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Mechanical properties of ceramic whiteware samples with different amounts of quartz addition

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ABSTRACT

Ceramic whiteware represents one of the most complex ceramics, formulated from a mix of china clay, ball clay and quartz are sintered to conform a ceramic composite. Ceramic whiteware has excellent technical characteristics. Nowadays, research of new materials, for example non-hazardous wastes, that are able to replace the traditional fluxing agent without changing the process or quality of the final products has been realized. The aim of this work is to study the possibility of the use of quartz, in ceramic whiteware mixtures, for manufacturing of electrical ceramic whiteware bodies. It was prepared by mixtures containing different amounts of china clay, ball clay, feldspar and quartz. The samples were fired reaching different maximum temperatures in the range 950-1250 ºC, with a soaking time of 1 hour. The fired samples were characterized and the use of small amounts of quartz in addition with whiteware samples showed good results of mechanical technological properties. The optimum quartz percentage (25%) S1 samples at 1250 ˚C gives the maximum bending strength.

Introduction

The mechanical properties of ceramic whiteware bodies have been studied extensively for almost a century. Recent development the preparation of ceramic whiteware bodies have concentrated on composition modification and the related processing technology [1,2]. The presence of porosity within a ceramic component will lead to a reduction in the load bearing area of the material and hence can be expected to lead to a reduction in strength.

The common industrial practice in Tamilnadu is to prepare ceramic bodies (for low tension electrical application) by mixing the two main types of clays (china clay & ball clay) in Cuddalore region (ceramic institute Vridhachalam, Cuddlore Dt, Tamilnadu). Worldwide, clays are the main raw materials exploited in the fabrication of diversified ceramic products for industry utilization. Due to inherent complex, physical, chemical and mineralogical characteristics, clays usually have unique properties related to their own natural digenesis [3-6] this gives a regional industry the properties of both unfired ceramic body and corresponding fired product.

The present work, which is a part of an extended research program, aims to elucidate the complex phenomena affecting ceramic whiteware strength development. In this respect from parameters were simultaneously investigated, in order to study their effect on mechanical and physical properties to a ceramic whiteware samples.

Experimental Techniques

Chemical analysis

The ceramic whiteware samples are made up of quartz addition with different proportions (S1 to S4). The samples were obtained from a Government Ceramic Institute (ceramic plant), Vridhachalam, Tamilnadu, India. Upon collection, it was ground with a crushing machine. Ceramic whiteware samples were subjected to chemical analysis with the aim to obtain accurate analysis for all elements present in the sample, in such a way that some of the elements were expressed as oxides which also reveal the type of the particles. The chemical analysis of the samples was made by using X-ray fluorescence (Bruker S4-Pioneer) instrument, Pondicherry University, Pondicherry, Tamilnadu, India.

It was prepared by different mixture whose compositions are reported in Table.2. The amount of Quartz added to mixtures was based on the amounts of China clay and Ball Clay of this composition (whiteware composition).

The dried raw materials were mixed in an alumina ball mill using alumina milling media on water for 1 hour. The slurry was dried at 100˚C in a rotator direr until 8-10% of humidity. The dried materials were crushed and sieved to pass through 500μm size. The resulting powder were moistened up to ~6 wt%water, hand granulated and uniaxially pressed at 45 Mpa in to 16 cm x 8 cm x 1.5 cm test piece (for electrical Low Tension applications). A total of four test piece for each composition were prepared to ensure the reproducibility of the measurements. Specimens were fired in a Laboratory electrical furnace simulating an industrial fast firing process in an air atmosphere involving basically: an average heating rate of 25 ºC/min, a soaking temperature of 950, 1050, 1150 and 1250 ºC hold hour and the furnace cooling was performed by natural convection after turning the furnace off and leaving the specimen inside.

Mechanical Properties

Water absorption test

Water absorption is a key factor affecting durability of ceramic whiteware samples. The less water infiltrates into a whiteware samples, the more durable is the whiteware samples and the better is its resistance to the natural environment.

The test specimens are whiteware samples in the form of

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bars. The dry whiteware samples were weighed and then submerged in water at a temperature between 55 ˚C and 30 ˚C. After 24 hours, the specimens were taken out of water. Then, the surface water of each specimen was wiped off with damp cloths and the specimens were weighed again.

$$\text{Percentage of water absorption} = \frac{w_2 - w_1}{w_1} \times 100$$

Where, w_1 – weight of the dry specimen and

w_2 – weight of the specimen after 24 hours of immersion in water.

