

Dielectric Behavior of Steatite Body

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스테아타이트素地の誘電特性

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(1963. 4. 22 受理)

Abstract

A review of the literature is cited. Little exact information exists on the relation between clay materials and talc. The raw materials which are used in making steatite body consist of talc, clay, feldspar, and flint mined in Korea.

The percentage absorption and linear burning shrinkage are measured and then discussed. The vitrified bodies were used in measurement of dielectric properties. The method of measurements for dielectric properties are described too.

要 約

粘土礦物과 滑石과의 關係에 對한 正確한 報告가 거의 없어, 이에 對한 磁器化溫度範圍 및 電氣의 絶緣性과 粘土含量의 關係를 究明하였다. 스테아타이트素地の 製造에 使用한 原料는 國産 滑石, 粘土, 長石, 珪石等이며, 吸水率, 燒成線收縮率을 測定 檢討하고, 또 磁器화된 素地물의 電氣의 絶緣性을 測定하였다.

그 結果 磁器化溫度範圍는 燒成維 1 乃至 3 番內에 있었으며, $MgCO_3$ 를 添加함에 따라 燒成收縮은 크게 일어났으나, 粘土含量이 20% 以下였을 때는 磁器化溫度範圍가 擴大되었다. 耐熱性은 全般的으로 良好하였으며, 粘土量을 增加시키면 따라 膨脹率, 誘電率, 絶緣耐力은 增加하고, 體積固有抵抗은 減少하였다.

1. Introduction

This program of experiments was planned with a view to studying the vitrification ranges and the relations between dielectric properties and clay contents.

The firing and dielectric properties have been observed in many studies. Thurnauer¹⁾ has attributed the superior electrical properties in part to the glassy phase, which is smaller in magnitude in steatite than in electrical porcelains. Stone²⁾ has shown that the firing range is materially lengthened but the maturing temperature would be about 1600°C when a composition contains 53 % of MgO in M_2S range. The addition of MgO

caused an even higher firing shrinkage when only talc is used. The addition of BaO and CaO to the body lower and shorten the firing range.

Rask and Warner³⁾ has explained that the short firing ranges of steatite body resulted primarily from low viscosity of the glass development during firing with the aid of chemical, X-ray, and differential thermal analysis. Smolenskii and Berkman⁴⁾ explained the effect of admixture of Al_2O_3 , MgO , ZrO_2 , Be , BeO , $ZrSiO_4$ and TiO_2 to steatite body that the addition of ZrO_2 and BeO raised the strength of the steatite and ZrO_2 steatite also showed high thermal resistance, adding them in amounts of 1 to 15%. Nagai and Inoue^{5,6)} showed that the addition of Al_2O_3 among miscellaneous oxides to steatite body lowered the

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firing temperature but increased the firing shrinkage and the compressive strength. There are many reports related to shrinkage control on steatite body^{7,8,9}. Comofero, Breedlove and Jhurnauer¹⁰ found that the addition of phosphoric acid to steatite body did not alter the firing range and the dielectric properties of phosphated-bonded talc are superior to those of natural block talc and hot pressed bodies seemed to have the lowest power factor. Alkali metals are known to have a detrimental effect of the dielectric properties of a body.

Rigterink¹¹ says, "The alkalis are conceded to be particularly detrimental while the alkaline earth oxides appear to be especially beneficial." Bleininger and Riddle¹² have pointed out the injurious effect of feldspar on the dielectrical properties of electrical porcelain.

Crystalline phase is most important for the dielectric properties. The dielectric loss of steatite bodies were considerably lower than those of porcelain. E. Albers-Schonberg¹³ has explained the fact that porcelain, containing 25 to 30% of feldspar, consists, after firing of about 60% crystalline and 40% glassy matter, whereas steatite bodies with a low feldspar content are composed of 10% glassy and 90% crystalline phase.

