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Evaluation of the Electrical and Mechanical Performance of the Ceramic (Bentonite Clay/Silica)

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Abstract: In this work, Iraqi clay has been modified with the addition of 20 wt% silica to prepare ceramic bodies for electrical insulating applications and raising the thermal withstand capability for them. By using forming pressure (100 MPa), the samples have been formed as a disc shape and then treated by using firing temperature (1000 ºC, 1100 ºC, 1200 ºC, 1250 ºC). The X-ray diffraction result (at1250 ºC) showed that the exist main phases are: Tridymite, Mullite, Cordierite and Corundum phase. The electrical behaviour has been investigated in the frequency range 50Hz to 1MHz. The parameters dielectric constant, dielectric loss, dissipation factor and A.C. Electrical conductivity has been calculated beside the mechanical measurements. Sample fired at 1250 ºC showed the best results of both mechanical and electrical measurements (at 1MHz).

Keywords: Ceramic, Silica, Bentonite, Mechanical properties, electrical properties.

INTRODUCTION

Clay plays superior role in human life because of their wide ranging properties, high resistance to atmospheric conditions and low price[1]. Bentonite clay is a highly plastic clay composed predominantly of smectite clay minerals (Na and Ca montmorillonite)[2]. The structure is able to absorbe water between the layers results in swelling of clay, hence this type of clay is termed an expanding lattice[3], and with

exploit this characterization for generating the porosity to enhance the insulating properties of the prepared ceramic bodies during the time of firing. As a basis of traditional and modern ceramic fabrication, raw material selection plays a vital role in the final product design[4]. Some researchers used bentonite clay as a matrix for producing ceramic bodies with the addition of alumina and magnesia and study their physical properties[5, 6]. While the researcher "H. Shatha", studied the addition of free silica to bentonite clay as matrix and studied the physical properties for the produced specimens[7].

The addition of silica makes the clay more refractory by reducing shrinkage and drying problems where the silica will combine with other minerals and form a glassy substance with fluxes in the clay during firing[8]. These glass, ceramic substances are optimized for high technical strength, high temperature capability, dielectric breakdown resistance[9]. In this research, insulating properties were studied for the best ceramic samples which prepared in the ref. [7] in terms of the least porosity and a plane for the future, we can study the improving insulation properties by coating the samples with a proper polymer for this purpose and utilizing them in applications that require a good electrical insulation and mechanical strength.

EXPERIMENT

The raw materials used for this study are:

Iraqi bentonite clay with fractions ≤ (25 μm). The chemical analysis of this clay is given in Table (1). Figure (1) shows the x-ray diffraction patterns for the raw bentonite obtained by using XRD unit model (7000), target Cu, (λ) =1.5405 °A, 40 Kv, 30 mA.

Table 1: Chemical analysis of ca-Bentonite sample

Material Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	MgO	SO_3	L.O.I.
Bentonite(wt%)	53.08	4.52	14.74	0.93	7.56	3.60	1.63	1.11

