Chapter 1

Cellular Ceramics Used as Catalytic Supports for Heterogeneous Catalyst Synthesis

Youssef Hairch
University of Chouaib Doukkali, Morocco

Ahmed E. S. Nosseir
https://orcid.org/0000-0001-6259-0956
Institute of Mechanical Intelligence Scuola Superiore Sant'Anna, Pisa, Italy

Meiram Atamanov
Kazakh National Women's Teacher Training University, Almaty, Kazakhstan

Rachid Amrousse
University of Chouaib Doukkali, Morocco

ABSTRACT

Cellular ceramics have become essential in various industrial applications. This chapter explores the types, shapes, and characteristics of cellular ceramics, and their potential uses in space propulsion and catalysis. There are different varieties, including foams, honeycombs, and reticulated structures, classified by their composition, structure, and production processes. These materials are favored for their high porosity, low density, excellent mechanical strength, and thermal stability. Their large surface area and enhanced mass transfer capabilities make them effective as catalyst supports in processes like hydrocarbon reforming, oxidation, and hydrogenation, where they immobilize catalytically active species to boost activity and selectivity. In space propulsion, cellular ceramics are used in thruster components due to their ability to withstand high temperatures and maintain structural integrity under harsh conditions.

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1. INTRODUCTION

Cellular ceramics, including honeycombs, foams, and 3D structures, are crucial in the field of catalytic supports due to their unique structural and material properties. These ceramics are characterized by their high surface area, excellent thermal stability, and exceptional mechanical strength, making them ideal for a wide range of catalytic applications. Honeycomb structures, with their orderly and interconnected channels, offer minimal resistance to fluid flow, thereby enhancing the efficiency of catalytic reactions. This architecture is particularly beneficial in automotive catalytic converters, where the reduction of toxic emissions is achieved through efficient catalysis. Foam ceramics, with their highly porous and interconnected networks, provide an even greater surface area for catalytic reactions. This structure facilitates the dispersion of catalytic materials, allowing for more active sites and improving reaction rates. These foams are extensively used in applications such as air and water purification, where rapid and thorough catalytic processes are essential. The advent of 3D-printed cellular ceramics has further revolutionized catalytic supports. The precision of 3D printing allows for the creation of complex geometries tailored to specific catalytic processes, optimizing the interaction between reactants and catalysts. This customization leads to enhanced performance in chemical synthesis, energy storage, and environmental remediation. Therefore, the importance of cellular ceramics as catalytic supports lies in their ability to enhance reaction efficiency, durability, and adaptability across a multitude of industrial applications. Their unique structures not only maximize catalytic activity but also contribute to the sustainability and effectiveness of catalytic processes in various fields.

Cellular ceramics are essential for a variety of technological applications due to their stability in harsh environments, excellent high-temperature properties, and superior thermomechanical characteristics (Gianella et al., 2012; Xu et al., 2020; Lou et al., 2020). Specifically, cellular ceramics offer lightweight load-bearing capabilities and high specific surface area because of their open-cell porous nature (Al-Ketan et al., 2017). Today, cellular ceramics are widely used in various engineering fields, such as catalysis supports, concentrated solar energy, thermal protection or thermal storage, heat exchangers, radiant burners, nuclear fusion, gas streams, and biomedical implants (Papetti et al., 2018; Santoliquido et al., 2017; Feng et al., 2020).

However, due to their complex shapes and open-cell structures, manufacturing cellular ceramics at a low cost is challenging. Traditional processing methods, such as direct foaming (Du et al., 2019), freeze casting (Frank et al., 2017), and gelcasting (Deng et al., 2017), are unable to produce cellular ceramics with the desired intricate structures (Stochero et al., 2020). Recently, additive manufacturing, commonly known as three-dimensional printing (3D printing), has been increasingly used to create complex cellular ceramics (Vlasea et al., 2015; Tabard et al., 2021; Zhang et al., 2022).

In this chapter, we explore various forms of cellular ceramics, including honeycombs, foams, and 3D structures, along with their compositions, such as carbon, cordierite, alumina, silicon carbide, and mullite. Additionally, we examine the mechanical, thermal, and acoustic properties of these materials. Finally, we illustrate the diverse industrial applications of cellular ceramics in areas such as thermal insulation, catalysis and chemical processing, energy applications, environmental solutions, acoustic applications, the aerospace and automotive industries, and biomedical fields.