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Dielectric studies on some industrially important rubber and polymeric materials at microwave frequencies

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ABSTRACT

Microwave measurements have been carried out on the industrially important rubber and polymer materials to study their dielectric behavior in X and K bands using microwave test benches equipped with Klystron and Gunn oscillators respectively and guided with rectangular wave guides. A decrease in dielectric constant with increase in microwave frequency has been observed for all samples. Some rubber materials were reinforced with carbon black as the reinforcing filler and vulcanized with sulphur as the principle vulcanizing agent in the industrial lab and their change in dielectric behavior was studied at microwave frequencies. The rubber materials after being reinforced and vulcanized have a high dielectric constant, low dielectric strength and hence have better electrical conductivity. One of the polymers Nylon 66 also showed an increase in dielectric constant after being reinforced with 30% glass fibre. To improve the applications of rubber derivatives, a blend is made between any two already available rubber materials which are thermodynamically compatible to one another. The dielectric behavior of two such polymer blends viz, NR+BIIR and NR+Reclaim was studied in the microwave frequency region. From the results obtained, it is observed that the electrical conductivity of the rubber derivatives increase after blending. Hence blending is a very important technique to improve the electrical properties of rubber materials.

Keywords: Dielectric constant, rubber and polymeric materials, microwave frequency, wave guides.

INTRODUCTION

The influence of a particular dielectric on the capacitance of a condenser is conveniently assessed by the dielectric constant, also known as the relative permittivity or rarely specific inductive capacity. For non-polar polymer materials (materials free from dipoles or in which the dipoles are vectorially balanced) the dielectric constant is due to electronic polarization only and will generally have a lower value. Since polarization is instantaneous the dielectric constant is independent of temperature and frequency. Power losses are also negligible irrespective of temperature and frequency. With polar molecules the value of the dielectric constant is additionally dependent on dipole polarization. The extent of dipole polarization will depend on frequency, an increase in frequency eventually leading to a reduction in dielectric constant. The dielectric properties of polar materials will depend on whether or not the dipoles are attached to the main chain[1,2]. When they are, dipole polarization will depend on segmental mobility[3] and is thus low at temperatures below the glass transition temperatures. Such polymers are therefore better insulators below the glass temperature than above it. The measurement of the dielectric constant of a material can provide information about the electrical environment of molecules. In the present work dielectric constants of about twenty five rubber and polymeric materials is evaluated in the microwave frequency region using the X-band and K-band microwave test benches.

Microwaves are electromagnetic waves, the frequency spectrum ranging from 1GHz to 30 GHz. The main characteristic features of microwaves[4] originate from the small size of wavelength in relation to the size of components or devices commonly used. Microwave measurements are carried out in terms of field amplitudes, phase differences and powers carried by the waves. A common method of microwave measurements is based on the study of a standing wave pattern formed along the line in the microwave test bench because of the interference of incident and reflected waves[5]. The microwave test bench incorporates a range of instruments capable of allowing all types of measurements that are usually required. The bench is capable of being assembled and disassembled in a number of ways to suit individual experiments. The functional block diagram of a microwave test bench used for the present investigation is shown in Fig.1. Transmission of microwaves along lines and cables is difficult mainly because of the losses that occur both in the solid and the dielectric needed to support the conductors themselves. It is possible to transmit microwaves through a metallic tube called a wave guide. The most common form of a guide is rectangular in cross section. To minimize power losses, the wave guide wall resistance is made as low as possible. Two important boundary conditions determine the mode of propagation of an electromagnetic wave along a guide, (i) Electric field must terminate normally on the conductor i.e. the tangent component of the electric field must be zero. (ii) Magnetic field must be entirely tangential along the wall surface i.e. the normal component of the magnetic field must be zero. Short circuits are used as termination of a waveguide for both X-band and K-band microwave test benches so that the microwave energy is completely reflected with as little absorption as possible. A direct and accurate method proposed by Von-Hippel[6] has been used to measure the dielectric constant of the rubber and polymeric materials of industrial importance.

Crude rubber isolated from white fluid called latex is not strong or elastic and hence does not possess the desirable properties. The desired properties in rubber can be improved by addition of compounding materials such as sulphur, accelerators and protective agents. Vulcanized rubber has much greater toughness and elasticity than crude rubber. It can withstand relatively high temperatures without softening and remains elastic and flexible at low temperatures. Vulcanization is the conversion of rubber molecules into a network by the formation of crosslinks. Vulcanizing agents are necessary for the crosslink formation[7]. Sulphur is the primary vulcanizing agent[8] used for the rubber materials taken for study. By crosslinking, the rubber changes from the thermoplastic to the elastic state. As more crosslinks are formed, the vulcanizate becomes tighter and the forces necessary to achieve a given deformation increases. Reinforcement[9] is another method of enhancing the desired properties in rubber by the addition of certain fillers to the rubber before vulcanization. Carbon black is used as the reinforcing filler for the present rubber materials. Such fillers will increase the stiffness of unvulcanized

