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Dependency of Dielectric Strength of Kaolin on Processing Method

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Authors' contributions

This work was developed in collaboration by both authors, who contributed equally to the literature review and writing of the manuscript. Both authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

This paper presents experimental results of a study to determine the dependency of dielectric strength of kaolin on processing methods. Two sets of electric insulators were made of porcelain; one set was made by wet pressing, while the second set was made by dry pressing. The porcelain were made from mixtures of kaolin, ball clay, flint, and feldspar compacted into discs of diameter 2.5 mm at pressures of 100 MPa before being fired to a temperature of 1250℃. The results show that the dielectric strength of electric insulators made by dry pressing exhibited generally higher dielectric strengths than those made by wet pressing. In addition, the study shows that dielectric strength of the insulators were much higher when tested while immersed in high grade transformer oil, than when they are tested while in air. The highest values when tested in oil and air were 22.5 kV, and 10.7 kV respectively.

Keywords: Breakdown voltage; dielectric strength; batch formulation; transformer oil; porcelain; forming method.

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1. INTRODUCTION

The demand for electricity in Uganda has been continuously rising due to increase in population and level of industrialization. The annual growth rate of grid connectivity is between 5.5% and 7%, according to the Ministry of Energy and Mineral Development [1]. Most times, electricity is transmitted over long distances using overhead cables. The efficiency of transmission and distribution of electric power depends among other factors on the quality of electric insulators, [2] since it has to prevent unwanted flow of electric current to the earth from its supporting points. Porcelain materials are among the major materials used for insulation on power transmission and distribution lines.

Electrical insulation is generally a vital factor in both the technical and economic practicability of complex power and electronic systems. Electric insulators now even play a more crucial role because of the energy shortage in Uganda, [3]. Porcelain materials are used for the production of electrical insulation materials, but they differ in chemistry, phase composition, porosity, and in thermal, mechanical and dielectric properties, [4]. Despite the existence of the requisite materials for the production of porcelain insulators locally, the national demand continues to be met by importation, [5].

Studies have shown that dielectric strength of compacted powered sintered kaolin increases as porosity decreases [6]. Similarly, Olupot et al. [7] showed that mechanical and dielectric strength of kaolin depends on the composition of raw materials, the mixing proportions and firing temperatures. Furthermore, the smaller the particle size the higher the dielectric strength, [8]. According to Moulson and Herbert, [9], electric strength depends remarkably on material homogeneity, specimen geometry, electrode shape and disposition, stress mode (d.c., a.c. or pulsed) and ambient conditions.

Porcelains are widely used as insulators in electrical power transmission systems due to the high stability of their electrical, mechanical, and thermal properties in the presence of harsh environment. According to Oladigi et al. [10], they are primarily composed of clay which gives plasticity to the ceramic mixture, feldspar which serves as a flux and a filler material, usually quartz that maintains the shape of the formed article during firing. These materials are widely available in Uganda though they have not yet been used to develop electrical insulators, [11].

This paper presents the results of an experimental study to determine dependence of dielectric strength on the forming methods of the porcelain ceramic samples of composition shown in Table 2.1.

2. MATERIALS AND METHODS

2.1 Materials

The raw materials used in this study were selected based on their suitability [11] and they were obtained from different parts of Uganda: kaolin, and feldspar from Mutaka deposits (Bushenyi district), flint from Lido Beach (Wakiso district), and ball clay from Mukono district.

The flint was wet milled for 120 hours to reduce on the particle size and then wet sieved through a 25µm sieve mesh before drying it using plaster of Paris and in the sun. The ball clay powder was prepared from a slip sieved through 45µm mesh. The slip was also dried using plaster of Paris and in the sun, while feldspar was wet milled, dried and sieved through 53µm mesh. The kaolin used was also prepared through standard procedures before sieving it through a 45µm sieve mesh.

The raw materials were weighed in grams in different proportions and then mixed to form batches A, B, C, D, E, F, and G in the compositions shown in Table 2.1.

For each batch formulation, the compositions were thoroughly mixed for 30 minutes to ensure that the powders were uniformly distributed.

2.2 Processing of the Samples

2.2.1 Wet pressing

A mass of 20g of each batch formulation was mixed with water equivalent to 20% of the mass of the batch. This was then compacted to a pressure of 100MPa to form discs of diameter 40mm and thickness of 2.5mm using a hydraulic press (Hydraulic Laboratory Manual Press-PW40). The samples were then left to dry in air for at least two days before firing in a kiln.

