Studying the Physical Properties of Ceramic Bodies Prepared by Slip Casting Technique

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Received 3 December 2013 ; Accepted 7 January 2014

Abstract

In this work, physical phenomena related to the growth and phase formation of alumina, (Al_2O_3), powder are investigated by experiments and computer calculations. The specimens were formed by slip casting technique. These specimens were fired at various temperatures (500, 1100 and 1600) °C. Alumina samples with different dopant percentages were prepared to study their various physical properties. Before casting, slurries with (60 wt. %) solid content and different percentages of dopant additions were prepared. The dopant used here is kaolinite with (0, 5, 10 and 15) percentage addition, where kaolinite is one of many types of raw materials that have plasticity and advantage of securing. Sodium carboxymethylcellulose (Na-CMC) solution was used as dispersant. The stability of the slip clearly depends on the percentage of dispersant added and the best ratio is found to be (0.33 ml) for each gram of solids. Kaolinite percentage increase leads to decreasing the porosity, water absorption and mass losses. But it leads to increase thermal conductivity, density and shrinkage.

Keywords: Slip casting, Alumina, Kaolinite and Na-CMC.

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دراسة الخصائص الفيزيائية للاجسام السيراميكية المحضرة بتقنية الصب الانزلاقي

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الخلاصة

في هذه البحث، تم دراسة الظواهر الفيزيائية المتعلقة بانماء وتحول الاطوار البلورية لمسحوق الالومينا (Al_2O_3) من خلال التجارب والحسابات. تم تشكيل العينات باستخدام طريقة الصب الانزلاقي. واحرقت هذه العينات بدرجات حرارة مختلفة ºC (500, 1100 و1600). حضرت عينات الالومينا بنسب تشويب مختلفة لدراسة خصائصها الميكانيكية والفيزيائية المتعددة. قبل عملية الصب، تم تحضير عوالق بتراكيز بنسبة وزنية محددة (60%), وبنسب تشويب متعددة (0, 5, 10 و15)%، اذ ان المشوب المستخدم هو مسحوق الكاؤولينايت، وهو احد المواد الخام التي تمتلك صفة اللدونة وميزة الربط. ان المادة المشتتة التي تم استخدامها هي محلول (Na-CMC). اذ ان استقرارية العالق تعتمد بشكل مباشر على نسبة اضافة المشتت، وافضل نسبة اضافة كانت (0.33 ml) لكل غرام واحد من المادة الصلبة. زيادة نسب اضافة الكاؤولينات يؤدي الى نقصان في المسامية، امتصاصية الماء والفقدان بالكتلة. بينما يؤدي الى زيادة التوصيلية الحرارية، الكثافة، التقلص.

كلمات مفتاحية: الصب الانزلاقي ، الومينا ، كاؤولينايت و Na-CMC.

Introduction

Some of the mechanical properties of ceramics have always been attractive to manufacturers. Their hardness, durability, and ability to operate effectively at high temperatures are unsurpassed by any metal, but their brittleness and difficulty in manufacturing complex shapes have been repelling factors to manufacturers [1].

Slip casting is an old and traditional process which comprises casting a slip (slurry) of particles such as ceramic particles, metallic particles, etc. which can be used as long as they are insoluble in solvent, and in particularly a method suitable for forming a cast article of high quality complex shaped bodies [2].

The common casting methods involve drain casting and solid casting; hollow bodies such as crucibles are prepared by drain casting whereas non hollow bodies are prepared by solid casting. Casting process begins by filling a mould with ceramic slurry having a pourable consistency. These common casting methods are based on colloidal system in which removal of the liquid is used to consolidate particles suspended in slurry. In slip casting consolidation of particles is accomplished as the liquid flows through a porous medium under a pressure gradient [3].

Aluminum oxide (alumina; Al_2O_3) has advantages such as its thermal, chemical, and physical properties when compared with several ceramics materials, and is widely used for firebricks, abrasives and integrated circuit (IC) packages [2].

Experimental Procedure:

For the preparation of samples through slip casting: fine powders were used such as micro alumina and kaolinite; Dispersant used is Sodium carboxymethylcellulose (Na-CMC); Solvent used is distilled water and the Plaster of Paris moulds were used for the casting. The flow chart of the slip casting process is shown in (Figure 1).

