Chapter 9

Comparative Analysis and Targeted Applications of Ceramic Fabrication Techniques

9.1 Introduction

This chapter provides an in-depth comparative analysis of three prominent fabrication routes for porous ceramic: the "Alumina Dissolution Process," the "Sucrose Dehydration Process," and the "Sacrificial Fugitive Method." The study delves into the intricate details of each method, exploring their impact on the physical, mechanical, and thermal properties of porous composites and foams. Key factors such as porosity, pore size, and application suitability are thoroughly examined and evaluated. The objective of this chapter is to offer valuable insights to researchers and practitioners, aiding them in selecting the most appropriate materials and methodologies based on specific needs and desired applications. By providing a comprehensive understanding of the various fabrication routes, this analysis aims to contribute to the advancement of porous ceramic research and facilitate informed decision-making in the field.

9.1.1 A Comparative Study

Table 9.1 Comparative data for physical and thermo-mechanical properties of porous and ceramic foams and composites prepared using different materials and process

Fabrication Technique	Primary Raw Material	Bulk Density (g/cm^3)	Total Porosity (%)	Open Porosity (%)	Closed Porosity (%)	Pore Type	Pore Size	Strength (MPa)	Thermal Conductivity
Alumina Dissolution Process	Alumina	1.61-2.59	34.43-59.24	21.12-28.8	14.18-32.09	Open ~ Closed	0.1-1500	27.84–53.21 (FS)	1.23
Alumina Dissolution Process	Coal Overburden Waste	1.00-1.09	64.10-70.23	3.62-24.57	45.55-60.48	Open < Closed	1-900	15-22 (CS)	0.28-0.59
Sucrose Dehydration Process	Silica	0.36–1.026	60–90	9-51	37.9–55.1	Open ~ Closed	319–1021	0.8–2.8 (CS)	0.0943–0.2571
Sucrose Dehydration Process	Coal Overburden Waste	0.31-1.34	56.24-89.81	11.88-50.55	31.83-48.58	Open ~ Closed	1-3000	2.2-13.8 (CS)	0.08-0.29
Sacrificial Fugitive Method (Rice Husk Ash)	Coal Overburden Waste	0.85-2.15	35.30-55.76	8.69-30.48	23.89-31.22	Open < Closed	0.1-200	6-35 (CS)	0.37-0.67

Table 9.1 presents a comprehensive overview of the physical, mechanical, and thermal properties of porous composites and foams obtained through three different fabrication processes: the Alumina Dissolution Process, the Sucrose Dehydration Process, and the Sacrificial Fugitive Method. Porosity, a key parameter for porous materials, shows a clear trend among the three methods. The highest porosity is achieved using the sucrose dehydration process, while the lowest porosity is observed with the sacrificial method. The alumina dissolution process falls in between, providing intermediate porosity levels.In contrast, the bulk density of the porous ceramics follows an opposite trend. The sacrificial method yields the highest densification, followed by the alumina dissolution process, and then the sucrose dehydration process. Further analysis reveals that the distribution of open and closed pores varies among the different fabrication methods. The sucrose dehydration process exhibits similar distributions of open and closed pores in samples, with a slightly higher open porosity in composites compared to the other two methods. However, as we move towards the alumina dissolution process and the sacrificial method, the open-to-closed pore ratio decreases. The sacrificial method shows a greater number of closed pores compared to the other two methods. The average pore size also differs significantly depending on the fabrication method. Samples prepared through the sucrose dehydration process have very large average pore sizes compared to the other two methods. This characteristic makes the sucrose dehydration process crucial for applications involving mass transport. The average pore size decreases with the alumina dissolution process and reaches the nano range when prepared using the sacrificial method. Strength, another important property, exhibits an inverse trend to porosity. Samples obtained from the sacrificial method demonstrate the highest strength, followed by the alumina dissolution method, and then the sucrose dehydration method. Interestingly, porous composites prepared using coal overburden wastes exhibit higher strength compared to monolithic porous samples for each fabrication process. This is attributed to the presence of mullite and other aluminosilicate phases in the samples made from coal overburden wastes, which contribute to enhanced strength compared to samples prepared solely using alumina or silica. Thermal conductivity displays a similar pattern to porosity, with samples obtained through the sucrose dehydration process exhibiting the highest thermal resistance. The alumina dissolution process shows intermediate thermal resistivity, while the sacrificial method yields the lowest thermal resistivity.

Considering the strengths and weaknesses of each method, the sucrose dehydration process stands out for applications requiring ultra-light foams, despite its lower strength. On the other hand, the sacrificial method utilizing rice husk offers porous composites with closed pores and high strength, making it suitable for applications that necessitate such characteristics. The alumina dissolution process strikes a balance between strength and porosity, providing intermediate values compared to the sucrose process and the sacrificial method.

