Characterization of Conductive Thermoplastic Composite Materials Using Multiple Measurements Methods

Authors:
Urban Lundgren, Jonas Ekman and Jerker Delsing

Reformatted version of paper originally published in:
Symposium Record, EMC Europe 2002, (Sorrento, Italy), 2002

CHARACTERIZATION OF CONDUCTIVE THERMOPLASTIC COMPOSITE MATERIALS USING MULTIPLE MEASUREMENT METHODS

Urban Lundgren  Jonas Ekman  Jerker Delsing
EISLAB
Luleå University of Technology
971 87 Luleå, Sweden

Abstract - In a study of conductive thermoplastic composite materials, samples were manufactured and measured. Samples with different base polymers, filler materials and different amount of filler made it possible to generate data for many combinations. The samples were characterized in terms of their complex permittivity and complex permeability, plane wave shielding effectiveness and near electric field shielding effectiveness. As can be expected materials that shows a relatively high shielding effectiveness for a incident plane wave also in general offers shielding in the near field situation that was studied. A correlation between SE and complex permittivity was also found.

I. INTRODUCTION

This paper describes the work to compare measurement methods to acquire electromagnetic shielding effectiveness (SE) of conductive thermoplastic materials. The frequency range in this study is 150 MHz to 1 GHz. It is desired to find a method to establish the shielding effectiveness for a box encapsulating electronic equipment. An easy to use measurement method would allow the study of new material mixtures and the effect on shielding effectiveness of varying process parameters. As a tool for the plastic manufacturing industry this will enable improvement of electromagnetic shielding effectiveness in plastic enclosures for electronics. A good method should also be as simple as possible regarding instrumentation so that necessary investments to be able to do the measurement are kept small.

Previously published work related to this problem has been found in [1] which reviews a large number of papers and summarizes in four measurement methods. As a near field measurement methods suitable for materials with insulative surface standards ASTM-ES-7 and modified MIL-STD-285 are suggested. Those two methods are also reviewed in [2]. In [2] and [3] two measurement methods are suitable involving a TEM cell. However the TEM cell limits the upper frequency to less than 1 GHz. Another method developed from the MIL-STD-285 is shown in [4]. This measurement method is suitable for both near field and far field measurements. For measurement of permittivity and permeability on a material, methods were found in [5] and [6]. The methods are using cavity resonance or transmission line loading techniques. In [2] a method is reviewed for estimating shielding effectiveness when knowing complex permittivity and permeability of a material.

Three different measurement methods are compared to test the validity of the methods. For the comparison of measurement methods a number of different composite materials were analysed in the study. Data from three of those are here used for the comparison of the three methods.

Measured data are also compared to give an indication how shielding effectiveness is affected by incident field impedance and by the permittivity and permeability of the material.

II. EXPERIMENTAL SETUP AND MATERIALS

The three thermoplastic composite materials used in the comparison have the base polymers Polycarbonate / Acrylnitrilbutadienestyren (PC/ABS) or Acrylnitrilbutadienestyren (ABS). The materials used are listed in Table I.

| Table I Materials for which measured data are presented in this paper |
|-----------------------|------------------------|
| **Base polymer**      | **Main additive**      |
| PC/ABS                | 1 vol. % Stainless steel fibre |
| ABS                   | 1 vol. % Stainless steel fibre |
| ABS                   | 1.5 vol. % Stainless steel fibre |

For each material test samples were made as boxes for near field SE, square plates for the far field SE measurement and two smaller rectangular plates for the permittivity and permeability measurement.

II.1 Shielding of a Electric Near Field Source

This measurement method mimics a shielding enclosure application by enclosing a radiating dipole with a box made of the sample material. This method was selected as reference since it provides the closest match to the desired application of the shielding material. The main
drawback of this method is the cost of making the boxes used as test samples and the expensive anechoic shielded room facility used for the measurement.

Because of the desire to evaluate the usefulness of the materials in an electronic equipment encapsulation application, near field measurements were made. A high impedance source generating mainly electric field was designed and used for measurement of the near field shielding effectiveness.

If the near field radiation mainly is an electrical field (high impedance) then conductive thermoplastic materials are expected to offer better shielding effectiveness than for mainly magnetic field (low impedance).

Figure 1 Transmitter for near field SE measurements

The battery powered comb generator was constructed (Fig. 1) with a fundamental frequency of 20 MHz and does produce strong frequency components well above 2 GHz. In this work the frequency range that have been used is 150 MHz to 1 GHz. The comb generator alone were placed on a table in an anechoic room and the emitted free-space signal spectra at 3 m distance were measured, see Fig. 2. This measurement data is used as the baseline in the insertion loss calculation.

A Rohde & Schwarz EMC/EMI test receiver was used for this measurement. The instrument causes a step in the baseline at 500 MHz, this is due to an internal compensation in the instrument and should not affect the measured values at the peaks according the manufacturer. However, even if the levels of the peaks are affected the step is about 4 dB and this error would not alter the conclusions in this paper.

The battery powered generator was enclosed in a box of the sample material with the dimensions 18 x 11 x 12 cm. To be able to access the interior of the box the boxes were made in two halves, see Fig. 3. To ensure good seal when closing the box the meeting surfaces were designed to have a male and female configuration, see Fig. 4, that offered a wave trap function. The thickness of the material is 5.0 mm in the bottom and 3.0 mm in the walls of each half of a box. The wall with thickness 3.0 mm was facing the receiving antenna.