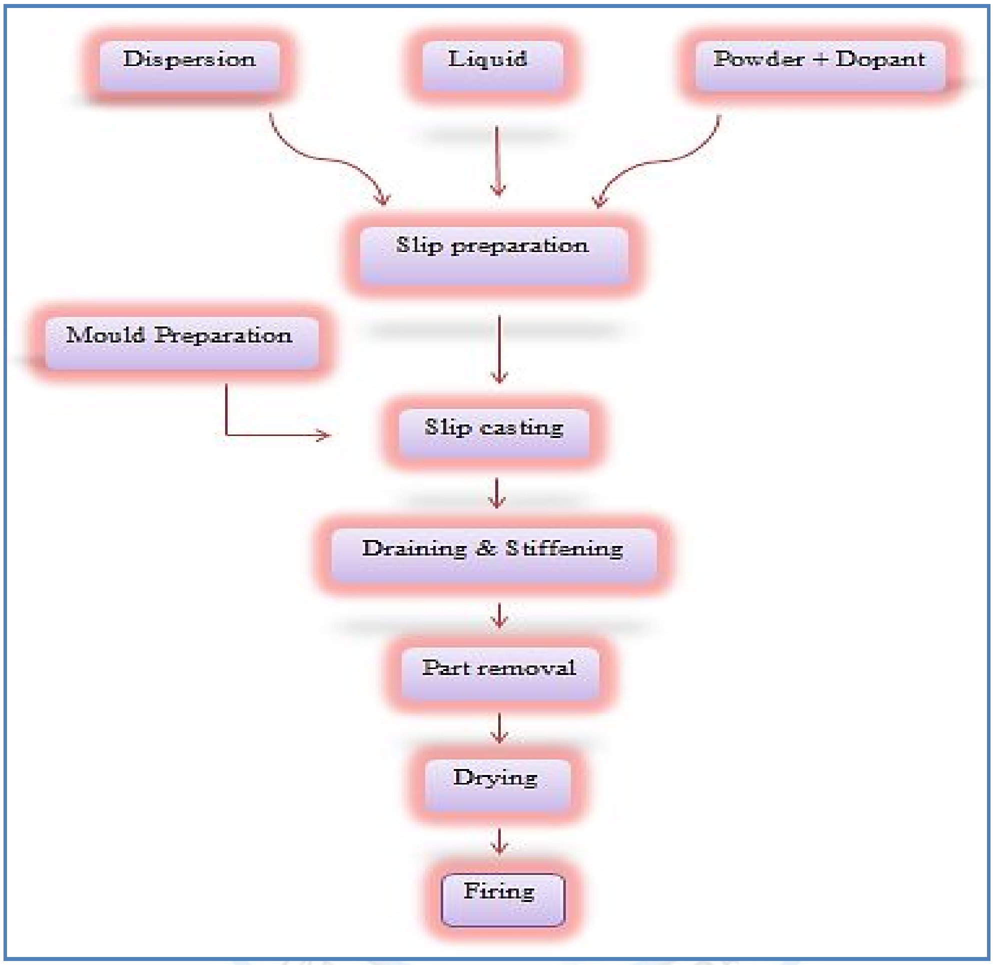


Figure (1): Flow chart of the slip casting process.

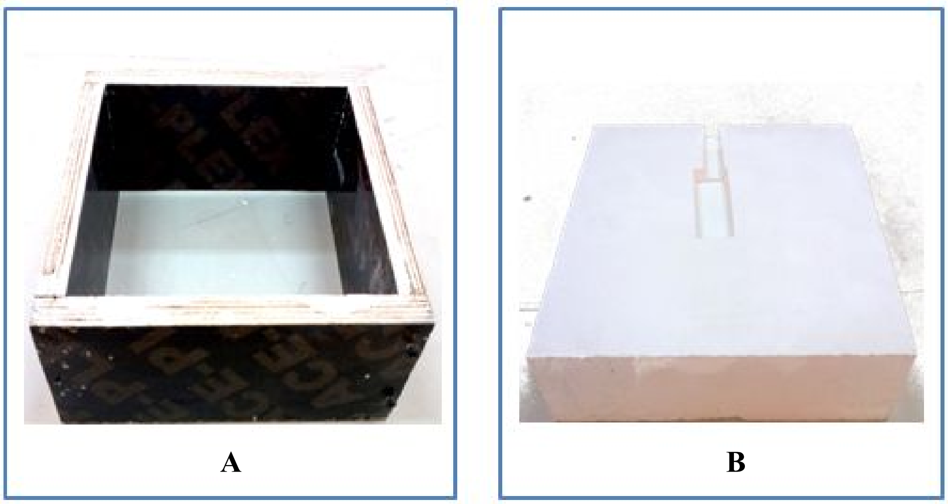
Materials

The starting materials used for this work were a commercial micro Gamma Alumina powder (γ - Al_2O_3) German origin, prepared by Merck Company with mean particle size (10 (μm)) and Purity (99.99 %).

