Experimental Study of a Soft Magnetic Composite Shielding Effectiveness

K. Benzaoui, A. Ales, A. Zaoui and D. Moussaoui

Abstract—This paper presents experimental study of a soft magnetic composite shielding effectiveness. This study discusses the electromagnetic shielding efficiency of both electric and electromagnetic field of a soft magnetic composite material according to the frequency band starting 20MHz to 1GHz. The study based on an experimental measurement, contains many steps. Firstly, we realize a plate with a polymer matrix (resin) mixed with conductive filler in the form of iron powder (Fe_3O_4, Sodium Stearate) with different concentrations. Secondly, an experimental setup via the dual TEM cell in order to validate the proposed model.

Index Terms—Soft magnetic composite materials, Shielding effectiveness, EMC, DTEM cell.

1 Introduction

Electromagnetic (EM) Shielding is one of the useful solutions applied to reduce electromagnetic interference (EMI) problems and to guarantees the safety of both people and electrical and/or electronic devices. Traditionally, metals are used in EM shielding applications because they are naturally conductive and apt to reflect EM waves. However, many problems appear about the use of those materials, which are mainly related to the weight/volume and the corrosion issue. Consequently, to get rid of these constraints, polymer composites with conductive fillers are preferred for EMI shielding in same special applications [1].

In recent years, research has focused on improving the shielding effectiveness "SE" against EMI with conductive polymers [2], while maintaining the simplicity of processing and manufacturing methods. The polymer has many advantages such as small density, high level of flexibility, conductivity control and manufacturing cost reduction [3], [4].

Presently, macromolecule polymer material is gradually replacing metals in many fields especially in electronics field and electrical industry. However, the EM radiation generated during the manufacturing of electronic equipment, causing the EM environment pollution in human survival space getting worse, it is not only affect the production, and even directly harm human health. Electromagnetic Shielding (ES) polymer materials are mainly divided into compound type and structure type [4].

However, compound ES polymer material use insulating polymer as matrix; it is made by adding a certain amount of materials with excellent conductivity properties. The conductive process is depending on the free electron carriers provided by the small particles of metal. Structural ES polymer material refers to the polymer with molecule structure itself can be conductive after being doped such as polyacetylene, polypyrrole and so on [4]. Conductive polymer-based composites are attractive alternatives to metals due, primarily, to their lightweight, versatility, low cost and process ability, excellent mechanical properties and absence of corrosion. Among their applications, soft magnetic composite materials (SMC) can be considered as ES materials to contain and exclude radiated emissions.

In this paper, two parts have been developed; the first phase is the realization of the SMC. The SMC are a combination of several materials with different and complementary individual properties, namely the reinforcement that consists of iron powder fillers and a matrix of a thermosetting polymer (resin) and a hardener (DER, DEH). The second phase is the measurement of the ES for a frequency band of 20 MHz-1GHz using the dual TEM Cell (DTEM).

2 Soft Magnetic Composite Shielding under study

The effect of electromagnetic shielding is to reduce the electromagnetic field effect in a certain area (not including these sources) generated by some radiation sources, and to effectively control the harm caused by electromagnetic radiation from one area to another. The principle of action is the use of low resistance conductor material, because the conductor material has a reflection and guiding effect on electromagnetic energy flow and within the conductor material it creates the current and magnetic polarization which is opposite with the source of electromagnetic field, thereby reduce the effect of radiation source in electromagnetic field, normally it represented by shielding effectiveness (SE) [5]. The SE refers to the ratio of the incident or reflection electromagnetic waves without to the reflection or transmission of EM wave under shielding at the same location, that is, shielding material to the attenuation value of EM signal, the unit is (dB) [5]. The expressions of electrical and magnetic efficiency from the cell are given, respec-tively:

$$SE = 20Log\left(\frac{E_{withaout}}{E_{with}}\right)_{dB} \quad (1)$$

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$$SH = 20Log\left(\frac{H_{withaout}}{H_{with}}\right)_{dB} \quad (2)$$

With: E and H are the components of the electric and magnetic fields in the presence of the sample and in the absence of the sample.

The measuring the Electromagnetic Shielding Effectiveness of planar materials is shown in Fig. 1.

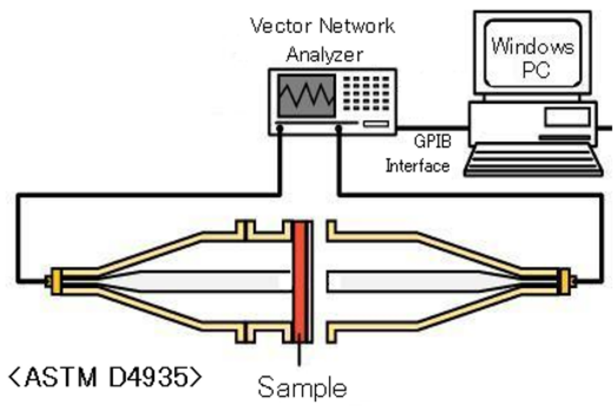


Fig. 1. Measuring the Electromagnetic Shielding Effectiveness.

