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Effect of Forming Pressure on the Microstructure and Mechanical Characteristics of Dense Porous Ceramics

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ABSTRACT

Ceramics are widely used in industrial applications due to their exceptional mechanical strength, thermal stability, and chemical resistance. However, the forming pressure during production significantly influences the microstructure and porosity, which in turn affect their mechanical properties. This study investigates the effects of varying forming pressures on the microstructure, porosity, and mechanical properties of dense porous ceramics, addressing the gap in understanding optimal forming conditions for enhanced performance. A composite of kaolinite clay, silica, feldspar, and carbon black as a pore-forming agent was uniaxially pressed at 10, 15, 20, 25, and 30 MPa and sintered at 1175°C for three hours. Microstructural analysis was conducted using field emission scanning electron microscopy, while density and flexural strength were measured using Archimedes' principle and mechanical testing, respectively. Results reveal that flexural strength increased from 22.9404 MPa at 10 MPa to a peak of 29.5365 MPa at 20 MPa, followed by a decline at higher pressures due to potential microcrack formation. The optimal forming pressure of 20 MPa provides a balance between mechanical strength and controlled porosity, making it suitable for applications requiring structural integrity and permeability. These findings contribute to optimizing ceramic production processes for diverse industrial uses.

1. Introduction

Dense and porous ceramics have different properties that are demanded in different applications. Dense ceramics, which have very good mechanical strength, thermal stability, and chemical resistance, find extensive applications in industries such as aerospace, automotive, and construction [1-3]. Low porosity combined with high density improves the mechanical strength and wear and corrosion resistance of these materials, making them suitable for load-bearing applications

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and as protective coatings as well [4]. The attainment of desirable characteristics in dense ceramics requires meticulous regulation of processing parameters, especially forming pressure, which has a considerable impact on the ultimate microstructure and porosity [5].

The main advantages of porous ceramics are thermal insulation, low density, and good chemical stability [6]. Such properties recommend them for thermal insulation, filtration, catalysis, and implants in living tissues [7-9]. Their functional and mechanical performance mainly depends on microstructural characteristics, among which pore size, morphology, distribution, and connectivity are crucial [10]. Application of the forming pressure has been found instrumental in regulating the microstructure and achieving a compromise between porosity and mechanical strength.

The interaction of the applied forming pressure with the resultant properties becomes particularly important for dense porous ceramics. In such materials, it is intended to combine synergistically the high mechanical strength typical of dense ceramics, along with the beneficial porosity present in porous ceramics. Whereas increased forming pressures usually reduce porosity and enhance mechanical properties, overly intensive densification may result in detrimental microstructural defects such as microcracks that may weaken it [11]. Conversely, low forming pressures favour higher porosity; however, this may dramatically reduce the material strength beyond acceptable levels for load-bearing applications [12].

Investigations have established that, in ceramic materials, pressure application affects the packing density and pore structure significantly, but it also impacts crystallographic phase and bond integrity [13,14]. In both dense and highly porous ceramics, a close relationship has been established between the forming pressure and the main properties of interest, such as thermal conductivity, flexural strength, and permeability [15,16]. However, a deep understanding of the effects of intermediate forming pressures on the properties of dense porous ceramics has yet to be fully realized. The lack of such knowledge hinders the optimization of processing parameters needed to concurrently achieve the desired structural integrity and functional porosity [17].

The importance of stringent control over forming pressure is further emphasized by its critical role in those applications where specific material properties are required. In the case of filtration applications, optimization of pore size and interconnectivity is crucial to achieve an optimum balance between filtration efficiency and mechanical strength. Similarly, in thermal insulation applications, the porosity of the ceramic material significantly influences its ability to act as a thermal barrier without compromising mechanical stability under mechanical load [18,19]. These factors highlight the importance of conducting detailed research on the influence of forming pressure on dense porous ceramics.

Dense porous ceramics have attracted much interest in bridging the fully dense with widely porous materials. They present a good combination of high strength and controlled porosity, which would make them potentially applicable for applications that require multifunctional properties, including energy-efficient building materials and lightweight structural components [20]. The preparation of dense porous ceramics strongly depends on the critical optimization of forming pressure required to obtain the desired microstructure and mechanical performance [21]. While comprehensive studies have investigated the behaviour of ceramics under different conditions of pressure, the specific effect of forming pressure on the characteristics of dense porous layers has not been explored.

While previous studies have investigated the dependence of the properties of ceramics on forming pressure, most have been concerned with either fully dense or highly porous materials, ignoring the crucial intermediate pressure ranges that are essential for the successful production of dense porous ceramics. This gap needs to be filled to improve the design and optimization of dense porous ceramics. Through a systematic study of the influence of forming pressure on microstructural

features and mechanical properties, this work provides valuable insight into what processing conditions are needed to achieve desired outcomes. The findings of this work have wide-ranging implications for all those applying advanced ceramic materials, from energy and construction to healthcare.

The objectives of this study are threefold which are to investigate the microstructural changes in dense porous ceramics induced by varying forming pressures, focusing on pore size, distribution, and connectivity. Besides, to evaluate the mechanical properties, such as flexural strength, of ceramics formed under different pressures; and lastly to identify the optimal forming pressure that balances porosity and mechanical strength for a range of industrial applications.

