

Techniques for the Industrialization of Porous Ceramic Composites using Characterization and Fabrication Methods

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ABSTRACT :

The utilization of ceramic materials as household hardware, industrial machinery, and structural applications has garnered significant acceptability among a variety of end users over the course of several decades. This is due to their high thermal stability, chemical resistance, abrasion resistance, weak conductivity, and high hardness. This group of materials has piqued the interest of researchers by delving deeper into advancing the development of ceramic products that can meet other specific needs. A systematic evaluation of the extant fabrication methods will be discussed in light of the relationship between the properties of porous ceramic materials and the fabrication techniques. Although porous ceramic has a wide range of applications. It is highly recommended that industrial experts and researchers focus more on determining the appropriate fabrication methods for the development of porous ceramics to ensure that the resulting microstructure, mechanical properties, and other physical properties are satisfactory.

Keywords: Mechanical Properties, Fabrication Method, Ceramic Composites, Characterization.

1. INTRODUCTION

Because of their high thermal stability, chemical resistance, strong wear resistance, weak conductivity, high hardness, and other properties, ceramic materials have been widely accepted for use in a variety of applications, including domestic hardware, industrial usage, and structural applications, over the course of many decades. In order to pique the curiosity of scholars, this collection of materials has been investigated further.

Advancing the development of ceramic products that can suit other particular needs. [1–4] Research has shown that the most significant drawbacks associated with the use of ceramic materials for structural applications are the brittleness of these materials and the continual development of pores within the microstructure, which serve as fracture sites, consequently weakening the structural integrity of this category of materials. The systematic regulation of these pores, on the other hand, has been directed toward the creation of porous ceramic materials that are appropriate for use in a broad variety of technologies, including filtration, thermal insulation, food processing, biomedical implants, and others. [from 5 to 9].

A significant number of homogeneous porous ceramics have been created primarily by the use of cutting-edge processing techniques [10]. In the meanwhile, it has been reported that the utilization of suitable fabrication techniques encourages the correct tailoring of pore networks in porous ceramic materials, which in turn causes an expansion in the application regions of these materials [11]. Moreso, for certain application areas, it is of

utmost importance to employ appropriate processing method that will establish the required tradeoff between the infused micro structure and the mechanical properties of the developed porous ceramics [12]. For example, the construction of scaffolds with infused porous networks for the application of bone tissue engineering necessitates the formation of a trade off between the requisite mechanical qualities and the amount of porosity of the scaffolds [13,14]. Specific conditions are important for their application as solid oxide fuel cells, where an open hierarchical pore structure with a diameter ranging from 50 to 150 mm is required for sufficient diffusion of the reactants to the active reaction region [15,16].

In light of the numerous studies that have been conducted up until this point on the development of porous ceramic materials and the prevalence of these materials in broad-based and strategic industrial technologies in the present day, there is an urgent need for the documentation of the various characterization techniques that are required for the evaluation of porous ceramic materials. In conclusion, the paper provides comprehensive information on the manufacturing processes and characterization methodologies for assessing the porosity, microstructure, and mechanical characteristics of porous ceramic materials. This is done with the intention of expanding the adaptability of porous ceramics for industrial applications.

2. FABRICATION TECHNIQUES FOR CREATING POROUS CERAMIC MATERIALS

Now that we've talked about the connection between fabrication techniques and the features of porous clay materials, we will talk about how to evaluate the current production techniques in a structured way. Even though porous ceramics can be used in many different areas, industrial experts and researchers should focus more on finding the best ways to make them because the microstructure, mechanical properties, and other physical properties are all very different. Depending on the method of production used. One way to make porous ceramics is through partial sintering, another is using a copy pattern, a third is using a pore-forming agent, and the fourth is direct foaming.

2.1 Partial Sintering Method

Different ways of making things have been said to make the partial sintering method the simplest for making porous ceramic materials with evenly spaced holes and solid strength. In this method, the name suggests that a partial sintering process is used along with surface diffusion, evaporation-condensation, recrystallization, or a solution-precipitation process to bind powder particles together. So, stopping full densification results in the formation of porous pottery with pores that are evenly spread out. Ohji and Fukushima suggested that the size of the powder particles must be two to five times bigger than the needed pore size in partially fused porous ceramic materials in order for holes of controlled size to form. The writers also pointed out that higher forming pressure, higher sintering temperature, and longer time intervals were the factors that led to less permeability.

