

PERMITTIVITY IN THE MICROWAVE REGION OF SOME SILICATE
AND FERRITE MINERALS AT LOW PRESSURES

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Abstract: The dielectric permittivity and attenuation of some silicate and ferrite minerals have been measured at very low pressures in the microwave region at 8.63 GHz using a standing wave method. Both dielectric permittivity and attenuation caused by the inserted sample are increased by increasing the pressure.

1. Introduction

The permittivity and dielectric loss in the microwave region can be determined by several methods¹⁻⁶). In this work, a method⁵) which depends on standing wave measurements in a rectangular waveguide is used.

Let the waves propagating from the source be incident normally at the surface of the material of dielectric constant ϵ^* . As a result of reflection a standing wave pattern is produced. From the shape and position of this pattern the reflection coefficient $|R|$ and the phase change on reflection Φ can be obtained.

From the transmission line theory the reflection coefficient R is $R = \frac{1 - S}{1 + S} e^{i\phi}$, where S is the reciprocal of the standing wave ratio. If S_0 and S_s are the reciprocal of the standing wave ratio in the open and short circuited cases, the reflection coefficient $|R|$ for the two previous cases denoted by $|R_0|$ and $|R_s|$ can be calculated.

According to Heath⁷⁾, the attenuation α in decibels for very low loss materials can be calculated from

$$\alpha = 10 \log \frac{|R_o| + |R_s|}{2} \quad (1)$$

From the standing wave ratio and phase shift, the input impedances r_o and r_s in the open and short circuited cases can be calculated using the Smith Chart and ϵ' and ϵ'' obtained from⁸⁾ the expression

$$\frac{1}{r_o r_s} = \frac{\epsilon' - q}{1 - q} - i \frac{\epsilon''}{1 - q},$$

where $q = \frac{\lambda}{\lambda_c}$; λ is the wavelength in air and λ_c is the cut off wavelength. By equating the real and imaginary parts ϵ' and ϵ'' can be obtained. The measured values denoted by ϵ'_m and ϵ''_m can be used to calculate ϵ' and ϵ'' of the material from^{9, 10, 11)}

$$\epsilon'_m = 1 + P(\epsilon' - 1) \quad (2)$$

and

$$\epsilon'' = \frac{\epsilon''_m}{P}, \quad (3)$$

where P is the density of packing of the material as given by the ratio of the volume of the material to the overall volume occupied. The volume of the material is obtained from the mass divided by density and the overall volume obtained from the dimensions of the space occupied by the material. The accuracy in ϵ' is better than 5 %.

2. Experimental

The apparatus used for the measurements of permittivity and attenuation caused by the inserted samples in the microwave region is described elsewhere⁸⁾. The cell used in the measurements is a piece of waveguide 4 cm long and closed from both sides by thin mica windows. The cell is closed by a shorting metal plate for the measurements in the short circuited case. For the measurements in the open circuited case, the cell is connected to a movable short adjusted to interpose a $\frac{\lambda}{4}$ air filled waveguide between it and the back face of the test material.

Measurements were carried out on clinostatite, forsterite, magnesioferrite, magnesiochromite, β -dicalcium silicate and tricalcium silicate. Each sample was dried at 200°C for six hours till a constant weight is attained and compressed inside

the cell by means of a plunger and an oil press. The voltage standing wave ratio is determined by taking the probe positions Δx at which the power equals twice its minimum value and substituting in the Equ^{1,2)} $S = \frac{I}{\sigma} = \frac{\pi \Delta x}{\lambda_g}$. Also, from the position of the first minimum from the interface, Φ can be computed. Knowing S_0 , S_s and Φ the values of r_0 and r_s can be obtained and used to find ϵ' and ϵ'' .

3. Materials

Clinoenstatite and forsterite minerals. Clinoenstatite and forsterite minerals have good dielectric properties and are extensively used in the production of insulators for high frequency equipment. Standard clinoenstatite ($\text{MgO} \cdot \text{SiO}_2$) minerals were prepared synthetically from the finely ground mixtures of MgO and silica in the molecular proportion of 1 : 1 and 2 : 1 respectively. The homogeneous mixtures were fired on two periods of 10 hours at 1350°C in case of clinoenstatite minerals and 1600°C in case of forsterite minerals with intermediate grinding.