2. Methodology

2.1 Materials

Ceramic samples were prepared using a composite blend of clay (kaolinite) obtained from Anji Runxing New Materials Co., Ltd., silica (silicon dioxide) sourced from CABOT Corporation, and feldspar from Multifilla™, which included microcline with the chemical formula $Al_2Si_2O_5(OH)_4$ + SiO_2 + $KAlSi_3O_8$. The total weight of the mixture was 100 g, with individual components weighed as 43.28 g of clay, 10.07 g of silica, and 46.65 g of feldspar, determined using stoichiometric calculations. Carbon black (CB), used as a pore-forming agent, was added at 5 wt% and weighted with an analytical balance to ensure precision.

2.2 Sample Preparation

The ceramic mixture was prepared by blending clay, feldspar, silica, and CB, followed by ball milling for three hours using alumina balls (5–20 mm diameter) as the grinding medium to ensure homogeneity. The resulting powder was sieved through a mesh screen to standardize particle size. Dense porous ceramics were fabricated by uniaxial pressing the powder at ambient temperature under pressures of 10, 15, 20, 25, and 30 MPa, forming discs of 13 mm diameter and 4 mm thickness.

A pore-forming agent containing 5 wt% CB was incorporated into the bottom layer of the discs or bar-shaped samples. The top layer, composed of pure ceramic powder, was uniaxially pressed at the specified pressures for one minute, followed by the bottom layer. The layered structure aimed to create a dense top layer with a porous bottom layer.

The samples were dried at 100 °C for 12 hours and sintered in a furnace at 1175 °C for three hours, using a ramp-up rate of 5 °C/min. The samples were allowed to cool naturally to room temperature (25–28 °C). The chosen sintering temperature of 1175 °C for this study is supported by the findings of Jalaluddin *et al.,* [22], which indicate its efficacy in attaining optimal microstructural properties in ceramic materials.

The selected forming pressures of 10, 15, 20, 25, and 30 MPa were determined through preliminary experiments and a literature review. Preliminary trials indicated that pressures below 10 MPa led to not sufficient densification, which compromised mechanical strength, whereas pressures above 30 MPa resulted in excessive densification, causing microcrack formation and diminished mechanical properties [23-25]. Previous research supports these findings, emphasising the necessity of investigating intermediate pressures to enhance the equilibrium between porosity and mechanical strength in dense porous ceramics.

2.3 Material Characterization

Archimedes' principle states that the buoyant force acting on an object submerged in a fluid is equivalent to the weight of the fluid displaced by the object. Density is determined by Archimedes' principle of buoyancy. *Wa* represents the dry mass, *Wb* denotes the mass of material suspended in water and *Wc* denotes the saturated mass. After heating the sample, its mass (*Wa*) was recorded accurately using an A&D FZ-300i EC balance for the calculation of the density. After brief submersion in distilled water, masses *Wb* and *Wc* of the sample were determined using the same high accuracy balance. Using the data collected a formula for calculating the density was obtained by comparing and confirming the gathered data. Finally, Eq. (1), as derived from the principle of Archimedes was applied to determine the density for every sample, respectively.

$$D = \frac{Wa}{Wc - Wb} \tag{1}$$

XRD analysis was carried out on the sintered samples, which had been treated using different forming pressures by using a PANalytical X'Pert PRO diffractometer. XRD analysis was done to determine the crystalline phase of the material, and therefore it provided knowledge of its chemical composition. XRD depends upon the diffraction patterns created from the interaction of X-rays with the crystal lattice of the material for determining the crystal structure. While XRD cannot determine the chemical structure of a material, it can indicate the presence of crystalline phases indirectly, which may be associated with certain chemical compounds or elements.

Field Emission Scanning Electron Microscopy (FESEM) is a high vacuum technique usually performed to obtain high-resolution images of material microstructures. In this study, microstructural images of the materials were obtained by using a Schottky FESEM SU5000 device. The FESEM technique was used to study the interfacial bonding between the dense (top) and porous (bottom) layers of the sintered sample. The materials analysed in this work require preliminary procedures, including heat etching, grinding, and polishing, before examination under a FESEM. Grits of 1000, 1500, and 2000 were employed to ground each sample. The grinding process is done by the rough paper's grain size to guarantee that the sample's surface is free of scratches. After quickly grinding the sample, 0.05 µm Al2O3 and a micro pad were used to polish it. Once the samples were polished and ground, they were rapidly dried for less than a minute at 60 °C. Following the process of drying, each sample is exposed to a temperature of 1100 °C for a minute to do thermal etching. It is necessary to clean and dry the sample completely before scanning. On aluminium stubs, samples were attached using sticky tabs. Venting allows air to be expelled from the vacuum chamber. The chamber door is then shut when the sample has been deposited within the sample container. The vacuum pump continues to operate until the highest possible vacuum is reached. The sample may now be tested when this is completed. This study examines the microstructure of porous ceramic samples, including the size distribution and morphology of the pores, using FESEM. Although it cannot directly quantify pore size, FESEM generates high-resolution pictures of sample surfaces. Rather, pore diameters from FESEM images are extracted using image processing techniques.

