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Improving mechanical and electrical properties of Ca bentonite for energy storage applications

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Abstract

In the present study the effect of silica and alumina addition on the electrical and mechanical properties of Iraqi calcium bentonite clay have been investigated. The prepared specimens were compacted at 100 MPa as a disc shape and then treated with firing temperatures of about (1000 ºC, 1100ºC, 1200 ºC, 1300 ºC). The samples were examined with XRD to identify the structural phases, also we have examined the physical properties (apparent porosity and apparent density) and the electrical behavior as a function to applied frequency range from 50Hz to 1MHz. While the mechanical tests include Brinell hardness test (BHN) and diametrical strength. The best electrical parameters at 1MHz have been showed for the sample fired at 1200 ºC while the best mechanical tests have been showed for the sample fired at 1100 ºC which has the mullite phase content as the dominant phase (57.5 %).

Introduction

All types of clays are Intervene in many industries, therefore many researchers were studied the subject of improving the different properties of clays like electrical and mechanical properties, so the selection of the type of raw materials plays a vital role in final products[1,2]. Because of the wide range applications of the bentonite clay, it has gained attention from some of researcher for using it as insulators devices used in an electrical circuits. Some of them studied the effect of magnesia and alumina addition on electrical behavior of the formed samples [3]. Also the effect of free silica addition which makes the clay more refractory is studied [4]. While our idea in this research is to study the effect of alumina addition beside the effect of silica to enhance the insulation properties of the bentonite clay. These type of additions to the bentonite, after sintering at high temperatures, produce very porous ceramics with microcrystalline and amorphous regions [5]. The reaction between $Al2O3$ and $SiO2$ result in the formation of mullite phase especially above 1400 C which plays an important role in the design's strength in terms of mechanical and dielectrically[6].

Material and Methods

Depending on the idea of mixing (20 wt%) silica with (80 wt%) Ca bentonite (7), we have fixed the ratio of the clay (80 wt%) and divide the additive into two portions (10 wt% silica and 10 wt% alumina). The ceramic samples were formed by wet mixing method for 8 hours with magnetic stirrer then dried at 100 ºC and compacted at 100 MPa for one minute by hydraulic press model (RINLNG) using steel die (with 25 mm in diameter and 3 mm in thickness), then fired with electric muffle furnace at heating rate 5 ºC/min till the temperature reaches to (1000, 1100, 1200, 1300) ºC and hold at these temperatures for 2 hours, after that the samples were left to cool at room temperature. The amounts of various phases which are present in the raw and fired ceramic bodies (figures 1-4 respectively) were investigated by powder X-ray diffraction technique using diffractometers model (Philips-pw 1840) with the following characteristics target Cu. Wavelength (λ)=1.5405Å, speed 3deg/min, filter Ni, power:40Kv, 20mA. The physical properties include apparent density and porosity of the sintered samples which determined by using Archimedes Method [8]according to ASTM (C20-18T) [9]. While the mechanical properties represented by the test of Brinell Hardness Number (BHN) as explained at the reference [10] and diametrical strength (σD) as illustrated in Ref.[11]. The dielectric parameters were evaluated by measuring the capacitance Cp and and loss tangent (tanδ) different frequencies ranging from (50Hz-1MHz) at room temperature. The method and equations used are described in details at Ref. [3].

