Study the effect of kaolin addition on some physical and mechanical properties of α-SiC powder

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Abstract:

The present work investigates the physical and mechanical properties based on α-SiC powder with different percentage addition of Duekhla raw kaolin. Samples have been prepared utilizing powder technology technique, then formed by uniaxial pressing and sintered at 1400 ˚C. The apparent density (A.D.) and apparent porosity (A.P.) for each sample were evaluated as a function of kaolin percentage. It was shown that the A.D. and A.P. decreasing with increasing kaolin content. These results are interpreted in view of that, the kaolin have density lower than the SiC. Mechanical properties show that the compressive strength, diametrical strength and hardness of ceramic samples increased significantly with increasing of kaolin content until it reached a maximum value with 20% kaolin addition. This phenomenon may be attributed to the presence of alumina and silica in kaolin composition which formed a new phases enhancement the mechanical properties of the prepared ceramic.

1- Introduction :

Silicon carbide is composed of tetrahedral of carbon and silicon atoms with strong bonds in the crystal lattice. This produces a very hard and strong material. Silicon carbide is not attacked by any acids or alkaline salts up to 800 C. in air,SiC forms a protective silicon oxide coating at 1200 C and is able to used up to 1600 C. the high thermal conductivity coupled with the low thermal expansion and high strength give this material exceptional thermal shock resistant qualities. SiC ceramics with little or no grain boundary impurities maintain their strength to high temperature, approaching 1600 C with strength loss [1]. SiC with its covalently bonded were exists in a number of forms. One of these structures is a cubic beta silicon carbide (β-SiC) which is produced by low temperature vapor phase reactions and changes irreversibly to alpha silicon carbide (α-SiC) at temperature of about 2000 C. pure cubic beta silicon carbide is a semiconductor with a band gap of approximately
2.2 eV [2].

Silicon carbide, like most other covalent materials, is not easily sintered from a powder compact. One process for producing a dense SiC structure is to bond silicon carbide grains together with fired clay, glass, silicon nitride, oxides, or by other propriety means. These materials are quite creep resistance and thus can be used for furnaces furniture and structural applications at high temperatures [3].

Clay bonded material is relatively low duty, low cost. Clay bonded still lower in SiC. Kaolin is used in ceramic white ware products, insulators, and refractories. In white ware, kaolin aides accurate control of molding properties, and add dry and fired strength, dimensional stability, and a smooth surface finish to the ware. In refractory application, the dimensional stability, high fusion point, and low water content, along with green strength, make kaolin an important constituent [4]. Kaolin bonded silicon carbide also offers high strength at elevated temperatures. The maximum used temperature for SiC is limited to 1400 ˚C in oxidizing atmospheres due to the oxidation of SiC to SiO_2[5].

2- Experimental Part:

A commercial α-SiC powder produced by Struers company (impurity 99.5%) with particle size <53 μm and Duekhla Kaolin Iraqi raw material supplied by (Ministry of Industry, General Company for Geological Survey and Mining). The chemical analysis for the Kaolin is shown in the following table (1-1). The crushing process of clay rock was achieved using crusher machine then sieved using electric rocking to obtained kaolin powder with particle size <53 μm, then kaolin at different percentage (5%, 10%, 15%, 20%) were added to α-SiC powder.

Table (1-1): Chemical analysis of Duekhla Kaolin.

Kaolin Composition	Weight %
Na_2O	0.25
CaO	0.15
K_2O	0.61
MgO	0.38
Al_2O_3	34.84
Fe_2O_3	1.32
SiO_2	47.26
TiO_2	1.4
L.O.I.	13.79

The batches were prepared by the weighting of the constituents using an analytical balance type (AD GF-300, precision of 0.001 g, Japan) then mixing in a porcelain jar laboratory blender for about 2h to achieve homogeneity. Five gram units of each batch were pressed to disks of 1.5cm diameter using a stainless steel cylindrical die and press (type iCL international – Crystal Laboratories–U.S.A.). The pressing time was 3 min and the pressure was 3 tons. The pressure was released slowly to obtain crack free samples. The prepared samples have been sintered at 1400°C for 4 h at a heating rate of 10°C/min, using programmable furnace type Carbolite.

3-Measurements:

3-1 Physical Properties:

3-1-1 Apparent density and Apparent porosity,

The density of a material has been defined as the relationship between it's mass and it's volume, i.e.

$$Density = \frac{Mass}{Volume}(g/cm^3)$$ Apparent solid density defined as the ratio of the mass of material to the apparent solid volume of the material (volume of solid component + sealed pores).

Pores are void spaces which must be distributed more or less frequently through the material if it is to be called "porous". The apparent porosity, expresses as a percent, is the relationship of the volume of the open pores of the specimen to its exterior volume [6].

Apparent Density and Apparent porosity measurements were carried out according to ASTM (American Standard for Testing Materials) C373-88 [7, 8]. The measurement procedure is outlined below:

(1) The samples are dried in an oven at 150°C the dry weight, W_1 is determined.