The standard for measuring three-point bending strength (ISO 10545/4) was used to evaluate mechanical strength. Using a Shimadzu Autograph AG 25TA equipment, experiments were performed on bar-shaped sintered samples of 75 × 10 × 5 mm. The displacement speed was adjusted to 1.0 mm/min. The porous layer is orientated downward when specimens are arranged.

3. Results

3.1 Density Variation in Dense Porous Ceramics under Different Forming Pressures

One important factor that directly influences the mechanical characteristics and overall performance of ceramics is their density. The impact of changing the forming pressure on the density of dense porous ceramics is examined in this work, with a particular emphasis on pressures between 10 and 30 MPa. Forming pressure is a significant factor in determining the final density of the sintered sample since it influences pore structure and particle packing.

Table 1 and Figure 1 shows the density variation of sintered dense porous ceramic samples as a function of forming pressure. The ceramic sample's density decreases with increasing pressure, reaching a minimum of around 2.040 g/cm^3 at 20 MPa, from 2.120 g/cm^3 at 10 MPa. Once the density reaches this minimum, it rises gradually once again, peaking at 30 MPa at 2.140 g/cm^3.

Although 20 MPa exerts the lowest density on the graph, it is crucial to understand that this pressure could be appropriate for uses that need increased porosity. Maintaining a balance between density and porosity in dense porous ceramics is essential for certain uses including thermal insulation, catalysis, and filtration. Because of the lower density at 20 MPa, this pressure may create structures with more linked holes, which may be advantageous when regulated porosity is crucial [26].

It is expected that the material would show a more porous microstructure with evenly dispersed holes at 20 MPa. A larger amount of open porosity, indicated by a reduction in density, can produce advantageous properties like increased permeability or decreased thermal conductivity [27]. Thus, when trying to achieve a combination of certain mechanical properties and regulated porosity, this pressure level might be regarded as optimal. Because there is less pore development and looser packing at lower forming pressures, like 10 MPa, the density is higher. However, at greater pressures like 30 MPa the density increases, indicating that the material gets denser. This results in less porosity and more mechanical strength. Higher pressures result in denser samples, but they may also have an impact on the porosity level needed for a particular use.

Table 1
Density variation of dense porous ceramics at different forming pressures

Pressure (MPa)	Sample	*Wa* (g)	*Wb* (g)	*Wc* (g)	Density of sample (g/cm^3)	Average density of sample (g/cm^3)	Density of the reference substance (g/cm^3)	Average density of the reference substance (g/cm^3)	Relative density (%)
10	1	1.96	1.04	1.99	2.063		2.230		
	2	1.93	1.08	1.98	2.144		2.248		
	3	2.05	1.14	2.09	2.158	2.122	2.247	2.242	94.65
15	1	1.97	1.09	2.07	2.010		2.246		
	2	1.91	1.06	1.96	2.122		2.244		
	3	1.97	1.09	2.05	2.052	2.062	2.251	2.247	91.74
20	1	1.93	1.08	2.04	2.010		2.267		
	2	1.89	1.05	1.94	2.124		2.244		
	3	1.88	1.05	2.00	1.979	2.038	2.244	2.252	90.50
25	1	1.91	1.06	2.00	2.032		2.244		
	2	1.93	1.07	2.00	2.075		2.239		
	3	1.91	1.06	1.97	2.099	2.069	2.259	2.247	92.05
30	1	1.92	1.07	1.98	2.110		2.253		
	2	1.89	1.06	1.93	2.172		2.242		
	3	1.90	1.06	1.96	2.111	2.131	2.230	2.242	95.07