The dopant that used here was Kaolinite micro powder ($Al_2Si_2O_5(OH)_4$), prepared by (LTD Chemicals Dearborn) Company with mean particle size (20 (μm)).

Mould making

The plaster moulds were prepared using water and Plaster of Paris in the ratio (3:4), and then the prepared mixture was slowly poured into the hollow cubical box to a certain predefined height. The body is kept for air drying for about (2 h). After (2 h) the body is removed from the wood box and kept for air drying for (24 h). Then the mould was kept in drier at (60 to 70) ºC for complete removal of water deposited at the pores (figure 2).



A B

Figure (2): Mould preparation (A) and the mould prepared for a bar sample (B).

Optimization of the Slurry

Optimization of the slip is necessary as it controls the stability, viscosity and many other casting phenomenon such as casing rates, defects generated during casting process and many more. The slurry is optimized by studying its properties so as to get a slip which is stable i.e. the suspended particles do not agglomerate or do not settle with changing time. The slip obtained by preparing samples with different dispersants and different percentage of dispersant. It was found experimentally that (Na-CMC) is the most prefer dispersant at the value of (0.33 ml) for each gram of powder, when the density of (Na-CMC) solution is (1.17 g/cm^3).

The alumina – kaolinite slurries solid content chosen to be (60 wt. %), three different weight percentages of kaolinite to alumina ((5, 10 and 15) wt. %) was used.

Casting, Drying and Firing

Once the slip is prepared, it is casted in the plaster moulds. The casting method that was used here is both the solid casting and the drain casting methods.

After casting the body, the casted body was kept away from an air draft or under direct sunlight to dry at room temperature. After (24 h) the mould is tapped slowly so as to remove the casted bodies.

The casted body is kept for air drying either under direct sunlight or at room temperature depending on the initial strength of the body. Then the sample is transferred to oven (made by (JRAD) company) for oven drying which is kept at about (60 ºC) for (24 h). So overall the drying process takes near about (2-3) days. After the bodies have dried up they are brought into shape by polishing their surfaces using a sand paper. Now the sample is ready to be fired.

Firing Program

The samples were fired in an English origin furnace made by (carbolite) company in three steps (figure 3):

a) **The first step:** Temperature rising from the room temperature with a temperature raising speed of (10 °C/min) and settled at (500 °C) for (2 hours).
b) **The second step:** Temperature rising with raising speed of (10 °C/min) from (500 °C) and settled at (1100 °C) for (2 hours).
c) **The third step:** Temperature rising from (1100 °C) with raising speed of (6 °C/min) and settled at (1600 °C) for (2 hours).

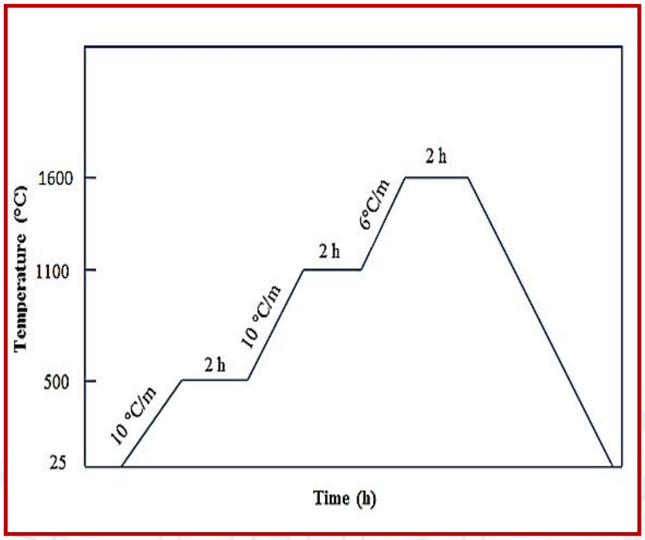


Figure (3): The firing program.

