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Dielectric behaviour of porcelain in relation to constitution

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Abstract

The dielectric properties of porcelain bodies prepared with and without the incorporation of mineralisers were investigated at different frequencies (1–10 MHz) and room temperature (25°C). The phase compositions and microstructures of the porcelain bodies were also determined. The influence of concentrations of mullite, quartz, cristobalite and glass as well as size of mullite crystals and the asymmetry of mullite crystal size distribution on dielectric constant, tanδ and loss factor were examined. The results suggested that frequency of the order of 10^6 Hz had almost no effect on the dielectric constant but influenced the loss factor substantially. Multiple regression equations connecting loss factor with the constitutional parameters of porcelain bodies were developed to calculate loss factor and the calculated and experimental values were compared. © 2000 Elsevier Science Ltd and Techna S.r.l. All rights reserved.

Keywords: C. Dielectric properties; D. Porcelain

1. Introduction

Porcelain is an aggregate of mullite and quartz crystals embedded in a glassy matrix [1]. In addition to these phases cristobalite crystals were also found in porcelains which were incorporated with metal oxides and subjected to prolonged heating [2]. The dielectric properties, e.g. dielectric constant, power factor (tan δ), loss factor, etc. of the porcelain body are dependent on the characteristics of each of these phases.

The glassy phase in porcelain is derived from the feldspar component and it is poorly conducting [3]. But the metal oxides or mineralizers which were deliberately added to the porcelain compositions became dissolved partially into the glassy phase [2] and increased its electrical conductivity to some extent. The quartz and cristobalite are low loss phases [4]. But mullite is a comparatively high loss phase and current loss through mullite varies with its structural characteristics [5]. While quartz and cristobalite have defect-free structures, the structure of mullite possesses inherent defect in the form of oxygen vacancy [6,7]. The possibility of a wide range of solid solution of different oxides in the mullite structure creates more defect centres in it [8,9] and current dissipates through these centres. Substitution of Al^{3+} ion in the mullite structure by the transition metal ions induces a semiconducting property in mullite [5].

Some authors [10,11] showed that the dielectric loss of poorly-conducting homogeneous glass could be increased as a result of the formation of some semiconductor type crystals. It was demonstrated [11] that the formation of a few crystals of magnesium aluminium titanate with semiconducting property in a glass decreased its ac/dc resistivity. The concentration, size, shape and distribution of semiconductor-like crystalline phases in the glassy matrix also influenced dielectric loss [12–14] of the glass.

The phase composition and microstructure of the porcelain body undergo change with the change in application temperature as well as continuous use at an elevated temperature. The dielectric properties of the porcelain body are, therefore, liable to vary under these conditions because they are sensitive to change in constitution. Porcelain bodies were, therefore, heated at a predetermined temperature (i.e. 1150°C) for a fairly long time (i.e. 50 h) till further change in phase composition and microstructure did not occur. The porcelain body assumed virtually stable constitution by this process of heat-treatment. The dielectric properties of porcelain

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bodies before and after being subjected to heat-treatment were then studied.

The dielectric properties are dependent on the frequency of the applied electric field [15]. Therefore, the dielectric properties of porcelain bodies were measured at different frequencies to ascertain the influence of frequency, if any, on the relationships between their constitution and dielectric properties.

2. Experimental procedure

2.1. Sample preparation

The disc shaped samples were prepared by the slip casting process. The slip was obtained by wet milling a mixture of pure china clay, quartz and potash-feldspar in the proportion of 63:12:25 wt.%, respectively with and without the addition of metal oxides called mineralizers. The selected mineralizers were Fe_2O_3, TiO_2, Cr_2O_3, V_2O_5 and Nb_2O_5. Each of them individually as well as their mixtures, e.g. $V_2O_5+TiO_2$ and $V_2O_5+Fe_2O_3$ were incorporated into the porcelain body. Nine compositions, one without and eight with the addition of mineralizers resulted. The discs were dried and fired in an electrically heated furnace at 1400°C for 1 h in air and cooled overnight. The discs were ground and polished to about 25 mm diameter and 3 mm thick.

2.2. Heat treatment

The discs were powdered and subjected to differential thermal analysis (DTA). Exothermic peaks were found to appear in the DTA traces at and around 1150°C indicating crystallization of the primary phase mullite at the temperature. Therefore, heat-treatment of the samples were conducted at 1150°C. One half of the discs of each porcelain composition was heat-treated at 1150°C for 50 h and the other half of the disc was left as such (unheat-treated). Thus, two sets of samples were obtained from each porcelain composition. One set comprised before heat-treatment samples and the other set comprised after heat-treatment samples.

2.3. X-ray diffractometry (XRD)

The identification and estimation of crystalline phases in the porcelain samples were carried out by X-ray diffractometry (XRD). The internal standard technique [16] was employed for estimation of mullite, quartz and cristobalite phases which were identified in the porcelain samples.

Pure mullite and amorphous diluent were mixed in different proportions to prepare standard mullite samples of the same weight but different mullite content. As an internal standard, NaF was added to each standard sample by 10% of its weight. Standard samples of quartz and cristobalite were prepared similarly from pure quartz and cristobalite with the addition of NaF. The experimental porcelain samples were powdered and mixed with NaF in the same proportion. The standard and experimental samples were scanned under identical conditions in an X-ray diffractometer to record the peaks of mullite (121), quartz (112), cristobalite (101) and NaF (200) and (202) and their heights were measured. Calibration curves were drawn to estimate the concentrations of mullite, quartz and cristobalite in the porcelain samples. The concentration of the glassy phase was calculated by subtracting total crystalline phase content from 100. The details of X-ray analysis was given in a separate paper [2].

2.4. Transmission electron microscopy (TEM)

The shape, size (length and breadth) and size-distribution of mullite crystals in the porcelain samples were investigated by a transmission electron microscope (TEM). A disc was polished and then etched with 40% HF for 1 min at room temperature. Carbon replicas of the etched surface of the disc were prepared by the two-stage replica technique and the replicas were observed under TEM.

The crystals were mainly needle shaped having a wide range of aspect ratio [17]. Except for a very few the crystals were of submicron size. The sizes (length and breadth) of more than 200 mullite crystals were measured from several TEM micrographs of a sample. The size-distribution parameters of mullite crystals were then calculated by statistical analysis and the distribution curves were drawn. The details of electron microscopy of the samples were presented in the earlier communication [17].

2.5. Dielectric property measurement

The dielectric constant, tanδ and loss factor of the porcelain samples were measured with the help of a Circuit Magnification Meter (TF 1245 of Marconi Instruments Ltd.).