In their research, Eom et al. found a connection between the elastic modulus and the ratio of the neck radius to the particle radius. The formation of the neck makes it possible to directly connect the elastic behavior with the sintering processes. A relatively low sintering temperature range (1550–1850⁰C) and the partial sintering method were used by Tuyen et al. to make reaction-bonded silicon nitride (RBSN) porous ceramics. Researchers looked at how different sintering temperatures affected the porosity and compressive strength of

porous RBSN ceramics. They found that as the sintering temperature went up, the porosity went down and the compressive strength went up. For example, samples sintered at 1550⁰C had porosity of 43.2% and compressive strength of 141 MPa, while samples sintered at 1850⁰C had 38% and 285 MPa.

2.2 Replica Template Method

In the past, the replica template approach has been used rather often by researchers as well as industry specialists for the purpose of fabricating porous ceramic systems that have a high porosity and hierarchical pores. The technique of manufacture is based on the impregnation of a conventional template, which may be a porous or cellular structure, with ceramic slurry or precursor solution (see Figure 1 for more information). For the purpose of generating porous ceramics that are free of defects, it is of the utmost importance that the template that is employed have open cell structures that are uniformly disseminated and sufficient ductility to allow for quick shape recovery after use. Due to the fact that it has the necessary characteristics that were discussed earlier, the polymeric sponge, which includes polyurethane, has been the synthetic template that has been employed the most often among the several natural and synthetic cellular materials that are accessible for the fabrication of the replica template.

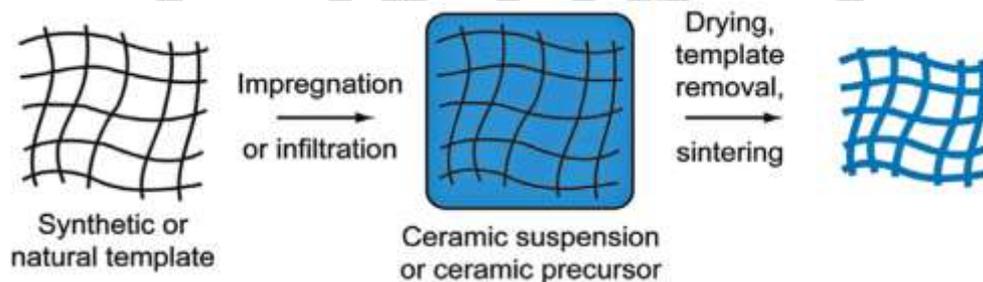


Fig. 1 Replica template method for fabricating porous ceramics.

By using polyurethane sponge for the construction of extremely porous ceramic foam and then burning the samples at 500⁰ degrees Celsius for thirty minutes in order to eject the polyurethane sponge, Soy et al. were able to effectively manufacture reticulated porous SiC ceramics. This was accomplished by applying the replica template approach. Because of the high sintering temperature (1300⁰C), the researchers were able to see the development of a refined microstructure. This was made possible by the existence of minuscule pores inside the pore walls, which acted as a substitute for shrinkage and promoted dimension control as well as liquid metal penetration. Porous SiC ceramics were made by Xue and Wang using the process of infiltrating porous carbon from carbonized waste cotton linter with liquid silicon in a vacuum oven at a temperature of 1550⁰ degrees Celsius. While this was going on, the authors of the study ascribed the outstanding features (porosity, bending strength, and fracture toughness) that were shown by the porous SiC ceramics to the effective management of the Si removal period. Using a hybrid sol as a precursor and melamine foam as templates, Li et al. created extremely porous zirconium carbide-silicon carbide (ZrC-SiC) ceramics. This was accomplished by adopting a hybrid sol.

