



Gas permeability and adsorbability of the glass-bonded porous silicon carbide ceramics with controlled pore size

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Abstract

Glass-bonded porous silicon carbide ceramics were fabricated by conventional method. The porosity and pore size could be tailored by changing the glass content and particle size of silicon carbide starting powder. The influence of microstructure on the gas permeability and the adsorption force between chucking work-pieces and porous SiC ceramic vacuum chuck was investigated. The permeability increased with the increase of porosity and average pore diameter. High permeability ($1.45\text{--}6.53 \times 10^{-12} \text{ m}^2$) of the porous SiC ceramics with a porosity of 32.1–64.7% could be achieved. Compared with porosity, pore size had a dominant effect on the permeability and adsorption force. The samples with the same porosity but smaller average pore size exhibited lower permeability and much higher adsorption force. The adsorption force of porous SiC ceramics was dependent on both microstructure and permeability. The P1000V70 sample with a pressure drop (ΔP) of 0.055 MPa and permeability of $1.94 \times 10^{-12} \text{ m}^2$ exhibited the highest adsorption force of 196 N/cm².

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1. Introduction

Porous ceramics have been considered one of the most promising candidates for hot gas cleanup, melt metal filtration, catalytic substrate, and thermal insulation [1,2]. Besides, it has also been developed for static-pressure-seal-type vacuum pin chucks or aerostatic-bearings that are highly capable of flattening a wafer right up to its periphery [3–5]. As a result, it could be used in the manufacture of highly value-added components, such as precision optics, coordinate measuring machines, and replication drums [3–5]. These chucks or bearings provide virtually frictionless linear motion using air as the fluid film. And it enables precise and smooth non-contact relative motion

of machine components. Clean compressed air is supplied to the bearing clearance through the extremely large number of pores [4]. As a result, the bearing gas-film pressure distribution is improved. This in turn results in an enhanced adsorption force between chucking work-pieces and porous SiC ceramic vacuum chuck and load-carrying capacity [6]. For silicon carbides, further advantages of the porous ceramics as aerostatic structure material are their low thermal expansion coefficient, long-term dimensional stability, and stiffness over a wide range of temperatures [6,7]. In practical application, in order to achieve desirable gas permeability and adsorbability of the chucks, porous ceramics with controllable microstructure and reproducible permeability are required.

The gas permeability and adsorbability are strongly dependent on the pore volume fraction and the microstructure of porous ceramics. Among them, pore size of the macro-porous SiC ceramics is a key factor for filters to allow gas flow [8,9]. The distribution of the pore size and shape of the pore space in porous ceramics is directly related to desired functions. Besides,

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the adsorption force of the porous ceramics as vacuum chucks material need to be quantified to investigate the efficiency and reliability in practical applications. One of the important factors in the gas flow filter process is the optimal compromise between permeability and adsorption force. The adsorption force is dependent not only on the permeability, but also on the microstructure of the porous materials. However, very limited information about the adsorption force or load carrying capacity of porous ceramics exists in the literatures. Particularly, there have been even less attention given to the adsorption force–microstructure relation in porous ceramics.

It is well known that the microstructural features of macroporous SiC ceramics (open porosity, pore size distribution, and pore morphology) are highly influenced by the processing route. Various processes, such as the partial sintering [10,11], replica method [2], sacrificial template [12], and direct foaming [13] were developed to fabricate porous SiC ceramics. However, all the above methods required high temperatures of $\geq 1500^\circ\text{C}$ for the processing if SiC powders were used as the starting material because of its strong covalent bonding characteristics. Bonding techniques generally offered a cheap, low-temperature processing route to prepare porous SiC ceramics with porosity ranging from 15% to 60%. The processing temperature was in a range of $800\text{--}1550^\circ\text{C}$, depending on the composition of the bonding material. On the other hand, the pore size of porous SiC ceramics could be easily tailored by changing the particle size of SiC powders through bonding technique [14].

In the present research, SiC powders with various particle sizes and glass bonding materials were used as the starting powders. And porous glass-bonded SiC ceramics with controllable porosity and pore size were fabricated at low temperature by conventional method. The gas permeability and adsorption force of porous SiC ceramics were evaluated by a homemade apparatus. The dependence of gas permeability and adsorption force on the porosity, pore size, and microstructure of porous SiC ceramics were investigated.