2.5.1. Dielectric constant

A porcelain sample (disc) was inserted between the plate capacitor in the test jig and the circuit was resonated at a fixed oscillator frequency and the capacitance (D_1) was recorded. The disc was removed and the circuit was again resonated with only the plate capacitor without altering the oscillator frequency to obtain the capacitance (D_2). The dielectric constant (K) of the sample was, therefore, $K=(D_1/D_2)$.

2.5.2. Tan δ

A suitable resonating inductor was connected to the circuit and the capacitance of the circuit was adjusted to minimum (C_1) by tuning the capacitor. The circuit was then resonated at a fixed oscillator frequency and the Q-reading (Q_1) was noted. The porcelain sample (disc) was then connected to the circuit. The circuit was resonated by tuning the capacitor but keeping the oscillator frequency unchanged and at resonance the capacitance was (C_2) and the Q-reading was (Q_2). Therefore, tanδ of the sample was,

$$\tan\delta = \left(\frac{Q_1 - Q_2}{Q_1 Q_2}\right)\left(\frac{C_1}{C_1 - C_2}\right). \tag{1}$$

The dielectric constant and tanδ of each porcelain sample were measured at three frequencies, 1, 5 and 10 MHz.

Table 1
Description of porcelain samples

Sample No.	Description
1	Base composition (BC)[a]
2	BC + 8.0 wt.% TiO_2
3	BC + 3.0 wt.% V_2O_5
4	BC + 2.6 wt.% Fe_2O_3
5	BC + 2.6 wt.% TiO_2
6	BC + (1.5 wt.% V_2O_5 + 1.3 wt.% Fe_2O_3)
7	BC + (1.5 wt.% V_2O_5 + 1.3 wt. % TiO_2)
8	BC + 2.5 wt.% Cr_2O_3
9	BC + 2.0 wt.% Nb_2O_5

[a] Base composition: China clay (63.0 wt.%) + quartz (12.0 wt.%) + feldspar (25.0 wt.%).

2.5.3. *Loss factor*

The loss factor of each sample was then calculated as dielectric constant × tanδ. The loss factor was also determined at 1, 5 and 10 MHz frequencies.

2.6. *Statistical analysis*

The multiple regression equations were developed by statistical analysis [18] of the values of loss factor at 1, 5 and 10 MHz frequencies and the constitutional parameters of the porcelain samples. These equations helped to understand the combined influence of the constitutional parameters on the loss factor. Values of loss factor of the samples were calculated with the help of these equations and compared with those obtained by experiment in terms of percentage difference, $(\frac{\text{Calc.}-\text{Expt.}}{\text{Calc.}})\times 100$.

3. Results and discussion

The compositions of the porcelain samples are shown in Table 1. The base composition (BC) was made from china clay (63 wt.%), quartz (12 wt.%) and K-feldspar (25 wt.%). The type and amount of mineralizers added to BC are also indicated. Eighteen samples resulted from nine parent compositions of which one set was not heat-treated and marked B and the other set was heat-treated and marked A.

The dielectric properties and the constitutional parameters of the porcelain samples are presented in Table 2. The dependence of dielectric constant of the samples

Table 2
Dielectric properties and constitutional parameters of porcelain samples

Sample no.	Dielectric properties														
	Frequency: 1 MHz			Frequency: 5 MHz			Frequency 10Mhz			Constitutional parameters					
	Dielectric constant (K)	Tanδ	Loss Factor (K tanδ)	Dielectric constant (K)	tanδ	Loss factor (K tanδ)	Dielectric constant (K)	Tanδ	Loss Factor (K tanδ)	Mullite (wt.%)	Quartz (wt.%)	Cristobalite (wt.%)	Glass (wt.%)	Mullite crystal size (μ)	Skewness
1B[a]	2.19	0.0273	0.0598	2.09	0.0120	0.0251	2.13	0.0106	0.0226	32.7	4.5	0.2	62.6	0.1364	0.5701
2B	2.73	0.0138	0.0377	2.73	0.0143	0.0390	2.59	0.0076	0.0197	28.5	6.5	0.0	65.0	0.1460	0.5549
3B	2.44	0.0408	0.0995	2.58	0.0100	0.0258	2.34	0.0106	0.0248	39.7	7.5	0.3	52.5	0.2428	0.5270
4B	2.31	0.0245	0.0566	2.50	0.0100	0.0250	2.35	0.0106	0.0249	33.5	10.7	0.0	55.7	0.1258	0.6110
5B	2.68	0.0146	0.0391	2.42	0.0300	0.0726	2.62	0.0168	0.0440	33.5	3.0	0.0	63.5	0.1790	0.3962
6B	1.76	0.0105	0.0185	1.88	0.0154	0.0289	1.84	0.0117	0.0215	36.0	8.3	0.4	55.4	0.1298	0.4985
7B	3.05	0.0163	0.0497	2.91	0.0117	0.0340	3.00	0.0093	0.0279	32.7	6.3	0.3	60.7	0.1233	0.5561
8B	2.19	0.0163	0.0357	2.19	0.0169	0.0370	2.19	0.0117	0.0256	29.7	5.5	0.4	64.3	0.1306	0.6176
9B	2.38	0.0163	0.0388	2.27	0.0150	0.0340	2.39	0.0117	0.0280	43.0	9.7	24.8	22.4	0.2084	0.4182
1A[b]	2.62	0.0193	0.0506	2.84	0.0159	0.0452	1.80	0.0133	0.0221	41.5	5.4	22.8	30.4	0.1443	0.5484
2A	2.19	0.0163	0.0357	2.36	0.0184	0.0434	2.29	0.0093	0.0213	35.5	3.7	27.8	33.0	0.1791	0.3213
3A	2.26	0.0366	0.0828	2.26	0.0113	0.0255	2.21	0.0209	0.0463	43.0	5.7	28.6	22.6	0.3228	0.7296
4A	2.40	0.0193	0.0463	2.41	0.0131	0.0316	2.40	0.0133	0.0319	41.5	6.2	25.2	27.2	0.1772	0.4165
5A	2.94	0.0146	0.0429	2.75	0.0120	0.0330	2.80	0.0165	0.0462	40.7	5.3	31.0	23.0	0.4473	0.6506
6A	1.94	0.0380	0.0738	1.99	0.0120	0.0239	1.96	0.0133	0.0261	43.0	5.6	25.6	25.8	0.2086	0.3799
7A	2.39	0.0334	0.0798	2.27	0.0143	0.0325	2.31	0.0107	0.0247	43.0	5.7	27.0	24.3	0.1500	0.2433
8A	2.56	0.0304	0.0778	2.55	0.0150	0.0382	2.54	0.0133	0.0338	43.0	5.0	24.4	27.6	0.1411	0.2766
9A	2.09	0.0336	0.0703	2.14	0.0120	0.0257	2.12	0.0106	0.0225	42.3	5.0	29.0	23.7	0.2550	0.4220

[a] B, sample before heat-treatment.
[b] A, sample after heat-treatment.

on each of the constitutional parameters is exhibited in Figs. 1–6. The relationships between loss factor of the samples and the constitutional parameters are displayed in Figs. 7–12. In each figure, B represents the samples before heat-treatment and A represents the samples after heat-treatment.