2.3 Pore-Forming Agent Method

In addition to the methods of manufacturing described above, holes can be added to the substructure of ceramic materials by adding the right amount of a pore-forming agent into ceramic powder particles. After the powder

mixture is mixed well, it is pressed into green pellets. These pellets will then be heated to get rid of the pore-forming agent and break it down. The pore-forming agent used to make porous clay products is shown in Fig. 2 as a schematic figure. In general, pore-forming agents can be broken down into four groups: (i) synthetic organic matters (like polymer beads and organic fibers); (ii) natural organic matters (like starch, cellulose, cotton, and so on); (iii) metallic and inorganic matters (like nickel, carbon, fly ash, glass particles, and so on); and (iv) liquids (like water, gel, emulsions, and so on).

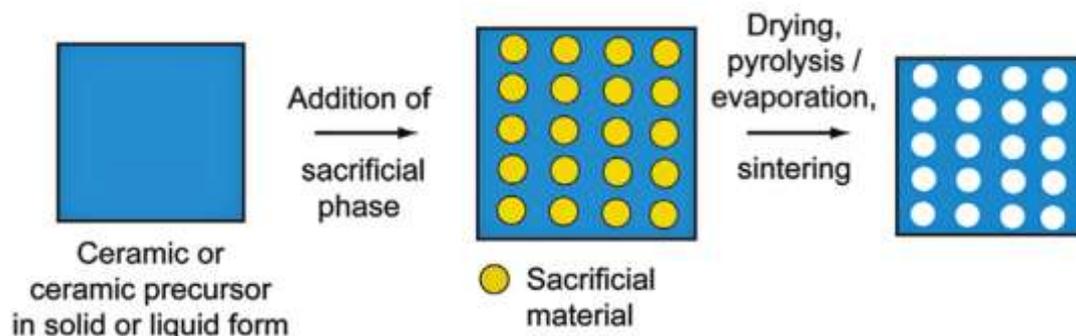


Fig. 2 Pore-forming agent method for fabricating porous ceramics.

In their study, Eom et al. talked about the different ways to get the pore former out of the clay matrix. Most of the time, synthetic and natural organic materials are thrown away by decomposing them at temperatures between 200 and 1000⁰ C. Liquids are removed by freeze drying, salts are removed by leaching with water, and carbon and silica templates are thrown away by oxidation and chemical leaching, respectively. It's important to note that the pore-forming agent method allows for the customization of the pore spaces in the microstructure of the newly created porous ceramic materials. This is possible with different pore-forming agent formulations and particle shapes.

Researchers have said that starch materials like cassava, potato, wheat, rice, and others have been used to make pottery that are very porous. In their study, Markovska et al. made porous mullite ceramics using waste aluminum oxide as the ceramic matrix and rice husk as both the source of silica and the material that forms the pores. By changing the amount and size of rice husk used as a pore maker, Mohanta et al. made porous alumina ceramics that are strong and have hierarchical pores. Earlier, Hu et al. looked into how NaCl salt can be used as a pore former to make porous Ti₂AlC ceramics with controlled porosity.

2.4 Direct Foaming Method

To make porous ceramics using the direct foaming method, a ceramic solution is foamed with blowing agents like air or gas to keep the foam stable. After that, the foam is dried and then put through a sintering process to make the porous ceramics that are solidified (see Fig. 3). People think that the straight boiling method is a cheap and simple way to make porous pottery with a porosity level of up to 95% . There are two main types of blowing agents, which are physical blowing agents and chemical blowing agents. When a chemical blowing agent is used, it causes a chemical reaction that gives off gases. On the other hand, when a physical blowing agent is used, the process of making bubbles or foam can be undone and does not involve any chemical reactions.

To make macro-cellular porous SiC foams, Fukushima and Colombo mixed a pre-ceramic polymer called polycarbosilane (PCS) with azodicarbonamide, a chemical blowing agent. The ball grinding method was used

to make the mixture, and then it was foamed up close to the PCS freezing point. After that, the foamed PCS went through a drying process and was pyrolyzed at 200°C and 1000°C. Finally, the open macro-cellular ceramic materials were foamed. The authors found that the developed porous ceramics had porosity and cell sizes ranging from 59 to 85% by volume and 416 to 1455 μm, respectively. This suggests that the method can be used to make porous ceramics with specific pore sizes and porosities. Barg et al. changed the standard foaming method and made porous ceramics with interconnected pore structures (size 0.5–3 mm and porosity 97.5%). They did this by adding foams to a ceramic solution and letting the emulsified alkaline droplet blowing agent evaporate.

