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An electrical study of chrysotile asbestos

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The dielectric constant (K) and dielectric loss ($\tan\delta$) of preheated chrysotile asbestos up to 900° C were measured in the frequency range 10^2 to 10^5 Hz. The K and $\tan\delta$ values were also measured as a function of temperature for hot pressed powdered pellets of chrysotile asbestos. The d.c. conductivity of hot pressed powdered pellets of chrysotile asbestos was also measured as a function of temperature. Dynamic d.c. conductivity was measured in the temperature range 58 to 580° C. The results have been discussed and attempts made to establish a correlation between the structural changes with the variation of dielectric properties.

1. Introduction

Chrysotile is a fibrous chain silicate clay mineral belonging to the serpentine group with 1:1 layers which curl into cylindrical rolls. Its ideal formula per half unit cell is $Mg_3Si_2O_5(OH)_4$. The silky fibrous variety of chrysotile is the most important asbestos, of great commercial importance and scientific interest because of its multiplicity of uses and complexity of structure. The flexibility and strength of the fibres, coupled with their high resistance to heat and electricity, show great potential for their industrial uses especially as an insulating material for various electrical devices. It is also well known that the insulating properties of any dielectric material are largely dependent on the temperature, and its physical and chemical nature which also varies with temperature. Besides this, the structure of the material which is likely to undergo transformation with temperature, plays a dominant role in deciding the electrical behaviour of the material. Apart from these facts, the dielectric properties also provide a measure of the amorphous and crystalline contents and are also sensitive to orientation effects, mobility effects and to the number and interactions of the dipoles participating. Hence, to explore the possibilities of this asbestos mineral for industrial applications as an insulating material, a thorough investigation of its various electrical properties and their temperature dependence become highly imperative. It is well known that the dielectric constant and electrical conductivity are the two most significant properties in determining the electrical behaviour of a mineral [1]. However, despite this fact it appears from the available literature that data reported on the electrical properties of asbestos to date are very scant. In view of this fact, the present work was undertaken to make an indepth study of the electrical properties and their temperature variation of this potentially useful mineral. The results of the investigations, which are likely to be useful to the potential users, are presented in this paper.

2. Experimental methods

A specimen of chrysotile fibre from Cuddapah, India supplied by Alminrock was selected for the present investigation. Methods of sample preparation and experimental procedures adopted and the instruments used in the present work were identical to those reported earlier [2, 3]. Results of chemical, thermal and X-ray analyses confirmed the specimen to be the fibrous variety of chrysotile. Electron microscopic studies revealed the tubular and lathlike fibrous nature of the sample. The differential thermal analysis (Fig. 1) is found to consist of one very strong and broad endothermal band with peak at about 660° C followed by sharp exothermal peak at 814° C, characteristic of chrysotile. The broad endothermal peak is however marked by a number of small peaks resembling necks on either side of the peak corresponding to 595, 715 and 753° C, respectively.

3. Results and observations

Results of the measurements undertaken are illustrated in Figs. 2 to 8. It is seen from Figs. 2, 3 and 4 that frequency variations of the dielectric constant (K) and dielectric loss ($\tan\delta$) follow the usual pattern for any dielectric. The room temperature dielectric constant (K), at low frequency is unusually high (~ 800) which is quite comparable to the K values along the longitudinal directions of other fibres such as pineapple [4] and tremolite asbestos [5]. However, it is interesting to note that the room temperature K value of the present sample at low frequency measured from hot pressed powder pellets is far higher than that reported for tremolite asbestos powder [3]. As with tremolite asbestos, here too K appears to vary considerably at low frequencies while at higher frequencies K becomes practically frequency independent for all samples heated to different temperatures. This low frequency behaviour may be attributed to a dominant space charge polarization in this frequency range arising from point defects [6] which always increase with temperature and are invariably present in a natural mineral sample [2]. Frequency independent low values of K corresponding to all temperatures clearly demonstrate that the contributions of dipolar and space charge polarizations decrease considerably while those from ionic and electronic are extremely small in this frequency range as expected. This type of vari-

