Physical and mechanical properties of microwave absorber material containing micro and nano barium ferrite

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Abstract

The rapid development of electronic systems and telecommunications has resulted in a growing and intense interest in microwave electromagnetic absorber technology and microwave absorber materials. In this study, thermoplastic natural rubber barium ferrite composite was developed using micro and Nano barium ferrite filler. This paper presented the improvement of the mechanical properties of the thermoplastic natural rubber barium ferrite (TPNR-BF) composite when the size of barium ferrite filler changed from 3 μm to 55 nm. TPNR was prepared as hosting material, and the barium ferrite with particle size 3 μm was used as filler. Five samples of the composite were prepared with barium ferrite content range from 0% to 20% by an increment of 5%. The same procedure was used to prepare five samples using barium ferrite with a particle size of 55 nm. Physical and Mechanical properties of the composite were determined such as density, SEM, hardness, stiffness, tensile stress, and strain. Also, the magnetic properties and hysteresis diagram and SEM were evaluated for both composites barium ferrite types. The results indicate that all mechanical properties decline with the increasing BF content due to the increasing size of the weak interfacial zone between the polymer and the filler. This trend could be enhanced by replacing the micro barium ferrite with Nanosize barium ferrite. The level of improvement in mechanical properties increases at high filler content. Copyright © 2019 VBRI Press.

Keywords: Mechanical properties, nanoparticles, microwave absorber, barium ferrite, natural rubber.

Introduction

In recent years, the world has witnessed a great problem of electromagnetic interference, which has affected many sectors due to the huge pollution of the world in electromagnetic and microwave waves due to the tremendous development in communications and electronics [**1, 2**].

Microwave absorber material is used to absorb unwanted electromagnetic and microwave signal and to reduce the interference of signals between electronic devices. Absorbers are used in a wide range of applications to eliminate stray or unwanted radiation that could interfere with a system's operation. Absorbers can be used externally to reduce the reflection from or transmission to particular objects and can also be used internally to reduce oscillations caused by cavity resonance. They can also be used to recreate a free space environment by eliminating reflections in an anechoic chamber.

Absorbers can take many different physical forms including flexible elastomers or foam or rigid epoxy or plastics. They can be made to withstand weather and temperature extremes. Absorbers have become a critical element in some systems to reduce interference between circuit components. Absorbers generally consist a filler material inside a material matrix. The filler consists of one or more constituents that do most of the absorbing. The matrix material is chosen for its physical properties (temperature resistance and weather resistance ability, etc.).

The use of electronic devices increased rapidly in the last few years. This leads to a tremendous increase in electromagnetic interference problems (EMIP). Therefore EMIP has increased interest and research in the development of materials that have the ability to absorb electromagnetic and microwave waves called microwave absorbers. These materials are produced from polymeric materials of natural origin such as rubber or petrochemical materials representing the incubator material. Magnetic materials are added in the form of granules of small size up to several microns distributed in incubators to convert them into composite materials possessing excellent electrical and magnetic properties [**3**].

Several materials could be used as filler to produce microwave absorber. Among these materials, Barium ferrite $BaFe_{12}O_{19}$ is essential components in permanent magnets, microwave, and high-frequency devices. The use of barium ferrite as a magnetic filler in microwave absorber because it possesses attractive properties such as high magnetization, remanence, coercivity, and electrical resistivity. One of the vital polymer hosting material in microwave absorber composite is the thermoplastic natural rubber (TPNR) and high-density polyethylene (HDPE). Several studied conducted to develop microwave absorber used TPNR and HDPE [**4-6**].

Recently intensive research conducted to develop microwave absorber composite using polymers and incorporated magnetic filler in micro and Nanoscale [**7, 8**]. Several electromagnetic and microwave testing methods were developed to determine the electromagnetic properties of the material such as microwave absorber. These methods including free space microwave method [**9, 10**], open-ended waveguide [**11**], coaxial transmission line method [**7**], and parallel plate capacitive or low-frequency dielectric cell [**12**]. These methods were used for advanced electromagnetic characterization and testing.

These materials suffer from the problem of low mechanical properties, especially when increasing the magnetic material. In addition, there is a limit to the filler content because of percolation point. Several researchers use a treatment process to overcome these problems such as ultrasound treatment, thermal treatment and using a mixing agent like LICA38. These treatment shows limited improvement of mechanical properties but the cost of producing process increased with treatment. This paper investigates the enhancement of the mechanical properties of microwave absorber using Nano filler material.