Results and Discussion

Porosity results show a sharp rise with the firing temperatures as shown in the figure [5] especially at 1300 ºC depending on bentonite structure where the creation of a pressure when raising the firing temperature which leads to make internal cracks and holes within the material [3], while the highest value for apparent density (figure 6) is at 1200 ºC due to the mullite concentration increment which has a high density (ρmullite= 3.12 gm/cm3). The Brinell hardness number (BHN) and the diametrical strength (σD) results of the specimens are shown in the Figures (7, 8) respectively. The higher value of (BHN) is found at the firing temperature 1100 ºC of about 70, as well as in the case of the maximum value of (σD) which is about 80 MPa at the same firing temperature. Because of the porosity effect which has the lowest values (7.4 – 9) at 1000 ºC and 1100 ºC. In regard with dielectric parameters, the dielectric constant (ε' r) values decrease with the applied frequency increment as shown in fig. (9) which refers to the polarization effect especially at the low frequencies while at high frequencies the space charge cannot shift orientation direction with applied field, leading to a decrease in polarization, consequence remaining only the electronic polarization effect which works efficiently at low frequencies [12]. The higher values of (ε' r)at low and high frequencies are found at the firing temperature 1200 ºC, which is about 5.6 at 1MHz, may be due to increase the mullite phase at the expense of cordierite phase. The results of the dielectric loss factor (ε r″) and dielectric loss tangent (tanδ) are plotted in the figures (10) and (11) respectively and showed a decreasing with their values with increasing the applied field. Also at 1 MHz, the values of (tanδ) and (ε r″) decreased with firing temperature increasing and the value of (tanδ) is almost close at 1200 ºC and 1300 ºC while the value of (ε r″) at 1200 ºC is higher than at 1300 ºC due to the effect of dielectric constant value which is higher at 1200 ºC. Figures (12 and 13) shows the results of both resistivity and alternating electrical conductivity. The maximum valu of the resistivity is at 1200 ºC due to the effect of mullite concentration which has > 1014 ohm.cm [13]. While the results of the break down voltage as a function to the firing temperature are shown in the figure (14). The maximum value was (25.6 Kv) for the sample fired at 1200 ºC due to the effect of decreasing the cordierite phase content in this sample. Figure (15) refere Dielectric strength (Kv/mm)with firing temperature for specimens.

