Experimental research of mechanical characteristics of porous ceramics on the basis of machine-building scrap

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Abstract
In the paper, mechanical characteristics of porous ceramics obtained on the basis of the scale of steel 18X2H4MA and natural mineral, that is saponite in the process of SHS are investigated. The regularity of change of mechanical properties depending on pressure of pressing and temperature of sintering is determined. Results of research have shown that the obtained material has good technical characteristics and can be recommended for obtaining the porous filtering elements.
Key words: SCALE, SAPONITE, CERAMIC FILTER, POROUS CERAMICS, STRENGTH

Introduction

Due to the development of modern equipment, more strict requirements to traditional ceramic products are laid down in recent years; it causes the necessity of production of new materials with specified complex of physical and chemical properties. Porous ceramic materials are the most advanced in this regard; they have long life, resistance to household effects, mechanical strength, simplicity of application and low cost. Porous ceramic materials have a number of advantages over the filtering elements of other materials (strength, resistance to impact of high temperatures and aggressive medium) and are widely used in modern production.

Problem statement

Operational characteristics of ceramic filters are caused by result of phase transformations in the course of sintering. But, one of the problems emerging during ceramics production is search of ratio between the size of porosity and strength of material depending on their functional purpose. It is known that porosity affects negatively the properties of ceramics; it concerns mechanical properties due to the fact that pores depending on their distribution by the sizes, geometrical form and their combination to canals are rather stress concentrators than relaxer, and also ceramic materials generally distinguishes by brittle behavior.

References analyses

In the paper [1], features of microwave sintering of porous hydroxyapatite ceramics are investigated. It is established that application of microwave heating at 1000 °C allows obtaining ceramics on the basis of biogenous hydroxyapatite with porosity 35 – 46.5% which is open by 90 - 95%. It is shown that increase in pressing pressure from 50 to 250 MPa is conductive to formation of more fine-grained structure and narrowing of existence interval of the basic amount of pores up to 0.2 – 0.7 microns. Authors [2] have investigated chemical and structural characteristics of ceramics magnesium-aluminum spinel ($MgO\text{-}nAl_2O_3$) obtained by method of hot pressing of furnace charge depending on technological parameters of its synthesis, phase structure, and also a deviation from stoichiometry. Optimum parameters of synthesis from the standpoint of crack resistance are temperature of synthesis of 1200 °C and time of 1 hour. Dependence of crack resistance on deviation degree of its composition from stoichiometry in the range of 0.96... 1.05 is obtained, and also in case of furnace charge alloying by transitional metals Mn, Cr or Fe. High-temperature annealing in the oxidizing medium leads to diffusive flows of Mg cations into the sample to the recovery surface and also to formation of structure of spinel of stoichiometry structure at ceramics surface layer. In the paper [3], samples of super-hard carbonaceous ceramics obtained by sintering under the conditions of high static pressures of powders of shock-wave synthesis. The structure of carbonaceous ceramics was studied, changes of structure, phase composition and microhardness of samples depending on sintering temperature were followed up by methods of electronic microscopy and x-ray diffractometry. Authors [4] have developed technology of obtaining the high-purity nanocrystal powder ZrO_2 and high-strength ceramics on its basis. Chemical and phase composition, micro structure and physicotechnical characteristics of ceramics have been investigated. It is shown that the developed material is characterized by high low-temperature phase stability and is highly competitive by technical characteristics and parameters with similar materials of well-known companies. In the paper [5], research of mechanical properties of ceramet of system Cr_2O_3 – Cr and Al_2O_3 – Cr obtained by methods of free sintering, hot pressing and hot quasiisostatic pressing in case of various pressure is conducted. It is shown that in case of increasing pressure of pressing, strength and hardness grow. Also strength is influenced by sintering method. At hot quasiisostatic pressing of materials, strength increases by three times than at free sintering caused by qualitative changes of structure and condition of phases. Authors [6] have carried out mechanical tests of the system $Si_3N_4\text{-}Y2O_3\text{-}Al_2O_3$ materials obtained by high-temperature deformation in the range of temperatures of 1750-1850 °C. It is established that material has the increased level of mechanical properties. It is shown that the deformation method at high temperature provides the content of material with directed microstructure. In the paper [7], a series of carbide-silicon ceramics samples with the varied characteristics of microporosity and strength is investigated. On the basis of dependence of ceramics strength on integrated porosity, it was established that strength is directly proportional to the average length of cross connections between micropores. The mechanism of influence of micro porosity on ceramics strength is determined; it is that cross connections between pores are concentrators of pessure, therefore they are broken down at load application to ceramics.

