DEVELOPMENT OF OPTIMUM SLIP RATIO FOR HIGH VOLTAGE PORCELAIN INSULATOR MANUFACTURING

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Abstract: ***The project work was carried out in an insulator manufacturing company. In this work, an effort will be made to analyze the optimum ratio of fresh slip, wet scrap and dry scrap and characterize the properties of porcelain insulators after firing. The insulator rods was prepared by extrusion using varied ratios of slips. The slip is a liquid clay body. The fired rods will be tested for density, Modulus of rupture, Modulus of Elasticity, Thermal Expansion and Hardness. The micro structural characterization will be carried out using SEM. This study is expected to provide an insight into the optimum usage of dry scrap, wet scrap and fresh slip ratios for manufacturing high voltage porcelain insulators. The F70 (Fresh slip 70%+Wet scrap slip 20%+Dry scrap slip 10%) gives optimum properties value when compared to other mixed ratios of slip.***

Keywords: Fresh slip, wet scrap slip, dry scrap slip.

1. INTRODUCTION

Porcelain is the most commonly used material for over head insulator. The name “porcelain” is believed to have originated from the Portuguese word “Porcellana” and presumably first denoted products manufactured from the shell mother-of-pearl [1].Porcelain is one of the most complex ceramic materials. The porcelain is aluminium silicate. The aluminium silicate is mixed with kaolin (clay), feldspar and quartz to obtain hard and glazed porcelain insulator material. Porcelain is heat treated to form a mixture of glass and crystalline phases. The surface is glazed so that water should not be traced on it. Porcelain should be free from porosity since the porosity is the main cause of deterioration of its dielectric property. It should be free from impurity which may affect the insulator properties.

Electroporcelain Insulators are used extensively in transmission lines. These products are of various configurations, such as disc shaped, hollow and solid core types. The basic raw materials are clay, quartz, alumina and other low temperature fluxes. The processing of such material is complex and many testing steps are involved to finally obtain a product which withstands high voltage application requirements [2]. The rejection during processing is generally divided into two types: Green and Fired. The fired rejection needs to be minimized as the fired rejects cannot be reused. Further, green rejections need to be controlled to reduce the fired rejections.

The manufacturing steps of porcelain insulators involves ball milling of raw materials, De-watering, Extrusion, Jiggering, pre-drying, Turning, final drying, Glazing and Firing. The slip is produced using the raw materials in different proportions in the ball mill. There are different scraps produced during the manufacturing like wet scrap and dry scrap. These scrap need to be reutilized to improve the productivity. The slip produced should be in varying proportion of the fresh, wet scrap and dry scrap, with higher proportion of fresh slip.

S L Correia et al [3] studied about the effect of raw materials and content on the properties of clay-feldspar-quartz compositions. The compositions were studied using design of mixture experiments. Characterization results were used to calculate statistically significant and valid regression equations, realting fired body properties with clay, quartz and feldspar contents in the unfired mixture. The statistically modeling is discussed against quantitative X-ray diffraction and scanning electron microscope. The mechanical strength and microstructure of the fired ceramic body was controlled by the glassy phase present.

Moses George Moyo et al [4] investigated the raw material needed for increased mechanical properties of porcelain insulator. Electrical insulation and bending strength is increasing with reduction of Kilimanjaro quartz content with increasing the content of pugu kaolin. Increasing pugu kaolin beyond 48 wt. % and Kilimanjaro quartz content below 6 wt. % is leading to the reduction of electrical insulation and bending strength. In addition, the mix with constituent’s percentage composition of 48 wt % pugu kaolin, 46 wt. % Kilimanjaro feldspar and 6 wt. % Kilimanjaro quartz is possessing the highest strength of 53.525Mpa. This mix proportion showed higher electrical insulation. The pugu kaolin for production of electrical insulators is encouraged as formation of mullite phase improves the mechanical strength and insulation resistance.