II. Experimental Procedure

The raw materials of steatite body used in this investigation are consisted of Kyulsung talc, Hadong kaolin, Pochen clay, Kyungjoo bentonite, and Anyang feldspar. The calcined talc was fired at 1,300°C. The batch was wet milled and passed through 200 mesh sieve, dried and crushed to 40 mesh sieve contains 10% of moisture.

The material was pressed at 7,000 p.s.i to give $2\frac{2}{8}$ in diameter by $\frac{1}{10}$ inch thick round tile.

The specimens were placed on a bedding of sand and fired from S.K 10° to 17° in an electric siliconit-heated kiln of 38 cm×13 cm×9 cm inside dimensions, and segel cones were appropriately placed to check firing uniformity, after the determination of maturing behavior, each body was fired at one or more selected temperatures within

its maturing range. The following fired properties were determined for each firing temperature: absorption (vacuum method) firing shrinkage, bulk specific gravity, thermal expansion, and thermal shock. Thermal shock was determined by the following method¹⁴. The test specimen was immersed in the ice water bath for ten minutes and then transferred as quickly as possible to the hot water bath, and allowed to remain there for ten minutes. The specimen was transferred back to the cold water and the cycles continued until the specimen breaks.

Dielectric measurements were made by the following method. The measurement were made with a Q meter (made by Heath Co.), a commercial instrument measuring power factor and capacity at frequency of 1 megacycle. The theory of measurement has been described by Thurnauer and Badger¹⁵, although Sindsay and Berberich¹⁶ state that they have fired-on Ag electrodes successfully. Evans¹⁷ has found that there is some sizzling of the electrodes at higher temperatures when silver is used.

All sliding contacts has been eliminated and a Pt-Ir alloy has been used by him on the face of the electrodes. But the author used the mercury electrodes in order to make the contact between electrodes and specimen complete according to specifications of DIN.

The power factor is determined by observing the difference in circuit Q with and without the test condenser connected into the circuit.

The Q of test condenser Qx is

$$Qx = \frac{(C_1 - C_2) Q_1 \times Q_2}{C_1 (Q_1 Q_2)}$$

$$\text{Power Factor} = \frac{1}{Qx}$$

where C_1 = Capacitance of Q - circuit alone

Q_1 = Q of Q - Circuit alone

C_2 = Capacitance of Q - circuit with test condenser connected to Q - circuit.

Q_2 = Q of the Q - circuit with test condenser connected to Q - circuit.

Qx = Q of test condenser

Dielectric Constant K is

$$K = 4.45 \text{ ct/s}$$

where c = capacitance $\mu\mu f$

t = average sample thickness(in)

s = electrode area (in²)

$$\text{Dielectric Loss Factor} = Kx \text{ (\% power Factor)}$$

III. Results and Discussion

All the raw materials are elutriated and then analysed. The results of analyses are shown in Table I. A series of the bodies composed of talc, kaolin, plastic clay, bentonite and flint were prepared so as to increase the clay content as is shown in Table II. Specimens X, Y and Z were prepared to determine the effect of particle size to the dielectric properties. Choongjoo talc was used at the expense of Kyulsung talc in the same composition. However when they were fired they turned yellow and they gave so short maturing range that they were not able to be vitrified so as to measure the dielectric properties. Consequently they were discarded.

1) Firing behavior

Bentonite was used to increase the plasticity and dry strength by small addition without affecting other properties such as shrinkage, firing range, and color etc.

As was mentioned above by Endel, Fenduos, and Hoffmann¹⁸⁾, it was added so as not to exceed 3% in amount. The batch composition was ground until passing through the 200 mesh sieve, as White¹⁹⁾ showed that the particle size between 200 mesh and 325 mesh was not affected the shrinkage.

Now, it is easier to find the maturing range by Fig. II and Table IV of the linear burning shrinkage vs. temperaure. It is very difficult to find the maturing range of the specimens S and P, because their burning shrinkages were becoming higher without standing still. However specimens M, O, and V have a firing range of two cones; and specimen U, one cone; and specimen N, three cones.