Two trends emerged in the relationships shown in Figs. 1–6. In one case the dielectric constant initially

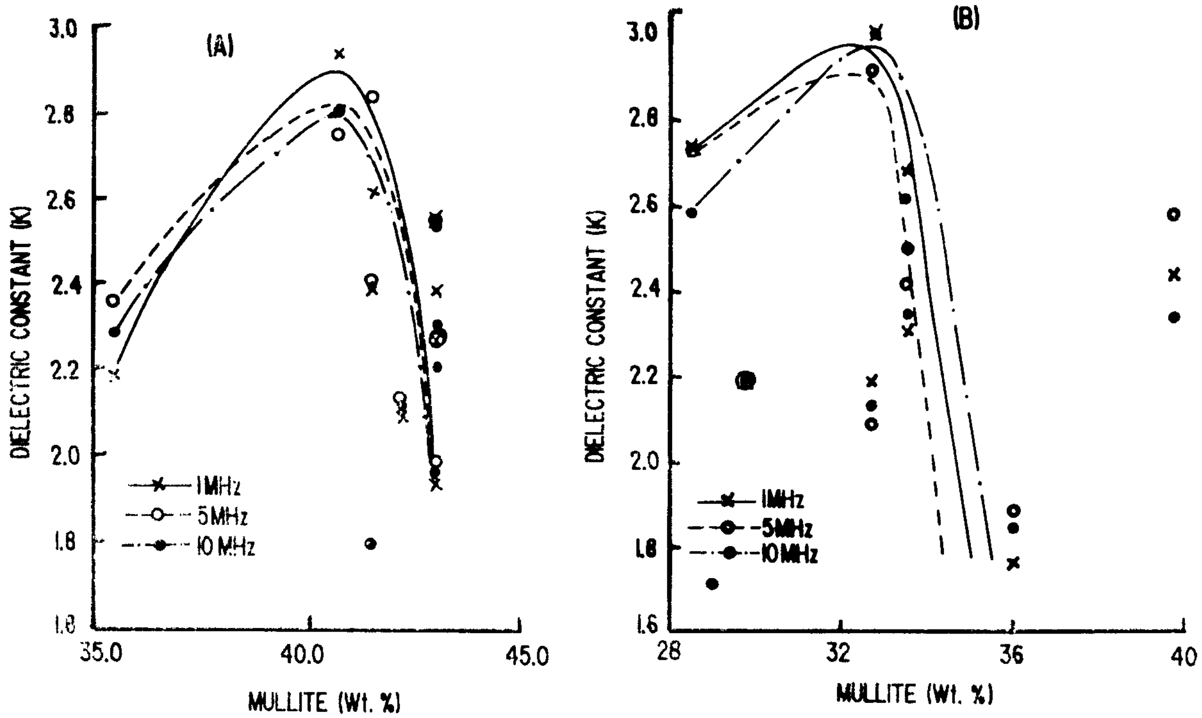

Fig. 1. Relationship between dielectric constant and concentration of mullite.

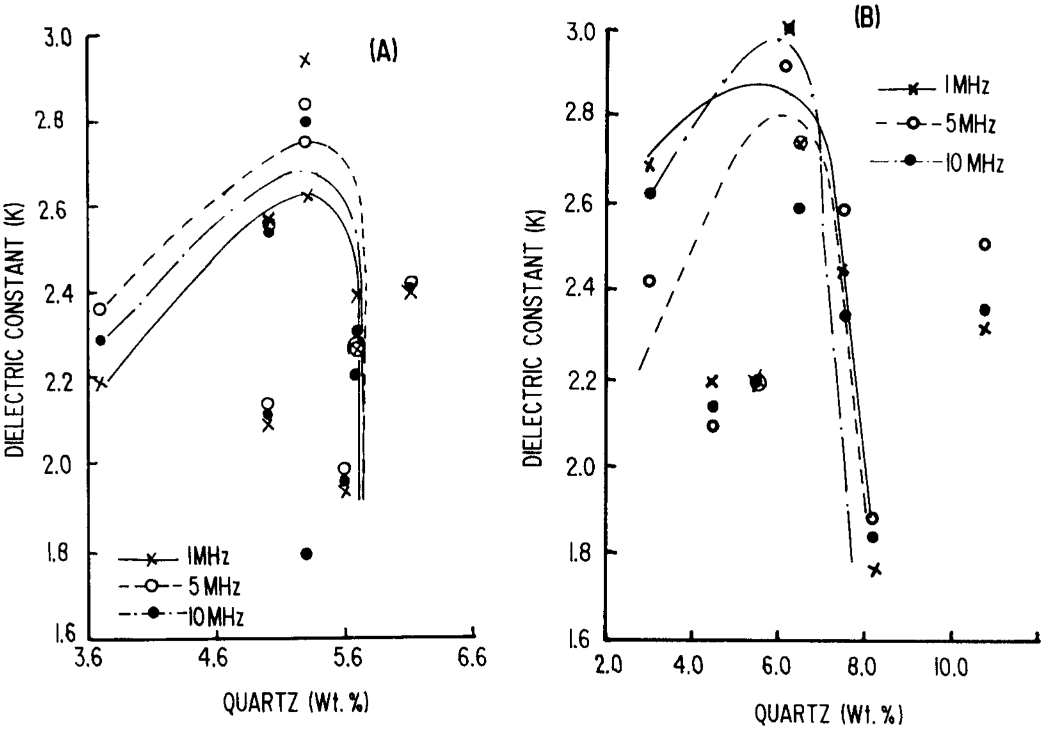

Fig. 2. Relationship between dielectric constant and concentration of quartz.

increased to a maximum value and then sharply decreased with the increase in the concentration of mullite (Fig. 1) and quartz (Fig. 2). In other cases the dielectric constant dropped quickly to a minimum value and then rose with the rise in the concentrations of cristobalite (Fig. 3) and glassy phase (Fig. 4), size of mullite crystals (Fig. 5) and the skewness (Fig. 6). Similar relationships appeared to hold between loss factor and constitutional parameters of samples from Figs. 7–12.