Linear Shrinkage test

Test specimens from each composition were dried at 110 ˚C for 24 hours to ensure total water loss. The test specimens were then measured (in terms of dimension) and their values were noted as dry lengths.

The test specimens were also fired in an electric furnace to temperatures of 950, 1050, 1150 and 1250 ˚C. They were allowed to cool. Then the specimens were weighed and measured, and the fired weight and fired length were recorded. For each sample, 4 different specimens were tested and the averages of the above parameters were calculated and recorded. The drying shrinkage, (linear shrinkage) was calculated for four specimens using the following formula [7].

% of Drying Shrinkage = (OL-DL)/OL X 100

Where: OL means original length and DL stands for dry length.

The drying shrinkage indicates to some degree of plasticity of the mixture. A large drying shrinkage means that mixture could absorb much water, which in turn indicates fine mixture particles. A high shrinkage normally means a lower melting point. The total shrinkage of refractory bodies tells how much bigger we should make our moulds [7].

Porosity

Role of porosity

The density or porosity affects a number of the properties of the whiteware samples but probably the most important effect is its strength [8]. Highly porous whiteware samples are mechanically weak. A ceramic whiteware sample with the lowest porosity has the greatest strength, thermal conductivity and heat capacity.

The water absorption method adopted to measure the porosity values of the ceramic body is described below.

The samples were heated continuously in boiling water for about six hours and left to cool over night which enables the pores to get filled up with water to saturation. The saturated specimens were then weighed by immersing in water as (w_1) and in air as (w_2). The samples were then placed in hot air oven at 200 ˚C and dried for about six hours to remove the water contents completely and then weighed as (w_3). To standardize the values of the results the percentage of porosity was calculated using the relation.

$$\text{Percentage of porosity} = \frac{w_2 - w_3}{w_2 - w_1} \times 100$$

The stated procedure was repeated a number of times until consistency in the values were obtained and the average value was taken.

Modulus of rupture test (M.O.R)

A widely used method that measures transverse breaking strength to construction materials. The test is made on test bars the ends of which rest on knife edges while force is applied through a knife edge that is lowered midway between the ends. The breaking knife edges are moved by a dynamometer which measures the weight applied.

Moduli of rupture tests were performed on a standard mechanical machine. Test specimens, measuring (16 X 8 X 1.5) cm for each ceramic whiteware samples composition were dried and fired at 950, 1050, 1150 and 1250˚C along side with the ceramic whiteware samples. Each of them was placed one after the other on the bearing edges of the compression machine positioned 7.0 cm apart. Loads were then applied at the middle of the specimen, uniformly at 1.25 kgf per minute.

The transverse breaking strength or modulus of rupture is calculate by the formula

$$\text{M.O.R.} = 3PL/2bd^2 (\text{Ncm}^2)$$

where,

L - the distance between two knife edges (cm), b - breadth of the specimen (cm), d - depth of the specimen, and P - breaking load in kg.

In the present study

In order to asses the strength of the various proportion quartz additive ceramic whiteware bodies obtained from Government ceramic institute Vridhachalam, Cuddalore Dt, Tamilnadu, India. From the four samples of ceramic whiteware bodies, which compositions were made with high strength and important factors affecting the quality of the whiteware body were also discussed.

This study discusses the strength analysis of the corresponding compositions and an attempt to interpret the chemical analysis of the composition in terms of their elemental composition. The chemical composition of the studied composition (determined by X – ray fluorescence at Pondicherry university laboratory Bruker S4-Pioneer) is present in Table 2. The behavior of the composition types regarding their chemical composition Vs their technological properties discuss in this paper.

Results and discussion

A homogeneous powder of ceramic whiteware body (Quartz addition) is obtained as result of mixing, milling and sieved steps, from Table1. Materials microstructure defines the decisive effect of the chemical- thermal reactions which are the basic prerequisites for achieving an optimum firing cycle.

The rate controlled sintering is used to achieve high densification of functional ceramics while avoid cracking, by maintaining a linear rate of sintering, that is a linear rate in shrinkage rather than a linear rate of heating, modifying the temperature profile of the kiln and adjusting the sintering rate. Some of the important steps are the heating up rate which depends on the thermal conductivity, moisture and gas evolution during drying and mineral decomposition, phase transformations such as α-β quartz, low viscosity liquid phase formation and solid state reactions as a function of temperature profile during sintering.