The addition of MgO to the body caused an even higher firing shrinkage than others when only talc is used as is related to the specimens M

and N. The addition of BaO to the body shorten the firing range as it enters into glassy phase with respect to the specimen M, and BaO has the characteristic of lowering the melting point rapidly as is shown on the curve M of Fig. 1.

Table I Analysis of raw materials

	Kaolin	Clay	Feldspar	Flint	Talc
SiO ₂	44.03	74.74	67.81	97.39	64.143
Al ₂ O ₃	38.97	16.14	20.73	1.15	0.746
Fe ₂ O ₃	0.44	0.69	0.33	0.09	0.140
MgO	0.22	0.68	0.35	0.12	29.223
CaO	1.43	2.43	0.61	0.32	1.704
Na ₂ O	0.62	—	8.53	—	—
K ₂ O	0.17	—	0.03	—	—

Loss on Ign.

Table II Batch composition

Raw Talc	M	N	O	P	S	U	V	X	Y	Z
Raw talc	19	30	87	85	19	79	74	82	82	82
Calcined talc	50	55	—	—	50	—	—	—	—	—
Clay	10	5	4	5	12	8	10	5	5	5
Kaolin	5	4	3	4	10	5	8	4	4	4
Bentonite	1	1	—	—	3	2	2	1	1	1
BaCO ₃	9	—	—	—	—	—	—	—	—	—
MgCO ₃	6	5	—	—	—	—	—	—	—	—
Whiting	—	—	—	—	—	—	—	5	5	5
Feldspar	—	—	6	—	6	6	—	3	3	3
Flint	—	—	—	6	—	—	6	—	—	—

X: 200 mesh, Y: 270 mesh, Z: 325 mesh.

Table III Percentage absorption vs. firing temperature

	10°	11°	12°	13°	14°	15°	17°
M	19.30	17.60	16.230	0.002	0.009	0.009	0.000
N	2.54	1.99	0.970	0.904	0.708	0.031	0.000
O	5.25	4.40	1.562	0.036	0.011	0.007	0.012
P	10.87	9.45	7.680	5.920	0.816	0.199	0.072
S	4.10	3.75	0.079	0.042	Fused	—	—
U	2.69	1.81	1.512	0.015	0.012	Fused	—
V	4.25	3.74	0.677	0.021	0.012	Fused	—
X	—	8.69	2.961	0.745	—	—	—
Y	—	—	—	1.070	—	—	—
Z	—	—	—	1.748	—	—	—
T	—	—	—	0.174	—	—	—

These results seem to correspond to the fact that Bowen and Schaien²⁰⁾ has pointed out. According to these facts, the high burning shrinkage and short maturing range of the specimen S seem to depend upon the clay content, so that the maximum clay content should be within the limit of 20%.

The results which Stone has shown that the small amounts of alkalis as impurities lowers the temperature of the first liquid formation and there by helps to lengthen the firing range had no relation with this investigation because there was no difference between specimen O which contains feldspar and specimen V which contains silica.

The coefficient of expansion increases with increasing the clay content as is shown in Fig. III and Table VI. It may depend upon the difference of the starting temperature (150°C) which is 100°C higher than others. Steatite bodies generally have a higher coefficient of thermal expansion, which is a property of the mineral clinoenstatite, and is therefore inherent in all bodies which contain clinoenstatite as the predominant compound.

The resistance to thermal shock was good as the cycles of transferring continued over 20 times without being broken.

2) Dielectric behavior.

The results of power factor and dielectric loss factor are shown in Fig. IV, volume resistivity in Fig. V and dielectric strength in Fig. VI and Table VII.

Volume resistivity was lowered than the ordinary steatite body, because it was not dependant on the clay content but on the relative humidity as was shown by Housner²¹⁾. They were determined at temperature of 90° F and 59% relative humidity.

