SOME MICROWAVE PROPERTIES OF YTTRIUM IRON GARNET AND MAGNETITE FILLED THERMOPLASTIC NATURAL RUBBER COMPOSITES

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Abstract: A thermoplastic natural rubber (TPNR) was prepared by melt-blending of polypropylene (PP), natural rubber (NR) and liquid natural rubber (LNR) in a weight ratio of 70:20:10 using a standard method. LNR as the compatibiliser was prepared earlier by photodegradation of NR in visible light . Samples of TPNR filled with different mixtures of YIG and magnetite powders were then prepared using the same method with a fixed TPNR content of 70% of the total weight. The effects of incorporating different composition of YIG and magnetite into the matrix of TPNR on the microwave properties were studied. The complex scattering parameters (S_{11}*, S_{21}* , S_{12}* and S_{22}*), microwave dielectric permittivity ($\varepsilon_r^* = \varepsilon_r' - j\varepsilon_r''$), magnetic permeability ($\mu_r^* = \mu_r' - \mu_r''$) and absorption properties of the samples were measured using a microwave vector network analyzer (MVNA) by means of coaxial two-port and single-port techniques in the frequency range of 0.3 – 13.5 GHz. The change in YIG and magnetite composition influences the values of the reflected (P_r), transmitted (P_t) and absorbed (P_a) power . The reflection loss, R_L is calculated from ε_r^* and μ_r^* using a metal-backed absorber model. R_L is found to depend on the thickness of the absorber. Two dips are found at low and high frequency regions for all the samples, which occur at the thickness of the material equal to $\lambda/4$ dan $3\lambda/4$ respectively, where λ is the propagation wavelength in the materials. The measured R_L curve from the single-port technique is in accordance with theoretical calculations. R_L under a transverse external magnetic field of 1 T decreases and the matching frequency shifts forward. The incorporation of different type and percentage of the ferrite into the matrix of TPNR has resulted in significant differences in the microwave properties of the composites. These composites can be used as an electromagnetic wave absorber based on a selective frequency band for samples with suitable thickness.

Keywords : Microwave absorber, Ferrite, Reflection loss, Permeability

INTRODUCTION

Utilisation of electrical machines and electronic equipment in households , public installations and industries has rapidly increased. Broadcasting and telecommunication systems that utilize radio frequency spectrum have been introduced widely into our society. As a result of our extensive use of these devices, the electromagnetic interference (EMI) becomes one of the major environmental pollution .The electromagnetic interference (EMI) refers to the unwanted electromagnetic emission being either radiated or conducted. These radiation can interfere with simple household appliances and can generates disastrous results in large scale computers [2]. Absorbers which act as alternative shields may keep away the electromagnetic radiation and provide protection for the specific equipment contained within the shield. Ferrites are the choice materials for microwave region application due to the high resistance , remarkable flexibility in tailoring the magnetic properties, ease of preparation and low in cost . One of the very attractive properties of the ferrites is the possibility of mixing different compositions. By creating mixed ferrites, the magnetic moments, the Neel temperature and the degree of inversion can be changed.. According to Debye, the precise nature of the frequency dependence of a relative dielectric constant depend on the shape and orientation of the particle. If the particles comprised of several different dielectric materials, each type would be characterized by its own relaxation time and there would be a broadband absorption. However, ferrites are brittle and hard in nature [3]. For design freedom [1] and to get excellent mechanical properties, ferrites are incorporated into the matrice of thermoplastic natural rubber which is flexible and environment friendly due to their recycleability.This paper reports the preparation of a thermoplastic natural rubber (TPNR) and a few compositions of TPNR/Yttrium iron garnet (YIG)/magnetite composites. The microwave absorption properties were investigated in the frequency range of 0.3 – 13.5 GHz. The aim is to produce absorber materials that can meet the standard requirements and specification in microwave absorption technology.