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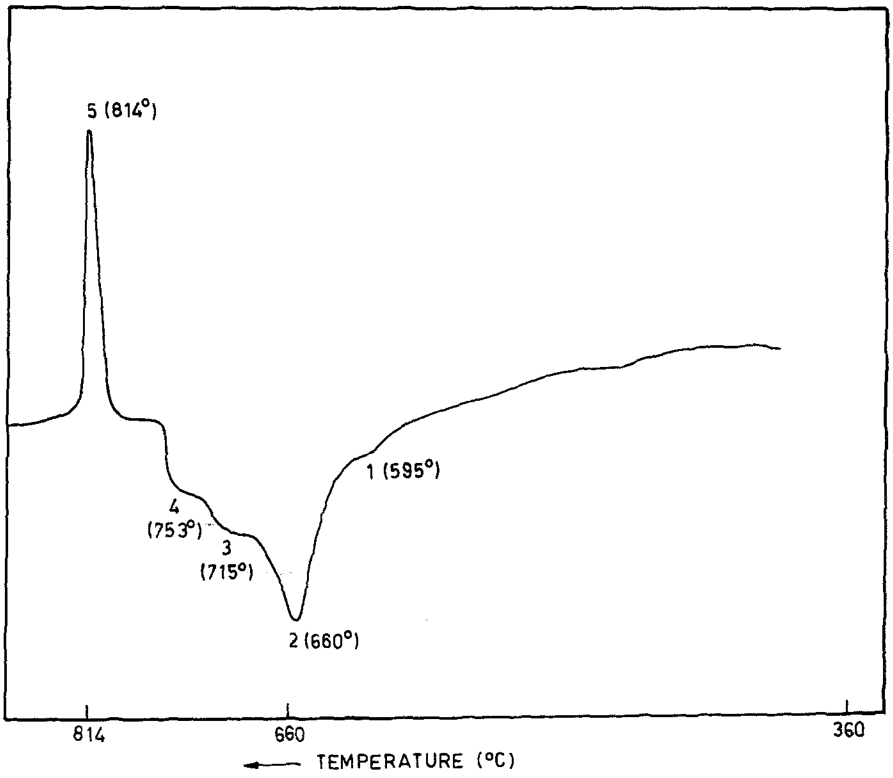

Figure 1 Differential thermal analysis curve of chrysotile asbestos.

ations is also observed in actinolite [1] and tremolite asbestos [3].

The temperature variation of K (Fig. 5) also follows, more or less, the same pattern with peaks in the temperature range 750 to 800° C corresponding to the end of the endothermal peak in the differential thermal analysis (DTA) curve. Dielectric loss ($\tan\delta$) (Fig. 6) also, as expected exhibits similar temperature variation. Similar results were also observed in tremolite asbestos [3]. This is indicative of a phase transformation due to the expulsion of structural water around this peak temperature, which is in conformity with DTA and X-ray data. The frequency variations of $\tan\delta$ for the samples (Figs. 2 and 4) shows peaks which correspond to resonance with dipole oscillations in the polar dielectrics [7]. Thus, the frequency variations of