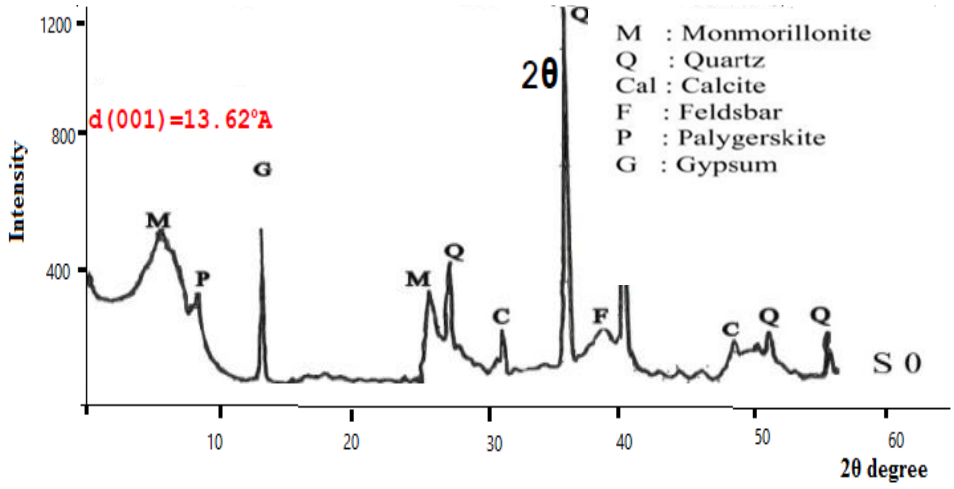

Fig. 1: X-Ray diffraction patterns of Bentonite material.

Silica (SiO_2) with 99.99%purity and particle size (10 µm) supplied by Fluka company. The best mixing ratios (bentonite 80 wt% and SiO_2 20 wt%) which have been showed the best results in the physical properties from reference[7] is used to prepare the ceramic bodies for this study, by using wet mixing method at 80ºC for 8hours using a mechanical stirrer then drying at 100 ºC followed by crushing to get best fine mixing. The crushed samples (6 gm for each) were compacted at 100 MPa for one minute using steel die (of 2.5 cm diameter and 0.3 cm thickness) by hydraulic press model (RINLNG). Then sintered using carbolite furnace at heating rate 5 ºC/min and up to firing temperature of about (1000, 1100, 1200, 1250) ºC for 2hours then left to cool at room temperature. The dielectric parameters were evaluated by measuring equivalent parallel capacitance C_p and dissipation factor D (tanδ) or the equivalent resistance R_p of the sample by using this equation:

$$\epsilon_r' = \frac{C_p}{C_o}, \epsilon_r'' = \frac{\epsilon_r'}{\omega C_p R_p} \text{ or } \epsilon_r'' = \epsilon_r' D \quad \ldots (1)$$

Where C_o= 0.08854 *A/t in P_f , is the geometrical capacitance of vacuum of the same dimensions as the sample. A and t are the area and thickness of the sample respectively and f the measuring frequency. C_p is the capacitance measured in P_f, (ε_r') the real dielectric constant and (ε_r'') the imaginary dielectric constant, D or (tanδ) is the loss factor[10]. The Brinell hardness test was calculated by dividing the load applied by the surface area of the indentation to evaluate the mechanical endurance of the specimens[11]. BHN = 2 P / (π D (D - (D2 - d2)1/2)) where BHN = Brinell Hardness Number, P = load on the indenting tool (kg), D = diameter of steel ball (mm), d = measure diameter at the rim of the impression (mm). While the equation used to calculate the ultimate tensile strength (UTS) is [12]:

UTS (MPa)= 3.45 * BHN … (2)

RESULTS AND DISCUSSION

Figure (2) shows the change of the dielectric constant values (ε_r') as a function of applied frequencies in the range (50 Hz – 1MHz). At low frequencies (≤ 1000Hz) a sharp rise in (ε_r') values refers to the polarization effect while a low change (approximately constant values for all firing temperatures) at frequency (1MHz), where the space charge cannot shift orientation direction with applied field and the polarization drops out, so only the electronic polarization remain[13]. At (1MHz) the values of (ε_r') increase as the firing temperature increases down to (1250ºC) which may due to the presence of mullite and cordierite phase (as shown in the Fig. 3) that lead to increase the space charge polarization and consequently the (ε_r') values increase. Figure (4) shows the results of dielectric loss factor (ε_r'') which decreases with increasing firing temperature and applied frequency down to $1.734*10^{-11}$ at 1250ºC and 1MHz. The loss tangent (tanδ) for the samples is plotted as a function of applied frequency (from 50 Hz to 1MHz) as shown in Fig. (5) and show very low values at 1MHz, the results of (tanδ) vary from $7.11*10^{-10}$ to $2.67*10^{-12}$ with the variation of firing temperature which consider to be in

