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Research Article

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To Compare the Properties of Porcelain Insulator by Varying Composition

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Abstract

An insulator, also called a dielectric, is a material that resists the flow of electric current. Ceramic porcelain insulators are widely used in electrical applications such as power transmission and distribution. These materials are usually operated in electrical systems because of their good electrical, mechanical, and thermal characteristics under unfavorable environmental effect. The present study shows the effect of alumina on physical and mechanical properties of porcelain bodies over high temperature. A group of three samples A_1, A_2, and A_3 of varying composition were prepared with the help of hydraulic press machine. Different instruments like Particle size analyzer, Universal testing machine, Porosity testing machine, etc. were used for determining the physical and mechanical properties. Chemical analysis of fired body was performed by using Gravimetric process in which % of silica, alumina, Fe_2O_3, TiO_2, CaO, and MgO were found. Properties like total shrinkage, bulk density, water absorption, porosity, extrusion moisture, and bending strength were found by physical and mechanical testing. Maximum bending strength was found for sample A_1 i.e., 82.614 MPa of high alumina content with total shrinkage 15.13%, bulk density 2.686 gm/cc, zero water absorption and porosity. The lowest bending strength was found for sample A_3 i.e., 55.245 MPa of lowest alumina content with total shrinkage 17.13%, bulk density 2.489 gm/cc, zero water absorption and porosity. This study shows that with varying composition of material, physical and mechanical properties of insulator also change. For the highest alumina sample strength was found to be maximum.

Keywords

Porcelain, Mechanical strength, Porosity, Density, Moisture

Introduction

Porcelain insulator was introduced in 1909. It has been well in use for over a century and also accepted by the industry. Ceramic porcelain insulators are widely used in electrical applications such as power transmission and distribution. Porcelain is made from natural raw materials like clay, quartz, feldspar. Clay 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 distribution line. The main constituents of electrical porcelain bodies are clays (as plastic material), fillers (such as silica and alumina) and feldspar ($Na_2OAl_2O_3.6SiO_2$) which act as flux material [1]. Porcelain, glass, and polymeric composites are generally utilized as electrical insulators in high voltage power networks. Ceramic materials are usually operated in electrical systems because of their good electrical, mechanical, and thermal characteristics under unfavorable environmental effects. The good

electrical, physical, and thermal properties of porcelain under severe environmental conditions reinforced their confidence performance in the power network and supported their continue use over the centuries [2]. Dielectric and mechanical strength are two most crucial properties of porcelain bodies in electrical application and some reasons the material became very popular [3]. Electrical insulators help to prevent the passage of current to other areas where it is not wanted or where it can cause harm or death to the living things that come in contact with it [4]. 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 50% wt.) and remaining substituents by alumina and feldspar to reduce the cost of raw materials. Three samples A_1, A_2, and A_3 of varying composition were prepared in which A_1 contains the highest alumina and reduces in the next samples. Testing samples show that the highest alumina sample has maximum strength among others.

Materials and Methods

Material

For compositional change in material preparation we increase the ball clay and decrease the concentration of alumina in base porcelain composition. Alumina-based ceramics have high strength and low thermal conductivity as compared to other ceramics. Particle size was determined by Particle size analyzer.

Methods

Firstly, take raw material with desired proportion for the process. Three samples (A_1, A_2, and A_3) to be prepared from each raw material. After completing batch put the material into ball mill. Now add water in equal amount of dry raw material and apply wet ball milling process for 24 hours. Particle size to be analyzed by particle size analyzer. After getting standard particle size the material is to be transferred for the further process. This slurry is passed through a 120 µm mesh and go through the filter press. After filter pressing, we get filter cakes which further pass through agitator. In agitator, homogenization of mixture takes place. After homogenization, this mixture further passes to the filter press from which we get filter cakes. This process continuously performed 3 times. After getting the final filter cake we pass it through pug mill. Pug mill removes the air bubble inside the pug mass using vacuum pressure. Now from pug mill 10 mm diameter green rod to be prepared. This rod is kept for natural drying for 2 to 3 days. After natural drying this rod is put into dryer for 110 °C For 2 days. After 2 days, rod to be kept out from the dryer and physical changes to be analyzed. After firing physical and chemical properties to be analyzed. The rods further send to kiln for firing. After firing physical and chemical changes to be analyzed.

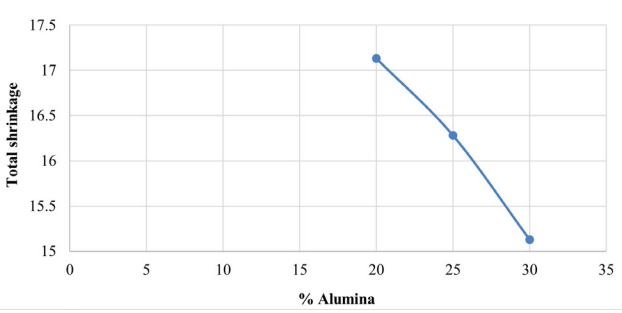

Figure 1: Comparison of total shrinkage with % alumina.