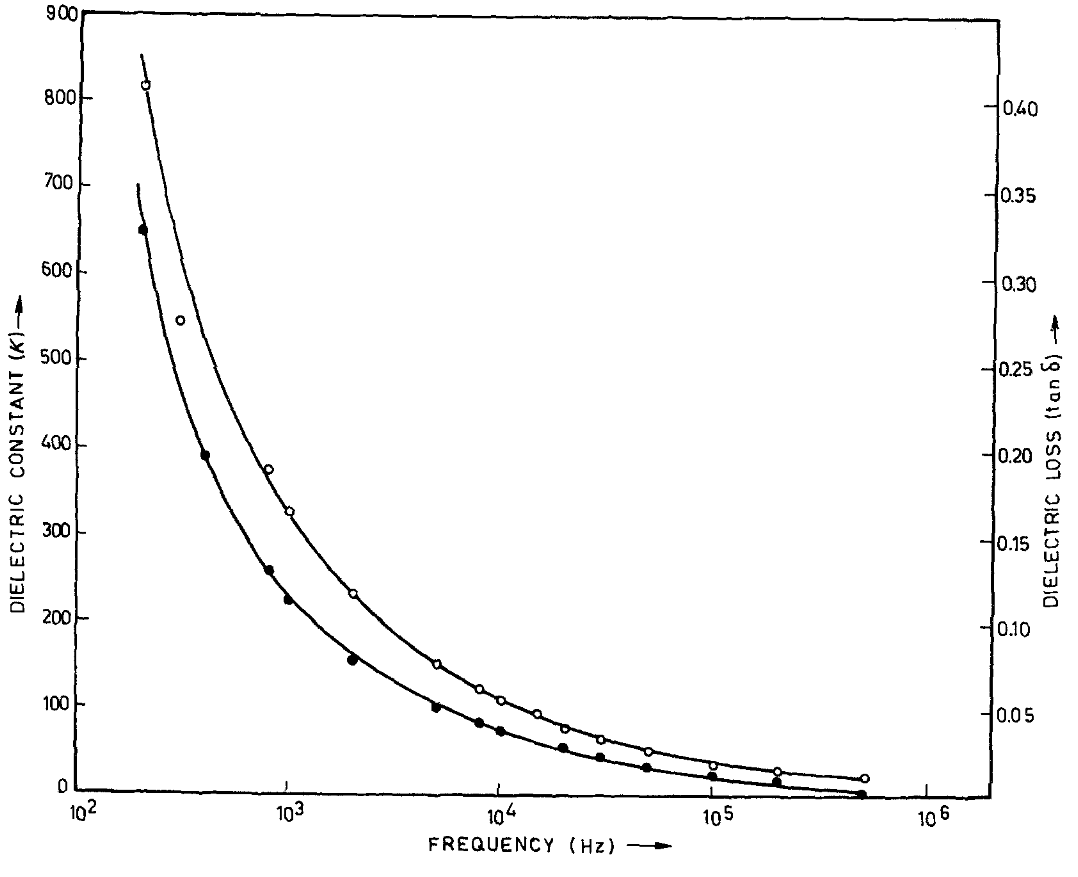

Figure 2 Variation of (○) dielectric constant (K) and (●) dielectric loss ($\tan\delta$) with frequency of chrysotile at room temperature (25° C)