acceptable range of industrial applications when compared it with some types of ceramic materials (such as: SiC=$5x10^{-2}$ and Al_2O_3= $3x10^{-4}$) [14]. It is observed from the Figure (6) that the alternating electrical conductivity ($\sigma_{a.c}$) increases as the applied frequency increases up to 1MHz. Also (σa.c) values decrease as the firing temperature increases to 1250 ºC especially at 1MHz which has the lower value of ($\sigma_{a.c}$) (0.1325 at 1000 ºC to $7.08*10^{-4}$ $(\Omega.cm)^{-1}$ at 1250 ºC due to the decrease in the impurities concentration and porosity values[15] and vacancies concentration, which change in composition in grain boundaries and crystal structure which has an effect on (ε_r'') and the loss tangent (tanδ), subsequently on the (σa.c) values[15].

The Brinell hardness number (BHN) and the ultimate tensile strength of the specimens are shown in the Figures (7, 8) respectively. The (BHN) are found to be in the range of (73 to 136). It becomes higher when the sintering temperature increases due to the porosity decreasing, which means the increasing of resistance to external bodies penetration and then wear resistance. Also the (UTS) values, show an increasing as firing temperature increases till it reached to (469.2 MPa) at 1250 ºC , due to decreasing of porosity and the presence of flaws[16] (as shown in the Table below).

Firing temperature	1000 ºC	1100 ºC	1200 ºC	1250 ºC
Apparent porosity %	33	28	21	11

CONCLUSION

Ceramic body prepared from calcium bentonite with the addition of silica gives a good results in the physical and electrical characterization compared with industrial insulating materials. The addition of 20 wt% from SiO_2 to 80 wt% of Ca bentonite fired at 1250 ºC gives best electrical behavior at 1MHz and optimum (BHN and UTS).

Fig. 2: Dielectric constant as **a** function to applied frequency.

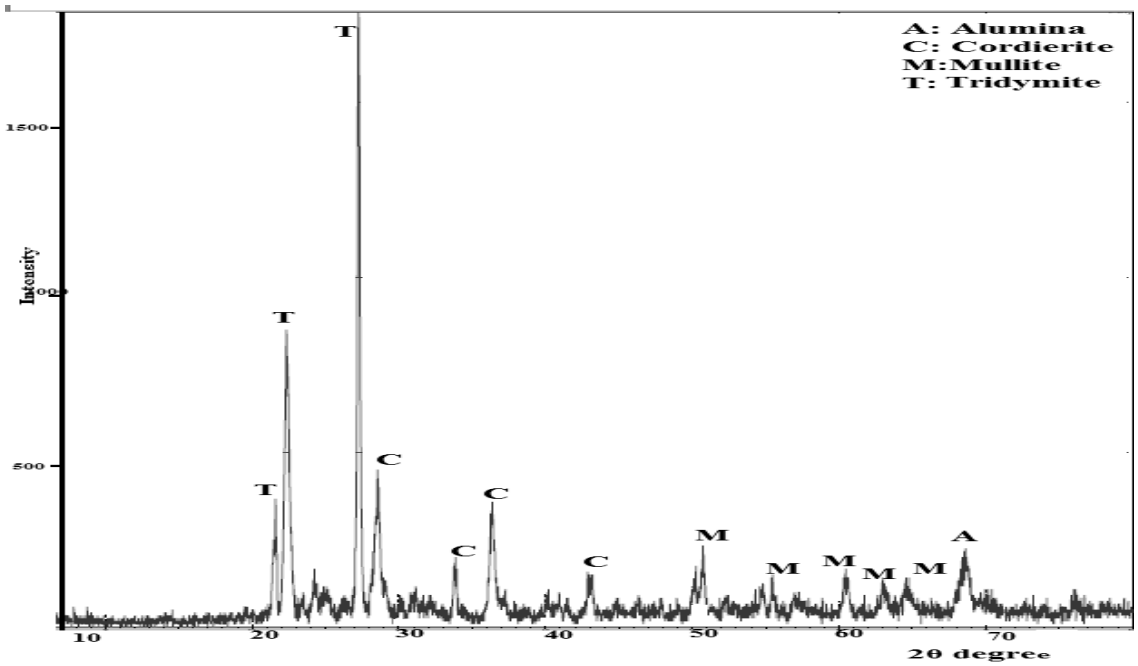

Fig. 3: X-Ray diffraction patterns for the fired sample at 1250 ºC.