Jose M Amigo et al [5] studied the X-ray diffraction microstructure analysis on the mullite, corundum and quartz by applying several integral breadth methods and Fourier analysis. This was performed on commercial samples of the silica and alumina porcelain insulators obtained at 1300°C.The apparent crystallite sizes determined for the mullite are direction dependent and within the group of samples, on average, the greatest values were obtained along the direction [0 0 1]. According to this microstructure analysis, there are little differences between the two groups of samples. Based on this analysis the crystallite sizes follow the order corundum> mullite> quartz. The result showed that the content of corundum to be the principle factor influencing their flexural strength.

Parvati Ramaswamy et al [6] investigated the cause for catastrophic failures of porcelain insulators in power lines can be minimized by understanding the structure-property relationship. The total alumina (Al_2O_3) content assure better performance in alumina based porcelain insulator. Impurities which arise out of raw materials (like oxides of Fe etc) should be restricted to less than 1.0%.

Yong Meng et al [7] studied on microstructure of high strength alumina and bauxite insulator. A comparative study was carried out on three high strength porcelain insulators by XRD, SEM and ceramography. The results obtained showed that there exists a negative relationship between the porosity and the content of amorphous phase of the material. The density of the insulator body is dependent on porosity. The use of calcined bauxite as a raw material will increase the porosity when compared to the alumina. The mechanical strength of porcelain insulator would be increasing the amount of quartz in raw material and increasing the amount if mullite in vitrified area.

A review of literature shows that very little information is available regarding the optimum mixing ratio of fresh, wet scrap and dry scrap slip. Hence there is plenty of scope to carry out studies relating to it. The results obtained will help to develop optimum slip ratio.

2. EXPERIMENTAL PROCEDURE

2.1 Preparation of test Specimens

The test specimens were produced using the slip. The slip was taken from different slurry tank. The slip was segregated into three types based on its production.

Fresh Slip = Slip produced from Ball Mill

Wet Scrap Slip = Slip generated from scrap (jiggering, turning).

Dry Scrap Slip = Slip generated from scrap after drying (breakage or cracks in the pieces).

The fresh slip will be added at major ratio and dry scrap slip will be in minor ratio. The raw materials used in the fresh slip were quartz, alumina, feldspar, clay etc. These raw materials were poured into the ball mill with required quantity of water. The ball mill would be run and then the raw materials would be mixed with water for making the fresh slip. The wet scrap slip was generated during jiggering, turning before it was dried. It contains impurities such as kerosene, coconut oil etc during jiggering operation. These impurities will only stick the outer surface they are not dispersed fully. These scrap would be mixed properly and many impurities were removed before making slip. The dry scrap slip was obtained by mixing the scrap generated because of cracks in the sample, or breakage due to mishandling. These contain impurities which were fully dispersed in the sample. The slips from three separate tanks were obtained and it was mixed according to the required ratio. The slip was made into eight different ratios. The slip was mixed and stirred for uniform mixing.

Table 1. Various slip ratios

Composition	Material in weight %
F100	Fresh slip-100%
F70	Fresh slip 70%+ Wet scrap slip 20% +Dry scrap slip 10%
F65	Fresh slip 65%+ Wet scrap slip 25% +Dry scrap slip 10%
F60	Fresh slip 60%+ Wet scrap slip 30% +Dry scrap slip 10%
F55	Fresh slip 55%+ Wet scrap slip 30% +Dry scrap slip 15%
F50	Fresh slip 50%+ Wet scrap slip 35% +Dry scrap slip 15%

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The body mass will be in the form of dough as shown below required for extrusion. The body mass prepared was extruded into rods of diameter 12.5mm. The samples were extruded and cut to a length that fits into the wooden stand.

The samples then dried in the electric drier in the temperatures from room temperature to 110ºC to reduce the moisture to less than 1%. Then the samples were sintered in a kiln at a temperature of 1250ºC.

3. RESULTS & DISCUSSION

3.1 Moisture Analysis

The moisture tests for dried samples are carried before the firing process. The moisture in the sample is calculated using AND MX-50 moisture analyzer and the values are given in the table 2.