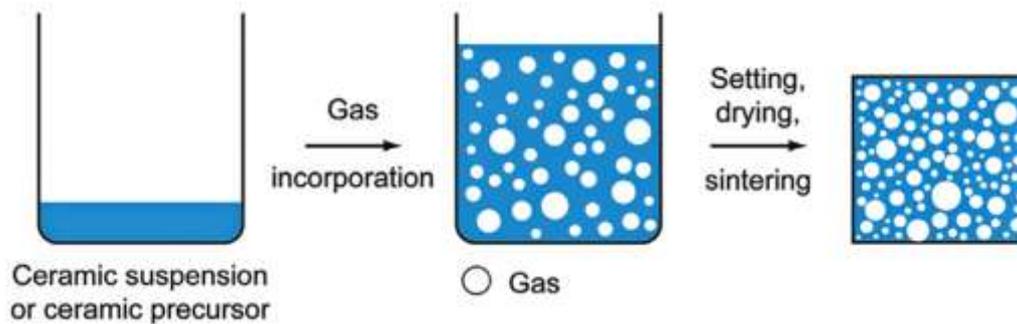


Fig. 3 Direct foaming method for fabricating porous ceramics.

3. RESULTS AND DISCUSSIONS

Mechanical Properties Characterization of Porous Ceramic Materials

When it comes to characterization of porous ceramic materials, there are four primary forms of mechanical properties testing that have been used by a number of studies. The flexural test, the compression test, and the hardness test are all included in this category.

3.1 Flexural Strength Test for Porous Ceramics

Among the many mechanical strength tests that have been employed by researchers over the years for the purpose of determining the bending strength capability of porous ceramics, the flexural strength inquiry is one of the most popular and widely used investigations. For the purpose of determining the flexural strength of advanced ceramics with designed porosity (honeycomb cellular channels) at room temperature, ASTM C1674 provides a description of the test setup, specimen preparation, and methods. Other standards developed by the American Society for Testing and Materials (ASTM) include ASTM C1161 and ASTM C1684, which determine the flexural strength of advanced ceramics with rectangular and cylindrical shapes, respectively, when subjected to testing at ambient temperatures. It is possible to carry out the test by using either the four-point-1/4 point or the three point loadings with the necessary spans and specimen geometries that are outlined in the standards that were presented earlier (see to Figure 4).