Procedure of Measurements

All the tests were calculated by take the average of over (4) specimens.

I. Mass Losses

(AS 2879.1—2000) was used as standard to determination the loss of mass by heating aluminum oxide at (60°C) and further loss of mass on ignition at sintering temperature . These mass losses are often referred to as moisture (MOI) and loss on ignition (LOI) respectively [4]. Equation (1) is used to calculate it.

$$L.O.I. = \frac{m_o - m}{m_o} * 100\ \% \qquad \text{.........................} \ (1)$$

Where;

m_o: Sample wet mass

m: Sample fired mass

II. Linear Shrinkage

(ASTM C326 – 09) [5] was used as standard to test the linear shrinkage of the specimens, and the (L.S.) is calculated from equation (2).

$$\%\ linear\ shrinkage = \frac{L_o - L}{L_o} * 100\ \% \qquad \text{.....................} \quad (2)$$

Where L_o: initial length of test specimen (before firing)

L: fired length of test specimen.

III. Bulk Density (BD), Apparent Porosity (% AP) and Water Absorption (A)

These tests were determined according to the (ASTM C20 – 00) [6]. The Bulk Density was calculated by using equation (3), the apparent porosity (% AP) was calculated by using equation (4) and the water absorption was calculated by using equation (5).

$$BD = \frac{Wd}{Wd - Wi} \qquad \text{.........................} \quad (3)$$

$$\%\ A.P = \frac{Ws - Wd}{Ws - Wi} * 100 \qquad \text{...................} \quad (4)$$

$$\%\ A = \frac{Ws - Wd}{Wd} * 100 \qquad \text{..........................} \quad (5)$$

Where:

Wd: dry weights

Ws: soaked weights

Wi: immersed weights

IV. Thermal Conductivity

Lee's disk method is used to measure the thermal conductivity of the specimens. The Lee’s disk apparatus made by (Griffin and George) company was used (figure (3-15). The thermal conductivity calculated from the equation (6) [7].

$$K\frac{(Tu-Tm)}{ds}=h(\,Tm+\frac{2}{r}\left(dm+\frac{1}{4}ds\right)Tm+\frac{1}{2r}dsTu) \qquad \text{.......... (6)}$$

Where, (T_U): temperature of disk (U), (T_M): temperature of disk (M), (r): radius of the disk, (d_M): thickness of the disk (M), (ds): thickness of the disk (S) (specimen) and (h): heat loss per (second/cm^2) for one degree in excess of temperature of disk over that of the enclosure.

Results and Discussion

Effects of Kaolinite Additions

Physical properties were measured to explain the effects of kaolinite additions on micro alumina samples.

I. Linear Shrinkage

Figure (4), shows the linear shrinkage percentage variations with kaolinite additions. Clearly, dimension shrinkage increases when kaolinite addition is increased. This is due to high shrinkage of kaolinite (28%) in comparison with alumina (less than 1%) [8, 9].

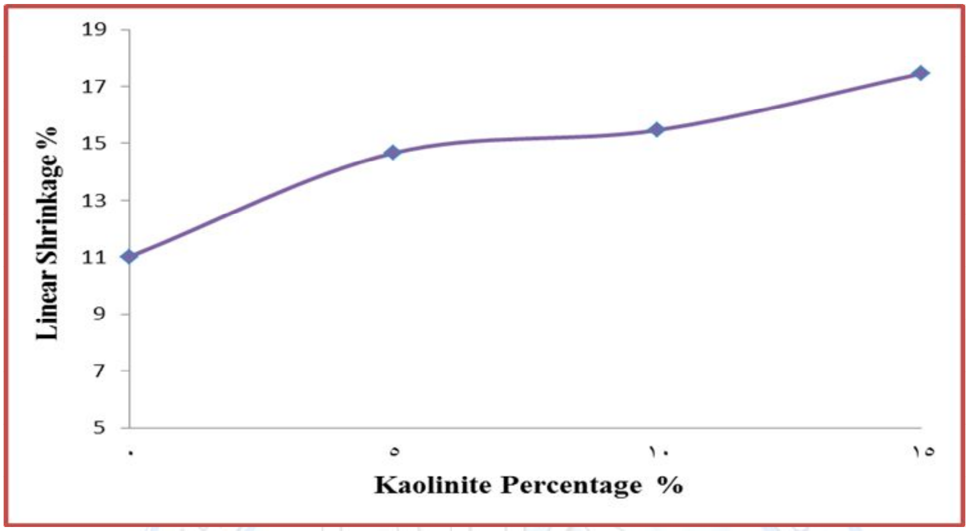


Figure (4): Effect of kaolinite percentage additions on shrinkage.