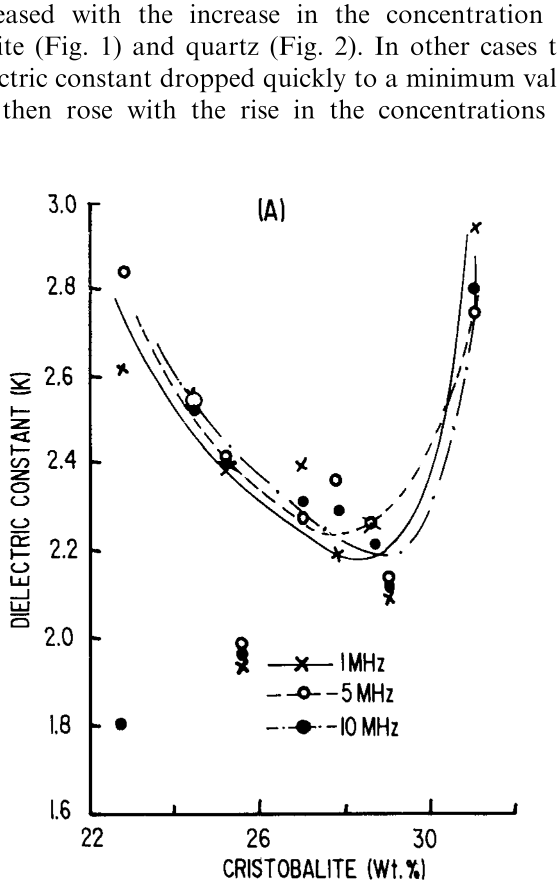

Fig. 3. Relationship between dielectric constant and concentration of cristobalite.

A general finding, as it appears from the curves (Figs. 1–6) is that the relationships between dielectric constant and constitutional parameters are independent of the frequencies used. The effect of frequency on the dielectric constant of ceramic samples is negligible up to 10^{10} Hz. Below this frequency dielectric constant is controlled predominantly by electronic and ionic polarization mechanisms which are basically independent of frequency [19]. So, the dielectric constant of the porcelain samples was unaffected by the comparatively low frequencies, i.e. 1×10^6– 10×10^6 Hz.

The curves (Figs. 7–12) showing relationships between loss factor (dielectric const. × tanδ) and the constitutional parameters are influenced by the frequencies used. The power dissipation factor or tanδ is substantially dependant on the frequency of 10^6 Hz order and thus controls the loss factor of the porcelain samples. Besides, loss factor of the glassy phase is sensitive to change in frequency [20].

The nature of the curves suggested that the dielectric properties of the samples were a complex function of their constitutional parameters. Multiple regression equations were, therefore, established by statistical analysis between loss factor and parameters for 1, 5 and 10 MHz frequencies, separately, because loss factor is a frequency dependant dielectric property.

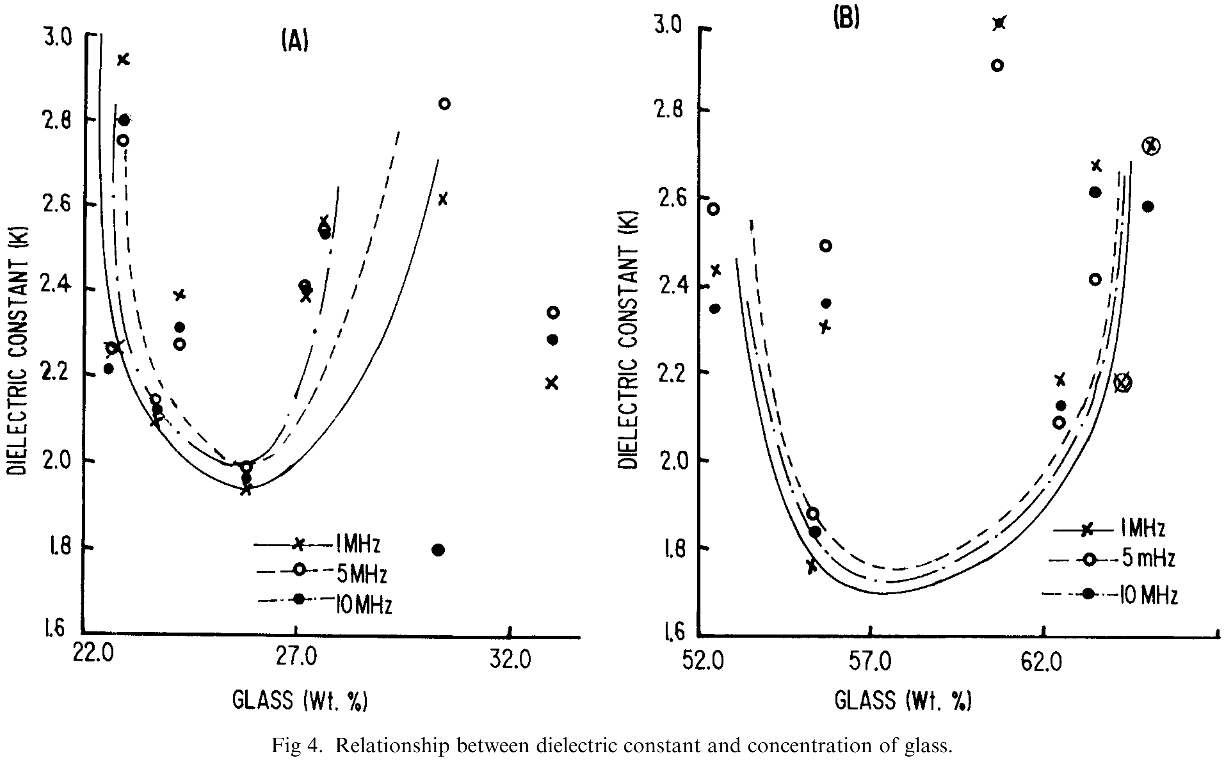

Fig 4. Relationship between dielectric constant and concentration of glass.

The constitutional parameters are denoted by x_1 (conc. of mullite), x_2 (conc. of quartz), x_3 (conc. of cristobalite), x_4 (conc. of glass), x_5 (mullite crystal size) and x_6 (skewness) in these equations. The loss factors of before and after heat-treatment samples are represented by Y_1 and Y_2 at 1 MHz, Y_3 and Y_4 at 5 MHz and Y_5 and Y_6 at 10 MHz frequencies in the equations. A general form of the equation is