Table 2.1. Composition of sample porcelains (wt %)

Compositions	Batches						
	A	B	C	D	E	F	G
Kaolin	30	33	35	37	38	40	42
Ball clay	15	17	20	18	17	20	18
Feldspar	35	30	25	25	25	20	25
Flint	20	20	20	20	20	20	20
Total (grams)	100	100	100	100	100	100	100

2.2.2 Dry pressing

Similarly, for dry pressing, a mass of 20g of each batch formulation was compacted to a pressure of 100MPa to form discs of diameter 40mm and thickness of 2.5mm using a hydraulic press machine (Hydraulic Laboratory Manual Press-PW40).

2.2.3 Sample firing

The samples were first dried in air at room temperature and then fired at a rate of 1.67℃/min to a temperature of 110℃ and held at this temperature for 3 hours in the furnace. This was done to remove the remaining water from the samples. The samples were then fired to a temperature of 1250℃ at a heating rate of 6℃/min and held at the top temperature for two hours before air cooling them in the furnace. However, firing above a temperature of 1250℃, results in progressive deterioration of the properties of the samples, [7]. Also, holding the temperature for two hours improves the mechanical and dielectric properties, and the microstructure of the samples, [7].

After firing, the samples were white due to having less ball clay in the compositions. These looked as shown in Fig. 2.1.

Fig. 2.1. Some of the fired samples formed by wet and dry pressing forming methods

2.3 Experimental Measurement

The BS 148: 1984 test was carried out on each sample and the corresponding breakdown voltages recorded. This was done using a D.C voltage loading with a frequency of 61.8Hz applied through a transformer to the testing equipment (The oil test set, AvoMegger foster OTS100AF/2). The testing was done at room temperature of 21℃ because the operating temperature of the equipment is between 0-40℃. The initial stand time was 3minutes and the voltage was rising at a rate of 2kV/s. The test conditions considered in the study were electrode configuration, specimen geometry, frequency and the rate of application of the test voltage. These conditions were fixed throughout the experiment.

The sample tested was placed between two mushroom shaped electrodes across high voltage terminals and then immersed in high grade transformer oil. When the maximum voltage was reached, the test voltage was automatically cut off and the break down voltage displayed was recorded. Five measurements for each sample tested were recorded at an interval of a stirring period of 2 minutes. An average of these was taken as the reading.

Two sets of samples were tested. One set of samples were tested when they were immersed in high grade transformer oil, while the second set were tested when they were not immersed in the transformer oil.

The dielectric strengths for each forming method was then calculated using equation (2.1).

$$Dielectricstrength \left(\frac{kV}{mm}\right) = \frac{V_B}{d} \quad (2.1)$$

Where V_B is the breakdown voltage and, $d,$ is the thickness of the sample.

For each sample formulation, 5 samples were tested. The mean values of voltage breakdown were obtained and used to calculate dielectric strengths for the respective formulations using equation 2.1.

The error bars in Fig. 3.1 were calculated using SPSS using a confidence level of 95% where, the standard error was 0.5 for dry pressing and that for wet pressing was 0.8. When the samples were tested in air, the standard error for both dry pressing and wet pressing was 0.6 as shown in Fig. 3.2.

3. RESULTS AND DISCUSSION

3.1 Discussion of Results for Batch Formability

Batches A, B, D, and F formed well and easily in both dry and wet pressing although many samples cracked during firing of wet pressed samples. The total clay content of about 20%, is insufficient to provide the requisite workability for wet processing, thus, the ceramic bodies would be better formed by dry pressing [12]. Batch C only formed well in dry pressing and Batches E and G only form well during wet pressing. This is attributed to the ratio of ball clay to kaolin which is 1:1.75 and 1:2.25 in Batches E and G respectively. Thus ball clay which is used as a binder does not work well with bigger amounts of kaolin without any amount of water, being added to it. This is because water helps to bring out its elastic property, [13].

However, it would be far more difficult to form bodies of intricate shapes by such dry pressing technique than by the wet process, [14]. Dry pressing techniques may be employed to form the ceramic bodies into simple shapes.