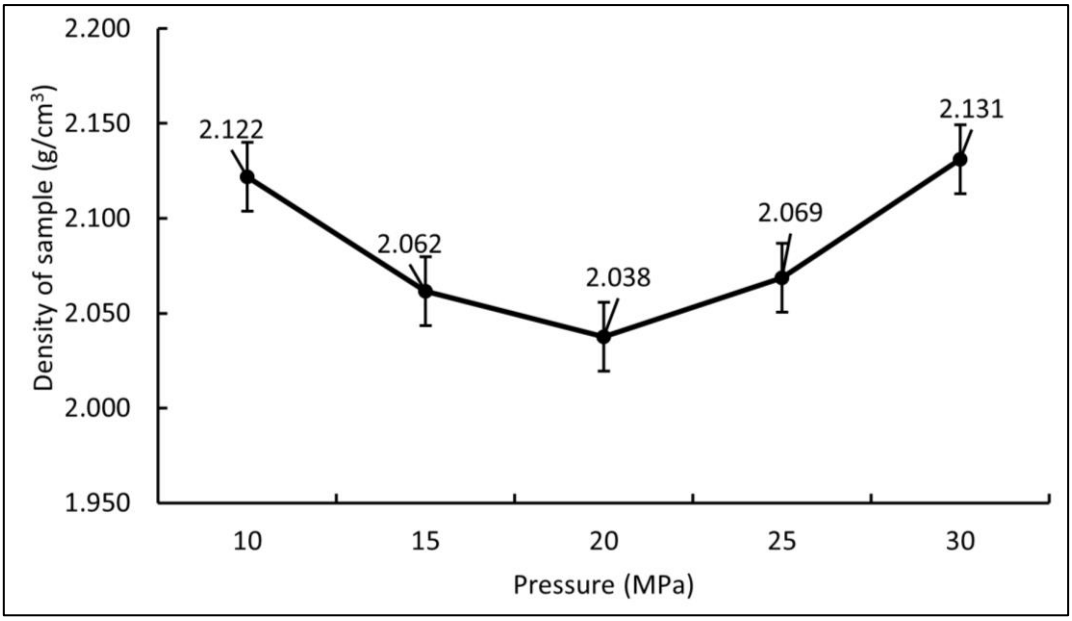

Fig. 1. Density variation of sintered dense porous ceramic samples as a function of forming pressure

3.2 Analysing the Phase Composition and Crystal Structure using XRD

When porous ceramics are subjected to pressures of 10, 15, 20, 25, and 30 MPa, their cross-sectional reflection patterns (XRD patterns) provide crucial details about the phase and structural characteristics of the substance. As seen in Figure 2, the two primary phases that have been found are orthoclase ($KAlSi_3O_8$) and silicon dioxide (SiO_2). The low-intensity peak in the XRD pattern at 10 MPa indicates a larger amount of amorphous material and a lower degree of crystallinity. As the pressure reached 15 MPa, the peak intensity dramatically increased, suggesting improved crystallinity.

The peaks sharpen and intensify as the pressure rises to 20 MPa, signifying an improvement in phase purity and crystallinity. This suggests that the ideal compaction equilibrium is achieved at 20 MPa, which promotes improved microstructure formation and stronger particle bonding. At 25 MPa, the pattern is still evident and shows notable peaks with increased intensity, indicating optimal crystal formation and fewer crystal imperfections in the structure. For silicon dioxide and orthoclase, the largest peak intensity, 2θ is seen at 26.48° and 30.98°, respectively, in the pattern at 30 MPa among the pressures under investigation. Here is where the crystallinity is at its maximum.

The intensity of silicon dioxide, 2θ, rises with pressure and peaks at 30 MPa. It also peaks at around 20.72°, 26.48°, and 49.94°. This implies that at greater pressures, there will be less amorphous material and getter crystal quality. In line with this, the orthoclase peaks, 2θ, at approximately 16.51°, 20.67°, 26.48°, 30.98°, and 33.17° likewise have an intensity that rises with pressure before peaking at 30 MPa, suggesting improved crystallisation and lesser imperfections.

Recent investigations have demonstrated that increasing forming pressure enhances the crystallinity of ceramic materials. For instance, a study by Ghosh *et al.,* [28] observed that higher compaction pressures led to more pronounced and sharper XRD peaks in alumina-based ceramics, indicating improved crystallinity and phase purity. This observation is consistent with the current study, where peak intensities increased with pressure, reaching optimal crystallinity at 30 MPa.

Similarly, Crystal *et al.,* [29] reported that in silicon dioxide ceramics, elevated forming pressures resulted in reduced amorphous content, as evidenced by the diminishing low intensity XRD peaks.

This finding parallels the current study's observation of decreased amorphous material at higher pressures, suggesting a general trend across different ceramic systems.