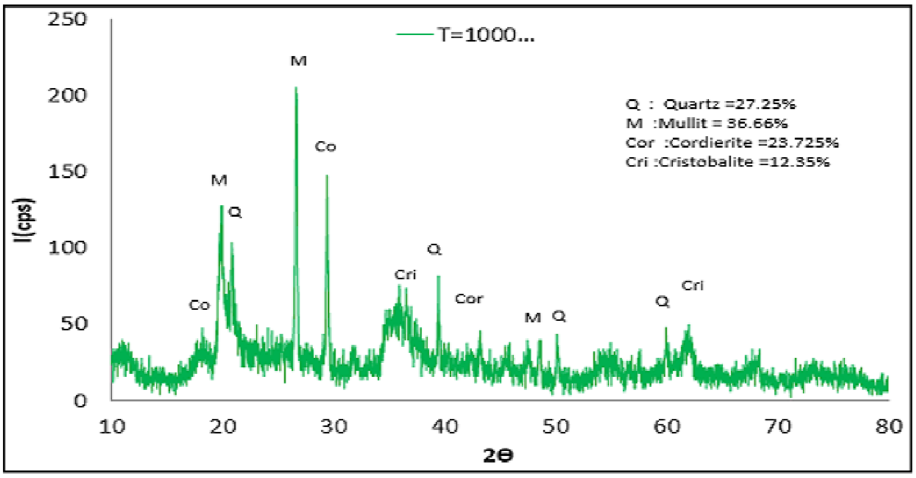

Fig. (1): XRD pattern for the fired specimen at 1000°C

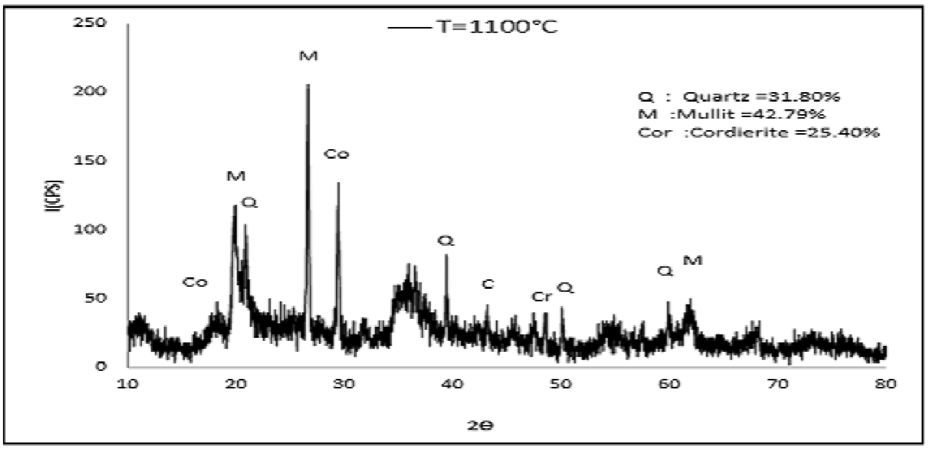

Fig. (2): XRD pattern for the fired specimen at 1100°C

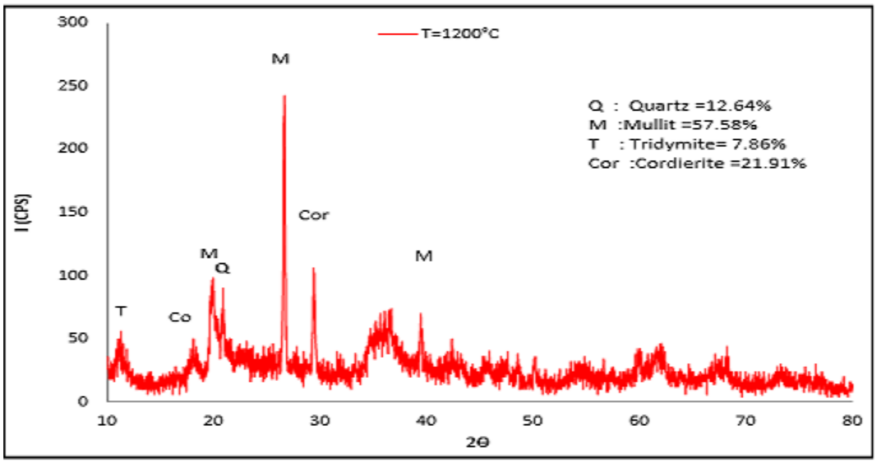

Fig. (3): XRD pattern for the fired specimen at 1200°C

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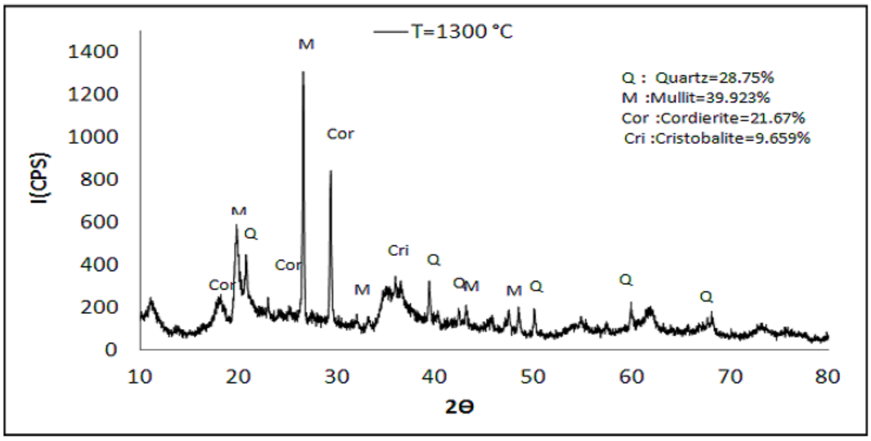