Magnesioferrite and magnesiochromite spinel minerals. Magnesioferrite ($\text{MgO} \cdot \text{Fe}_2\text{O}_3$) and magnesiochromite ($\text{MgO} \cdot \text{Cr}_2\text{O}_3$) spinels are important in high frequency engineering as nonmetallic materials with high electric resistance.

Standard magnesioferrite spinel was obtained from the finally ground mixture of MgO and Fe_2O_3 in a stoichiometric ratio. Homogenization of the mixture in a special steel ball-mill was carried out for a period of 6 hours followed by firing to the sintering point at temperature ranging between 1000 — 1300°C in the presence of the stream of oxygen.

Standard magnesiochromite was prepared from a mixture of finely ground MgO and Cr_2O_3 in the molar ratio 1 : 1. The presence of 0.5 — 1% excess Cr_2O_3 is necessary due to sublimation of Cr_2O_3 . The homogeneous mixture is fired at 1200°C for a period of 6 hours followed by grinding and firing at 1200°C for other 6 hours. The product is reground, moulded and fired at 1600°C for a period of 10 hours. Check by chemical analysis was necessary to ascertain that MgO and Cr_2O_3 molar ratio remains 1 : 1.

β -dicalcium silicate and tricalcium silicate minerals. β -dicalcium silicate ($2 \text{CaO} \cdot \text{SiO}_2$) and tricalcium silicate ($3 \text{CaO} \cdot \text{SiO}_2$) minerals are present in Portland cement. β -dicalcium silicate mineral inverts on cooling at 675°C to the γ -form. The preparation of standard β -dicalcium silicate was carried out by heating a mixture of finely ground CaO and SiO_2 in the molecular ratio 2 : 1 at 1450°C. The process of regrinding reheating was repeated until the preparation was homogeneous. The product is then reground, moulded and fired at 1600°C for a period of 10 hours, cooled slowly till 1000°C and then quenched in air to obtain the B-form of dicalcium silicate.

Tricalcium silicate is stable only over a temperature range from 1250–1900°C and decomposes both above and below this range into dicalcium silicate and CaO. The preparation of standard tricalcium silicate necessitates a series of burns. A mixture of CaO and SiO₂ in their molecular ratio was heated at 1200°C for a period of 6 hours. This process was repeated until the combination was complete. The product was ground, moulded and fired at 1600°C for a period of 10 hours followed by quenching rapidly in air. X-ray diffraction patterns of the prepared minerals proved their complete formation.

4. Results and discussion

The minerals are pressed in the cell under low pressures less than 100 kp/cm². The packing density P is calculated from the specific gravity of the samples and the dimensions of the cell. The true value of the dielectric constant ϵ' is calculated from the measured value ϵ'_m using Equ. (2). The attenuation α is calculated using Equ. (1). The results obtained for ϵ'_m , ϵ' and α are given in the Table.

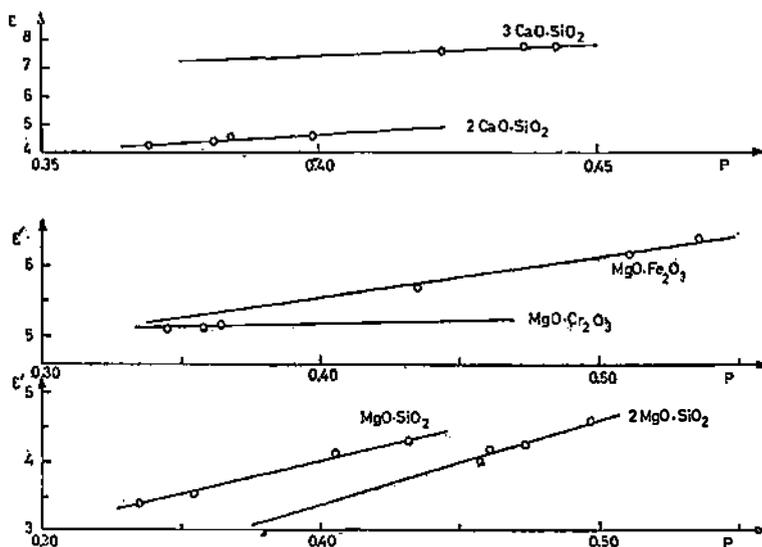


Fig. 1. Dielectric constant ϵ' versus packing density P for different samples.