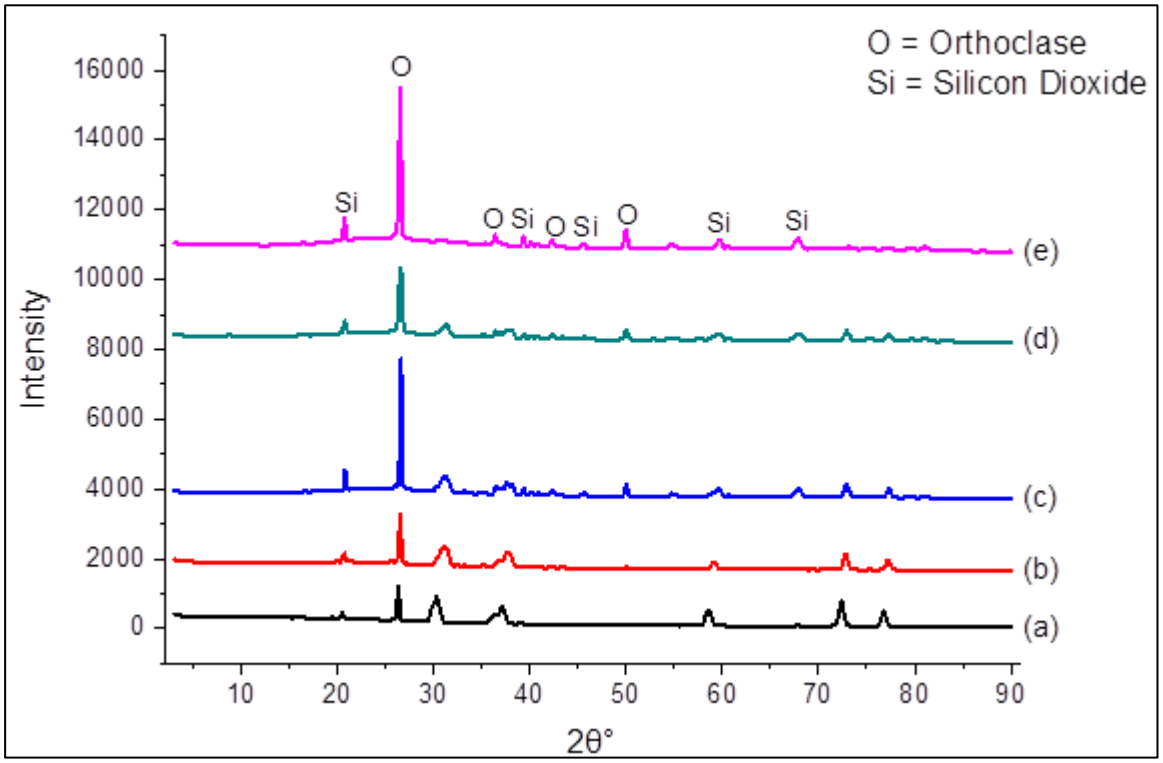

Fig. 2. XRD patterns of sintered dense porous ceramic samples at different forming pressures (a) 10 MPa, (b) 15 MPa, (c) 20 MPa, (d) 25 MPa and (e) 30 MPa

3.3 Morphological Analysis of Porous Structures in Ceramic Layers under Varying Forming Pressures

The mechanical characteristics and overall performance of porous ceramics are significantly influenced by their morphology, specifically the size, shape, and distribution of their pores. This work uses CB as the pore-forming agent to examine the effects of changing forming pressures on the morphological properties of compact porous ceramics. Pore structure development during sintering is directly impacted by the packing density of ceramic particles, which is influenced by the forming pressure.

The FESEM picture of the sintered sample on the dense porous surface, with pressure variations of 10, 15, 20, 25, and 30 MPa, is displayed in Figure 3. The ceramic material's grain boundaries, crushed at 10 MPa, are seen in Figure 3(a). This picture illustrates the network of grain boundaries that characterise certain ceramic characteristics. The borders denoting distinct features are represented by each of these black lines that divide areas of greater brightness. Because there is less compaction and density at this pressure, the sample has bigger, more asymmetric grains. More of the original grain morphology has been maintained in irregularly shaped grains due to their minimal deformation.

The consistently formed and compact grains were visible in the FESEM micrographs of the ceramic material pressed at 20 MPa, in contrast to the material pressed at 10 and 15 MPa. The black lines that represent the effective linkages between grains indicate how sharply defined and tightly connected grain boundaries are. Greater pressures effectively close more gaps and leave fewer holes in samples pressed at higher pressures than in samples pressed at lower pressures [30]. As the surface roughness

diminishes and the particle arrangement improves, the appearance becomes more uniform and smoother.

Strong intergranular bonding and clearly defined grain boundaries are seen in the FESEM micrographs of the material pressed at 25 and 30 MPa. Grain boundaries are clearly black and form a densely linked network with few gaps and great bonding between grains. High pressure causes equiaxed, tiny features to be significantly distorted and rearranged, resulting in a high degree of homogeneity and compaction [31,32].