Although the extra high dielectric constant of a specimen N may follow the high density of glassy phase in steatite body as was found by Hopkins²²⁾, specimen S and V or N may be explained that the conductivity increased very rapidly with temperature at a rate of about 2%/°C as

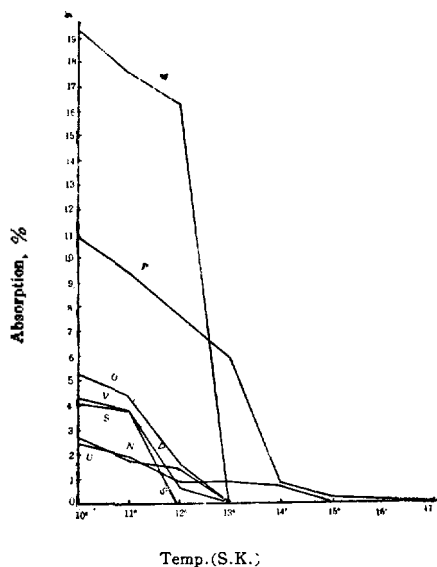


Fig. I

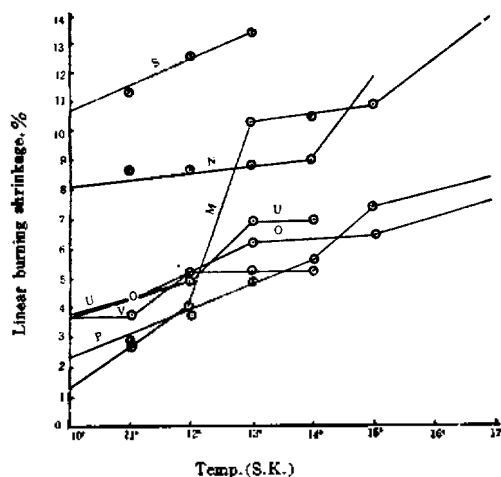


Fig. II

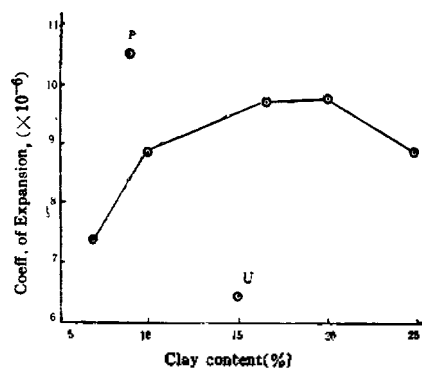


Fig. III

Table IV Percentage linear burning shrinkage

	10°	11°	12°	13°	14°	15°	17°
M	1.30	2.72	4.11	10.38	10.41	10.83	13.83
N	8.15	8.62	8.66	8.73	9.02	11.87	—
O	3.62	4.22	5.17	6.21	6.29	6.44	7.63
P	2.24	2.98	3.76	4.89	5.51	7.34	8.41
S	10.75	11.36	12.51	13.40	—	—	—
U	3.76	4.21	4.99	6.98	6.99	—	—
V	3.59	3.76	5.16	5.16	5.17	—	—
X				5.34			
Y				7.18			
Z				7.12			
T							

Table V Bulk density

	10°	11°	12°	13°	14°	15°	17°
M	1.86	1.92	1.97	2.69	2.87	2.70	2.72
N	2.25	2.28	2.36	2.44	2.75	2.88	—
O	2.27	2.31	2.34	2.43	2.45	2.50	2.50
P	2.11	2.25	2.27	2.48	2.53	2.56	2.60
S	2.36	2.45	2.56	2.40	—	—	—
U	2.33	2.38	2.45	2.58	2.48	—	—
V	2.27	2.28	2.38	2.49	2.49	—	—
X		2.12	2.52	2.71			
Y				2.60			
Z				2.58			
T				4.07			

Table VI

	Coefficient of Expansion		Resistance to Thermal shock
	($\times 10^{-6}$)	Degree C	
M	9.56	40 to 800	Good
N	8.90	100 to 800	//
O	7.49	60 to 800	//
P	10.41	20 to 800	//
S	8.88	150 to 800	//
U	6.46	60 to 800	//
V	9.66	20 to 800	//

Honemann²⁴⁾ had concluded.