2. Experimental procedure

Commercial silicon carbide powders with particle mesh size of #120, #500, #1000, and #2000 (Showa Denko K. K, Japan) and glassy bonding materials (median particle size: $10\ \mu\text{m}$, Nano TEM Co. Ltd., Niigata, Japan) were used as the starting powders. The chemical composition of the glass materials was as follows: 61 wt.% SiO_2 , 24% Al_2O_3 , 5% CaO , 2% Na_2O , 2% K_2O , and 6% other materials. The volume fractions of SiC were 65, 70, 75, 80, and 85 vol%. The green compacts ($\varnothing 50\ \text{mm} \times 10\ \text{mm}$, $\varnothing 20\ \text{mm} \times 10\ \text{mm}$) were obtained by uniaxial pressing of the powder mixture under a pressure of 30 MPa. The green bodies were sintered by conventional sintering method at 850°C for 1 h with a heating rate of $300^\circ\text{C}/\text{h}$. The codes of P500V65 and P1000V80 were used for the samples, where “P” represented the particle size of SiC powder and “V” represented the volume percent of SiC powder.

The porosity was measured by Archimedes method. The pore size distribution was determined by mercury porosimetry (autoporeIV9500, Micromeritics Instrument

Co., Norcross, GA, USA). The microstructure of the sintered samples was investigated by scanning electron microscopy (VE-7800TM, KEYENCE, Co. Ltd, Osaka, Japan).

As shown in Fig. 1, the gas permeability was measured by the permeability tester (designed and installed in Ishizaki Lab, Japan) at ambient temperature using compressed air as the working medium. The sintered samples were machined off so that all the samples with the same height could be fitted into the sample chamber of the permeability tester. During the test process, the samples were sealed by a rubber ring and the differences between inlet and outlet pressure were measured by pressure sensors. The permeability was calculated by Eq. (1) [15]:

$$\psi = \frac{\eta Q t}{A(P_1 - P_2)} \quad (1)$$

where ψ is the permeability, the dynamic viscosity η of air as used for calculation is $1.822 \times 10^{-5}\ \text{Pa} \cdot \text{s}$ [16], Q is the flow rate, t is the thickness of the sample, A is the cross-section area of the sample, P_1 and P_2 are the inlet pressure and outlet pressure, respectively. P_1 , P_2 , and Q were measured by using this system. For each specimen, the permeability measurement was conducted at different pressures. The inlet pressure increased from 0.05 MPa to 0.5 MPa with a step of 0.05 MPa. The adsorption force was measured by the system (designed and installed in the Ishizaki Lab), as shown in Fig. 2. The flat plastic ($\varnothing 35\ \text{mm} \times 3\ \text{mm}$) was used as holding objective. The porous SiC ceramics

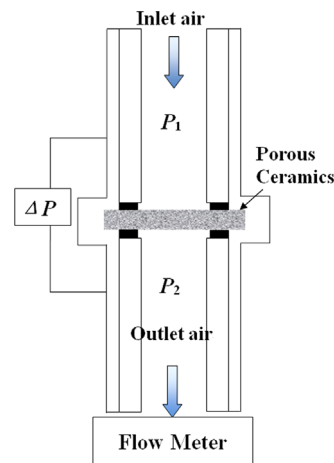


Fig. 1. Schematic diagram of the permeability tester.

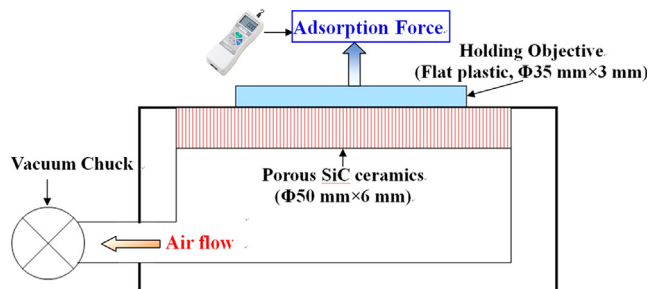


Fig. 2. Schematic diagram of the adsorption force measurement system.

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