While the focus of this study has been on the thermo-mechanical characteristics of the developed porous composites for thermal applications, it is important to note that these composites have potential uses beyond thermal applications. The wide range of porosity and pore size, coupled with the intrinsic properties of ceramics, makes them suitable for various applications, such as hot gas and molten metal filters, water filters, and catalyst supports.

To provide readers with a clear understanding of the potential applications, two figures summarizing the applications based on porosity range and pore size have been included (Figures 9.1 and 9.2). These figures highlight that the sucrose dehydration process is particularly well-suited for mass transport applications, such as hot molten metal filters, hot flue gas filters, and water filters, due to its high porosity and average pore size. Additionally, it is also suitable for solar absorber applications.

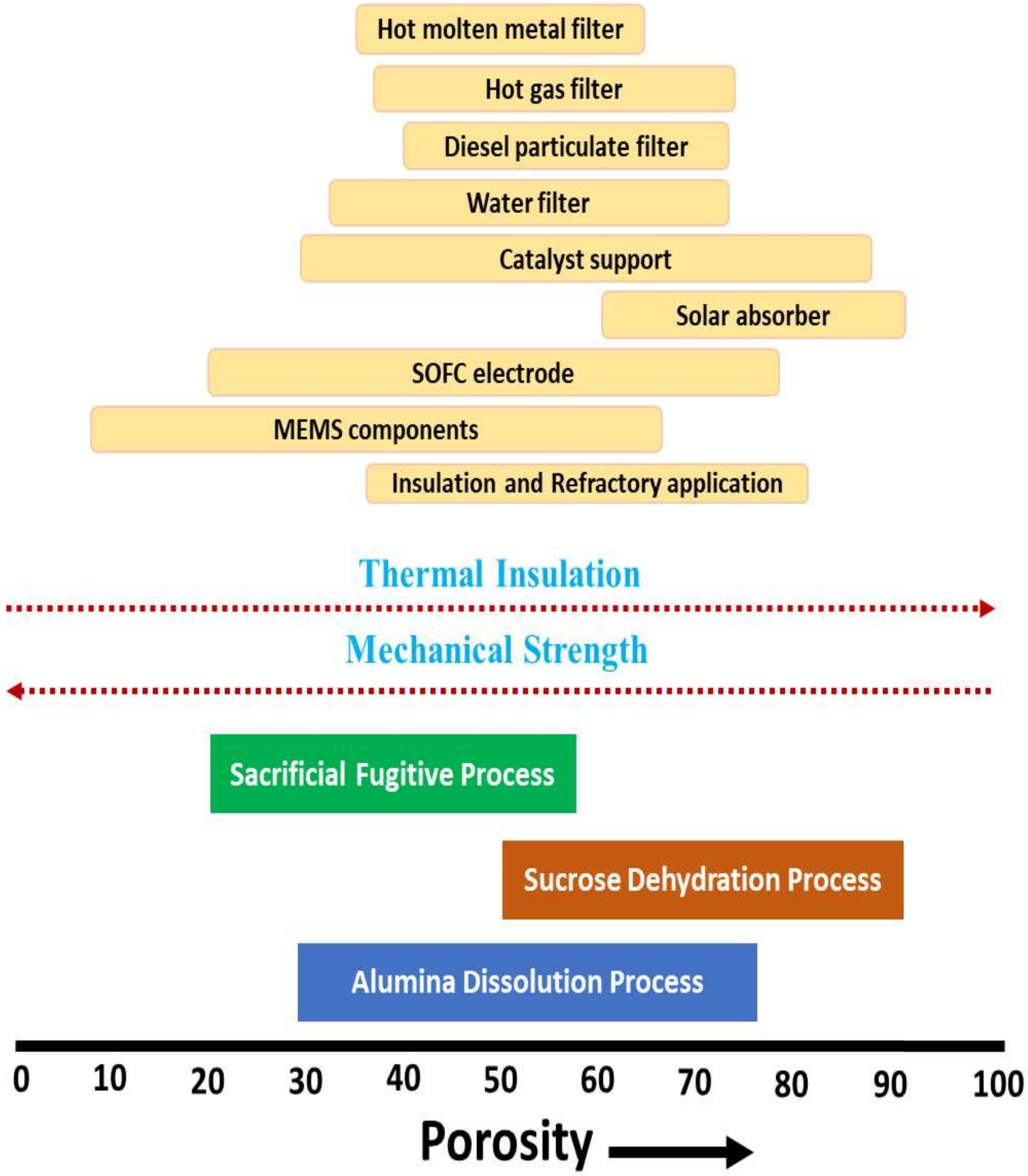

Fig. 9.1 Application according to porosity obtained through various methods

The alumina dissolution process demonstrates a wider range of applicability, including insulation applications, as well as applications such as water filters, solar absorbers, and catalyst supports.