MATERIALS AND METHODS

The YIG ($Y_3Fe_5O_{12}$) and magnetite (Fe_3O_4) were obtained from CERAC Incorporated in powder form of 200 mesh with purity of 99.9% and 97% respectively. The TPNR matrix was prepared by melt-blending polypropylene (PP), natural rubber (NR) and liquid natural rubber (LNR) in a weight ratio of 70:20:10 using the standard method. The LNR as the compatibiliser was prepared by photosyntesized degradation of NR in visible light Different samples of YIG and magnetite filled thermoplastic natural rubber composites with a fixed TPNR content of 70 wt% of the total weight were prepared. The composites were then molded into a thin sheet of 3.0 mm thick , under a pressure of 700 MPa at 175 °C . The homogeneity of the filler in the matrice of TPNR was determined from the saturation magnetisation analysis of samples from different locations using the vibration sample magnetometer (VSM). Toroidal samples of 3.5 mm outer diameter and 1.6 mm inner diameter were prepared by injection molding. The scattering parameters of the toroidal samples that correspond to the reflection (S_{11}* and S_{22}*) and transmission (S_{21}* and S_{12}*) of a TEM wave with and without an external transverse magnetic field of 1 T were studied using a Hewlett Packard 8719D microwave vector network analyzer in a frequency range of 0.3 – 13.5 GHz. The toroidal sample was tightly inserted into a 3.5 mm coaxial line of 15.0 cm air-length for the measurements. Full two-port calibration was initially performed on the test set-up in order to remove errors due to the directivity, source match, load match, isolation and frequency response in both the forward and reverse measurements. The complex dielectric permittivity ($\varepsilon_r^* = \varepsilon_r' - j\varepsilon_r''$) and the complex magnetic permeability ($\mu_r^* = \mu_r' - j\mu_r''$) were determined from the complex scattering parameters using the Nicholson-Ross model for magnetic materials. For a microwave –absorbing layer backed by a metal plate, the normalized input impedance (Z_{in}) at the absorber surface is given by

$$Z_{in} = \sqrt{(\mu^*/\varepsilon^*)} \tanh{(j2\pi/c)} \sqrt{(\varepsilon^*\mu^* fd)} \quad (1)$$

Where μ^* is the complex magnetic permeability , ε^* is the complex dielectric permittivity , c is the velocity of electromagnetic waves in free space, f is the frequency and d is the thickness of the absorber. The reflection coefficient or reflection loss (R_L) is a function of the normalized input impedance (Z_{in}) which can be expressed as,

$$R_L = 20 \log |\Gamma| = 20 \log |(Z_{in} - 1) / (Z_{in} + 1)| \quad (2)$$

The determination of R_L from experiment were also done by mean of the single-port technique. R_L was calculated then by ,

$$R_L = 20 \log (S_{11}^*) \quad (3)$$

For determining R_L under a tranverse external magnetic field, the wave-guide that contains the toroidal sample were placed in a perpendicular position with the external magnetic field that was generated by a magnetic field generator. The generator was calibrated earlier with the alternating current . The specimens for the magnetic measurement were molded into a very thin disc of about 0.5 mm in thickness and 3.0 mm in diameter. Initial magnetization, initial susceptibility and magnetic hysteresis in a maximum field of 10 kOe at room temperature (298 K) were measured using a vibrating sample magnetometer model LDJ 9600. Magnetic parameters such as saturation magnetisation, remanence, coercivity, susceptibility, initial permeability and saturation magnetic field were determined from the hysteresis loops.

RESULTS AND DISCUSSIONS

The homogeinity of the fillers in the matrice of TPNR were confirmed from the saturation magnetization analysis from which the approximate filler content is calculated .

Table 1: The saturation magnetization of the composites at different locations.

Sample	M_s (5000 Oe)	M_s (5000 Oe)	M_s (10000 Oe)	Ms (10000 Oe)
PP0Y30M	25.05	25.12	25.39	25.45
PP5Y25M	19.72	19.63	20.32	20.26
PP10Y20M	17.72	17.98	18.22	18.49
PP15Y15M	15.14	15.17	15.55	15.62
PP20Y10M	12.47	12.73	12.70	12.98
PP25Y5M	9.78	9.89	9.92	10.00
PP30Y0M	6.62	6.69	6.36	6.40