Fig. (4): XRD pattern for the fired specimen at 1300°C

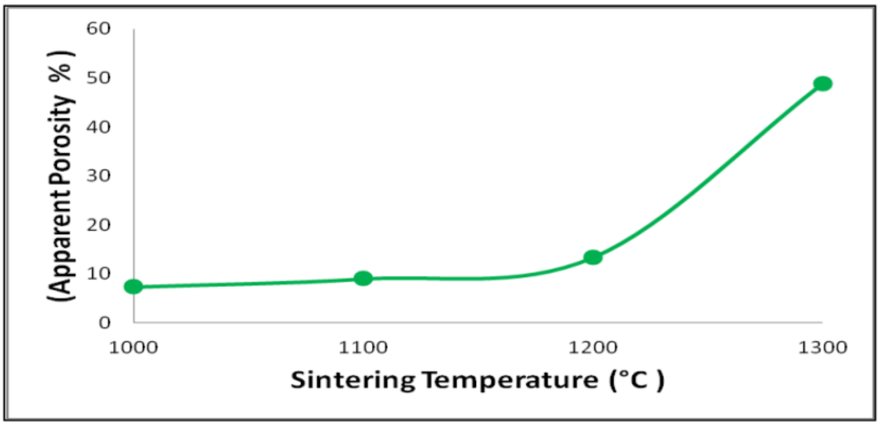


Fig. (5): porosity with firing temperature for specimens compacted to 100MPa with different sintering temperature.

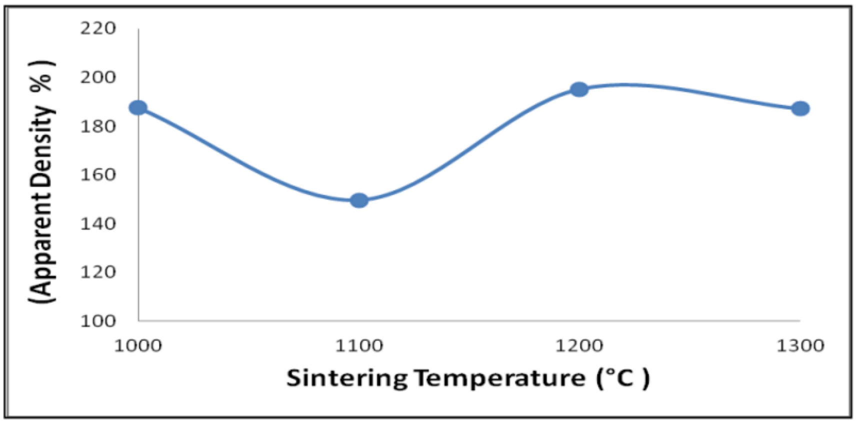


Fig. (6): The apparent density with firing temperature for specimens compacted to 100MPa with different sintering temperature.

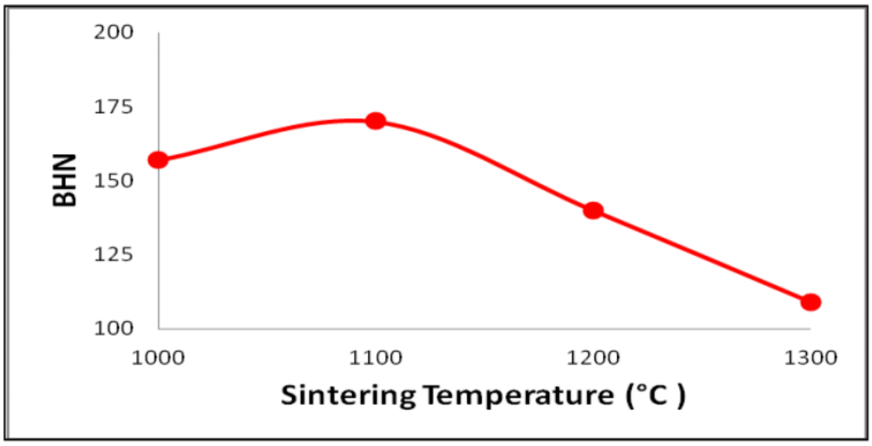


Fig. (7):: Brinell Hardness Number (BHN) for specimens compacted to 100MPa with different sintering temperature.