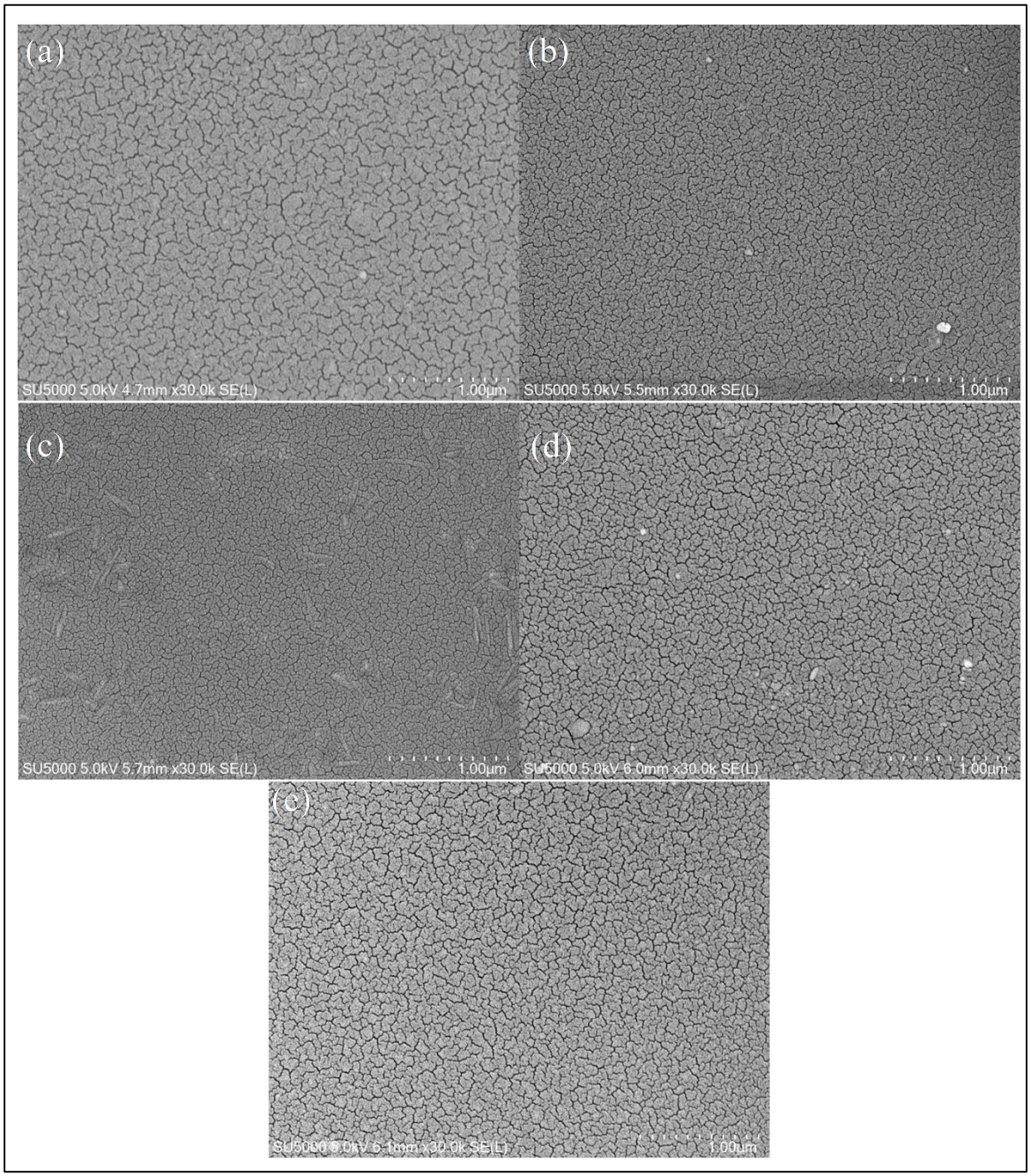

Fig. 3. FESEM images showing the microstructure of dense porous ceramics at different forming pressures: (a) 10 MPa, (b) 15 MPa, (c) 20 MPa, (d) 25 MPa, (e) 30 MPa

Figure 4 shows cross-sections of dense porous ceramic materials pressed at 10, 15, 20, 25, and 30 MPa. Every micrograph demonstrates the effect of applying pressure on the microstructure with a dense upper layer and a porous bottom layer. The FESEM picture showed massive irregular holes and a highly porous structure at 10 MPa. Because of the weak pore walls, there was inadequate density of particles during manufacturing. The holes were rounder and denser as the pressure rose to 15 and 20 MPa, and their total porosity significantly decreased. Improved densification and particle rearrangement are facilitated by higher formation pressure, which results in smaller pores and more homogeneity [33].

The images representing pressures at 25 and 30 MPa show highly dense microstructures with closely packed features and low amounts of visible porosity. There is an obvious rise in the number of isolated smaller pores, along with much more spherical and homogeneous pore morphology. These results suggest that the particles have been well compressed, which has resulted in a reduced volume and thus increased mechanical strength of the material. The noted microstructural differences through the pressure spectrum show that forming pressure strongly influences the final ceramic microstructure. The lower forming pressures give a structure with lower density and, hence, higher porosity, which is suitable for applications requiring a high permeability but could also have a lower mechanical strength [20]. Conversely, higher forming pressures result in a denser, more homogeneous structure with lower porosity, thus increasing the mechanical properties of the material, such as flexural strength.

FESEM micrographs showed that the material pressed at 20 MPa exhibited the smoothest surface compared to the materials pressed at 10, 15, 25, and 30 MPa. At 20 MPa, the grain boundaries are clearly defined and tightly interconnected, suggesting effective intergranular bonding. Grains have optimal particle packing density due to their consistent, dense, and minimal pore formation. In the end, there is reduced surface roughness and a more uniform microstructure with improved particle organisation. A study by Sun *et.al.,* [34] emphasized the importance of achieving a flaw-free green microstructure through optimal dry pressing techniques. Their research highlighted that appropriate compaction pressures lead to uniform particle packing and reduced surface roughness, resulting in enhanced mechanical properties in the sintered ceramics.

Similarly, a study by Bahanurddin *et.al.,* [35] on KNN ceramics demonstrated that variations in compaction pressure significantly influence grain growth and microstructural uniformity. The research indicated that optimal pressures promote homogeneous grain structures, which are crucial for the material's functional properties.