Experimental

The materials used to develop the thermoplastic natural rubber barium ferrite composite were solid natural rubber (NR), high-density polyethylene (HDPE), liquid natural rubber (LNR) and two barium ferrite ($BaFe_{12}O_{19}$) with an average diameter of 3 μm and 55 nm and purity of 99.9% as filler. NR, LNR, and HDPE as raw materials are used as the thermoplastic natural rubber matrix composite (TPNR). Mixing NR, LNR, and HDPE with the following percentage respectively 20:10:70 makes the TPNR matrix. TPNR matrix will be grounded to small pieces then mixing with the prepared dry powder filler (barium ferrite). The composite mixture will be prepared using different filler content 0, 5, 10, 15 and 20 by mass. The composite will be melted using Plasticorder Brabender PL2000 at 140 °C, the speed of wheel rotation will be 135 rpm for a period of 20 min. First set of microwave absorber material was prepared using the micro barium ferrite with size equal to 3 μm. The second set of material was prepared using Nano barium ferrite with size equal to 55 nm.

Results and discussion

Both micro and Nano microwave absorber developed in this study were characterized to determine its physical and mechanical properties. The effect of barium ferrite size on the physical and mechanical properties was evaluated. The results are discussed in detail in the following sections.

Physical properties

The picture of TPNR-BF microwave absorber with 0% and 20% ferrite filler are shown in **Fig. 1**. Also shows the dumbbell samples according to ASTM D412 used for mechanical properties tests. The color of TPNR with 0% barium ferrite is dark yellow while the color of TPNR-BF converts to black with increasing barium ferrite content.

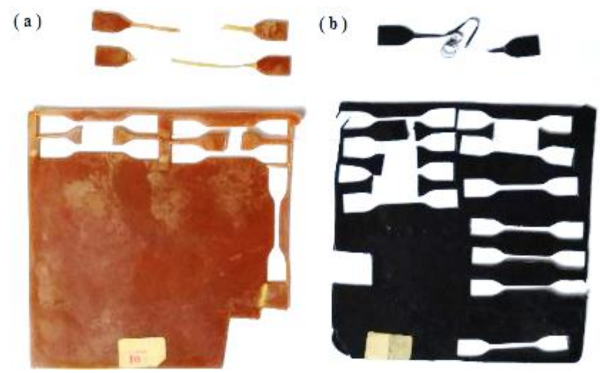

Fig. 1. TPNR-BF microwave absorber, (a) BF 0% and (b) BF 20%.

The density of TPNR-BF microwave absorber is given in **Table 1**. The results show that the density increase with increasing barium ferrite filler content for both micro and Nano barium ferrite. This is expected because of the higher density of barium ferrite compared with polymer hosting material (TPNR). To determine the significant difference between the density of micro and Nano microwave absorber a t-test using SPSS package was used. The t value of the t-test was -5.88 and the significance level equals 0.005. Therefore, the results of density indicate that there is no significant difference between the density of micro and Nano microwave absorber.

Table 1. The density of Micro and Nano microwave absorber.

Microwave absorber	Density (gram/cm^3)	
	Micro-ferrite	Nano-ferrite
TPNR-BF (0%)	0.892	0.892
TPNR-BF (5%)	0.933	0.936
TPNR-BF (10%)	1.012	1.014
TPNR-BF (15%)	1.190	1.191
TPNR-BF (20%)	1.349	1.352

The SEM of TPNR-BF containing 20% micro and Nano barium ferrite filler are shown in **Fig. 2.** SEM indicated that the microparticles of barium ferrite accumulate near each and form larger interfacial zone between the filler and hosting polymer material. This may reduce the mechanical properties of the composite. The use of Nanoparticle material results in a good dispersion of the barium ferrite filler in the hosting material leads to more homogeneous composite. This may attribute to improving all properties of the microwave absorber material. This result is in good agreement with a previous study and reported research [**7, 8**].