3 Metal oxide based polymer matrix electromagnetic shielding composite material

The polymer /metal composite material are synthesized from mixing metal powder or fiber and other good conductor are mixed with polymer. When the metal particles content reach a certain ratio in the polymer matrix, it forms a micro-conductive net-work, in order to achieve the shielding properties of composite materials [6]. The sample under test is realized at the laboratory, according to the process described below.

3.1 Reinforcement

The iron powder, which will constitute the conductive charge of our materials, has been supplied to us in packets shown in Fig.2.(A). The analysis with the densimeter shown in Fig.2.(B) With a value of $5.1441 g/cm^3$ of Iron Oxide density (Fe_3O_4).

(A) (B)

Fig. 2. (A) Package of Iron Powder; (B) Densimeter.

3.2 Polymeric matrix

To realize the polymeric matrix, we mix the resin and hardener, which are in the form of a viscous liquid, to form a three-dimensional network of macromolecular chains linked together by bridging. After firing, we get the final material with a density of $1.12 g/cm^3$; rigid, translucent, colorless, insoluble and infusible.

4 Elaboration Protocol Of The Magnetic Composite Materials

The Iron-Polymer composite samples under test are plate forms of size $10\times10\times0.3 cm^3$ or a volume of $30 cm^3$ made by an Aluminum mold for its high heat resistance. The design protocol for SMC plates is based on the following steps.

4.1 Determination of chemical characteristics

4.1.1 Calculation of stoichiometric coefficients

The preparation of the polymer is done according to a very concise ratio (hardener mass) / (resin mass) which is computed according to the following steps: label=—

- A volume of the polymeric resin is poured into beakers.
- We add the hardener, to each beaker, with different ratios of the volume of the resin (Table.1).

TABLE 1
Weight ratio (Resin mass)/(Hardener mass).

	E1	E2	E3	E4	E5
Vresin(ml)	10	10	10	10	10
Vhardener/Vresin	1/2	1/3	1/4	1/5	1/6

The determination of the densities and hardener is done using a pycnometer (Table.2).

TABLE 2
Density values.

	distilled water	resin	hardener
m (g)	25.0882	30.6078	29.8547
D	/	1.22	1.19

4.2 Surface treatment of the powder

For the affinity reasons between mineral fillers and the organic polymer matrix, sur-face-active agent treatments are used on mineral fillers to modify the interfacial stress of the phases and promote charge-polymer interactions. This type of treatment consists in covering the surface of the charges with an organic substance. Among the organic compounds used, we find mainly fatty acids and mainly Sodium Stearate shown in (Fig.3).

The addition of a coupling agent to the composites increases significantly the homo-geneous distribution of particles in the epoxy matrix.

The coupling agent has a structure with two different functions, one, which is attract-ed by the resin and the other, which is attracted by the surface of the charge shown in

Fig. 3. Sodium Stearate Powder.

Fig.4, which (a) Distilled water, Ethanol, Iron powder; (b) Sodium Stearate Ethanol ;(c) Ultrasonification; (d) Sedimentation and finally (e) - Drying.

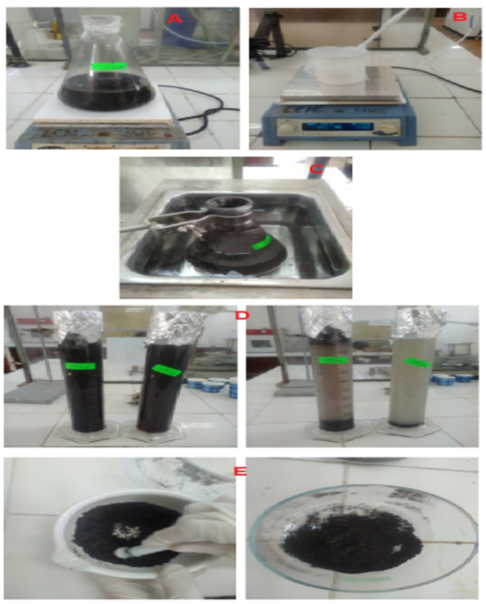


Fig. 4. Powder processing steps.

4.3 Realization of the Plates

The mold with the composite mixture is left for about 24 hours to degas shown in Fig.5. (a) and (b), then, the mixture is put in the oven to complete the manufacturing procedure.

5 Experimental setup and results

In order to measure the SE [7], we have installed an experimental setup composed by five instruments shown in Fig.6.

Experimental setup contains a radio frequency signal generator (Agilent N5181A), Power amplifier (Amplifier Research AR), dual TEM cell (DTEM) cell (TESEO), and hybrid junction and spectrum analyzer (RIGOL DSA1030A).

The graphical interface to computerized the measurement process and to avoid the point by point frequency injection, we developed a computing interface under the Lab view software to check the frequency scanning, synchronize between the different measuring devices, enter limit frequencies for the working range and saving measurement data.

The DTEM cell consists of two TEM cells connected by an opening in a common wall used for transmitting and receiving the EM field [8].When the emitting cell is excited, part of the EM field is transmitted via the opening to the receiving cell shown in Fig.7.

When a sample is placed on the opening, the coupling between the two cells is reduced, giving a direct measure of the shielding efficiency.