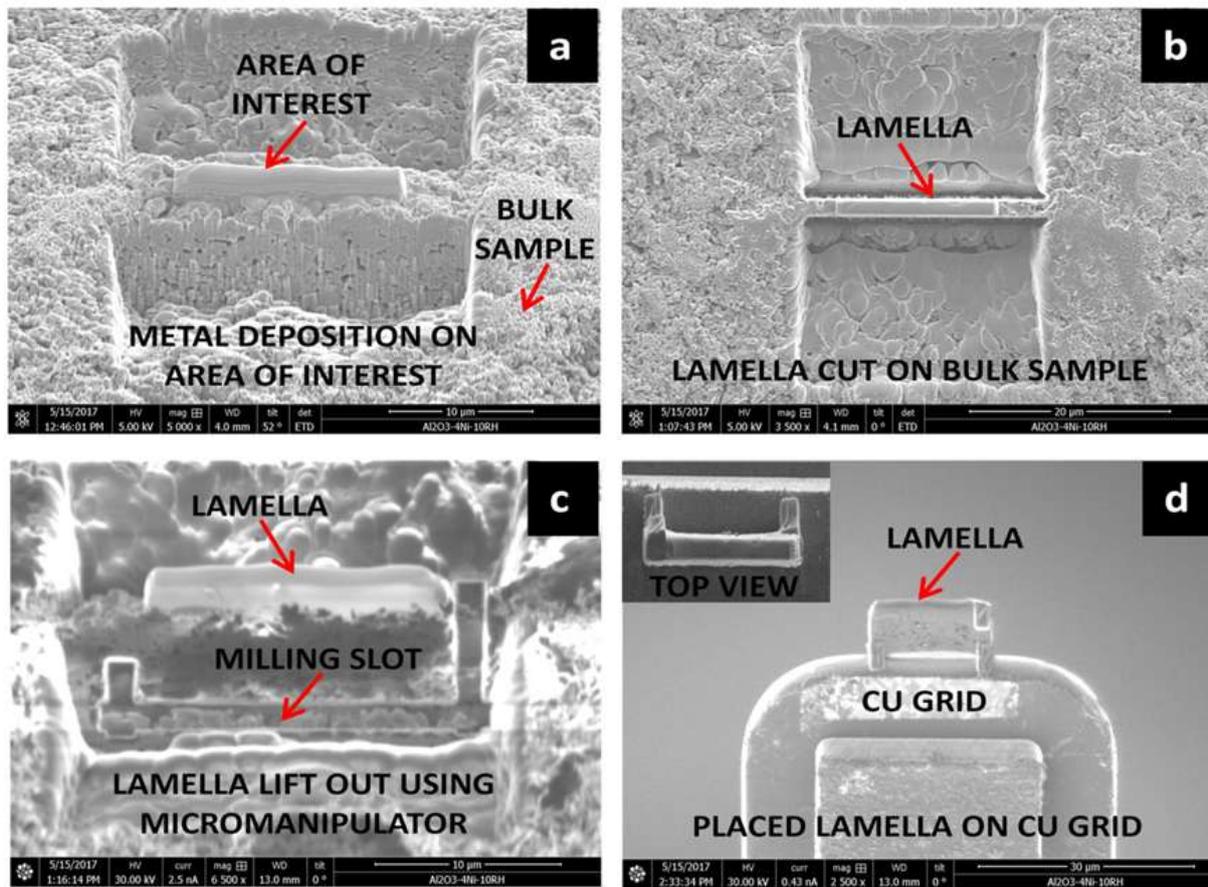


Fig. 4 Dual beam sample preparation for TEM analysis of porous ceramic materials: (a) metal deposition on area of interest, (b) lamella cut on bulk sample, (c) lamella lift out, (d) lamella placement on copper (Cu) grid.

3.2 Hardness Test for Porous Ceramics

Researchers have used the hardness measurement as an important test method for many years to find out how resistant porous ceramic materials are to rubbing forces like wear. People often use ASTM C1327 as the usual test method for advanced ceramics to see how hard they are to dent with a Vickers tool. The following expression can be used to find the hardness value (HV number):

$$HV = \frac{1.8544F}{d^2}$$

Where F is the applied load (N) and d is the average length (m) of the two diagonals left by the indenter. Ali et al. used different pore-forming agents to make porous alumina ceramics. They found that the hardness values dropped from 172.6 to 38.1 HV and from 160.6 to 15 HV as the porosity increased for samples shaped with graphite (37.3%–61.1%) and yeast (30.2%–63.8%) pore-forming agents. On the other hand, the hardness values were different for examples that were formed with rice husk ash because alumina and rice husk ash combine to make mullite. In the same way, Nam et al. saw a drop (932–7 HV) as porosity went up (53%–73%). According to Li et al., the Vickers hardness values of porous alumina samples slowly dropped from 0.53 to 0.56 GPa to 0.49 to 0.53 GPa as the porosity increased from 48% to 49% to 51% to 53% [69]. This happened even though the amount of CaSO₄-dextrin body-forming agent increased (4–20 wt%). Chen and Brandon used a computer study to show that the porosity-dependence of hardness was consistent with values expected using empirical expressions.

4. CONCLUSIONS

Through the presentation of this study, a record of the production procedures and characterisation methodologies for porous ceramic materials is provided. For the purpose of generating porous ceramics, the article provides a detailed overview of manufacturing procedures that are both dependable and inexpensive.

Fabrication approaches, such as the pore-forming agent method, have been brought to light as a method that is economically feasible for the creation of porous ceramic materials on a laboratory scale. In addition to that, this article has offered the necessary standards, as well as the research that support them, concerning the characterisation of porosity, microstructure, and mechanical characteristics. This article, in its whole, provides the knowledge that is essential for the production of very durable porous ceramic materials that may be used in modern applications such as thermal insulation systems, separation membranes, catalyst supports, and other applications.

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