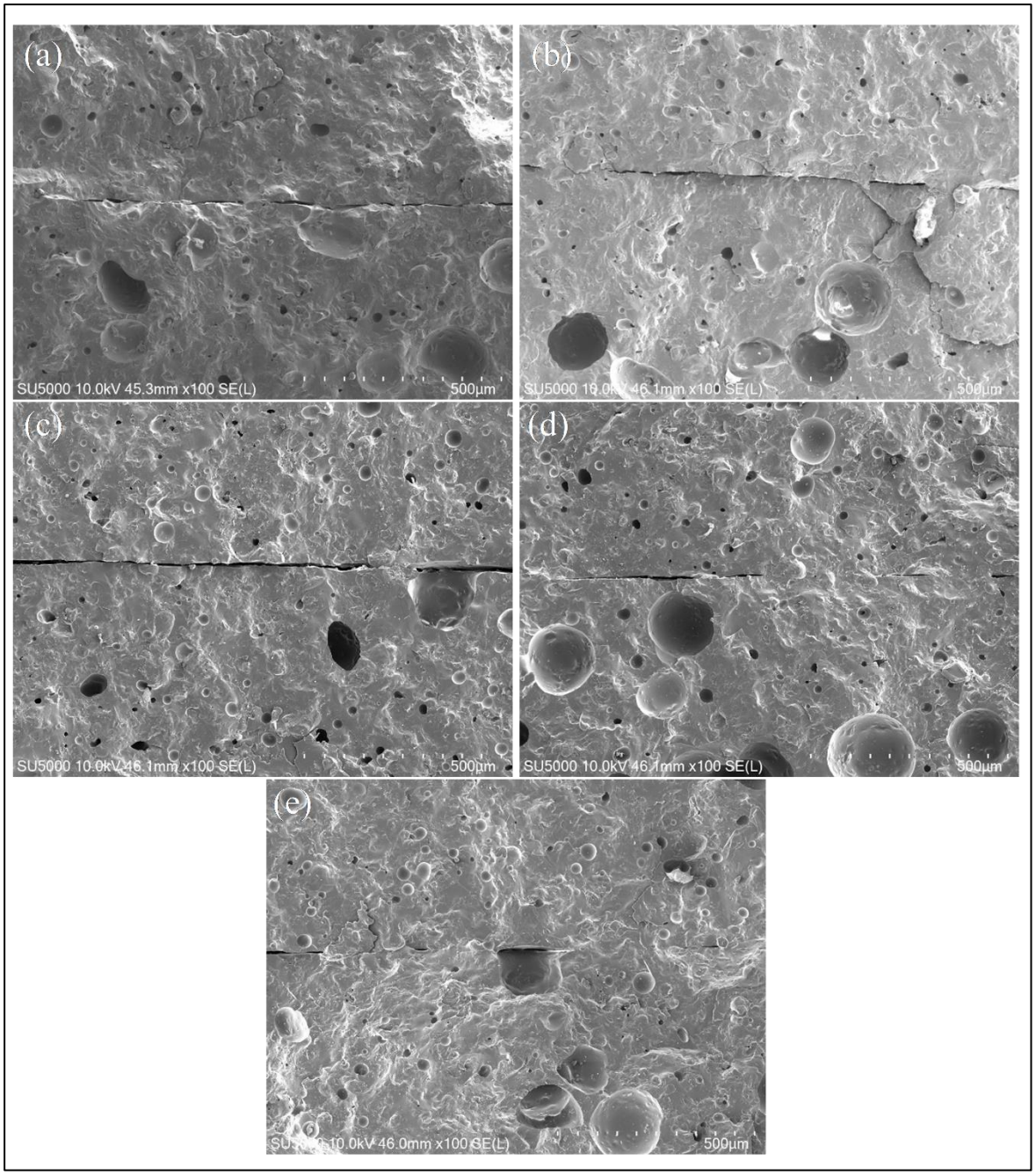

Fig. 4. FESEM images showing the porosity in dense porous ceramics at different forming pressures: (a) 10 MPa, (b) 15 MPa, (c) 20 MPa, (d) 25 MPa, (e) 30 MPa

3.4 Evaluation of Mechanical Properties under Varying Forming Pressures

For dense porous ceramics to be suitable for a variety of industrial applications, their mechanical characteristics are crucial [20]. This research examined ceramics produced at pressures of 10, 15, 20, 25, and 30 MPa for their mechanical properties. The primary focus is on flexural strength since it has a direct bearing on the material's performance and structural integrity [36]. Figure 5 shows the maximum stress at various pressures for dense porous ceramics. The data values display a distinct pattern whereby the maximum pressure increases significantly initially, then falls after peaking as the pressure increases from 10 MPa to 30 MPa.

The strength is around 22.9404 MPa at 10 MPa of pressure, climbs quickly to 23.6863 MPa at 15 MPa of pressure, and reaches its maximum of 29.5365 MPa at 20 MPa of pressure. When the strength reaches its peak, it subsequently decreases to 28.8863 MPa at 25 MPa of pressure and then to 22.0779 MPa at 30 MPa of pressure. As can be seen from the Figure 5, the highest maximum strength value of 29.5365 MPa is attained at an optimal pressure of 20 MPa and this pressure demonstrates the ideal compromise between porosity, microstructure, and mechanical performance. The peak stress of 29.5365 MPa at 20 MPa indicates the most efficient particle packing and structural integrity. However, a decline in mechanical strength to 28.8863 MPa at 25 MPa and 22.0779 MPa at 30 MPa suggests underlying microstructural factors impacting the mechanical performance.

This reduction can be attributed to several mechanisms, primarily related to excessive particle compression. At higher forming pressures, microcrack formation becomes a significant factor as the ceramic particles experience over-compression, leading to stress concentrations at grain boundaries. These microcracks act as defect sites, compromising load distribution and mechanical integrity [37].