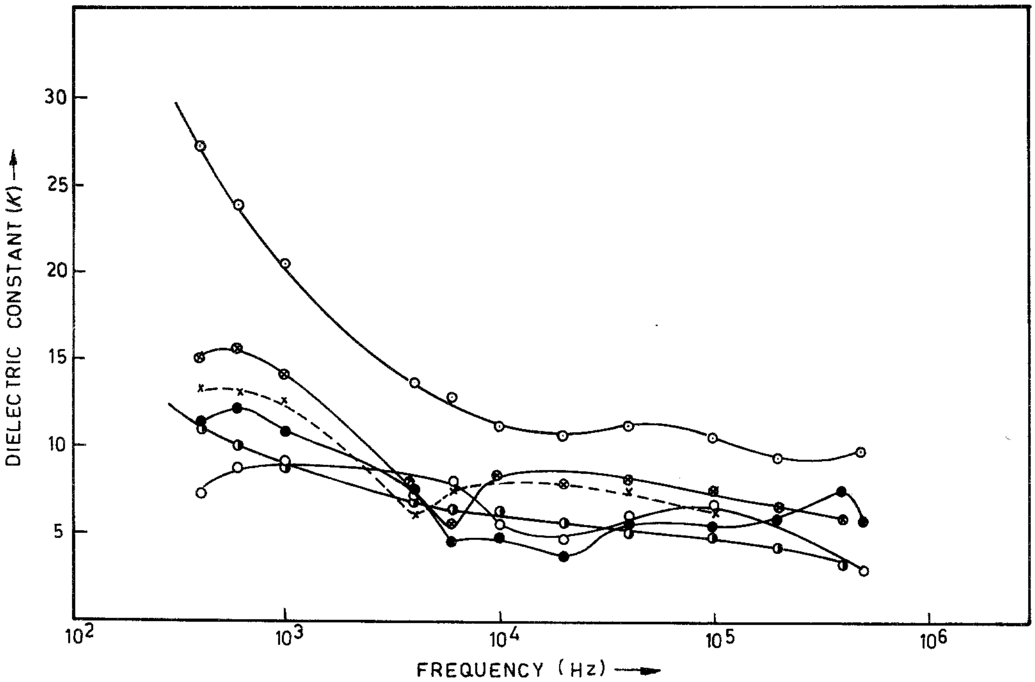

Figure 3 Variation of dielectric constant (K) with frequency for preheated chrysotile samples at different temperatures. (⊙) 580° C, (⊗) 640° C, (◑) 700° C, (×) 750° C, (●) 800° C and (○) 900° C.

K and $\tan\delta$ manifest the presence and dominance of the different types of polarization at different frequency ranges as usual.

Figs. 7 and 8 show the results of d.c. conductivity measurements of hot pressed samples preheated to different temperatures and for samples heated dynamically. Both the graphs show some peculiar behaviour. The conductivity is found to decrease sharply with a sharp bend around 700° C for statically preheated hot pressed sample. However, it is well known [7] that dielectrics lose structural water upon heating to certain temperatures; the loss of this water may sharply increase the resistivity and consequently decrease the conductivity. This type of behaviour has been observed in asbestos tape [7]. In the present sample, as is shown by DTA, the first phase up to