II. Mass Loss

Mass loss is shown in figure (5) for the specimens, it is decreasing with increasing kaolinite additions, this is natural situation because of the decreasing of moisture by increasing of kaolinite ratio [4].

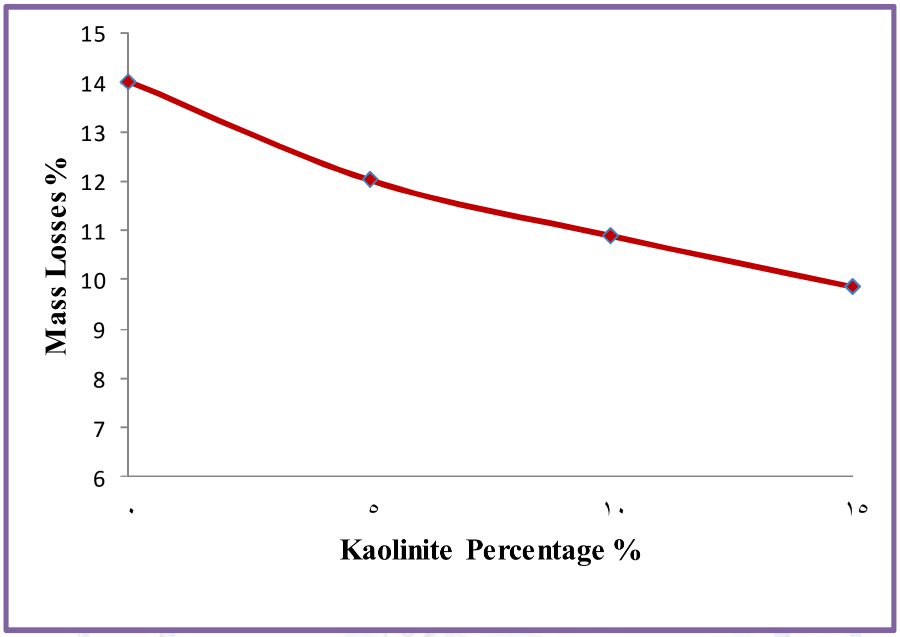


Figure (5): Effect of kaolinite percentage additions on loss on ignition.

III. Density, Porosity and Water Absorption

Lower density of addition materials leading to decreasing the density of specimen. But here in the case of (alumina – kaolinite) slip casting the contrary was occurred, and that is a normal situation because of tow main reasons; the first is the low percentage addition of kaolinite (5 – 15)%, and the second is the effect of casting rate which increase by the increasing of kaolinite ratio because of the plastic property of clay, and that lead to increase the density because of the high reduction of porosity during forming process [10, 11]. Therefor the density is increasing with increasing of kaolinite and that is clear in figure (6). Figure (7) and (8) shows the decreases of porosity and water absorption respectively with kaolin additions for the same cause.