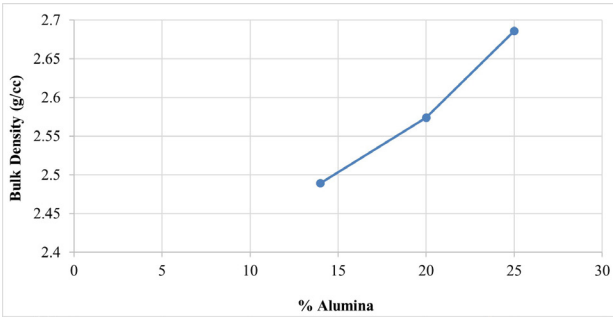

Figure 2: Comparison of bulk density with % alumina.

Physical characteristics

Physical properties such as Moisture content, linear shrinkage, Water absorption, Porosity, Bulk density, and Mechanical strength of the sintered specimens were carried out.

Moisture content

From sample cut a piece. Remove the outer layer from all sides by cutting. Round off the sharp angles and corners of the sample. Weight the sample correctly in physical balance. A sample of 50 gm weight is preferable. Dry the sample in drying oven for 5 hours. Remove the samples and cool it at room temperature. Take the dry weight of the sample. Cool the sample in desiccator and take its weight. Calculate the percentage moisture content on weight basis.

$$\% \text{ Moisture} = \frac{W_1 - W_2}{W_1} \times 100 \quad (1)$$

Where, W_1 = Weight of sample before drying and W_2 = Weight of sample after drying.

Linear shrinkage

Extrude 10 mm diameter rods of approximately 120 mm length in pug mill. Immediately after extrusion mark 2 points, 100 mm apart from each other on the rods using Vernier Calipers. Dry these rods at room temperature overnight. Next day keep these rods in laboratory oven for slow drying. Remove the rods after drying and cool in desiccator. After cooling, measure the distance between two points. With the difference

Table 1: Particle size distribution.

Sr. No.	Raw Material	Particle Size (µm)
1.	Alumina	80
2.	Ball clay	120
3.	Kaolin	120
4.	Feldspar	120

in length calculate the percentage shrinkage on drying. After calculating dry shrinkage, send these samples to production kiln for firing. Collect the samples after firing and again measure the distance between two points. Then calculate percentage shrinkage on firing.

$$\% \text{ Dry Shrinkage} = \frac{L_1 - L_2}{L_3} \text{ x } 100 \quad (2)$$

$$\% \text{ Fired Shrinkage} = \frac{L_2 - L_3}{L_3} \text{ x } 100 \quad (3)$$

$$\% \text{ Total Shrinkage} = \frac{L_1 - L_3}{L_3} \text{ x } 100 \quad (4)$$

Where, L_1 = 100 mm (Original Length), L_2 = Dried Length, and L_3 = Fired Length.

Water absorption

The boiling method was used for this test at 100 °C for 2 hours. The test pieces were subjected to a two-hour boiling followed by an additional four-hour water soaking. Water absorption was calculated as a function of the specimen's weight difference prior to and after water submersion [5]. The water absorption was computed using the equation.

$$\% \text{ Water absorption} = \frac{W_S - W_D}{W_D} \text{ x } 100 \quad (5)$$

Where, W_s = Soaked weight after boiling at 100 °C for 2 hours and W_D = Dry weight.

Porosity

The non-porous property of insulators is checked by porosity test. For this purpose, a solution of methyl spirit and dye (1%) is prepared. Broken pieces of insulators are dropped in the solution and then pressure is applied by the compressor to the insulator loaded chamber for some hours. Then broken samples are taken out and again broken to check porosity. Pressure in the chamber should not be less than 153 kg/cm^2.

Bulk density

Bulk density was calculated using a direct volume measurement method. This method exploits the relative density of a substance multiplied by the density of water to obtain the required bulk density. Equation was used to obtain the bulk density in g/cc.

$$\text{Bulk Density} = \frac{W_D}{W_D - W_{SP}} \text{ x } \textit{Density of water} \quad (6)$$

Where, W_D = Dry weight and W_{SP} = Suspended immersed weight.

Mechanical strength

The mechanical strength of the ceramic insulators was recorded by using a universal testing machine. Bending strength was analyzed for fired glazed insulator.

$$\text{Bending Strength} = \frac{32PL}{\pi D^3} \quad (7)$$

Table 2: Composition of raw material (%wt.).