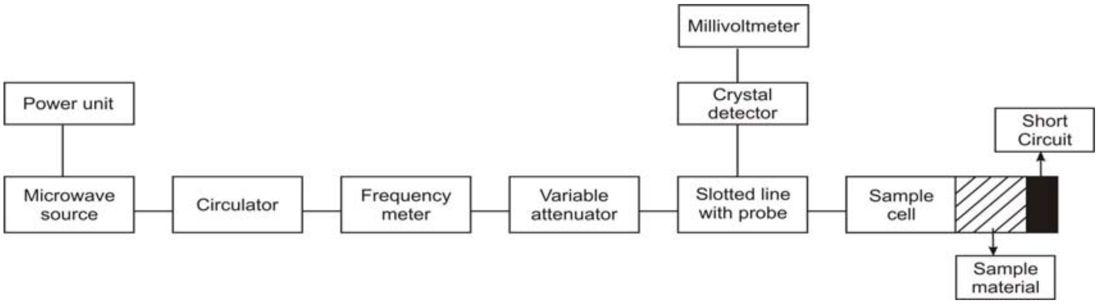

Fig. 1: Functional block diagram of a microwave test bench

compounds and improve a variety of vulcanizate properties like tensile strength, abrasion resistance and tear resistance. The incorporation of special grades of carbon black to the rubber increases the electrical conductivity and dielectric constant. To further improve the properties of rubber, a blend can be made between any two already available rubber materials[10]. In order to obtain a good covulcanization of the blend partners, it is important that the rubbers in the blend are as thermodynamically compatible as possible[11,12]. Blend combinations of relatively compatible rubbers are used on a large scale for tire production.

The present work is devoted to the study of dielectric properties of industrially important rubber and polymeric materials viz, Natural rubber (NR), Reclaim rubber, Ribbed Smoked Sheet (RSS), Styrene-Butadiene rubber (SBR), SBR-1958, SBR-1502, Acrylonitrile Butadiene Rubber (NBR), Hydrogenated Acrylonitrile Butadiene Rubber (HNBR), Butyl Rubber (IIR), Bromobutyl Rubber (BIIR), Brown crepe rubber, Chlorosulphonated Monomer (CSM), Silicone rubber, High Density Poly Ethylene (HDPE), Poly Ethylene Terephthalate (PET), Nylon 66, 30% glass fibre filled Nylon 66 (30%GFNylon 66) and Acrylonitrile Butadiene Styrene (ABS). The dielectric behavior have been studied in the microwave region using X-band and K-band microwave test benches equipped with Klystron oscillator and Gunn oscillator respectively and guided with rectangular wave guides. The change in dielectric behavior of some reinforced and vulcanized rubber materials viz, Natural rubber, HNBR, CSM, Silicone rubber, Reclaim rubber and the polymer Nylon 66 reinforced with 30% of glass fibre has been studied at microwave frequencies. Dielectric studies were also carried out for the two polymer blends NR+BIIR and NR+Reclaim in the microwave frequency region.

EXPERIMENTAL

The industrially important rubber materials viz, Natural rubber, Reclaim rubber, RSS, SBR, SBR 1958, SBR 1502, NBR, HNBR, IIR, BIIR, Brown crepe rubber, CSM and Silicone rubber were procured from Industrial Rubber Products (IRP), Chennai, India. The polymers HDPE, PET, Nylon 66, 30%GFNylon 66 and ABS were procured from Central Institute of Plastic Engineering and Technology (CIPET), Chennai, India and have been used as such as the source. The dielectric constants of the rubber and polymeric materials were evaluated using the X-band and K-band microwave test benches. The change in dielectric behavior was studied for Natural rubber, HNBR, CSM, Silicone rubber and Reclaim rubber after reinforcing and vulcanizing them in the industrial lab. Carbon black is used as the reinforcing filler and sulphur is used as the principle vulcanizing agent for these rubber samples. The dielectric constants obtained for the rubber samples in the vulcanized state are higher than the values obtained for the rubber samples in the raw state. Similarly, the glass-fibre-reinforced Nylon 66 has a higher dielectric constant than unfilled Nylon 66. Further, Natural rubber was blended with BIIR and reclaimed rubber in the industrial lab and the dielectric studies were carried out for the polyblends NR+BIIR and NR+Reclaim using the standing wave measurements in the microwave test bench.