The sacrificial method, specifically using Rice Husk, is best suited for applications like Micro-Electro-Mechanical Systems (MEMS) and Solid Oxide Fuel Cell (SOFC) electrodes, along with insulation applications. However, this method can also be extended to filter applications by tailoring the porosity and pore size through the use of varying sizes of Rice Husk, as reported in existing literature.

It is important to note that the applications discussed in this study are a result of the primary work conducted using limited material sources. The scope of applicability can be further expanded by utilizing porous composites prepared using different materials and additives. This opens up opportunities for exploring a broader range of applications and tailoring the properties of the composites to meet specific requirements in various fields.

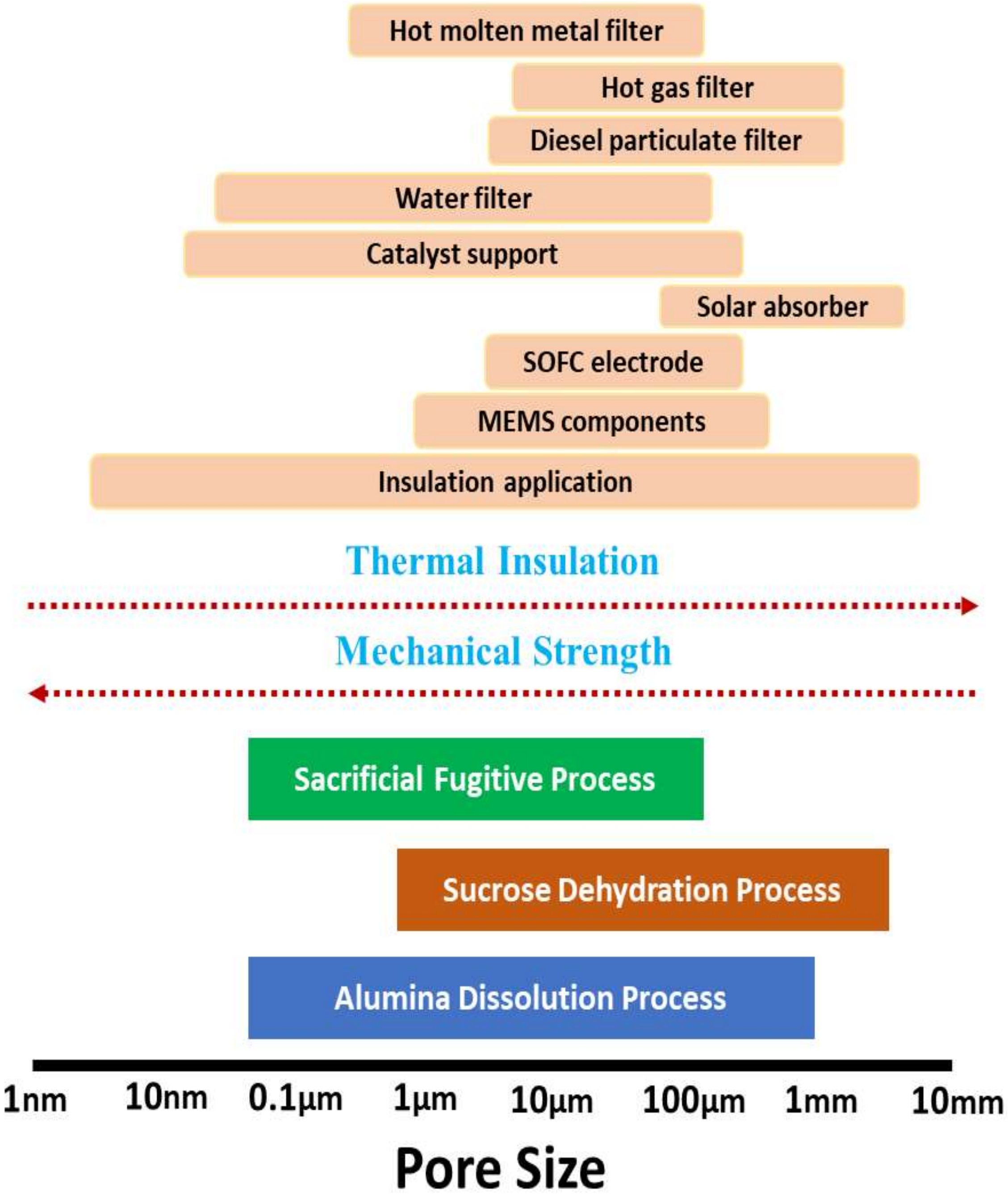

Fig. 9.2 Application according to pore size obtained through various methods