The operation maximum frequency of the cell is 1GHz and the experimental conditions are as follows [8]: label=—

- Input power: 0dBm ;
- Frequency range: from 20MHz to 1GHz;
- Scanning step: 1MHz.

We measured the electrical and magnetic shielding efficiency by the measuring de-vice for 5 types of SMC samples containing different percentages of Iron are pre-sented in (Table 3).

TABLE 3
Percentages of Iron present in SMC samples.

Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
90%	75%	09%	07%	01%

The results of measuring the efficiency of the electrical and magnetic shielding of the plates are shown on the Fig.8 and Fig.9.

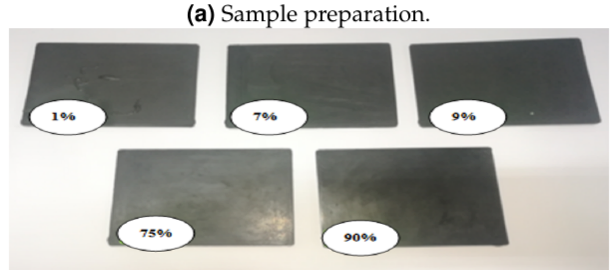
The shielding efficiency of composite materials (polymers including conductive metal particles) is classified according to Table 4. [9]

TABLE 4
Protection ranges.

Level	Excellent	Very good	Good	Modest	Just
Range	$SE>30dB$	$20dB \leq SE<30dB$	$10dB \leq SE<20dB$	$7dB \leq SE<10dB$	$SE<7dB$

We find that the shielding efficiency of the samples at 90% and 75% iron can be classified as excellent.

(a) Sample preparation.



(b) Percentages of Iron present in SMC samples.

Fig. 5. Realization of plates.

Fig. 6. Shielding efficiency measurement bench.

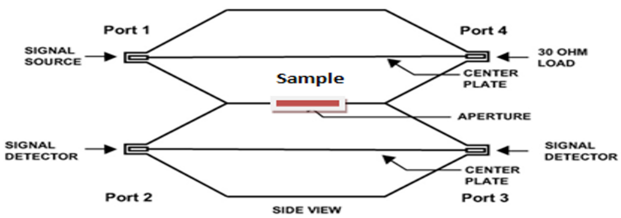


Fig. 7. Principle for measuring the efficiency of electrical and magnetic shielding.

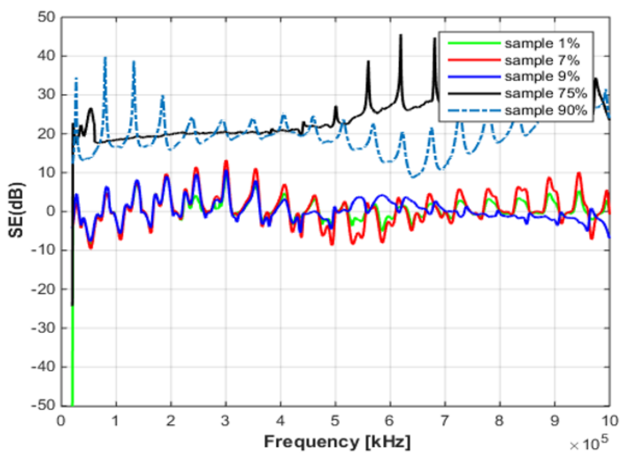


Fig. 8. Variation of the electrical shielding efficiency.

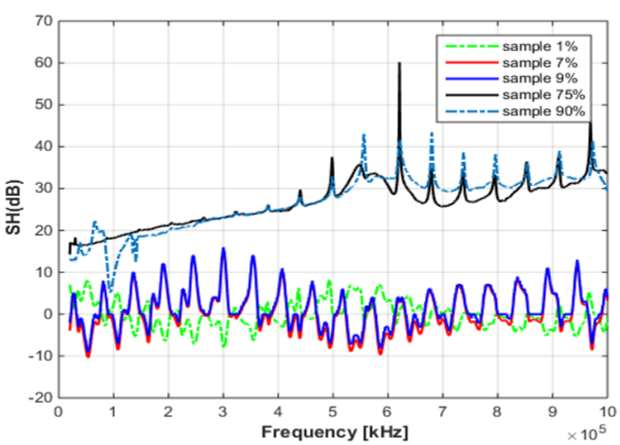


Fig. 9. Variation of the magnetic shielding efficiency.

6 Conclusion

Electromagnetic shielding materials have important social and economic benefits. Therefore, the polymer based electromagnetic shielding composite material as a new type of shielding material should be developed toward aspects of the shielding effec-tiveness, shielding bandwidth, comprehensive performance and other more excellent aspects The electromagnetic shielding performance of the material is related to the physical and chemical properties of the material, the frequency (or wavelength) of the electromagnetic wave, the physical size of the test specimen, the size of the test space, the distance of the radiation source and the test environment. In the specific selection of test methods, we should fully consider these factors, especially the characteristics of the sample, the characteristics of the radiation source and the adaptabil-ity of the selected test method otherwise the results obtained by the test cannot be accurate to evaluate the electromagnetic properties of the material.

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