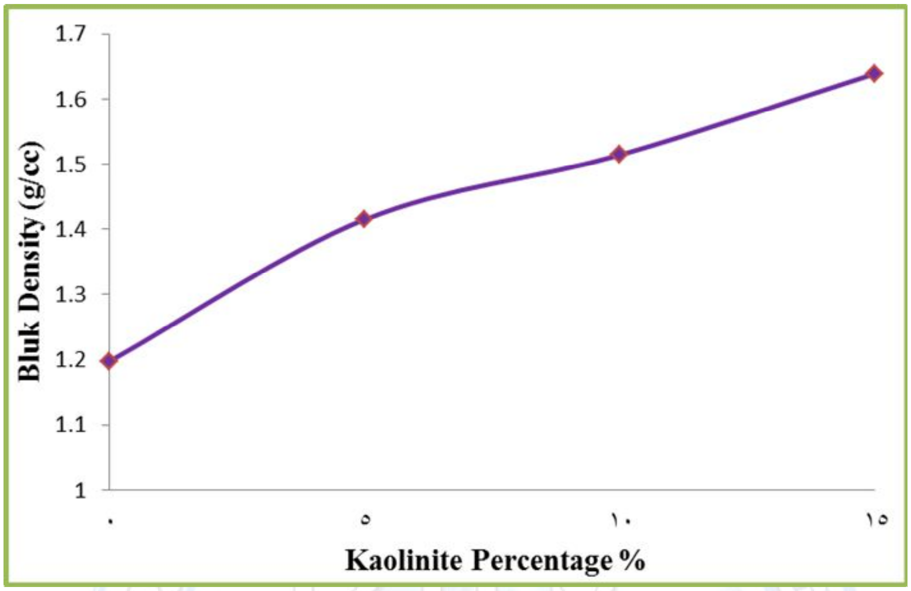


Figure (6): Effect of kaolinite percentage additions on bulk density.

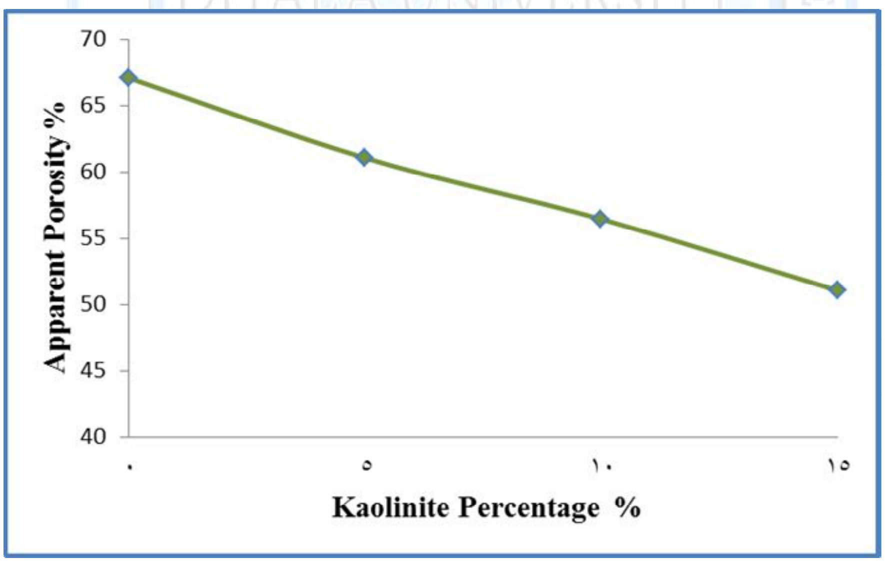


Figure (7): Effect of kaolinite percentage additions on apparent porosity.

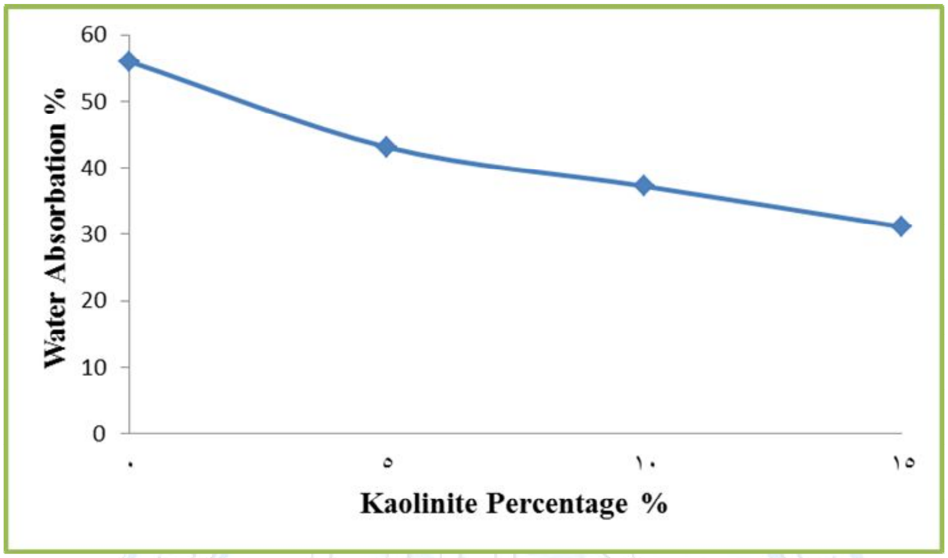


Figure (8): Effect of kaolinite percentage additions on water absorption.