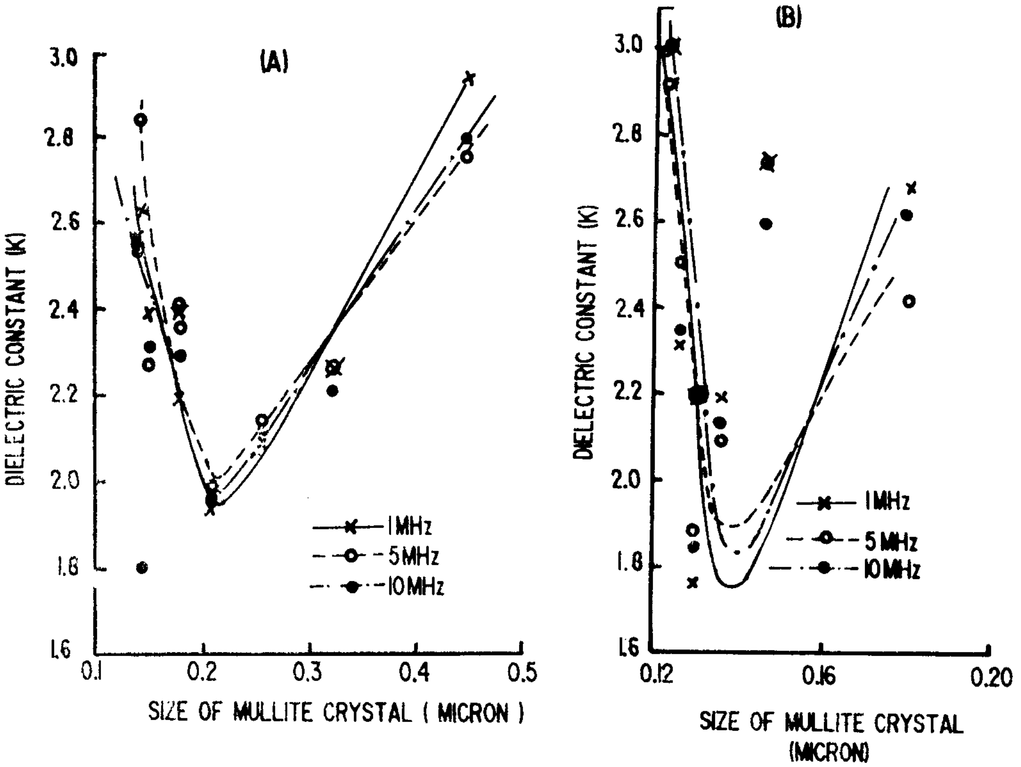

Fig. 5. Relationship between dielectric constant and size of mullite crystal.

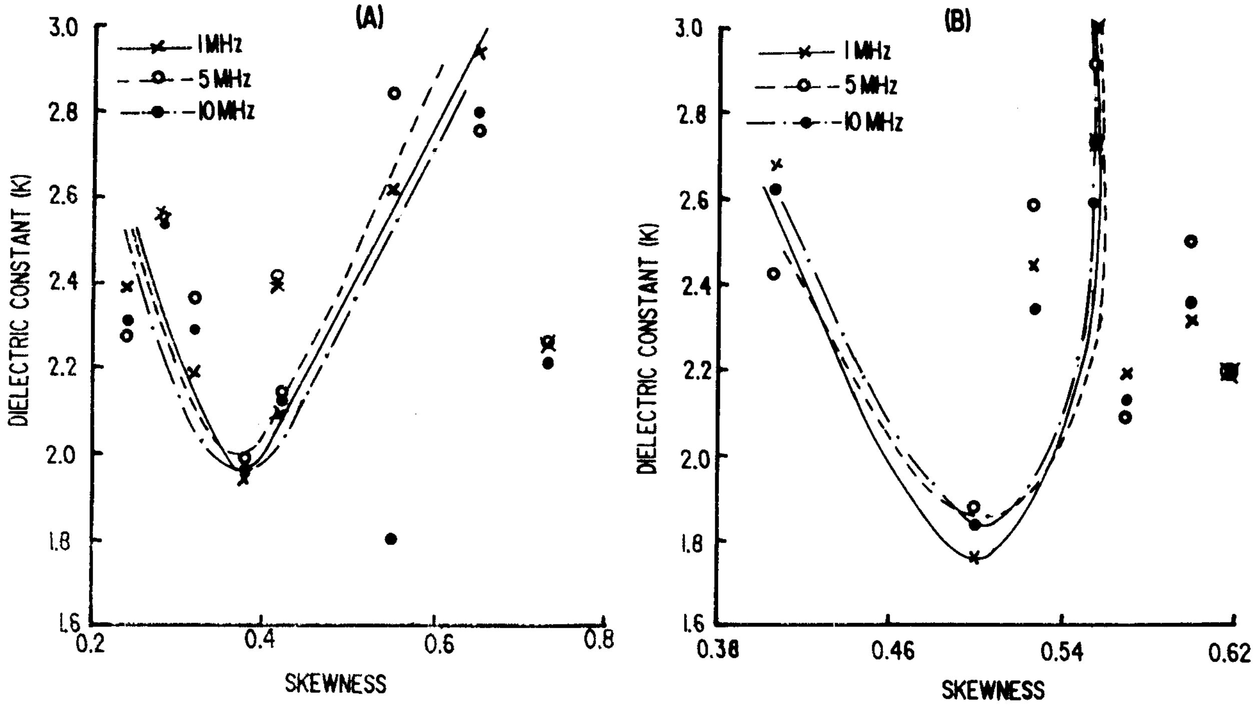

Fig. 6. Relationship between dielectric constant and skewness.

$$Y = ax_1 + bx_2 + cx_3 + dx_4 + ex_5 + fx_6$$

where a, b, c, d, e, f are the correlation coefficients of x_1, x_2, x_3, x_4, x_5 and x_6, respectively.

The values of correlation coefficients were determined and tabulated in Table 3. The loss factors of the samples which were obtained experimentally and also calculated by the equations at 1, 5 and 10 MHz frequencies are included in Table 4. The difference between the calculated and experimental values of loss factors (Table 4) of the samples indicated the extent of deviation of a single parameter vs loss factor relationship from that expected due to the joint effect of all the parameters.

It appeared from Table 2 that heat-treatment brought about significant changes in the phase composition and microstructure of the porcelain samples. The concentrations of mullite and cristobalite increased by 3–13 wt.% and 23–31 wt.%, respectively in the samples after heat-treatment (lA–9A) from those in the samples before heat-treatment (1B–9B). The glass content of the (1A–9A) samples decreased by 28–40 wt.% from that of the (1B–9B) samples. The amount of quartz in the (1A–9A) and the (1B–9B) samples had but little variation. The heat-treatment helped growth of mullite crystals so that the size of the crystals in the (1A–9A) samples was always bigger than that in the (1B–9B) samples. The