Moreover, excessive compaction can lead to fracturing of the particles and grain boundary damage, mostly in brittle ceramic systems. When the grains fracture, it forms a stress concentrator that diminishes the material's ability to bear up the applied load efficiently [38]. This agrees with the observed drop in pressure to 25 MPa and to 30 MPa, wherein mechanical strength even decreases with the increasing compaction. Besides, decreasing porosity is an essential factor for this. While controlled porosity adds to mechanical stability by dissipating pressure, excessive pressure may eliminate beneficial pore structures, which results in a reduced energy absorption capacity and, consequently, a brittle fracture response [39].

The high pressures during forming could further have an impact on sintering behaviour because of non-uniform densification and residual stress development. This, in turn, might further cause localized grain distortion because of differential shrinkage during sintering and hence further diminish mechanical performance [40].

Another critical factor influencing changes in mechanical strength is sintering behaviour. Recent studies by Kim *et al.,* [41] have shown that higher forming pressures can result in nonuniform densification during the sintering process, hence creating residual stresses that deteriorate mechanical strength. The results of the present study, which show a decrease in strength above 25 MPa, are in line with these observations and indicate the role of residual stress in mechanical failure.

Similarly, Han *et al.,* [42] tested silicon carbide composites and found the threshold at 20 MPa, beyond which the mechanical performance levelled off due to grain boundary stresses and microcrack initiation. The present findings show a similar trend, which may mean that the mechanical strength behaviour in this work could be a universal trend in ceramics with brittle grain structures and similar porosity-controlling mechanisms.

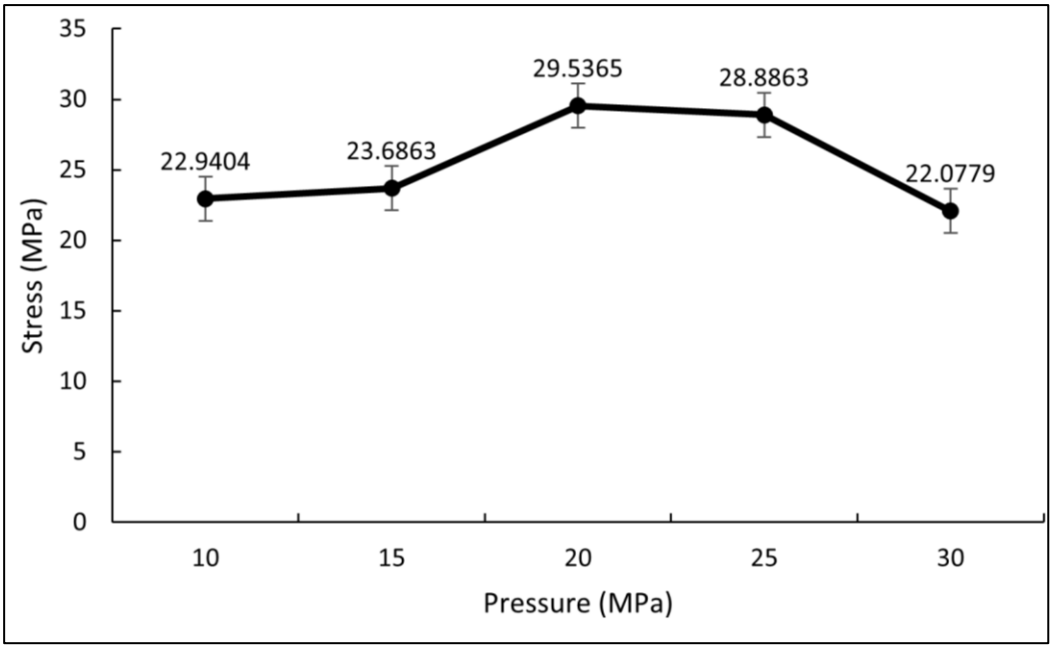

Fig. 5. Variation of flexural strength of dense porous ceramics at different forming pressures

4. Conclusions

In conclusion, it can be stated that the study has fulfilled its main goals as it has checked the connection between high forming pressure and the mechanical strength of the dense porous ceramic with the results. According to the results, the maximum mechanical strength of about 29.5365 MPa was reached at a forming pressure of 20 MPa. The maximum mechanical strength of approximately 29.5365 MPa was observed at the forming pressure of 20 MPa. This formed one of the best conditions that contributed to a balance being created between porosity and mechanical integrity by not creating structural imperfections and by facilitating efficient particle packing and densification.

Moreover, the mechanical strength decreased at 25 MPa, but it was very significant at 30 MPa (22.0779 MPa). The drop in the strength is mainly due to the presence of microcracks that are formed and grain boundary stress that is experienced when it is compressed. These thus become the reasons for the decrease in the load-bearing capacity of the ceramic lie. The results give the main conclusions about the relationship between the forming pressure, the structure, and the mechanical properties.

The findings further attest to the significant and inevitable interplay between mechanical strength and pore control. While too much compression bothers the microstructural defects in the ceramic, the condensation/tightening can improve the mechanical performance. This study is a very important contribution to ceramic technology for structural applications by the creation of informative results on how to choose the right forming pressure.

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