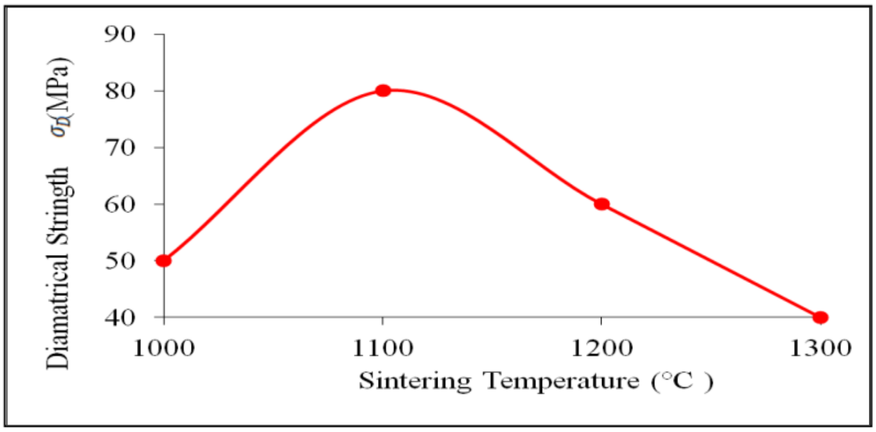
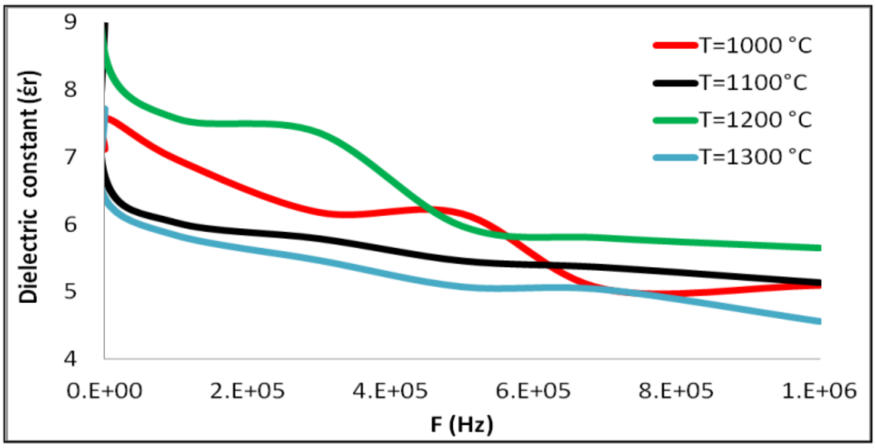


Fig. (8): diametrical strength (σD) with firing temperature for specimens compacted to 100MPa with different sintering temperature.



Figre (9) Dielectric c nstant (ε' r) with frequency for specimens compacted to 100MPa with different sintering temperature.

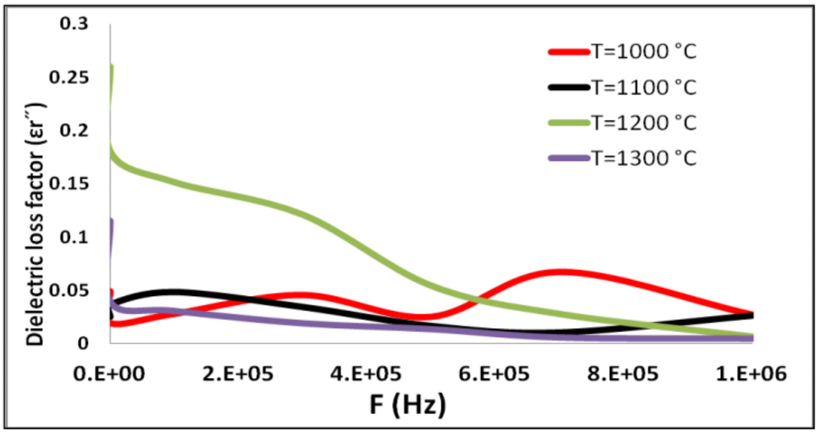


Figure (10): ielectric l ss fact r (εr″) with freq ency for specimens compacted to 100MPa with different sintering temperature.