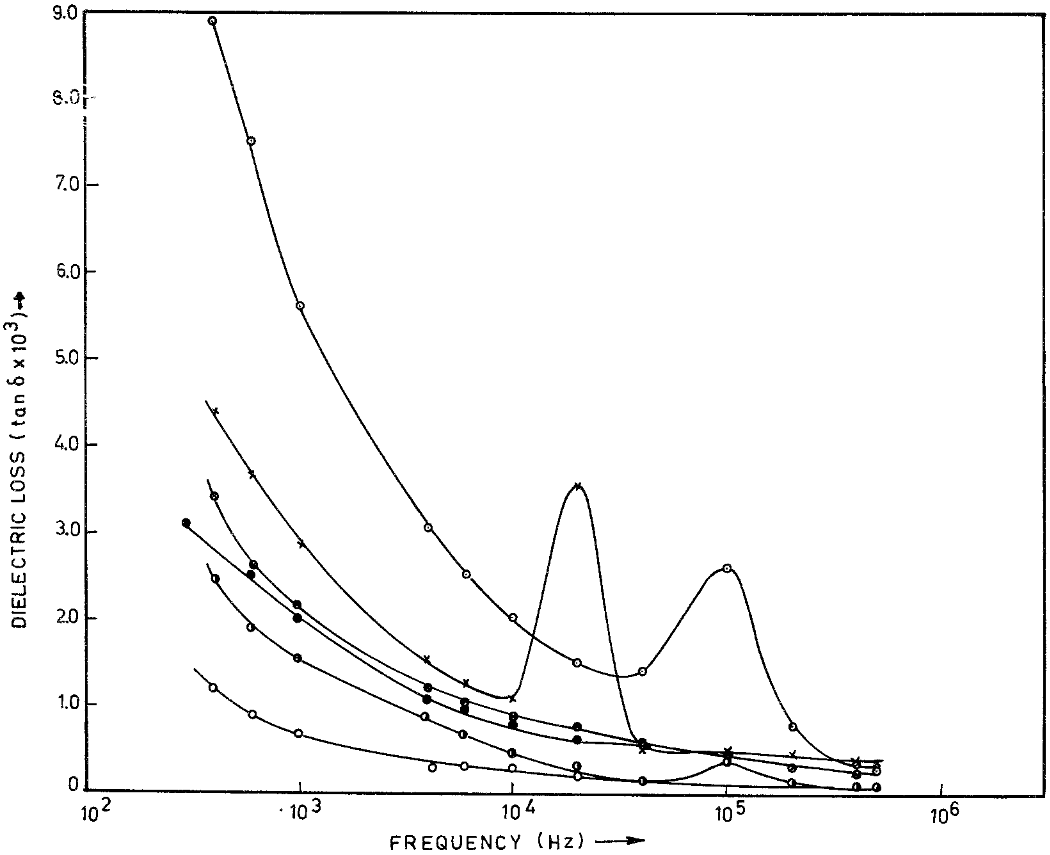

Figure 4 Variation of dielectric loss ($\tan\delta$) with frequency for preheated chrysotile samples at different temperatures. (⊙) 580° C, (⊗) 640° C, (◑) 700° C, (×) 750° C, (●) 800° C and (○) 900° C.