Effect of quartz addition on the properties of ceramic white ware compositions

The effects of quartz addition as a substitution on the mechanical properties of ceramic whiteware samples were studied. The design envisaged producing a ceramic whiteware from two clays, each having the different composition and with different median particle sizes, and only a small amount of clay (~10 to 15%) to minimize the firing shrinkage. The increase in strength has been attributed to decrease in porosity of the material as well as to the reduction of free quartz content in the composition. The aim of this work is to study the possibility of the use of quartz in the ceramic whiteware samples. It was prepared by mixture containing different amount of ball clay, china clay, feldspar and quartz. The samples were fired reaching different maximum temperatures in the range 950-1250 ^{0}C, with a soaking time of 1 hour. The findings would be helpful to improve the mechanical technological properties of ceramic whiteware.

The results of chemical analysis (raw material) are tabulated in Table 2. Complete chemical analysis of ceramic whiteware body with 30% addition of quartz given in Table 2. From the Table 2. ceramic body presented high SiO_2, Al_2O_3 and Fe_2O_3 contents, reaching up to 96%. From the chemical compositions of the sum of Fe_2O_3 and Tio_2 is 1.22%. Many studies have described the influence of these mineralizes in enhancing the process of sintering of ceramic matrix and the formation of mullite [9, 10]. Ti^{4+} and Fe^{3+} play an important role by either substituting Al^{3+} or by their integration in to the structure intensities of the matrix.

Shrinkage of ceramic whiteware samples

The S_1 specimen which has highest clay content with respect to other bodies ($S_1$and S_4), showed the highest shrinkage values. And the compositions, with quartz added, as expected, showed small shrinkage (Table 3 and Fig.1).

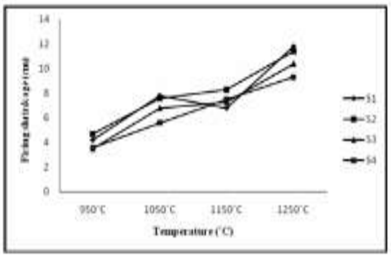

Fig.1 Firing shrinkage for six different ceramic whiteware samples at different temperature

The firing behavior shown by the compositions S_1 to S_4 present an increase of shrinkage from 1150 to 1250 ˚C (Fig.1), that indicates an over firing, this phenomenon only occurs from 1150 to 1250˚C in S4 (Fig.1), it means that highest amount of feldspar extends the firing range.

Ceramic whiteware water absorption.

The internal structure of the ceramic whiteware body must be compact enough to avoid the intrusion of water. Water absorption is used to estimate the pore ratio of ceramic whiteware specimens. High water absorption in whiteware is characterized by a high pore ratio [11], requires the water absorption of ceramic bodies be less than 16% . Whiteware specimens decreased by about 3-4% with the addition of quartz, as can be seen in Fig. (2).

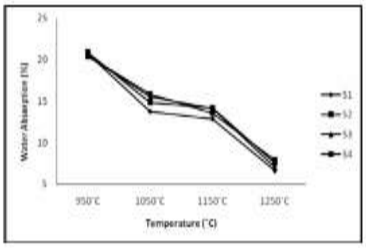

Fig.2 Water absorption for four different ceramic whiteware samples at different temperature

From the Table 3 and Fig.2 we realize that all the specimens with addition of quartz resulted is a highest firing temperature only for the specimen S_1 that reach values of approximately 6% (S_1) at 1200 ˚C. The samples of ceramic whiteware bodies from different proportions of quartz and they produced different values of water absorption.

Porosity of ceramic whiteware samples

The porosity affects a number of properties of ceramic materials but probably the most important effect is on its strength. The lowest porosity has the greatest strength.