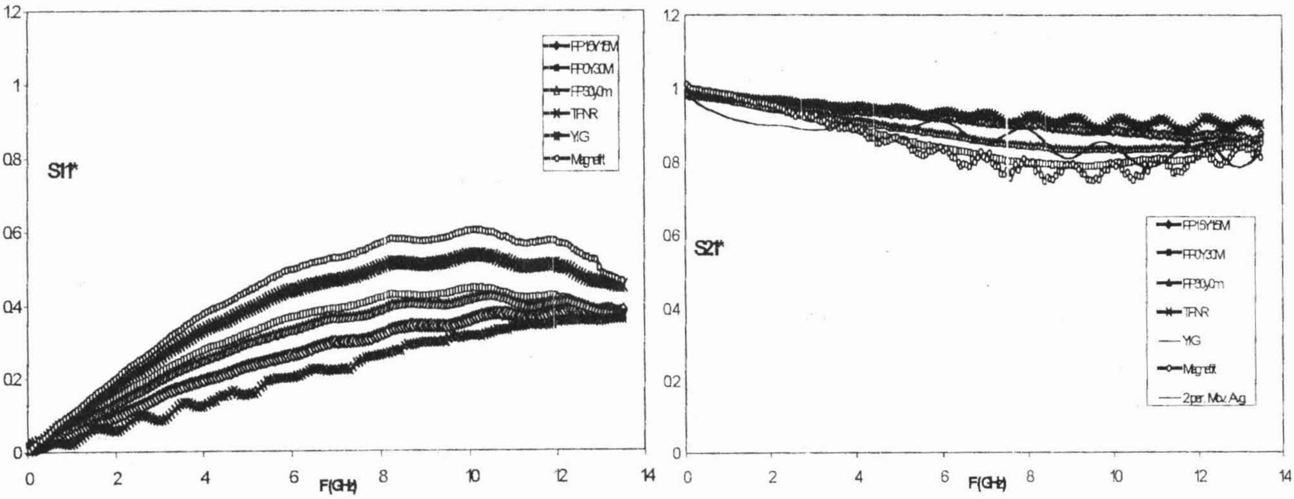

Figure 1: The frequency dependence of scattering parameters (S_{11}* and S_{21}*) of the composites.

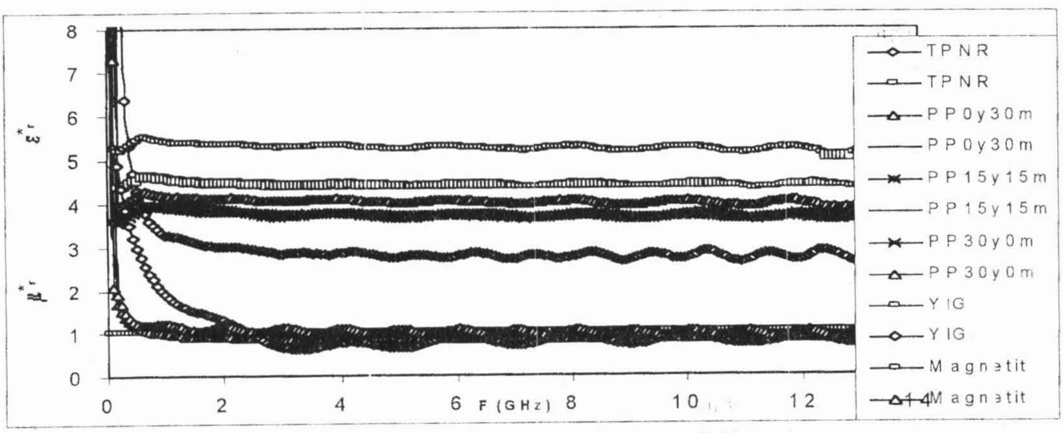

Figure 2: The frequency dependence of complex dielectric permittivity & magnetic permeability of the composites

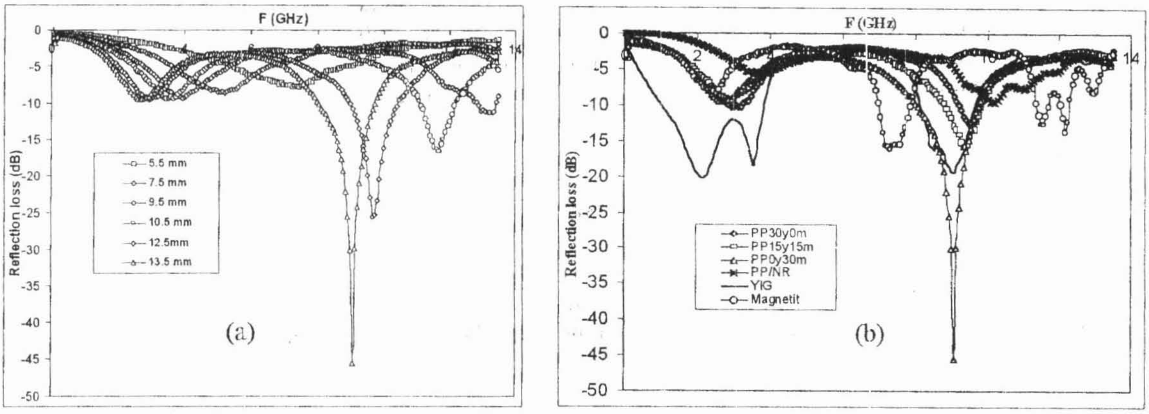

Figure 3: The frequency dependence of reflection loss for (a) different thicknesses of composite filled with 30 wt % of magnetite, (b) different composites with thickness = 13.5 mm

