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Influence of alumina and silica addition on the physico-mechanical and dielectric behavior of ceramic porcelain insulator at high sintering temperature

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ABSTRACT

The high-strength electrical porcelain insulator plays a vital role in the power industry. The present study investigates the effect of alumina and silica addition on the physico-mechanical and electrical properties of porcelain bodies over high sintering temperatures. The pallets were prepared in different shapes and dimensions with the help of hydraulic press machine by pressing at 160 MPa for a period of 10-min. Different characterizations techniques such as; dilatometer, X-ray diffraction (XRD), and scanning electron microscopy (SEM) used to evaluate the thermal, structural, and microstructural changes, respectively by increasing the concentration of silica (0–20 wt.%) and decreasing alumina (45–25 wt.%) concentration for the base composition of porcelain insulator. The measurement of mechanical strength and physical behavior were analyzed for all the samples prepared with different compositions of alumina and silica with varying sintering temperature (1250 and 1350 °C). The sample with a composition having silica 10 wt.% of alumina 35 wt.% and sintered at 1350 °C, shows the maximum density of 2.55 g/cc with water absorption of 0.94%. This sample also shows the highest value of bending and compressive strength of 129 ± 5 and 202 ± 5 MPa respectively. The highest dielectric value of 5.75 and minimum dielectric loss of 0.05 at a frequency (2–20 GHz) is achieved for the same composition with silica 10 wt.% of alumina 35 wt.% sintered at 1350 °C. The composition having silica 10 wt.% with alumina 35 wt.% sintered at 1350 °C, has enormous potential to serve as a high strength refractory and a dielectric ceramic material for microwave applications.

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Influencia de la adición de alúmina y sílice en el comportamiento físico-mecánico y dieléctrico del aislador de porcelana cerámica a alta temperatura de sinterización

Palabras clave:
Densidad
Constante y pérdida dieléctrica
Resistencia mecánica
Porosidad
Expansión térmica

RESUMEN

Los aisladores de porcelana de alta resistencia eléctrica juegan un papel vital en la industria de la energía. El presente estudio investiga el efecto de la adición de la concentración de alúmina y sílice sobre las propiedades físicomecánicas y eléctricas de los cuerpos de porcelana a alta temperatura de sinterización. Se prepararon muestras con diferentes formas y dimensiones mediante una prensa hidráulica a una presión de a 160 MPa con un tiempo de retención de 10 minutos. Se utilizaron diferentes técnicas de caracterización como dilatometría, difracción de rayos X (XRD) y microscopía electrónica de barrido (SEM) para evaluar los cambios térmicos, estructurales y microestructurales debidos al aumento de la concentración de sílice en la alúmina en la composición base de la porcelana. Se midió la resistencia mecánica y el comportamiento físico para todas las muestras de diferentes composiciones. A 1350° C, para la composición que tiene sílice 10% con alúmina 35% en peso. %, la densidad máxima de 2,55 g/cc con absorción de agua de 0,94%. El valor más alto de flexión y resistencia a la compresión se encontró para la misma composición siendo 129 y 202 MPa respectivamente a 1350° C. Para esta misma composición se encontró el valor más alto de constante dieléctrica 5,75 y la pérdida dieléctrica mínima de 0,05 a una frecuencia (2-20 GHz) y temperatura ambiente. La adición de 10% de SiO2 con 35% de Al2O3 sobre la composición base de porcelana cerámica tiene un enorme potencial para servir como material refractario de alta resistencia y como cerámica dieléctrica para aplicación en microondas.

Introduction

Porcelain insulator introduced in 1909, it is well in use over a century and also accepted by the industry. The application of porcelain material has most often considered as a safe choice. Ceramic porcelain insulator is widely used in electrical applications such as power transmission and distribution. Porcelain is made from natural raw materials like clay, quartz, feldspar. Clays such as ball clay and kaolin are used as an essential material for the porcelain insulator. This clay possesses different physical and chemical properties depending on the geophysical and geological environment. The major function of these ceramic porcelain insulators is to provide insulation from electricity to the distribution lines. The main constituents of electrical porcelain bodies are clays (as plastic materials), fillers (such as silica and alumina) and feldspars ($Na_2OAl_2O_3{\cdot}6SiO_2$) which act as a flux material. The raw materials used for porcelain fabrication have excellent interest among the research community due to their availability and low price compared to industrial chemicals. The ceramic material insulators have a very long lifetime ranging from 10 to 20 years even some are over 70 years or more and consist of all the significant characteristics of ceramics such as; insulating capabilities, dimensional stability, hardness, thermal resistance, and resistance to corrosion [1–3]. The filler material plays a vital role in porcelain body to provide additional strength by filling the pores of the insulator such as; quartz (silica) which is unreactive at low temperatures and forms a highly viscous liquid at a very high temperature of sintering. In the previously reported paper substitution of quartz in alumina has yielded alumina-based porcelain insulators, which is noted for its better strength [1,4–6]. The alumina addition increases the electrical resistivity and reduces the loss tangent (tan δ). The study of composite materials, i.e., mixtures consisting of at least two phases of different chemical compositions, has been of great interest from both a fundamental and a practical standpoint. The primary goal in recent decade is to develop a high voltage insulator with the properties such as; an insulator having excellent mechanical strength, high electrical insulation, and exceptional thermal properties in the presence of harsh environments [7–9]. The present work mainly focuses the effect of alumina–silica (Al_2O_3–SiO_2) mixtures on the base composition of porcelain starting powders and sintering on the mechanical and electrical properties. The dielectric constant and loss tangent are important electrical properties of the porcelain insulator [10]. A dielectric material, also known as an electrical insulator, gets polarized with the application of electric field. The introduction of an electric field across the dielectric insulator allows the dielectric polarization to come into existence due to which positive charges shifts toward the applied electric field and negative charges move away from the applied field. The dielectric polarization does create a dipole effect but reduces the overall field inside the dielectric material [11–14].

The motive of the present work is to prepare a mechanically and electrically strong porcelain insulator by mixing an optimum amount of low-cost clay (up to 45 wt.%) and remaining substituents by silica and alumina to reduce the cost of raw materials. To achieve aforementioned, we increase the silica