Statement of the basic material

In course of research, the basis of composite components of furnace charge for obtaining porous materials is formed by industrial wastes of machine-building production; these are oxides of metals and metal

powders. As initial materials, the following materials were taken: scale of steel 18X2H4MA (30%), powder of aluminum oxide TU 48522-87 (30%), natural mineral - saponite (30%) Tarasovskyi deposit and carbamide CH4N2O (10%). Mixing of powders of initial reagents was carried out in ball mill, which is horizontally arranged rotating cylinder with a set of steel balls with diameter of 20 mm. Mixing continues for 6, 8 12 and 24 hours before homogeneous mass obtaining. Pressing of initial furnace charge is performed by hydraulic press of the model PSU 500 in pressure range of 10 - 25 MPa. Samples have the cylindrical form Ø 30 and height 60 mm. Synthesis was carried out in the laboratory reactor, which had been produced at the Lutsk national technical university. As the obtained material is recommended to be used as the filtering material, it is reasonable to carry out researches of its mechanical characteristics. According to the ISO 19 standard, the main mechanical properties for porous ceramics are the following: hardness, strength and crack resistance.

Hardness of sintered sample was measured using Vickers microhardness testers at loading 1.96 N (300 g) during 15 seconds. Results of tests are presented in Figure 1.

Figure 1 shows dependence of Vickers hardness of sintered sample in the form of function from sintering temperature. From graphic dependence it is seen that the lowest hardness is measured for all the samples sintered at 800 °C while the maximum value of hardness is noticed for all samples sintered at a temperature of 1600 °C. The general tendency which is observed in Figure 1 shows that hardness increases in case of temperature from 800 to 1600 °C; however, at further temperature increase (over 1600 °C) this tendency is not observed. It can be explained by the fact that such temperature is conductive to amorphous transformation in scale lattices. Sintering temperature below 1400 °C gives no way for essential quantity of intermetallide from oxides of metals, and there takes place only partial introduction of atoms of aluminum into iron.

For all samples crushed by time from 6 to 24 hours and sintered at a temperature from 800 to 1650 °C, hardness was higher than the minimum limit of 35 MPa for ceramics as ISO 19 standard requires.

From dependence, it is seen that density for samples crushed within 6 hours increases sharply with increase in hardness. For the samples mixed within 8, 12, and 24 hours, hardness is correlated by linear change of volume density. It means that hardness is regulated by change of volume density. Besides, for the samples crushed within 6 hours nonlinear variations of hardness with volume density were observed. It is explained by the big sizes of grains which are harmful for hardness of sintered samples.

Test sample compressive strength was determined at the room temperature by machine NIKIMP 1231 U10 at loading 150 N.

Figure 3 shows dependence of compressive strength on temperature of sintering of the samples pressed at various pressures. In total, it is possible to emphasize two stages from dependence: strength increases to temperature of 1300 °C, and with temperature increase (more than 1300 °C) strength decreases. The first stage is explained by the fact that partial intermetallide formation between oxides of metals takes place. Porosity grows with increase in temperature of sintering. Porosity of the samples sintered to 1300 °C varies within 11-12%, porosity of the samples sintered at high temperatures reaches 15-18% that negatively affects mechanical characteristics. It explains reduction of strength in case of sintering at temperature above 1300 °C. However, at specified sintering temperatures, the strength was higher than the minimum limit of 35 MPa for ceramics as ISO 19 standard requires.