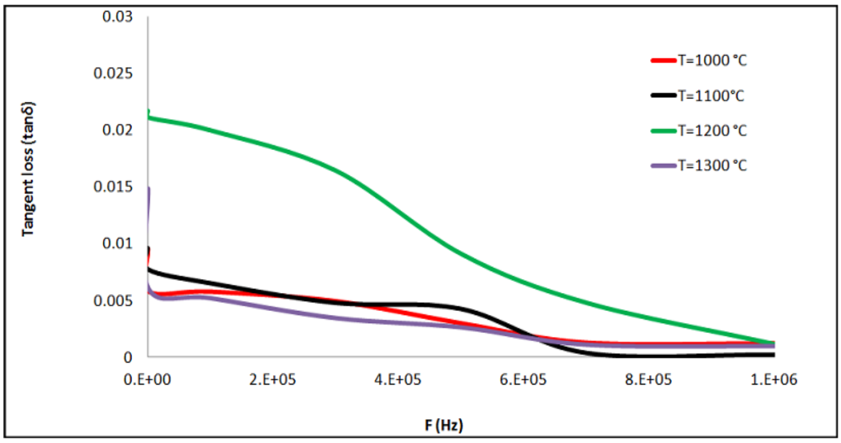


Figure (11): Tangent l ss (tanδ with frequency for specimens compacted to 100MPa with different sintering temperature.

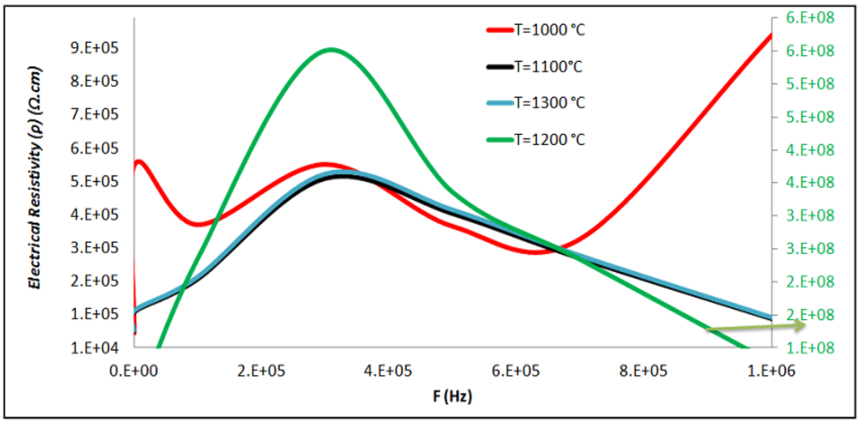


Figure (12): Electrical Resistivity (ρ (Ω.cm)with frequency for specimens

compacted to 100MPa with different sintering temperature.

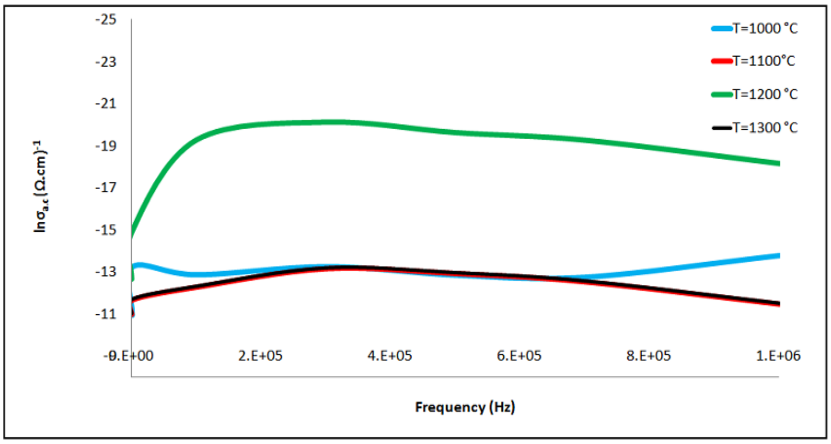


Figure (13) Alternating Electrical Conductivity with frequency for specimens compacted to 100MPa with different sintering temperature