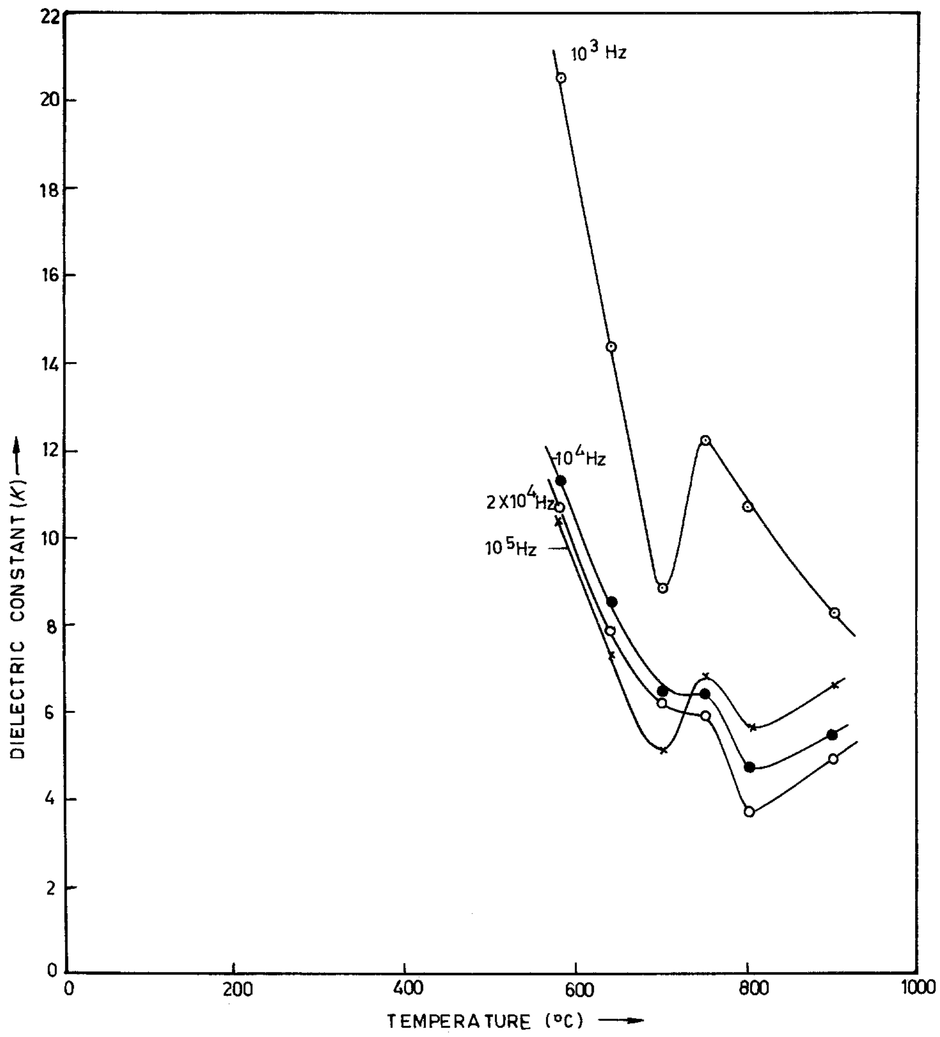

Figure 5 Variation of dielectric constant (K) with temperature for chrysotile samples at different frequencies. (⊙) 10^3 Hz, (●) 10^4 Hz, (○) 2×10^4 Hz, (×) 10^5 Hz.

around 700° C corresponds to the entire range of the endothermal peak – hence to the removal of the structural water causing a sharp fall of conductivity as in asbestos tape [7]. The order of the magnitude of conductivity in this temperature range is quite comparable with the results of resistivity measurements for asbestos tape [7]. The second stage, the slowly decreasing part, corresponds to a phase change as is revealed by the exothermal peak (800 to 835° C) in the DTA curve and the appearance of new lines in the X-ray diffraction pattern [8]. The new phase appears to be less conducting owing probably to its greater crystalline nature which promotes less mobility to the ions compared to amorphous state in this type of

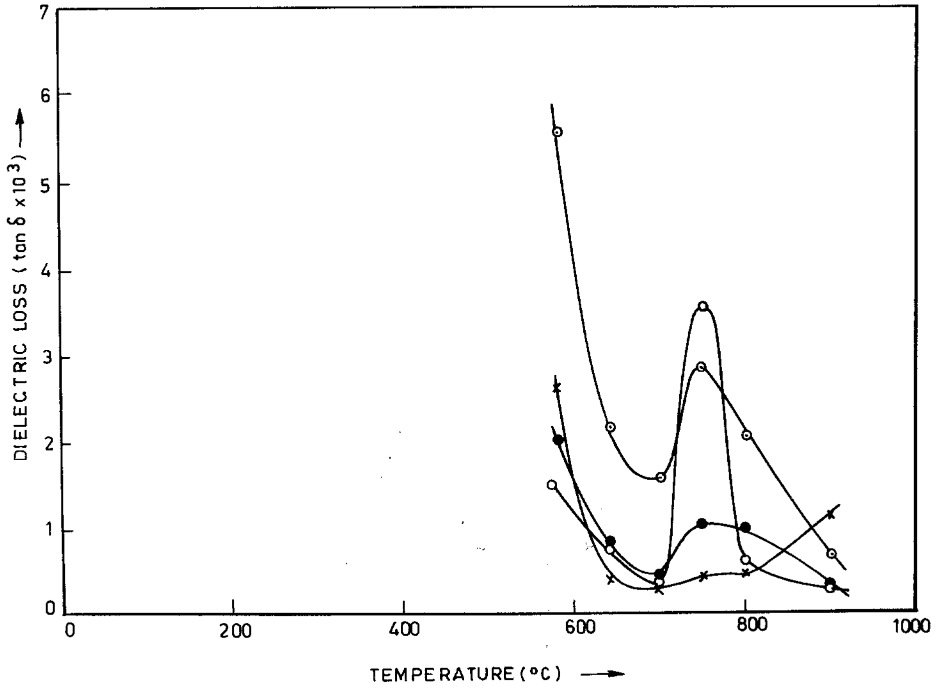

Figure 6 Variation of dielectric loss ($\tan\delta$) with temperature for chrysotile samples at different frequencies. (⊙) 10^3 Hz, (●) 10^4 Hz, (○) 2×10^4 Hz, (×) 10^5 Hz.