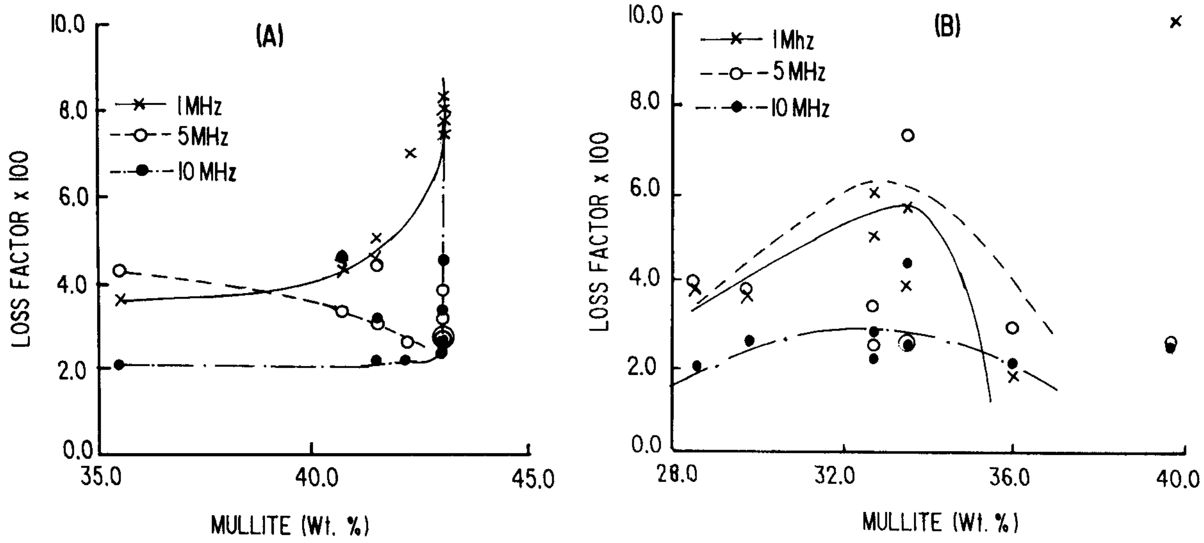

Fig. 7. Relationship between loss factor and concentration of mullite.

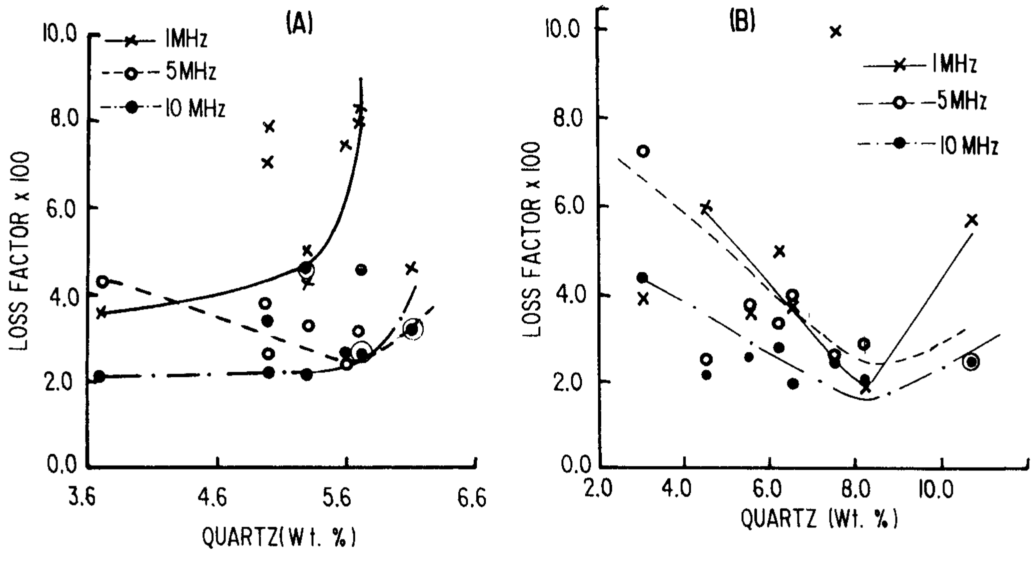

Fig. 8. Relationship between loss factor and concentration of quartz.

skewness or asymmetry of mullite crystal size-distribution was reduced in the majority of the (1A–9A) samples but less in the (1B–9B) samples.

Mullite crystal has inherent structural defect and further defect centers are generated in it due to the solid solution of the mineralizers present in the porcelain compositions. Mullite crystals, therefore, behaved like a semiconducting phase dispersed in the matrix of the samples. Quartz and cristobalite exist as discrete insulating particles in the sample matrix. The function of the feldspar glass which was the matrix of the samples was more like an insulator than a conductor. The great structural stability of crystalline K-feldspar up to its melting point and above and also the high viscosity of the feldspar glass firmly held the charge carrier alkali ions to it. Thus, movement of the alkali ions was restricted.

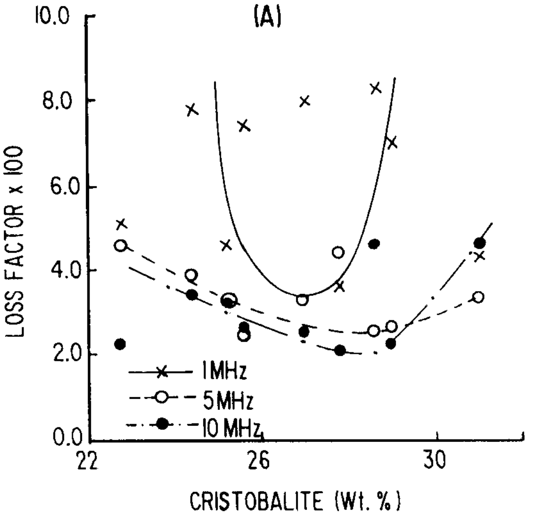

Fig. 9. Relationship between loss factor and concentration of cristobalite.

The electrical conductivity of the crystalline and glassy phases in the porcelain samples has considerable influence on their dielectric properties. The relationship, ($\tan\delta = \sigma/2\pi f K' E_0$) [15], suggests that the dielectric loss factor (K' $\tan\delta$) is directly proportional to electrical conductivity (σ) but dielectric constant (K') and σ are inversely related. Among the crystalline phases, therefore, mullite should increase the loss factor and decrease the dielectric constant of the samples but quartz and cristobalite should have a reverse effect on these properties. The effect of glassy phase on these properties should be similar to that of quartz and cristobalite.

The boundaries between mullite crystals are considered to be the paths that allow dissipation of current from the sample. The number and length of such boundaries or continuous paths also called the mean-free-paths control uninterrupted flow of current through the sample in a manner so that longer boundaries constitute longer mean-free-paths resulting in more current and dielectric loss. Longer mean-free-paths are formed by bigger mullite crystals. The loss factor of the sample, therefore, increased with the rise in mullite crystal size.

The skewness is a measure of asymmetry of mullite crystal size-distribution. The greater asymmetry of distribution improved the compactness of packing of mullite crystals in the sample and enhanced the dielectric loss and the loss factor increased with rise in skewness.