The reason of increasing power factor and lowering volume resistivity with increasing clay content depends upon kaolinite content which increase the glassy phase more than the crystalline phase.

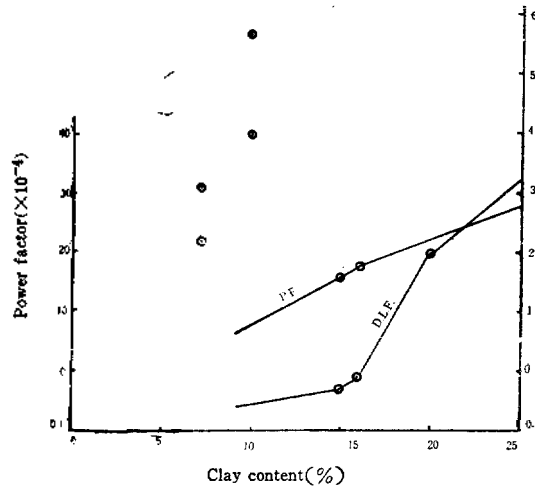


Fig. IV

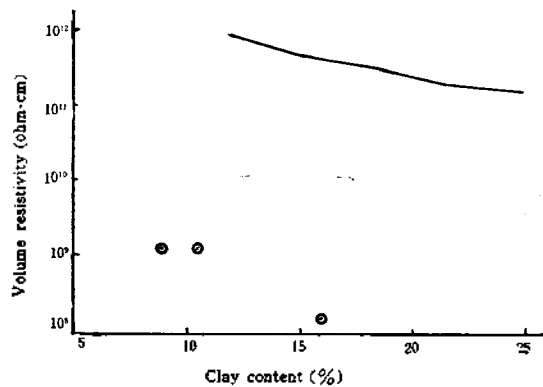


Fig. V

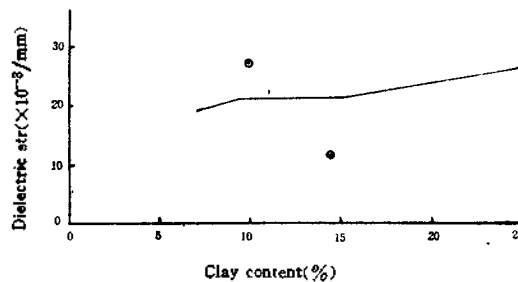


Fig. VI

V. General Summary

- 1) Vitrification range is variable from cone 1 to cone 3.
- 2) The addition of MgCO_3 to the body and high clay content body containing more than 25% of clay showed the high burning shrinkage, but the

former lengthen the vitrification range.

3) The coefficient of expansion was increased with increasing clay content.

4) Resistance to thermal shock is good.

5) Power factor was increase with increasing clay content, while volume resistivity was lowered.

6) Dielectric strength was increased with increasing the clay content.

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Table VII Dielectric properties

	Dielect- ric constant	Power factor I M C at 30°C ($\times 10^{-4}$)	Dielect- ric Loss Factor	Volume Resistivity 60c/s, at 30°C ($\times 10^8$)	Dielectr- ic stren- gth in volt/mm ($\times 10^3$)
M	5.32	17.27	9.919	2.09×10^8	21.05
N	14.70	39.20	5.77	4.92×10^{11}	26.50
O	6.44	31.02	2.19	1.45×10^{10}	19.55
P	11.52	6.50	0.42	1.54×10^9	20.53
S	7.43	27.50	3.17	1.58×10^{11}	26.30
U	9.26	10.51	0.79	6.85×10^{11}	12.13
V		21.68	2.08	2.79×10^{11}	23.88
T					