed in cylindrical form and is used to load the powder. To ensure easy de-molding, it is necessary to line the graphite inside wall with boron nitride. A graphite foil can also be used to serve the same purpose. To regulate the sintering temperature, the voltage-current output is used. Furthermore, a pyrometer or a thermocouple is necessary to monitor the temperature.

Preparation and Handling of Colloidal Powders

The methods of synthesizing ceramics have been evolving over a period of more than 70 years. Initially, ceramic powder was synthesized by means of solid state chemistry. The process was popularly known as mixed oxide route and is still being used by manufacturers of various metal oxides devices today. However, there are major shortcomings associated with this process. For instance, it requires that the reacting components diffuse to high levels. In turn, it makes it difficult to realize phase pure materials at the end. Presently preparation of ceramic powders is achieved through the precipitation method. Here, a solution under acidic conditions is used to stabilize the reagents. They are then precipitated by rapidly increasing the acidic level. This results in the production of powder of hydroxides, citrates, or carbonates which can be homogeneous or amorphous. Just like the other approaches of synthesizing ceramics, sol-gel process is sensitive to the different reagents in addition to processing choices since they impact the rate of hydrolysis. Moreover, they influence particle properties including the size and shape of aggregation.

Product Separation/Purification

For many years, sieves have been applied to separate particles into various fractions depending on their sizes. This method is still applied in the ceramic industry. The classification of particles is done based on their size, which dictates whether or not they can get through an aperture whose size is controlled. Usually, different types of sieves are used and range from 20 micrometers to 10 mm. They are made from wire mesh. The size of the mesh is determined by the number of wires that are placed for sieve screen’s liner inch.

Although sieving can be done in the wet state, most industries carry it out in the dry state. A machine is used to induce shaking, vibration, and rotation of the materials placed on the sieving screen. The system consists of several sieves arranged such that the one whose mesh aperture is coarsest is put at the top while the smallest is located at the bottom. The separation or purification of the material begins at the topmost sieve. To minimize or avoid loss of material, the sieve at the top contains a lid. At the bottom of this system of sieves, there is a closed pan that serves to collect the final material, referred to as fines. The vibration and shaking of each stack are carried out for a given fixed time. Afterward, measurements of residual powder are taken. The routine classification according to the American standards states that sieving is done for approximately 30 minutes.

Limitations

For particle sizes below 40 micrometers, screen clogging and agglomeration of the fines are commonly experienced. To solve the problem, the air in form of pulsed jets is used to reduce clogging. Moreover, wet sieving can be done. The second limitation is that it takes considerable amounts of time to adequately separate particles and obtain a final product of the required purity. Most sieving operations produce fines with approximate particle size distribution. For most advanced ceramics in which the size of the particle is less than one micrometer, sieving cannot be used. Moreover, this method of separation is not appropriate in processes where the clean powders are required due to possible contamination as a result of the metallic impurities coming from the sieves.

Cost Analysis

The sol-gel process provided a cost-effective method of producing ceramics from cheap raw materials. However, the method relies on sieving to create powders whose fineness is quite limited. Additional processes such as milling add impurities to the final product. Moreover, it considerably increases the cost associated with the whole process. For the last few years, the sol-gel process has been used to produce ceramic powders that of higher purity. As researchers continued to develop new more economical techniques aimed at scaling up production of high-quality powders, it is expected that the cost involved in chemically producing these powders will decrease in future as the market for these products gradually increase.