The resonant cavity and waveguide method has been employed here using microwave test benches (X band and K band) to measure the permittivity of the rubber and polymeric materials. The X band consists of a Klystron oscillator and a rectangular waveguide of dimensions 2.2 × 1cm. The K band mainly comprises of a Gunn oscillator and a rectangular waveguide of dimensions 1.1×0.4 cm in the dominant $TE_{1,0}$ mode. All the samples are shaped to the dimensions of the waveguide in order to minimize the errors present due to the presence of air medium between the inner wall of the waveguide and sample surface. A direct and accurate method of Roberts and Von Hippel has been considered here. This method is based on the measurement of shift in the minimum of the standing wave produced by a short circuit when a sample is placed before the short circuit. The measurements are repeated for all the four faces of the shaped samples. The dielectric constant is calculated using the relation, $\mathrm{E}_r = [(\lambda_0/ \lambda_{g2})^2 + (\lambda_0/ \lambda_c)^2]$ where, λ_0 is the wavelength of microwaves in free space, λ_c is the cut of wavelength, λ_{g2} is the wavelength of dielectric filled space. As the microwave frequency decreases the dielectric constant increases for all

Table 1: Dielectric constants of rubber and polymer materials

Sample material	Dielectric constant (ε_r) in X-band (9.6GHz)	Dielectric constant (ε_r) in K-band (26GHz)
NR	4.6015	1.2633
IIR	3.4780	2.3621
BIIR	4.0540	2.6874
NBR	2.7541	1.5857
HNBR	3.2462	1.8143
SBR	4.3860	2.4235
SBR-1958	5.0261	2.7254
SBR-1502	4.5275	2.5816
CSM	2.6050	1.3811
Silicone rubber	4.8272	3.1585
Reclaim rubber	3.5213	2.0463
RSS	3.8710	2.2856
Brown crepe rubber	3.7215	1.7325
PET	5.9230	2.9354
HDPE	4.9225	2.3841
ABS	5.6624	2.8126
Nylon 66	4.6620	3.2866
GF Nylon 66	6.5615	4.8730

Table 2: Dielectric constants of rubber derivatives in the vulcanized and blended states

Sample material	Dielectric constant (ε_r) in X-band (9.6GHz)	Dielectric constant (ε_r) in K-band (26GHz)
NR (V)	5.7862	3.0635
HNBR(V)	4.0621	2.9652
Silicone rubber (V)	5.4420	4.1621
Reclaim rubber (V)	5.2644	3.6184
CSM (V)	4.9380	3.3690
NR+BIIR (V)	6.7285	4.5672
NR+Reclaim (V)	6.3379	4.2709

V- Vulcanized state

the samples. This is however an expected result. The dielectric constants for the samples under study have been evaluated and summarized in Table 1 and dielectric constants of rubber derivatives in the vulcanized and blended states is presented in Table 2.

RESULTS AND DISCUSSION

The dielectric constants of the rubber derivatives and polymer materials taken for study were calculated using the X-band (9.6 GHz) and K-band (26 GHz) microwave test benches at room temperature. From the results obtained in Table 1, it is evident that dielectric constants evaluated for all the rubber and polymeric materials in K-band is lower than in X-band. The dielectric constant decreases with increase of frequency for all the samples and this result is in coincidence with literature[13]. Further it is seen from Table 2 that Natural rubber, HNBR, CSM, Silicone rubber and Reclaim rubber have higher dielectric constants in the vulcanized states than in their raw states. Dielectric measurements were carried out for the polymer blends NR+BIIR and NR+Reclaim and it is observed that the two blends have high dielectric constant values than compared to the values obtained for the individual rubber materials[14]. Thus the microwave measurements in X and K bands allow useful qualitative predictions to be made. The rubber materials in the raw state have very low dielectric constant and high dielectric strength. Hence they can be used for electrical insulation purposes. Reinforcing and vulcanizing the rubber samples increases their dielectric constants. So the vulcanized rubber samples have low dielectric strength and better electrically conducting properties. Thus reinforcement and vulcanization of rubber samples increases their electrical conductivity[15,16]. Also Table 1 shows that dielectric constant of glass fibre filled Nylon 66 is higher than the unfilled Nylon 66.

CONCLUSION

In the present work, dielectric constants were evaluated for some selected rubber and polymeric materials at microwave frequencies employing the X-band and K-band microwave test benches. The changes in dielectric behavior of some rubber derivatives in the vulcanized and blended states are studied. The vulcanized and blended rubber materials have a higher dielectric constant than crude rubber. The polymeric material Nylon 66 also has a higher dielectric constant after undergoing 30% glass fibre reinforcement. Thus the electrical conductivity of rubbers and polymers can be enhanced by vulcanization and reinforcement. Blending is yet another technique to improve the electrical properties of rubber materials. It is evident from Table 2 that the two rubber blends NR+BIIR and NR+Reclaim have high dielectric constant, low dielectric strength and have better electrical conductivity.

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