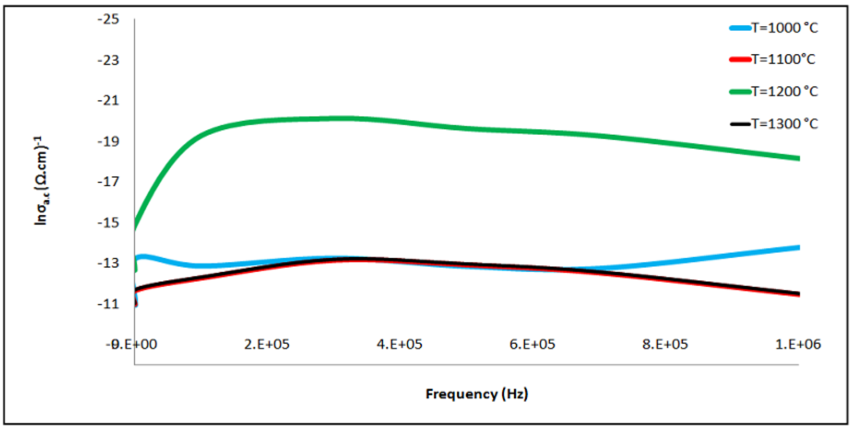


Figure (13) Alternating Electrical Conductivity with frequency for specimens compacted to 100MPa with different sintering temperature

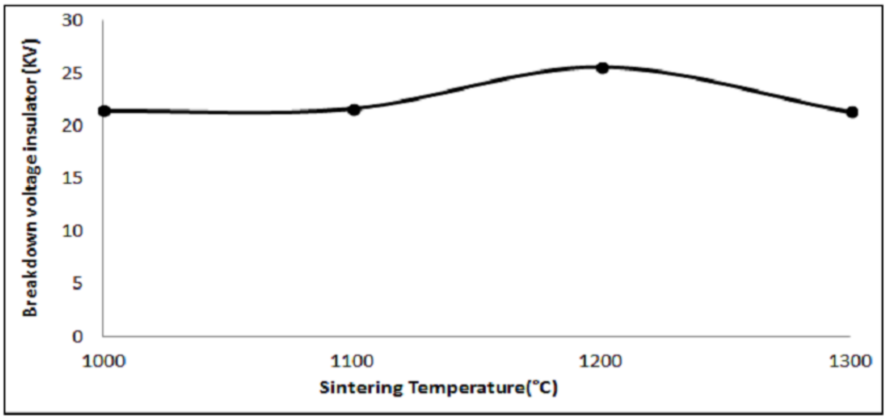


Figure (14): Breakdown voltage insulator (KV) with firing temperature for specimens

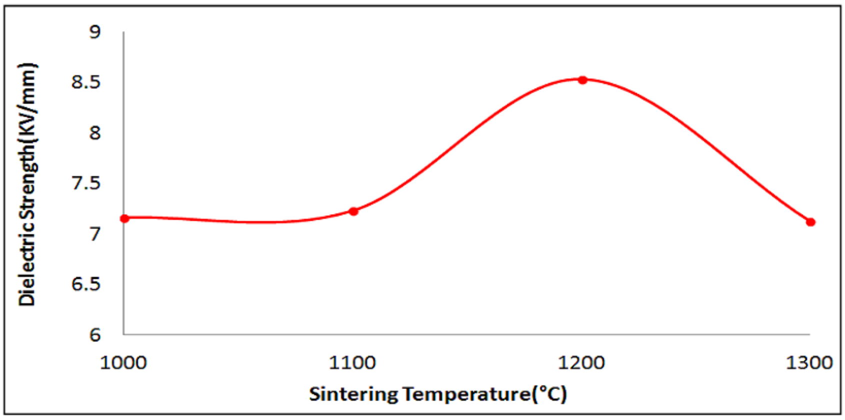


Figure (15): Dielectric strength (Kv/mm)with firing temperature for specimens

Conclusions

The effect of silica/alumina addition on the bentonite insulation behavior has been investigated with XRD and dialectical parameters and mechanical characteristic. The ultimate results of mechanical properties was at the sample fired at 1100 ºC while the best electrical properties was with the sample fired at 1200 ºC.

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