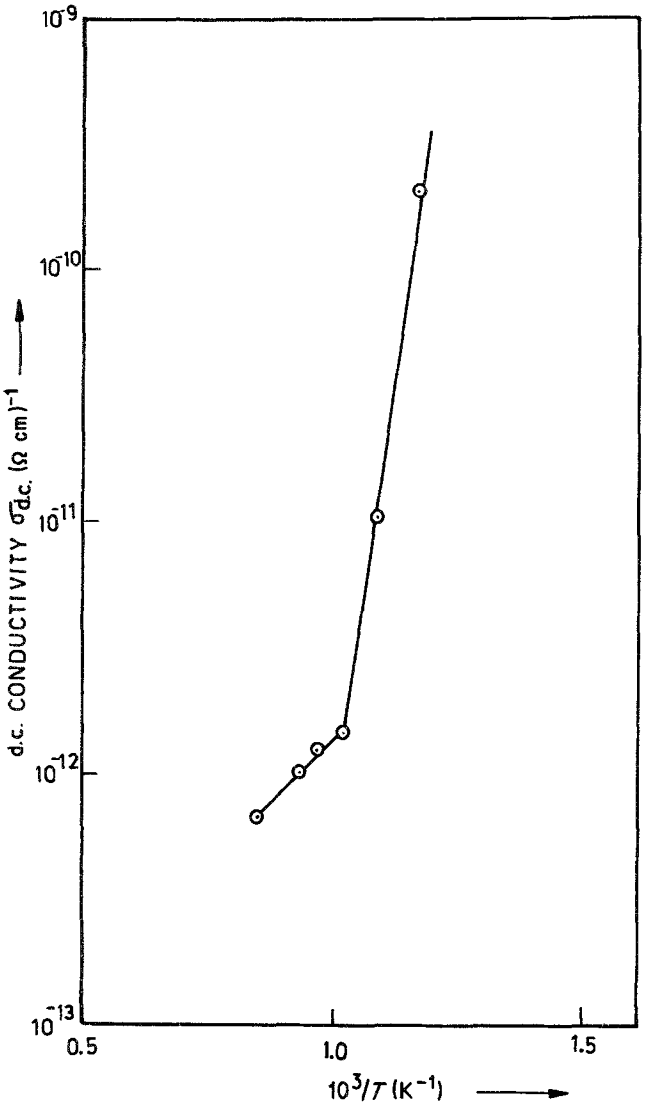

Figure 7 Variation of d.c. conductivity ($\sigma_{d.c.}$) with temperature of chrysotile samples.

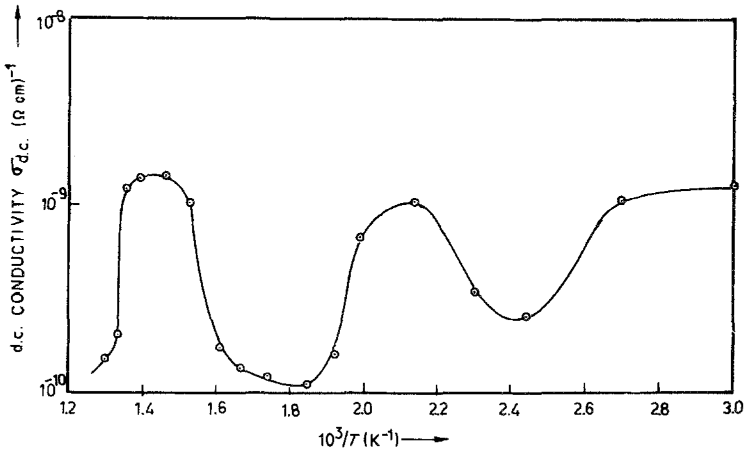

Figure 8 Dynamic variation of d.c. conductivity ($\sigma_{d.c.}$) with temperature of chrysotile samples.

dielectric which behaves like an ionic conductor [7]. The irregular variation of d.c. conductivities measured under dynamic heating conditions in the temperature range 58 to 580° C, i.e. until the beginning of the endothermal peaks is most probably due to the moisture contents and the defect and impurity concentrations which vary irregularly with temperature in this temperature range and with this duration of heating.

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