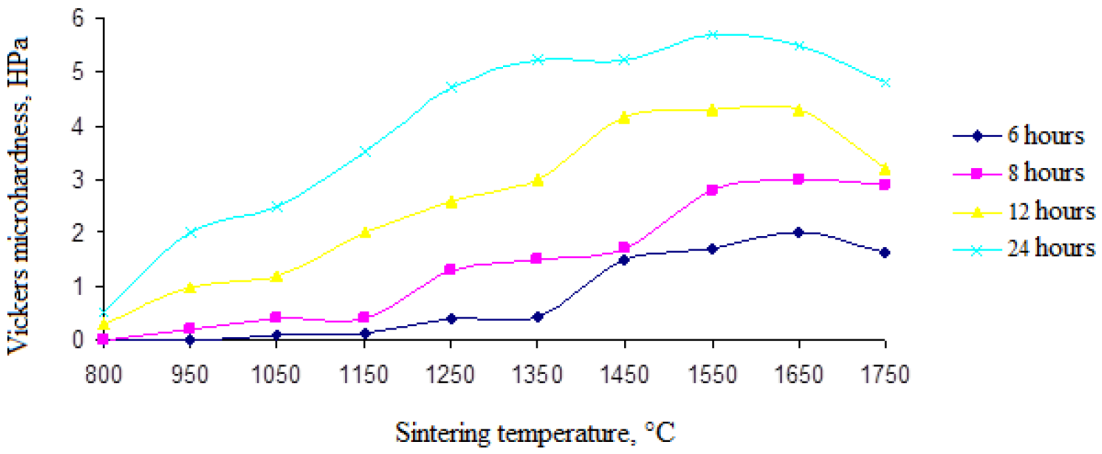

Figure 1. Hardness of material depending on sintering temperature

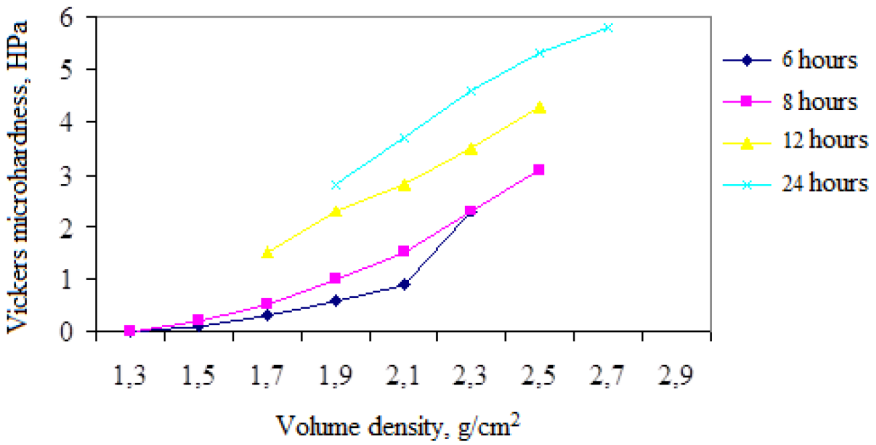

Figure 2. Dependence of hardness on volume density

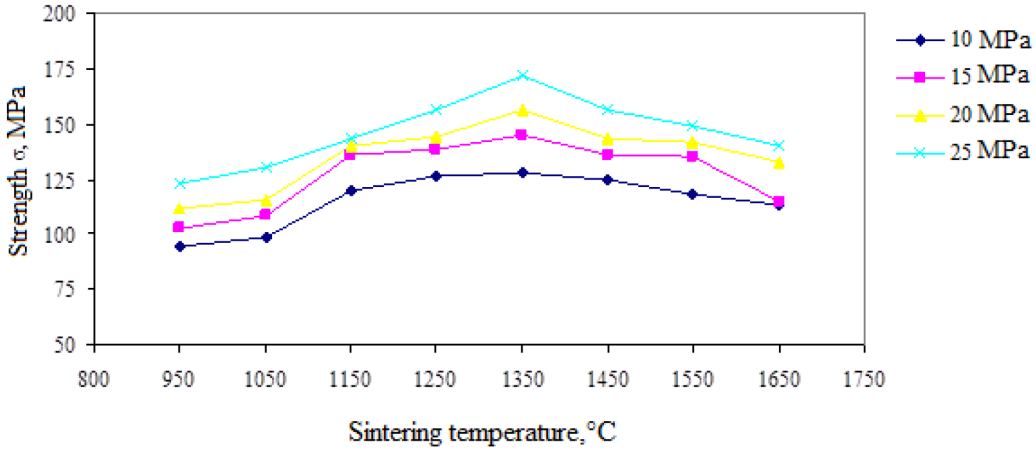

Figure 3. Sample strength depending on temperature of sintering and pressure of pressing

The main problem of ceramic materials is their brittle behavior that leads to destruction at tension which is significantly lower than tensile strength by growth of crack of more critical size which increase leads to decrease in critical pressure of destruction. The value K_{1C} determines ability of material to resist to crack formation. Higher value K_{1C} means lower danger of brittle fracture.