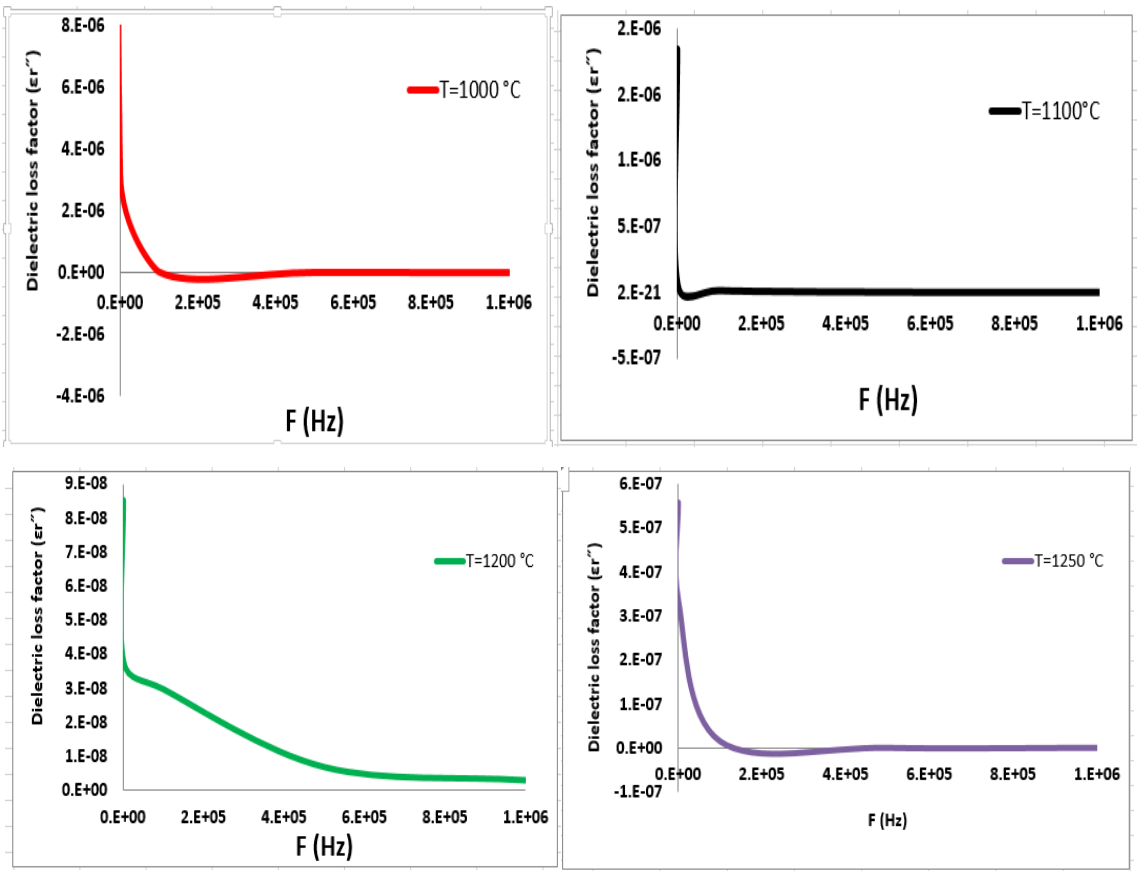

Fig. 4: Dielectric loss factor as **a** function to applied frequency.