To discuss the dielectric behaviour of these crystalline materials, it will be helpful to estimate their dimensions from the atoms and ions radii^{1,3}). For the first approximation, the atoms and ions can be considered as rigid spheres, and the crystal radius taken as the sum of the radii concerned. For more accurate interpretation we have to take into consideration the polarisation and deformation properties.

It is also worthy to find the variation of the packing density in the crystal from one mineral to another. As shown in the Table, the volumes of the crystals are calculated using the estimated radii and the ratios of the atomic weight to the corresponding volume are given. This ratio is proportional to the packing density in the crystal and is given also in the Table.

TABLE

Results of the dielectric constant ϵ' and attenuation α for the investigated samples

Substance	r A°	V (A°) ³	Atomic weight	$\frac{At \cdot wt}{V}$	Spec. Gra- vity	P	ϵ'_m	ϵ'	α d b
Clinostatite (MgO · SiO ₂)	5.28	630	100	0.160	3.19	0.335	1.80	3.39	-0.235
						0.355	1.89	3.51	-0.280
						0.405	2.27	4.13	-0.400
						0.432	2.41	4.27	
Forsterite (2MgO · SiO ₂)	7.34	1630	140	0.012	3.22	0.458	2.37	3.99	-0.240
						0.461	2.46	4.17	-0.255
						0.474	2.52	4.21	-0.275
						0.497	2.68	4.37	
Magnesiochromite (MgO · Cr ₂ O ₃)	7.52	1740	192	0.011	4.39	0.345	2.41	5.09	-0.192
						0.358	2.47	5.11	-0.203
						0.363	2.51	5.16	
Magnesioferrite (MgO · Fe ₂ O ₃)	7.54	1805	200	0.011	4.20	0.435	3.03	5.67	-0.205
						0.511	3.63	6.16	-0.255
						0.536	3.90	6.40	-0.280
β -Dicalcium silicate (2CaO · SiO ₂)	8.00	2150	168	0.078	3.28	0.369	2.19	4.22	-0.150
						0.381	2.29	4.39	-0.270
						0.384	2.37	4.57	-0.300
						0.399	2.40	4.52	-0.400
Tricalcium Silicate (3CaO · SiO ₂)	10.39	4720	228	0.040	3.15	0.422	3.78	7.60	-0.255
						0.437	3.95	7.74	-0.275
						0.443	3.97	7.73	-0.300

The relation between ϵ' and P is illustrated in Fig. 1 for the three groups investigated in this work. As expected ϵ' increases linearly with P , i. e. with the pressure. Similar behaviour was found before in the case of titanate ceramics¹⁴⁾. It is interesting to find that for each group, the mineral of lower specific gravity has the higher dielectric constant the same packing density. ϵ' for calcium compounds at any pressure are higher than the magnesium compounds. This was noticed before in the case of Mg and Ca-titanates¹⁴⁾.

Attenuation of the samples is shown in Fig. 2 at the different packing densities. MgO · SiO₂ having the smallest radius of all the investigated magnesium minerals exhibits the highest attenuation, while MgO · Fe₂O₃ having the largest radius the lower attenuation. The attenuation of the other samples lies within these two curves. This may lead to the conclusion that the attenuation in this frequency range depends upon the dimensions of the crystal. Since MgFe₂O₆ has low attenuation and high electrical resistance (known to be between 10² and 10⁶ Ω), it can be used for cores in high frequency coils. It is to be added that tricalcium silicates possess high dielectric constant and low attenuation as shown in the Table, which are the properties of a good insulator.

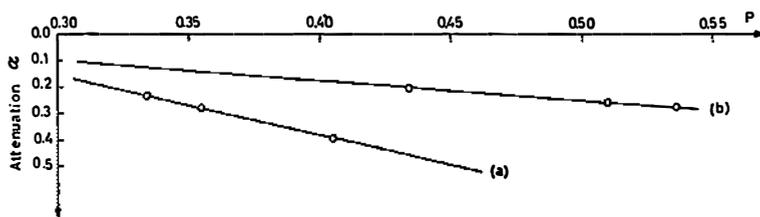


Fig. 2. Attenuation α versus packing density P for
 a) MgO · SiO₂,
 b) MgO · Fe₂O₃.

The dielectric loss ϵ'' of the investigated materials is low and the reflection method adopted here was not suitable for its determination. A method described by Roberts and Von Hippel⁵⁾ using two sample lengths is more convenient but it was difficult to press two samples under the same pressure and so ϵ'' could not be measured by the method used in this work.

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