Tests for determination of coefficient of crack resistance K_{1C} were carried out by hardness testing machine TP-7R-1 with Vickers indent at load of 150 N. The sizes of prints and length of cracks were measured by an optical microscope "MMR-4". 8-10 prints were applied to each sample, and 5 samples were tested for obtaining average value of material crack resistance.

Crack resistance K_{1C} was determined by a technique [8] which is that Vickers pyramid is pressed into a flat surface of sample and by the size of print and length of radial cracks K_{1C} is determined by formula:

$$K_{1C} \cdot \frac{F}{H} \cdot \sqrt{a = 0{,}15K(c/a)^{-3/2}}, \qquad (1)$$

where a – half of print diagonal; c - length of a radial crack measured from the center of print; K = 3.2 - proportionality coefficient; F - hardness relation to yield strength which is determined by March formula for brittle materials [9]:

$$F = \frac{Hv}{\sigma T} = C_1 + B\ln Z, \qquad (2)$$

where Hv - Vickers hardness; σT - yield strength,

$$C_1 = 0{,}32;\ K_1 = 0{,}52;\ B = \frac{3}{3-\lambda};\ z = \frac{3}{\lambda - 3\mu - \lambda\mu}, \qquad (3)$$

where E – Young modulus; v – Poisson ratio.

The ratio $\sigma T / E$ may be determined by the ratio Hv/E from the diagram presented in [9].

Stability of strength values of the deformed material was evaluated by value of the Weibull modulus m, which was counted by two-parameter scheme:

$$P_f = 1 - \exp(-\sigma_i / \sigma_0)^m \qquad (4)$$

where P_f - probability of destruction at pressure σ_i.

The coefficient of crack resistance K_{1C} for the samples pressed in case of various pressures and sintered in the range of temperatures 800-1750 °C is presented in Figure 4.

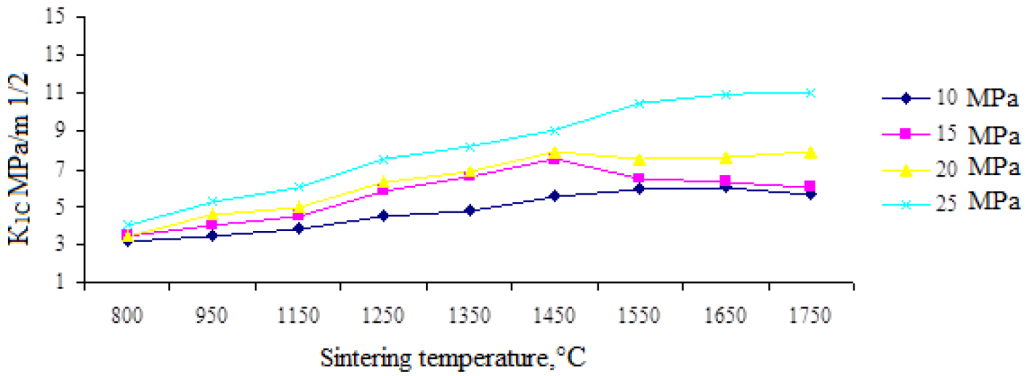

Figure 4. Crack resistance of the deformed samples

As it is seen from Figure 4, coefficient K_{1C} increases with growth of samples sintering temperature. The highest crack resistance was shown by the samples pressed by pressure of 25 MPa. As the researches have shown, the optimum temperature of sintering is 1550-1600 °C for this material, as in case of further temperature increase significant changes of mechanical properties are not observed.

Conclusion

On the basis of the conducted researches and the analysis of obtained results, it is possible to draw conclusions that physical and mechanical properties of the obtained ceramics are determined by a ratio of phase components, size and density of pores distribution, their form and arrangement. The main problem of ceramic materials is their high brittleness that leads to destruction at pressure significantly lower than strength. The highest crack resistance, which allows its application as filtering diaphragms with static character of loading, is significant advantage of the obtained material. The highest crack resistance was shown by the samples pressed by pressure of 25 MPa. As the researches have shown, the optimum temperature of sintering is 1550-1600 °C for this material, as in case of further temperature increase significant changes of mechanical properties are not observed. Porosity of the samples sintered to 1300 °C varies within 11-12%, porosity of the samples sintered at high temperatures reaches 15-18% that negatively affects mechanical characteristics. It explains reduction of strength in case of sintering at temperature above 1300 °C.

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