(2) The specimens is placed in a baker filled with distilled water and boiled for 2 h, then the specimens is allowed to soak for an additional 24 h, a second weight W_2 is recorded while the sample is suspended in distilled water.

(3) After that each specimen is lightly wiped with a moistened smooth cotton cloth to remove all excess water from the surface, and the saturated weight, W_3 is recorded. Calculating the Apparent Density (A.D) and Apparent Porosity (A.P.) accomplished utilizing equations (1-1) and (1-2) respectively.

$$A.D = \rho_L \frac{W_1}{W_1 - W_2} \quad .....(1-1)$$

$$A.P\% = \left[\frac{W_3 - W_1}{W_3 - W_2}\right] \times 100 \quad .....(1-2)$$

ρ_L: Density of the Liquid.

W_1 : Weight of the dry specimen.

W_2: Weight of the soaked immersed specimen.

W_3: Weight of the saturated specimen.

3-2 Mechanical Properties:

3-2-1 Compressive Strength

When an external force is applied to a body or specimen of material under-test, an internal force, equal in magnitude but opposite in direction, is set up in the body. For simple compression or tension the stress is given by the expression, Stress =F/A, where F is the applied force in N, and A is the cross-section area. A stress resisting a compression force which is referred to as a Compressive strength [9.10].

ASTM standard –C773, was used to testing the compressive strength for disk ceramic samples. The Compressive Strength is calculated from the relationship:

$$Compressive\ Strength = \frac{F}{A}\ (MPa) \quad .....(1-3)$$

Where F= total load on the specimen at failure (N)

A= Cross section area of the specimen (mm^2).

3-2-2- Diametrical Compression (splitting strength)

The strength of material is its capacity to withstand destruction under the action of external loads. The stronger the material the greater the load it can withstand. It, therefore, determines the ability of a material to withstand stress without failure [9, 10]. PHYWE test machine (model 1757793, Japan) has been used in its compression mode. The applied load can be varied up to 30 tons. The crosshead speed has been fixed to 0.07mm/sec. The diameter and thickness for each disk sample have been measured and the force at fracture point (at which the sudden decrease in the load force is observed) is obtained. Equation (1-4) has been used for calculation of the splitting tensile strength.

$$\sigma_D = \frac{2F}{\pi Dt} \quad ....(1-4)$$

Where σ_D is the splitting tensile strength in Pascal (Pa), F is the maximum applied load in Newton (N), D and t are the cylinder diameter (m) and thickness (m) respectively [11,12].

3-2-3 Hardness

Hardness is the resistance to penetration various procedures are used to measure hardness. Selected specimens have been tested by Vickers indenter. The instrument uses in this test is a pyramidal indenter with a square base, made of diamond. The angle between the face is 136° [10, 13].The indenter is attached with optical microscope (Model Micromit, ADOL PHI. BUEHLER INC., optical and Metallurgical instruments, U.S.A., 60204). All the samples were ground and polished to mirror like surface. The indentation load was 500g for loading time of 40 sec. Three indents were made on each sample surface and the average diagonal dimensions of these indent was calculated to find the Vickers hardness using equation (1-5) [9, 12].

$$V.H.N. = \frac{2P\sin(\alpha/2)}{{l_{av}}^2} = \frac{1854.4P}{{l_{av}}^2}\left[\frac{kgf}{mm^2}\right] \quad .....(1-5)$$

Where: 1.854 is a constant

F = load (Kgf)

l_{av} = average of indentation diameter (mm) = $(l_1 + l_2)/2$

4-Results and discussion:

4-1 Apparent density and Apparent porosity:

Figure (1-1) and (1-2) show the Apparent density and Apparent Porosity for the SiC prepared with different kaolin content. These figures show that the (A.D.) and (A.P.) decreases monotonically (i.e. no maxima or minima) with the increasing of the Kaolin content. The decreased in densities and porosity with the increasing of the kaolin contents are normally with the lower density for kaolin (2.8 g/cm^3) comparable with the density of SiC (3.1 g/cm^3).

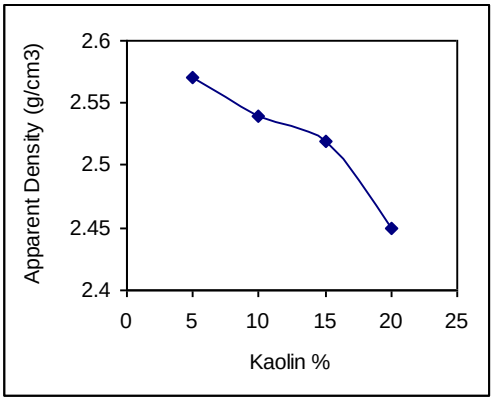

Figure (1-1): Apparent Density versus different wt% of kaolin.