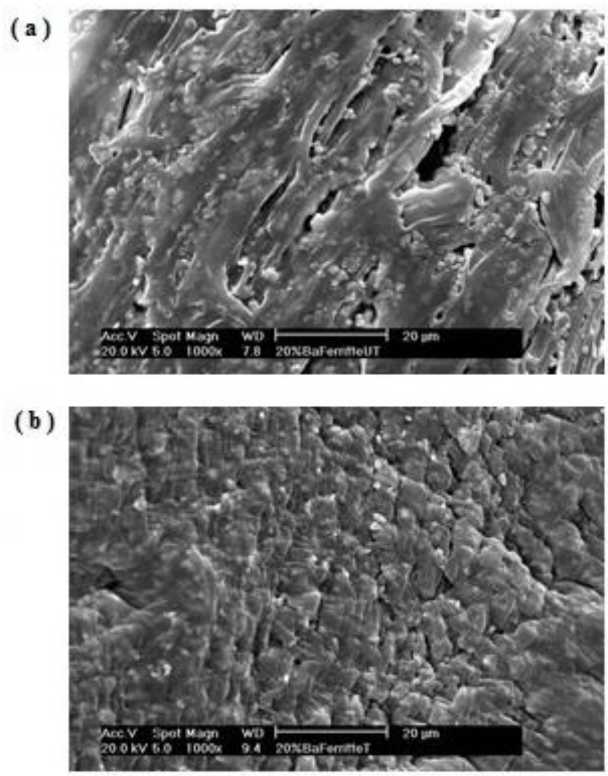

Fig. 2. Scanning electron micrographs (SEM) of the microwave absorber composite. (a) 20% Micro BF, (b) 20% Nano BF.

Mechanical properties

The hardness of the TPNT-BF microwave absorber for both micro and Nano filler and at different filler content are given in **Table 2**. The surface hardness of TPNR-BF composite was measured using durometer hardness after 3 seconds after the pressure foot is in firm contact with the specimen. The hardness increased from 39 to 41 for 0% and 20% respectively. The result of hardness does not show any significant difference due to filler size or filler content. The melting point decreased with increasing filler content were also observed. This may result from increasing thermal conductivity of the composite with increasing filler content.

Table 2. The hardness of Micro and Nano microwave absorber at different filler content.

Microwave absorber	Hardness ($gram/cm^3$)	
	Micro-ferrite	Nano-ferrite
TPNR-BF (0%)	39	39
TPNR-BF (5%)	40	40
TPNR-BF (10%)	40	41
TPNR-BF (15%)	41	40
TPNR-BF (20%)	41	41

The mechanical properties such as stiffness, tensile stress and tensile strain of the TPNR-BF at different filler content are shown in **Fig. 3**, **Fig. 4** and **Fig. 5** respectively. All mechanical properties of the composited decrease with increasing BF content for both micro and macro barium ferrite composite. This is expected as the interfacial zone between the hosting polymer, and the metal particles are the weaker zone in the material. This weak zone increase with increasing filler content and reduce the tensile stress, tensile strain, and young modulus of the composite. It is recommended to improve the bonding between BF filler and polymer matrix using available treating processes such as heating, epoxy or ultrasound method. It is also noted that the metal filler could pull out from the polymer matrix near the surface. This is due to the weak bond between the BF filler and matrix.

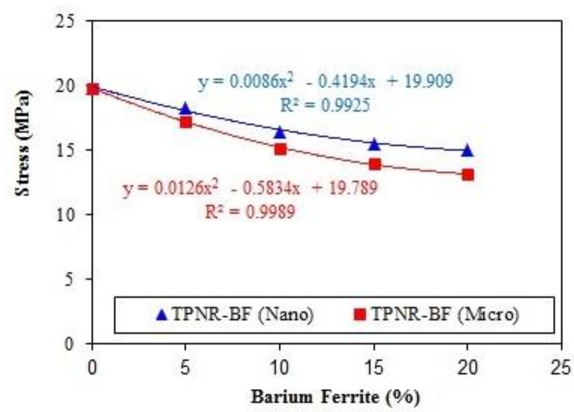

Fig. 3. The tensile stress of TPNR-BF microwave absorber for both micro and Nano barium ferrite filler and at different filler content.

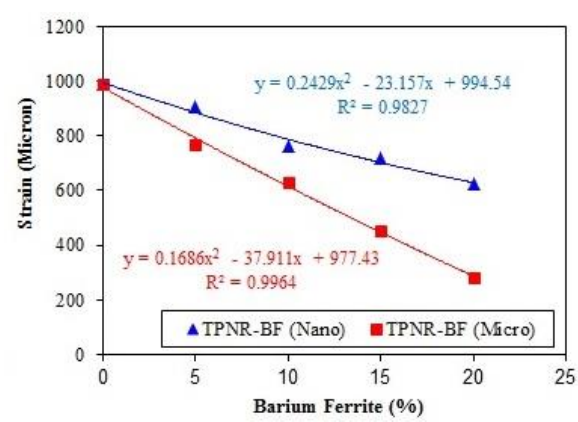

Fig. 4. The tensile strain of TPNR-BF microwave absorber for both micro and Nano barium ferrite filler and at different filler content.