Sample	Ball clay	Alumina	Kaolin	Feldspar
A_1	40	30	10	20
A_2	45	25	10	20
A_3	50	20	10	20

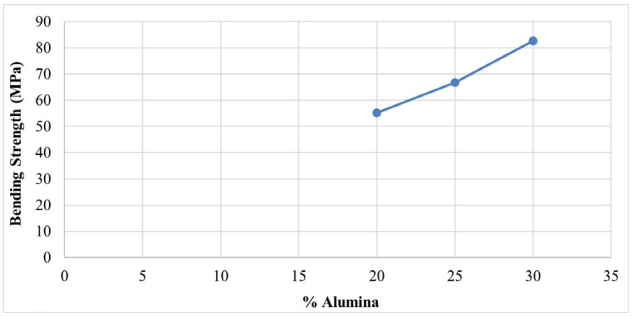

Figure 3: Comparison of bending strength with % alumina.

Where, P = Breaking Load, L = Length of insulator from broken point, and D = Diameter of rod in mm at broken point.

Chemical characteristics

First of all, take sample from fired insulator and grind it by pristle mortar to reduce particle size. Then pass this sample to 200 µm mesh. Now put that sample at 110 °C in dryer for 2 hours to get constant weight. Now that sample is fused in muffle furnace adding fusion mixture (Na_2CO_3 + K_2CO_3) using platinum crucible. After melting at 1000 °C we get liquid mass. Now by using Gravimetric process we can find out % of silica, alumina, Fe_2O_3, TiO_2, CaO, and MgO from that liquid mass. By using a flame photometer, we can find % of Na_2O and K_2O from that liquid mass. This whole process is to be done for all three samples A_1, A_2, and A_3. The viscosity of the slurry is determined by Brook Field Viscometer.

Results and Discussion

A total of three specimens were prepared for physical, chemical, and mechanical analysis. Silica content was present in the sample which continuously increased and alumina content decreased. So, the effect of decreasing alumina can be analyzed on the body. By Gravimetric analysis all components like Fe_2O_3, TiO_2, CaO, MgO, etc. were found with their % composition so that impurities like iron content, etc. can be analyzed in the body. Physical and mechanical properties of the specimen are described here.

Total linear shrinkage

The total linear shrinkage of the sample was found to be increased as the alumina in the sample decreased and silica content increased. The shrinkage was analyzed by drying and firing of the specimen and getting result by using physical testing. The shrinkage was varying from 15.13% to 17.13% which is increasing as alumina content decreases. Total shrinkage was calculated by dry and fired shrinkage. Here dry shrinkage was

Table 3: Chemical composition of fired sample (%).

Elements	A_1	A_2	A_3
SiO_2	43.2	44.26	45.3
Al_2O_3	45.7	43.26	40.10
Fe_2O_3	0.86	0.86	0.87
TiO_2	0.61	0.62	0.62
CaO	0.70	0.71	0.69
MgO	0.31	0.30	0.30
K_2O	3.19	3.19	3.19
Na_2O	1.16	1.16	1.16

5.25% and fired shrinkage was 9.39% for sample A_1, which gives total shrinkage of 15.13%. Similarly, for sample A_2 and A_3 total shrinkage was analyzed. The result shows that as alumina decreases in the body strength also decreases as shrinkage increases.

Bulk density

The bulk density of the samples was decreased as the alumina content decreased in the body. In other words, as the silica content of the body increased, the density of the bodies decreased because of increased porosity induced from micro cracks around silica grains. The maximum bulk density of the sample was found to be 2.686 gm/cc for sample A_1.

Water absorption and porosity

The water absorption of bodies decreased with increased firing temperature because pores and open porosities of the bodies decreased and there was increased glassy phase content in the body. In addition, as the silica content in the body decreased (and alumina increased), water absorption of the bodies decreased because of decreased micro cracks and pores. In the case of high voltage insulators water absorption must be zero. For a good insulator, the porosity must be zero. For high voltage insulators, the porosity was found to be zero. Particle size, as well as its distribution determine how particles are packed together which will invariably affect the bulk density of sample produced.

Bending strength

Bending strength was determined using the universal testing machine. The Bending strength was calculated for fired glazed insulator sample. The bending strength for sample A_1 was found 82.614 MPa, for A_2, 66.764 MPa and for A_3, 55.245 MPa. Bending strength was found to be maximum for sample A_1 of highest alumina content. Bending strength increases because of decrease in porosity and increase in bulk density of the sample.

Table 4: Physical and mechanical properties.

Sr. No.	Properties	A_1	A_2	A_3
1.	Total Shrinkage (%)	15.13	16.28	17.13
2.	Bulk Density (g/cc)	2.686	2.574	2.489
3	Water Absorption (%)	0	0	0
4.	Porosity	N.P.	N.P.	N.P.
5.	Extrusion Moisture (%)	18.06	18.19	18.20
6.	Bending Strength (MPa)	82.614	66.764	55.245

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Conflict of Interest

The authors declare that they have no known conflict of interests that could have appeared to influence the work report in this paper.

Credit Author Statement

Ramnarayan Sharma: Conceptualization, Methodology, Writing - original draft preparation, Resources; Sunil Kumar Katheria: Formal analysis, Writing - review and editing, Supervision; Kapil Nahar: Resources. All the authors read and approved the manuscript.

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