3.2 Results of Dielectric Strength and % of Kaolin Content of Samples Tested in High Grade Transformer Oil

The dielectric strength as a function of the amount of kaolin in each batch formulation is shown in Fig. 3.1. The dielectric strengths for samples prepared by dry pressing are higher than those prepared by wet pressing. The highest dielectric strength of 22.5kV was obtained in batch D where kaolin was 37% of the composition. This is attributed to the elimination of coarse micro pores and macro pores since pores have a great influence on the properties of ceramics, [15].

The low dielectric strength of the wet pressed samples is attributed to water used during pressing. As the water dries out; it leaves some pores which might not fill up completely during sintering. The occurrence of gas discharges within pores is an important factor. According to Moulson and Herbert, [9], ceramics are rarely homogeneous, and porosity is a common inhomogeneity, therefore breakdown can be initiated at pores. Liquid phase sintering degrades the mechanical and dielectric properties of the material although it leads to a reduction in processing costs, [16].

3.3 Results of Dielectric Strength and % of Kaolin Content of Samples Tested in Air

The dielectric strength of samples tested in air, for different batches are shown in Fig. 3.2. The average dielectric strength of about 10kV was registered for all batches except batch C where the kaolin content was 35%. In this batch, the ratio of ball clay to kaolin was 1:1.75. The value of dielectric strength is also influenced by its temperature, ambient humidity, any voids or foreign materials in the specimen, and by the conditions of test, [17].

Comparing the results for each batch shown in Figs. 3.1 and 3.2, the dielectric strength of the samples were higher when the samples were tested when immersed in transformer oil. This is because the transformer oil, helps to fix the surface heat transfer so as to minimize stimulation of breakdown through injection of electrons at point contacts into the sample being tested, [18]. When testing electric strength, there is the risk of ‘flash-over’ across the specimen surface between the electrodes, [9]. The transformer oil displaces the air from the ceramic surface, thus improving on the insulation properties of the sample, hence high values of dielectric strength are obtained. However, in practice, insulators are used while in air where things like dirt, pollution, salt and particularly water on the surface of the insulator create a conductive path across it, [19], where the flash over voltage can be more than 50% lower when the insulator is wet. This is demonstrated by the values shown in Fig. 3.2 as compared to those in Fig. 3.1. Thus the porcelain insulators have to be glazed. Glazes when fired fuse to the ceramic surface, creating a permanent coating. This is to avoid air generation of carbon around them while in air as a result of corona discharge, [20].