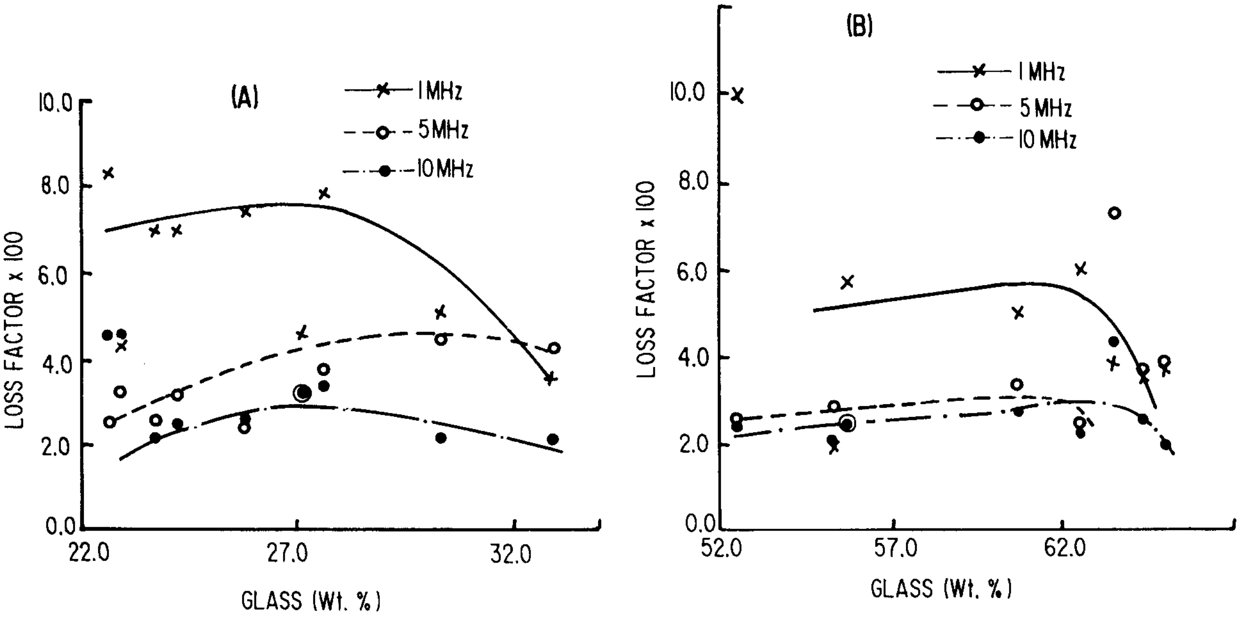

Fig. 10. Relationship between loss factor and concentration of glass.

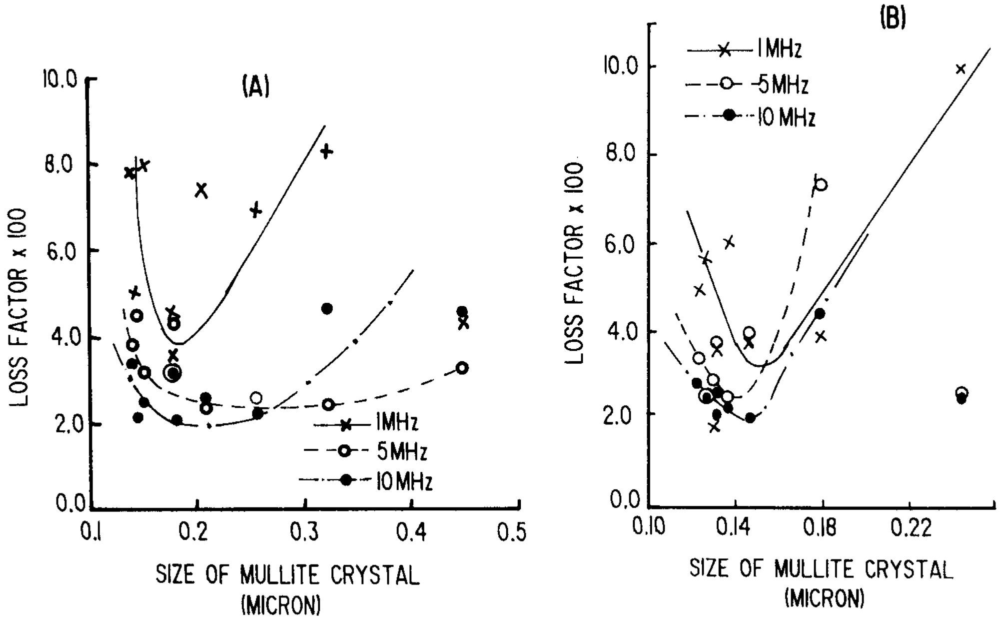

Fig. 11. Relationship between loss factor and size of mullite crystal.

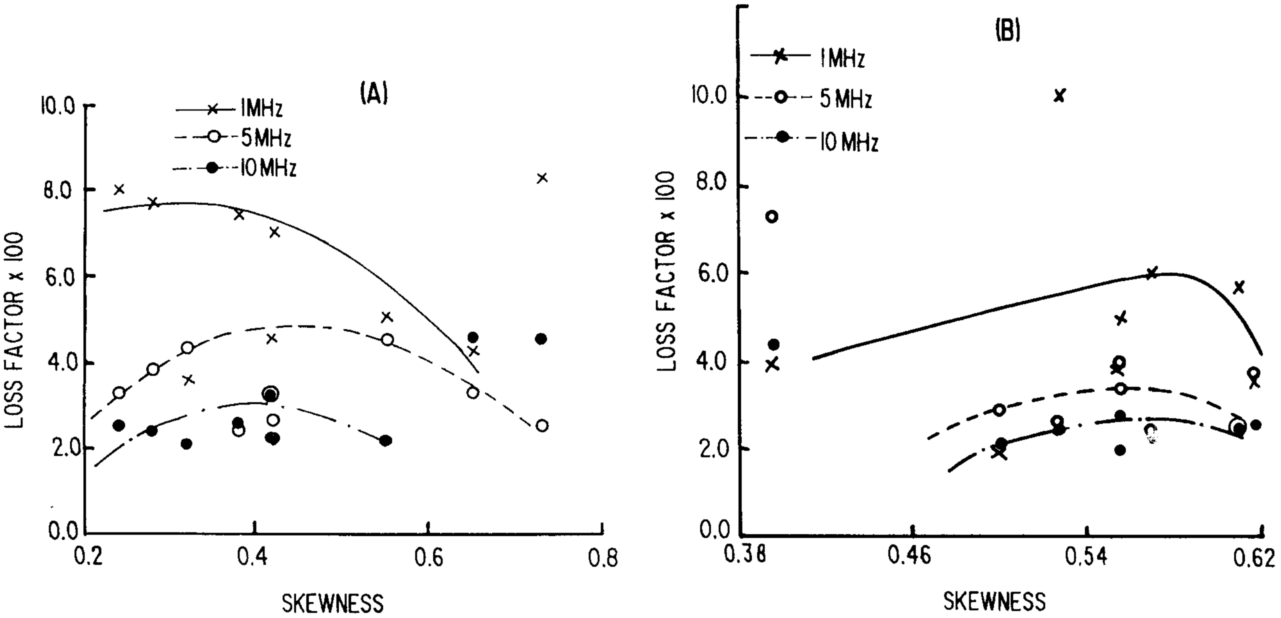

Fig. 12. Relationship between loss factor and skewness.