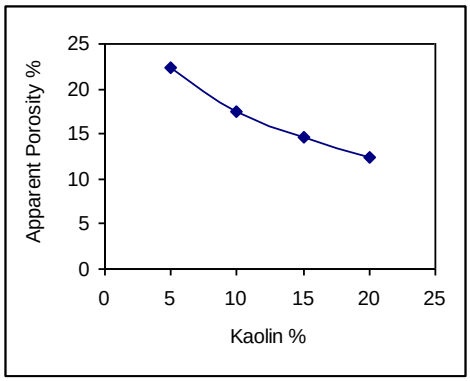

Figure (1-1): Apparent Porosity versus different wt% of kaolin.

4-2 Mechanical Properties

Compressive Strength, Diametrical Strength, and Hardness measurements were obtained and Fig (1-3, 1-4, and 1-5) show the above properties versus different kaolin content. It can be seen that the Compressive Strength, Diametrical Strength and Hardness firstly increases and then be constant as the addition content increases. The maximum improvement is attained with 20% of kaolin. The mechanical properties enhancement through the addition of kaolin content can be explained by the growth of new phase result from the alumina and silica which were already existence in kaolin composition, and good sintering temperature may also contribute to some extent to the compressive and diametrical strength enhancement [14,15].

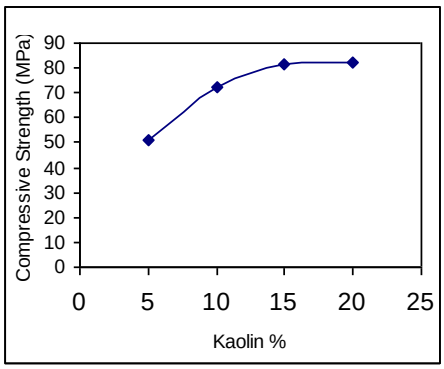

Figure (1-3): Compressive strength versus different wt% of kaolin

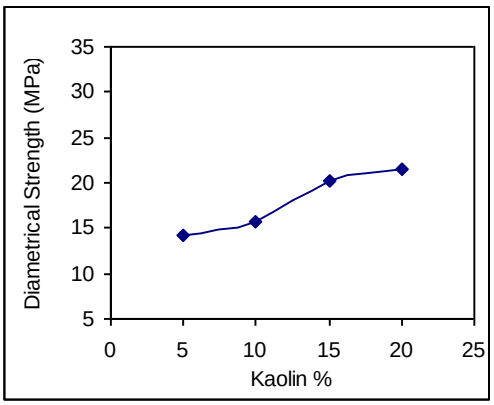

Figure (1-4): Diametrical strength versus different wt% of kaolin

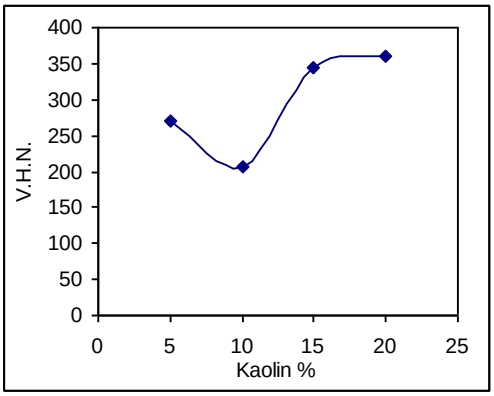

Figure (1-5): Vickers microhardness versus different wt% of kaolin

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دراسة تأثير اضافة الكاؤلين على بعض الخواص الفيزياويه والميكانيكيه لمسحوق الفا اربيد السيليكون α-SiC

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الملخص

تم في هذا البحث دراسة الخواص الفيزياويه والميكانيكيه لمسحوق الفا كاربيد السيليكون α-SiC مع اضافة اوزان مختلفه لكاؤلين دويخله. تم تحضير جميع النماذج باستخدام تقنية المسحوق بعدها تم تشكيل النماذج بواسطة الضغط وتم تلبيدها بدرجة 1400°C . ان الكثافه الظاهريه والمساميه الظاهريه لجميع النماذج تم حسابها كداله لاوزان المئويه للكاؤلين وقد بينت ان الكثافه الظاهريه والمساميه الظاهريه تتناقص مع زيادة وزن الكاؤلين وهذه النتائج يمكن تفسيرها على اساس ان كثافة الكاؤلين اقل من كثافة كاربيد السليكون. الخواص الميكانيكيه بينت ان متانة الانضغاط والمتانة القطريه والصلاده للنماذج السيراميكيه تزداد مع زيادة وزن الكاؤلين حتى تصل الى اعلى قيمه عند 20% من الكأولين المضاف هذه الظاهره يمكن ان تعزى الى وجود الالومينا والسيليكا في تركيب الكاؤلين والتي تشكل اطوار جديده تحسن من الخواص الميكانكيه السيراميك المحضر