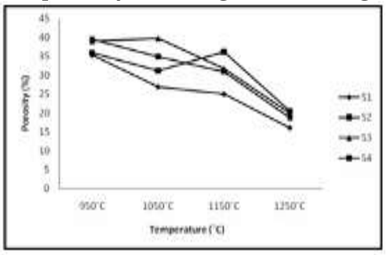

Fig.3 Porosity for six different ceramic whiteware samples at different temperature

Porosity was determined by the boiling method which is the standard procedure. From the Table 3 and Fig. 3 the values of porosities of samples from S_1 to S_4 vary for different temperatures. The porosity of the fired sample is associated to other physical properties such as shrinkage and water absorption Table 3 shows the former properties as function of firing temperature at the 1150 – 1250 ˚C range. Water absorption directly related to open porosity, its value decrease in the overall temperature range. The variation of mechanical properties with porosity for the composition with different quartz particle size. The occurrence of 25% quartz does not substantially change the values of water absorption and open porosity, which decrease sensitively 40% quartz added, only samples of the series S_1 to S_4 show an appreciable important in their mechanical behavior when they reached 1250 ˚C.

Modulus of Rupture

Firing method affects strength because it determines degree of sintering that is attained with a given paste. Various methods of testing strength are employed commercial ceramic practice for special purpose, but they all require some apparatus.

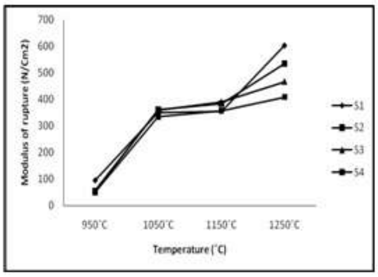

Fig.4 Modulus of rupture for six different ceramic whiteware samples at different temperature

Modulus of Rupture (MOR), values are shown in Table 3. In all series as four different temperatures (950, 1050, 1150 and 1250 ˚C) an increasing bending strength is observed from samples fired at 1250 ˚C, 25 wt % of quartz while for 40 wt % of quartz, a small strength reduction is appreciated Fig. 3 this high value may be attributed to the pre distribution and the verification level of the whiteware body. The α-β Quartz transformation usually causes micro cracks. So avoiding large amount of Quartz was advantageous.

Conclusion

The porosity to increase the mechanical characteristics of a standard body mix for ceramic whiteware samples by the addition of quartz the use of small amount of quartz (25%) in association with China clay and Ball clay showed good result of mechanical properties. From present study the S1 is (at 1250 ˚C) only product (for low tension electrical application) that can be classified as ceramic whiteware body due to its low tension properties. Bending strength is affected by quartz percentage in the ceramic body by the vitreous phase and indirectly through the development of a favorable micro structure. The optimum quartz percentage (25%) S1 samples at 1250 ˚C gives the maximum bending strength. The higher percentage of quartz addition results is reduced bending strength due to the development of a detrimental micro structure for the mechanical properties. In addition, replacing (>25%) part of quartz content with fired ceramic whiteware did not result in a positive effect on bending strength.

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Table.1 Mixtures compositions (wt %)

Samples	Raw materials (wt %)			
	Quartz	Ball clay	China clay	Feldspar
S1	25	30	30	15
S2	30	25	30	15
S3	35	20	30	15
S4	40	15	30	15

Table. 2 Chemical compositions of ceramic whiteware samples in wt % (Raw material)

Element composition	Sample (S2) (%)
Al_2O_3	27.450
CaO	0.166
Cr_2O_3	0.016
CuO	0.006
Fe_2O_3	0.468
K_2O	1.843
MgO	0.161
Na_2O	0.321
P_2O_5	0.043
Rb_2O	0.005
SiO_2	68.580
SO_3	0.127
SrO	0.006
TiO_2	0.747
ZnO	0.004
ZrO_2	0.020

Table. 3 Mechanical properties of the ceramic whiteware samples at different temperatures

Sample	Temperature˚C	Firing Shrinkage (cm)	Water Absorption (%)	Porosity (%)	M.O.R (N/cm^2)
S_1	950˚C	4.2	20.72	35.4	94.41
S_2		4.7	20.84	36.04	55.98
S_3		3.5	20.43	39.06	53.88
S_4		3.6	20.49	39.49	50.35
S_1	1050˚C	7.8	13.75	27.03	349.43
S_2		7.6	14.81	31.28	361.24
S_3		6.8	15.54	39.76	359.01
S_4		5.6	15.86	34.91	334.43
S_1	1150˚C	6.8	12.87	25.09	354.7
S_2		8.3	14.2	36.26	384.37
S_3		7.3	14.14	31.73	390.87
S_4		7.5	13.54	30.95	358.07
S_1	1250˚C	11.8	6.6	16.16	602.75
S_2		11.4	7.53	20.5	534.69
S_3		10.4	7	19.95	466.78
S_4		9.3	7.89	18.77	408.47