It is evident from the results presented in Table 2 that (i) the concentration of mullite, (ii) the size of mullite crystals, and (iii) the concentration of cristobalite in the samples marked A were higher than those in the corresponding samples marked B. The (iv) concentration of glass and (v) the skewness in the samples marked A were less than those in the corresponding samples marked B. It was, therefore, expected that due to (i), (ii) and (iv) the samples marked A should have lower dielectric constant and higher loss factor than those of the corresponding samples marked B. This expectation was fulfilled with half of the samples (Table 2) but not with the rest of the samples. This anomalous result was obtained owing to (iii) and (v).

The plots of individual parameter vs dielectric constant (Figs. 1–6) and individual parameter vs loss factor (Figs. 7–12) were not linear but parabolic with either a maximum or a minimum value of the property at a fixed value of the parameter. In these figures one segment of the parabolic curve obeyed the expected relationship between the dielectric property and the constitutional parameter but the other segment did not. This may be

Table 3
Correlation coefficients of constitutional parameters and loss factor at different frequencies of porcelain samples

Sample no.	Frequency (MHz)	Loss factor	Coefficients of constitutional parameters					
			a	*b*	*c*	*d*	*e*	*f*
1B–9B[a]	1	Y_1	0.0029	−0.0090	−0.0810	−0.0033	0.2408	0.3476
1A–9A[b]	1	Y_2	0.0060	−0.0181	0.0016	−0.0042	−0.1801	0.0358
1B –9B	5	Y_3	−0.0005	0.0017	−0.0030	0.0022	0.0633	−0.1840
1A–9A	5	Y_4	0.0002	−0.0018	−0.0007	0.0018	0.0209	0.0015
1B–9B	10	Y_5	0.0011	−0.0011	−0.0147	0.0005	−0.0417	−0.0421
1A–9A	10	Y_6	0.0004	0.0023	-0.0009	0.0001	0.0876	0.0033

[a] B, sample before heat-treatment.
[b] A, sample after heat-treatment.

Table 4
Calculated and experimental values of loss factor at different frequencies of porcelain samples

Sample no.	Loss factor								
	Frequency: 1 MHz			Frequency: 5 MHz			Frequency: 10 MHz		
	Calculated	Experimental	Difference (%)	Calculated	Experimental	Difference (%)	Calculated	Experimental	Difference (%)
1B[a]	0.0618	0.0598	3.2	0.0321	0.0251	21.8	0.0281	0.0226	19.6
2B	0.0365	0.0377	−3.3	0.0469	0.0390	16.8	0.0257	0.0197	23.3
3B	0.0988	0.0995	−0.7	0.0266	0.0258	3.0	0.0254	0.0248	2.4
4B	0.0585	0.0566	3.2	0.0196	0.0250	−27.5	0.0209	0.0249	−19.1
5B	0.0404	0.0391	3.2	0.0667	0.0726	-8.8	0.0396	0.0440	−11.1
6B	0.0191	0.0185	3.1	0.0332	0.0289	12.9	0.0248	0.0215	13.3
7B	0.0444	0.0497	−11.9	0.0328	0.0340	−3.6	0.0266	0.0279	−4.9
8B	0.0371	0.0357	3.8	0.0294	0.0370	−25.8	0.0199	0.0256	−28.6
9B	–	0.0388	–	–	0.0340	–	–	0.0280	–
1A[b]	0.0566	0.0506	10.6	0.0414	0.0452	−9.2	0.0279	0.0221	20.8
2A	0.0321	0.0357	−11.2	0.0448	0.0434	3.1	0.0197	0.0213	−8.1
3A	0.0749	0.0828	−10.5	0.0273	0.0255	6.6	0.0397	0.0463	−16.6
4A	0.0490	0.0463	5.5	0.0332	0.0316	4.8	0.0297	0.0319	−7.4
5A	0.0457	0.0429	6.1	0.0290	0.0330	−13.8	0.0463	0.0462	0.2
6A	0.0663	0.0738	−11.3	0.0323	0.0239	26.0	0.0314	0.0261	16.9
7A	0.0793	0.0798	−0.6	0.0269	0.0325	−20.8	0.0246	0.0247	−0.4
8A	0.0760	0.0778	−2.3	0.0359	0.0382	−6.4	0.0250	0.0338	−35.2
9A	0.0800	0.0703	12.1	0.0282	0.0257	8.9	0.0306	0.0225	26.5

[a] B, sample before heat-treatment.
[b] A, sample after heat-treatment.

accounted for by considering both the sign and magnitude of the effect of each parameter on the property.

The correlation coefficients *a*, *e* and *f* were mostly (+ve) and, therefore, the associated parameters, i.e. concentration of mullite, size of mullite crystal and skewness, respectively should increase the loss factor. The other parameters, i.e. concentrations of quartz, cristobalite and glass with mostly (−ve) correlation coefficients *b*, *c* and *d* (two values approached zero), respectively tended to decrease the loss factor (Table 3). Among the coefficients *e* and *f* had very high magnitude but *a* had low value and *b*, *c* and *d* had appreciably lower value than *e* and *f* (Table 3). The influence of parameters of high magnitude dominated the relationships between an individual parameter and the loss factor resulting in parabolic curves (Figs. 7–12).

Similar explanations could be accorded to the parabolic nature of the curves (Figs. 1–6) for individual parameter vs dielectric constant by developing multiple regression equations for dielectric constant and constitutional parameters.

The results presented in Table 4 showed that the difference between the calculated and experimental values of loss factor increased from 1 to 10 MHz frequency for samples marked B and A ranging from 4 to 15% for B and 8 to 15% for A. In spite of a small number of data available for regression analysis and contradictory effects of the parameters on the dielectric properties, the loss factor of the porcelain samples can be predicted within ±15% accuracy.

4. Conclusions

The effects of the constitutional parameters worked simultaneously on the dielectric properties and were dependant on their sign (increasing or decreasing) as well as magnitude (intensity). Thus, the plot showing the relationship between a parameter and a property assumed a parabolic curve rather than a straight line.

The loss factor could be predicted within ±15% of the experimental value by the multiple regression equations connecting the loss factor with all the parameters.

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