IV. Thermal Conductivity

Thermal conductivity of alumina samples, naturally, decreases with clay additions [7]. But here the thermal conductivity increases with kaolinite additions, the main cause is the increase in kaolinite ratio leads to decrease in the porosity and consequently increase in thermal conductivity (figure (9)) [7].

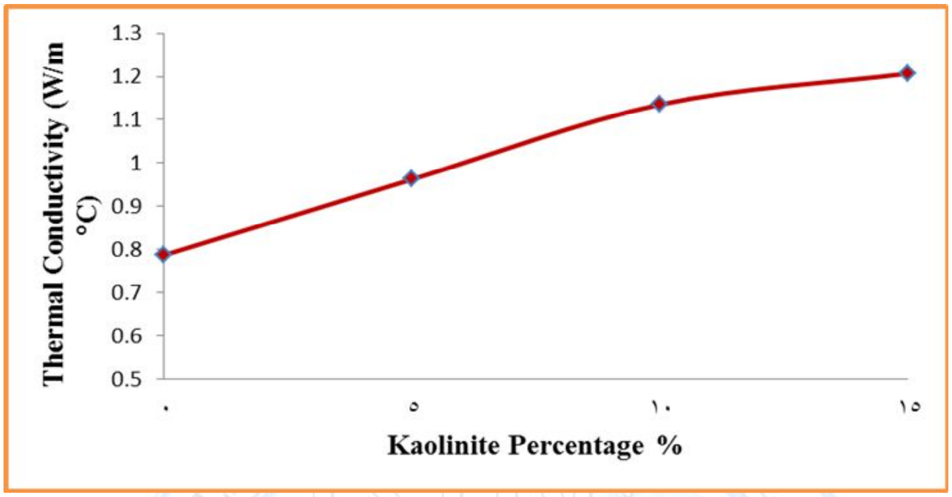


Figure (9): Effect of kaolinite percentage additions on thermal conductivity.

Conclusions

The high porosity of samples and low thermal conductivity make a possibility of using them in the thermal insulation, filters, light blocks and furnaces lining. Among many dispersants available here the (Na-CMC) act as a good dispersant and binder. The Kaolinite act as a binder for the alumina particles.

References

1. A.G. Lamas, M. Almeida, H.M.M. Diz, "Slip-casting of alumina bodies with differential porosities", Journal of the American Ceramic Society, 85, (2002), (pp. 3126 – 3132).
2. T. Natori, T. Shimaguchi, T. Yamada, "Method of forming cast article by slip casting", United states patent, 4, (1989) (pp. 621 632).
3. J. S. Reed, Principles of Ceramics Processing, 2nd edition Wiley, New York (1995).
4. AS 2879.1, "THE IMPORTANCE AND TESTING OF DENSITY / POROSITY / PERMEABILITY / PORE SIZE FOR REFRACTORIES", (2010).
5. ASTM C326 – 09, "Standard Test Method for Drying and Firing Shrinkages of Ceramic Whiteware Clays", Annual Book of ASTM Standards, (2009).

6. ASTM C20 – 00, "Standard Test Methods for Apparent Porosity, Water Absorption, Apparent Specific Gravity, and Bulk Density of Burned Refractory Brick and Shapes by Boiling Water", (2010).
7. S. A. Z. Al-Jeboori, Ph.D. Thesis, University of Technology, (2005).
8. N. Claussen, T. Le and S. Wu, "Low shrinkage reaction bonded alumina", Journal of the European Ceramic Society, 5, 1, (1989), (pp. 29–35).
9. K .H. Mohammed, "Reducing Kaolin Shrinkage by Using Kaolin Grog", Journal of Babylon University, 18, 4, (2011), (pp. 713 -724).
10. Y. Zhang, J. Binner , "Enhanced casting rate by dynamic heating during slip casting " Journal of the European Ceramic Society, 22, (2002), (pp. 135–142).
11. C. Falamaki, M. Beyhaghi, "Slip casting process for the manufacture of tubular alumina microfiltration membranes "Materials Science-Poland, 27, 2, (2009), (pp. 427-441).