The scattering parameters (S_{11}*, S_{21}*, S_{12}* & S_{22}*) and the reflected (P_r), transmitted (P_t) and absorbed (P_a) powers are found dependent on the composition of the fillers in the composites. The complex dielectric permittivity ($\varepsilon^*_r = \varepsilon'_r - j\varepsilon''_r$) and complex magnetic permeability ($\mu^*_r = \mu'_r - j\mu''_r$) for the all the samples showed significant variation throughout the whole frequency domain. The dielectric properties are suggested due to the interfacial and orientational polarization while the losses are due to the electron hopping activity between Fe^{2+} and Fe^{3+} which contributed to the conductivity. The magnetic properties are most probably contributed by the mechanism of domain wall displacement and wall turning motion .

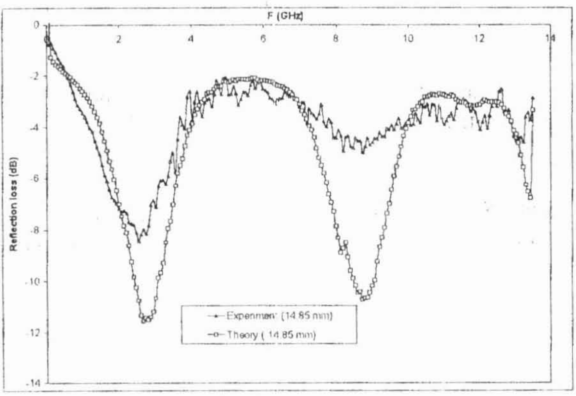

Figure 4: The comparison of theoretical and experimentally measured values of reflection loss with frequency

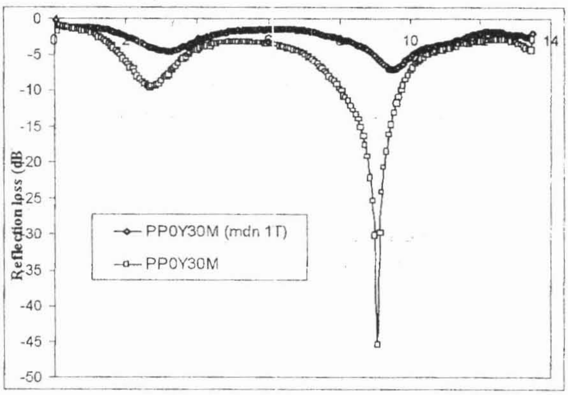

Figure 5: The comparison of frequency dependence of reflection loss for composite (PP0Y30M 13.5 mm) with the reflection loss under external transverse magnetic field of 1 T

All the samples show two dips in lower and higher frequency regions which correspond to the thickness of the sample equals to $\lambda/4$ and $3\lambda/4$ where λ is the wavelength in the material. These are suggested due to the total cancellation of the initial and reflected wave on the surface of the absorbers [6]. The reflection loss (R_L) is dependent on the thickness of the samples. The measured R_L curve from the single-port technique is in accordance with that of the theoretical calculation . The slight mismatching however is suggested due to experimental errors from the wave-guide, surface irregularity and the unstability of frequency source [5]. The incorporation of various composition of magnetic fillers into the matrice of TPNR results in significant differences in R_L. The external magnetic field of 1 T which was applied perpendicularly on the wave-guide during the determination of the scattering parameters influenced the values of the reflected, transmitted and absorbed powers. The reflection loss dips also decreased and the matching frequency shifted forward. These are discussed as due to the change in the precession frequency when external magnetic field is applied. The change in precession frequency is suggested equivalent to introducing a demagnetizing field. As a conclusion, the performance of an absorber is dependent on the composition, thickness and types of fillers incorporated into the composite. Under the external transverse magnetic field of 1 T, the efficiency of the absorber reduced.

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