Table 2. Moisture analysis after drying

Sample	% Moisture
F100	0.73
F70	0.74
F65	0.73
F60	0.66
F55	0.79
F50	0.78

The moisture of the dried samples before sintering should have moisture less than 1%.

3.2 Density, Porosity and Water Absorption

The bulk density, apparent porosity were measured after sintering and the values are given in table 3.

Table 3. Density, Porosity and Water Absorption

Sample (ROD)	Bulk Density (gm/cc)	Apparent Porosity (%)	Water Absorption (%)
F100	2.475	0.139	0.056
F70	2.523	0.169	0.067
F65	2.521	0.213	0.084
F60	2.524	0.343	0.136
F55	2.537	0.262	0.103
F50	2.487	0.200	0.080

The Bulk Densities for the combinations ranging from 2.475 to 2.537 gm/cc. The apparent porosities range from 0.139 to 0.343%. The bulk density of all the slip ratios are nearly equal, but the F55 (Fresh 55%+Wet 30%+Dry 15%) sample gives higher density. F70 (Fresh 70%+Wet 20%+Dry 10%) is better because the porosity is less when compared with the other ratio.

3.4 Vickers Hardness Test

Hardness was measured by Vickers Hardness Tester. The Vickers hardness H_v for different combination was measured and is given in the Table 4.

Table 4. Hardness value for different slip ratios

Sample	Vickers Hardness
F100	650±10
F70	609±20
F65	537±10
F60	584±9
F55	454±13
F50	489±18

The H_v value was found higher for dry scrap sample. But we can't use the fresh slip only the F70 (Fresh 70%+Wet 20%+Dry 10%) will be better among the different mixed ratios. The increase in hardness will impact on the MOR.

3.5 Thermal Expansion

The thermal expansion test was conducted for all the samples and the following results are obtained.

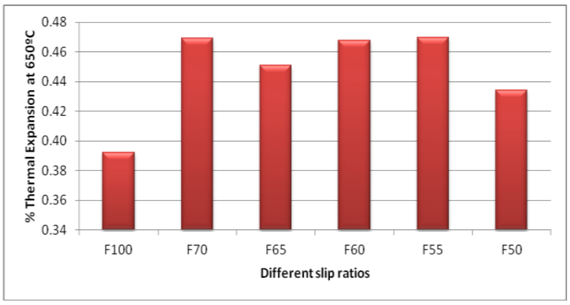

Fig -1: Coefficient of thermal expansion for different slip ratios at 650°C

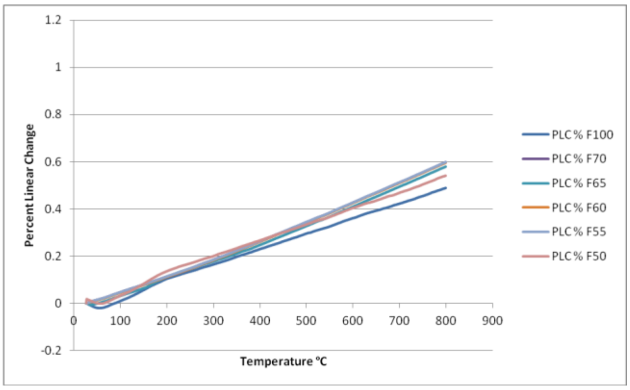

Fig -2: Thermal Expansion for different slip ratios

The behaviour in thermal expansion coefficient was studied from room temperature to 650ºC. It was observed that thermal expansion value for F100 is low than other samples. The F100 has only the fresh mixed slip and no other impurities and scrap is present in the slip. There was not much change in the values observed due to the same composition of the samples.

3.6 Modulus of Elasticity

Modulus of Elasticity (MOE) is a function of the bond strength of a material and hence it is considered as a material property. This test is of prime importance in assessing the spalling resistance of the samples. MOE rods were measured by using resonance frequency method. Yong's Modulus was evaluated by Dynamic Elastic Properties Analyzer (DEPA) is based on an impulse excitation technique (ASTM C1259). The rods were placed on the platform containing sensors and were tapped by a metal rod and it displays a test specimen's complete frequency signature.