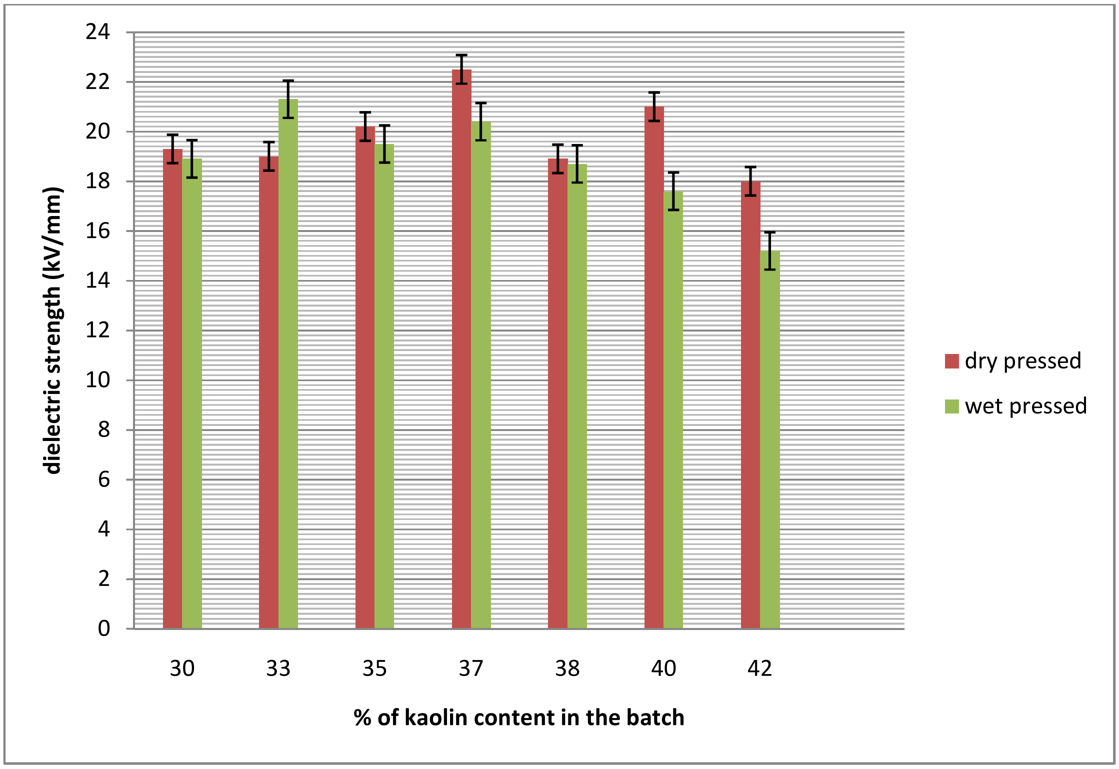

Fig. 3.1. A graph of dielectric strength against kaolin content for samples tested in transformer oil

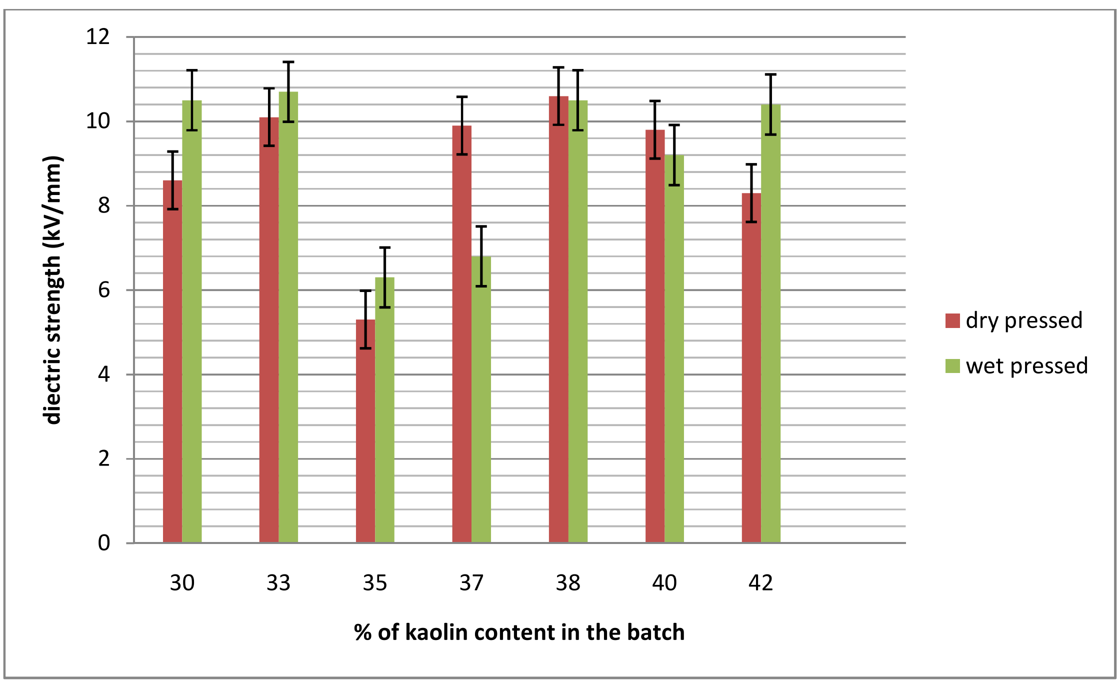

Fig. 3.2. A graph of dielectric strength against kaolin content for samples tested in air

4. CONCLUSION

The salient conclusions that arise from this experimental study are as follows:

1. Batches are formed well when the amount of ball clay is nearly or half the amount of kaolin for both dry and wet forming.
2. Dielectric strength of electric insulators made by dry pressing is generally higher than those made by wet pressing.
3. The best batch formulation of kaolin: ball clay: Feldspar: flint by % wt is 37:18:25:20. This is obtained during dry pressing method. However all batches had good values of dielectric strength since porcelains have a dielectric strength of about 4-10kV/mm, [21].
4. Much higher dielectric strength is obtained when the insulators are immersed in high grade petroleum oil.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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