Compare the result of the mechanical properties of micro and Nano barium ferrite composite show enhancement of the mechanical properties in the Nanocomposite. The percent of improvement in the mechanical properties increase with increasing filler content. This may attribute to the reduction of the interfacial zone in the Nanocomposite. In addition, the use of Nano barium ferrite shows the possibility of increasing the percolation limit of the filler content which may increase the efficiency of the composite in absorbing the microwave signal.

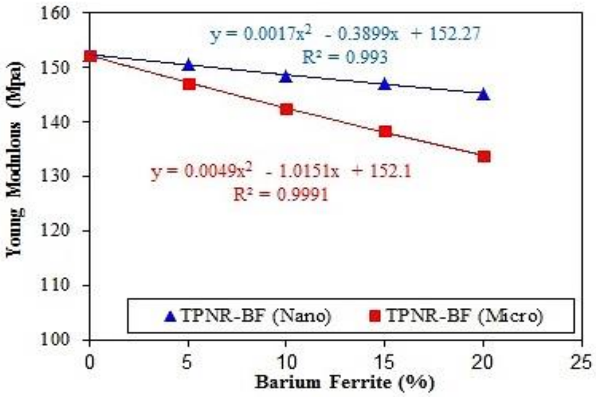

Fig. 5. Stiffness (Young Modulus) of TPNR-BF microwave absorber for both micro and Nano barium ferrite filler and at different filler content.

Magnetic properties

Magnetic hysteresis curves are shown in **Fig. 6**. Magnetic properties such as the coercive force (H_C), the remanence (M_R) and the saturation magnetization (M_S) increase with increasing BF filler content for both micro and Nano TPNR-BF. This result is in good agreement with a previous study and reported research [**9**]. The results also indicate that H_C, M_R, and M_C decrease when the micro barium ferrite replaced by Nano barium ferrite.

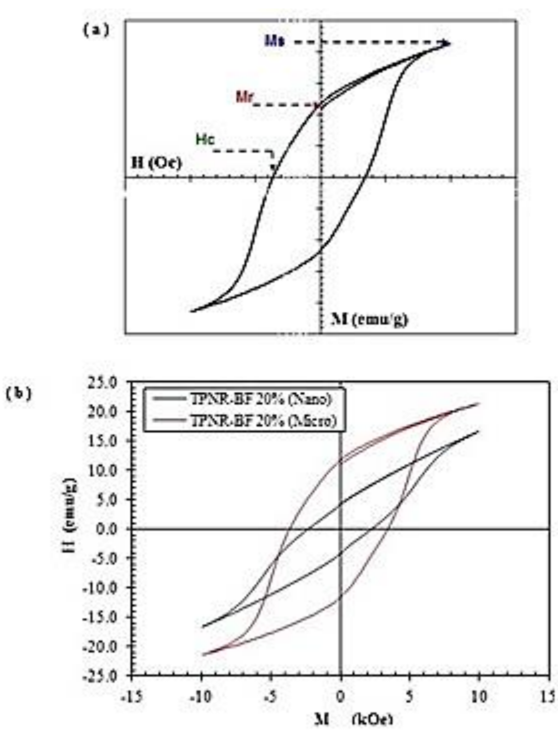

Fig. 6. Magnetic hysteresis curves (H vs M curve) of TPNR-BF composite (a) Typical curve, (b) TPNR-BF (20%).

Conclusion

A microwave absorber composite material called thermoplastic natural rubber barium ferrite (TPNR-BF) was first developed using 3 μm barium ferrite filler and then re-developed with 55 nm barium ferrite. The mechanical properties decline with the increasing BF content due to the increased size of the weak interfacial zone between the polymer and the filler. This trend could be enhanced by replacing the micro barium ferrite with Nanosize barium ferrite. The enhancement of the mechanical properties results from the decrease of the weak interfacial zone and the well dispersed Nano filler in the hosting polymer material. This finding may save cost by avoiding the need of treatment processes to improve the mechanical properties of this type of composite. The results also show an increase in the density of the microwave absorber with increasing filler content and no significant difference in the density and hardness of material due to filler size.

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Author's contributions

Both authors contribute in all work to produce this paper including, conceived the plan, performed the experiments, data analysis, and wrote the paper. Authors have no competing financial interests.

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