The mean resonance frequency and Modulus of Elasticity of the sintered samples are shown in Fig. 3.

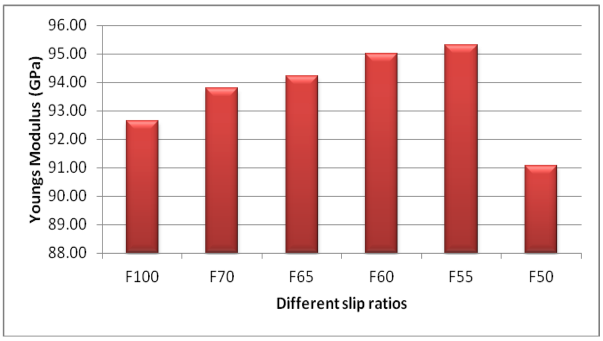

Fig -3: Mean resonance frequency and young's modulus of sintered samples

3.7 Modulus of Rupture

Test samples are prepared in sizes according to the standards-IEC 60672-1. Sintered cylindrical bars of dimension 10 mm dia and 120 mm length are used.

The three point bend strength of the samples has been given in the Fig. 4.

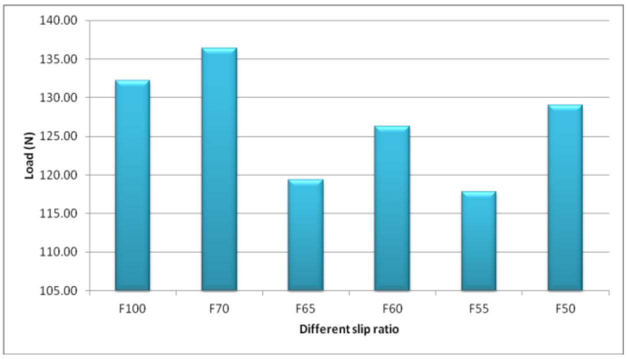

Fig -4: Variation of MOR for different slip ratios

The Fig. 4 shows the MOR of the fired samples. The dry scrap sample has higher MOR when compared with other samples. The F70 samples have better MOR value next to dry scrap. The MOR value would be even better if the mixing is done in the pot mill. The more homogeneous mixing results in better properties. The MOR value is having direct relation with the MOE. The MOE of the dry scrap is more for green and fired samples. So the MOR values are justified.

3.8 XRD

Sample Preparation:

Sintered body was cleaned and fine powdered using a cleaned mortar and pistil. Around 10-15 gm of sample was taken for qualitative XRD.

Fig. 5 depicts the Qualitative X-ray Diffraction analysis of the sample F70. The crystalline phases present are Quartz, Mullite, Corundum and Cristobalite. Details are given in table 5.

Table -1: Phase present in F70 sample

Phase Name	Intensity (cps)	2 Theta
Quartz	1027	26.74
Mullite 1	930	26.38
Mullite 2	811	26.12
Corundum	875	25.68
Cristobalite	1404	21.98