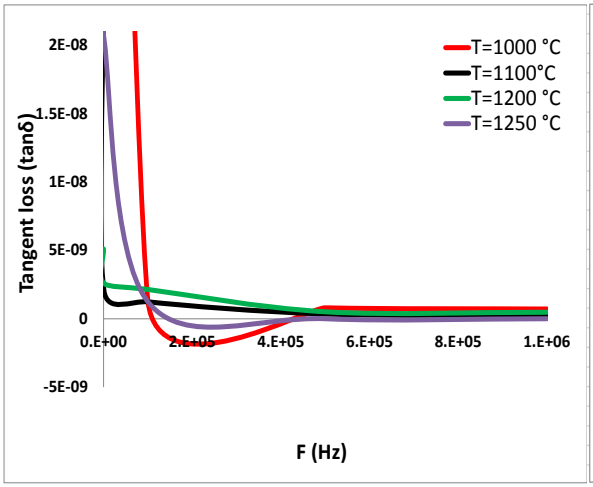

Fig. 5: Tangent loss factor as a function to applied frequency

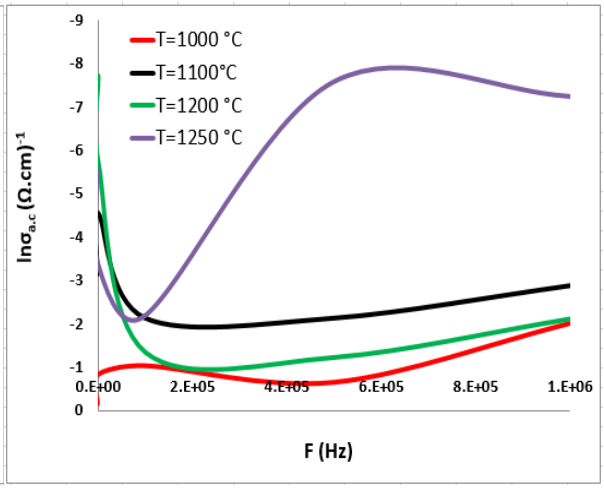

Fig. 6: A.C electrical conductivity as a function to applied frequency

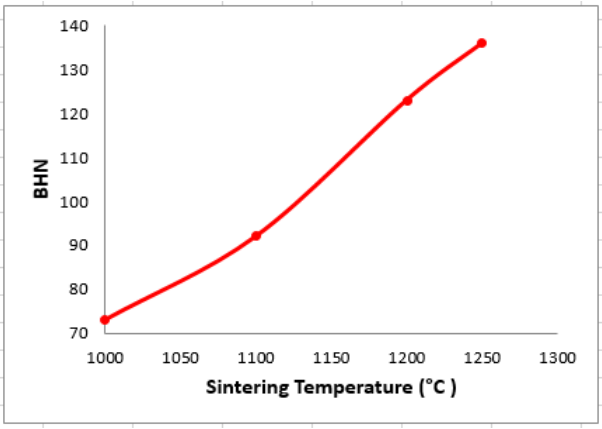

Fig. 7: Brinell hardness number as a function to applied frequency

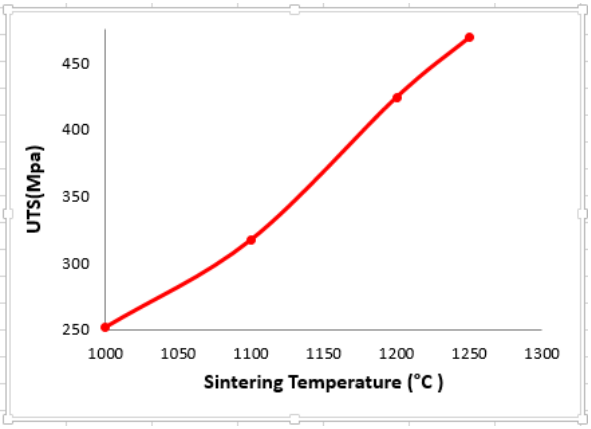

Fig. 8: Ultimate tensile strength as a function to applied frequency

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