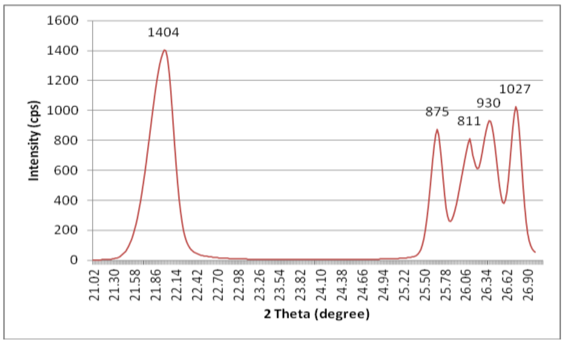

Fig -5: Powder XRD patterns for F70 sample

3.9 MICROSTRUCTURAL CHARACTERIZATION

Ceramographic Specimen Preparation

Ceramographic specimen preparation normally requires a specific sequence of operation such as sectioning, mounting, grinding, polishing and etching. Further to obtain an accurate interpretation of a microstructure the prepared specimen should be representative of the material being examined. The samples were cut from the parent piece of a sintered porcelain insulator samples using a diamond cutter. The cut samples were coarse ground to remove the burs produced during sectioning and to make it flat surface. An automatic grinding and polishing machine was used for grinding and polishing the sample. The samples were rough polished using grit size of 320, 600, 800, 1000 silicon carbide emery paper. Then fine polished velvet cloth using diamond paste to a 1μm finish. The samples were chemically etched using 40% hydrofluoric acid solution for 10 second. Specimens that are electrical insulators can be studied by coating them with a thin (10nm) conductive film of gold.

Microstructure Analysis was carried out using Scanning Electron Microscope S3400, Hitachi, Japan at an accelerating voltage of 5KV at magnifications ranging from 100 to 3000.

The scanning electron micrographs of cylindrical bars sintered by conventional method for different slip ratios are shown in Fig. 6 and Fig. 7. The pores can be seen in the 100X magnification. Composition in spot A corresponds to the presence of quartz. Composition in spot B corresponds to corundum (α-alumina). Composition in spot C corresponds to Mullite needles. The remaining area is of glassy phase.

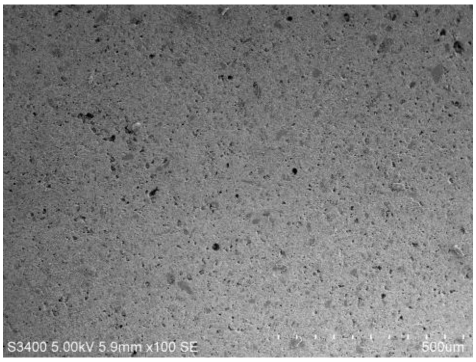

Fig -6: SEM photomicrograph of sintered F70 at 100X magnification

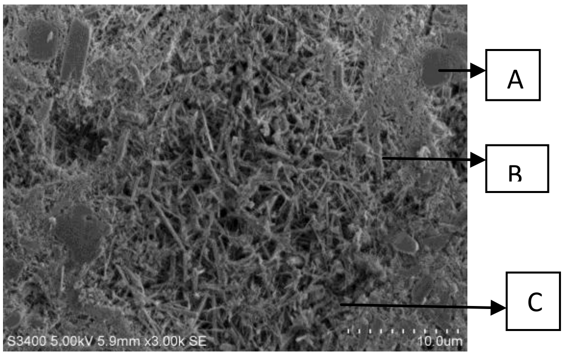

Fig -7: SEM photomicrograph of sintered F70 at 3000X magnification

The insulator body is regarded as a composite of glass phase, mullite, corundum etc. The glass phase is continuous is of low mechanical strength. It is regarded as the weak part of the body. If the needle shaped mullite formed during sintering, it has an effect on both the mechanical and physical properties by increasing the mechanical strength and thermal shock resistance. So the insulator property depends on the mullite.

4. CONCLUSIONS

The present work deals with development of optimum slip ratio for the high voltage porcelain insulators. The insulator rods were prepared by extrusion using varied ratios of slip. The fired rods tested for flexural strength, modulus of elasticity, hardness and thermal expansion. The micro structural characterization is carried out using SEM. Based on the experimental results and associated discussions the following conclusion can be drawn.

- ➢ The samples having less porosity would have low water absorption. So F70 slip ratio is better.
- ➢ The coefficient of thermal expansion for fresh sample is less when compared to other ratios.
- ➢ The MOE of the fired samples of F55 was high.
- ➢ The MOR of the F70 sample is more when compared to other sample.

Based on the results obtained shows that F70 (Fresh 70%+Wet 20%+Dry 10%) slip ratio gives the better properties among the slip ratio tested. The dry scrap in this is very low 10% and also the fresh slip was used to a maximum extent.

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