In this method the thermoplastic material is very close to
the signal source like in most shielding applications. This means that the barrier, the thermoplastic material, is in the near field of the source and the impedance of the emitted electromagnetic wave is unknown. The results from these measurements are therefore 'unique' to this test set-up and can not be directly applied to other shielding applications.

II.2 Far Field Shielding Effectiveness Measurement

Another method was used to measure the plane wave shielding effectiveness (shielding material located in far field from radiator). It is implemented in a nested anechoic chamber set-up, similar to [4]. The test samples in this case are simple flat slabs but this method uses an expensive anechoic shielded room facility.

A miniature anechoic chamber is located inside a large anechoic chamber with 3 meter measurement distance, see Fig. 5. The miniature chamber is a cube of brass with the sides 0.6 meter. It is lined on all inside surfaces with ferrite tiles that absorbs radio frequency electromagnetic fields and reduces reflections. A top loaded monopole antenna is used as receive antenna and is mounted over a 20 x 20 cm ground plane. This arrangement is located in the centre of the cube. The transmit antenna located in the larger chamber 3 meters from the aperture wall of the cube is a wideband CHASE bilog antenna often used for EMC testing.

The attenuation of electromagnetic plane waves is measured as the insertion loss when closing an aperture with a test sample. The aperture size is 90 x 90 mm corresponding to the sample size of 95 x 95 mm. The shielding effectiveness is obtained as the difference between the antenna coupling with open aperture and the antenna coupling with a sample fitted in the aperture. The samples were squeezed between the wall of the brass cube and a 20 x 20 cm brass frame with a 90 x 90 mm aperture. Between the sample and the metallic surfaces a fabric over foam conductive gasket was used.

A Rohde & Schwarz ZVR vector network analyzer was used in conjunction with an Amplifier Research power amplifier to measure the attenuation in the transmission between the antennas. The frequency range was chosen to 150 MHz to 1 GHz because of the restrictions induced by the small aperture and limitations of the power amplifier used.

The useful dynamic range for this set-up was investigated by first measuring a baseline attenuation with the aperture open. Then closing the aperture with a 5 mm thick brass plate and using conductive tape to seal thoroughly around the plate. The attenuation was measured again and the insertion loss was calculated as the difference between this reading and the baseline. The dynamic range is more than 50 dB in the chosen frequency range, see Fig. 6.

II.3 Transmission line technique for complex permittivity and permeability measurements

The third method offers a compact way to estimate the shielding effectiveness by theoretical calculations based on measured complex permittivity and complex permeability. This is the least costly method in terms of sample preparation and test facility. The complex permittivity and complex permeability were measured indirectly using the transmission line technique described in [6].

The transmission line was constructed using two coaxial cables with characteristic impedance, $Z_0 = 50 \, \Omega$ connected to a rectangular metallic housing as seen in Fig. 7. The metallic housing impedance, $Z_L$, is $50 \, \Omega$ when the medium between the center conductor and the
housing is air (see Fig. 8) and is thereby matched to the coaxial cables.

Figure 7 Transmission line fixture for \( \varepsilon_r \) and \( \mu_r \) measurements

Figure 8 Unloaded test fixture

Figure 9 Test fixture loaded with Polyethylene

The transmission line fixture was loaded with test samples resulting in a change in characteristic impedance, \( Z_L \), proportional to the material properties. The dimensions of the test samples were \( t \times 43 \times 0.48 \) mm where \( t \) was 20 mm and 40 mm and represents the length along the propagation direction in the transmission line. The samples are mounted in the fixture in pairs on each side of the flat center conductor. See Fig. 9. The change in \( Z_L \) introduces reflections in the transmission line structure that was measured using a Rohde & Schwarz ZVR vector network analyzer. From the measured scattering parameters, \( S_{11} \) and \( S_{12} \), the complex properties are calculated (1) – (5). For a complete theoretical derivation, see [3].

\[
\varepsilon_r = \frac{k}{k_0} \frac{1 - R}{1 + R} \tag{1}
\]

\[
\mu_r = \frac{k}{k_0} \frac{1 + R}{1 - R} \tag{2}
\]

where

\[
k_0 = \omega \sqrt{\mu_0 \varepsilon_0} \tag{3}
\]

\[
k = \cos^{-1} \left( e^{-j4\pi f t} + S_{12}^2 - S_{11}^2 \right) \tag{4}
\]

\[
R = \frac{S_{11}}{e^{-j2\pi f t} - S_{12} e^{-j2\pi f t}} \tag{5}
\]

To verify this technique, measurements on polyethylene were performed. In Fig. 10 the real part of relative permittivity \( \varepsilon_r \) for polyethylene is shown. The dotted lines indicates the published constant value \( \varepsilon_r = 2.25 \) for \( \text{Re}\{\varepsilon_r\} \) [7]. The measured values differs from the correct by \( \pm 7\% \).

Figure 10 Real part of permittivity for polyethylene

The measured data of the permittivity and permeability is used to calculate theoretical plane wave shielding effectiveness for an infinite flat shield. Since the reference case in this comparison is the near field shielding with a box a thorough theoretical model would be too complex and the assumptions is made that this simplified case is a good approach. The total shielding effectiveness is the sum of absorption (\( A \)), reflection (\( R \)) and correction (\( B \)) also called re-reflection loss. See (6) – (9) found in [2]:

\[
SE = A + R + B \text{ dB} \tag{6}
\]

where

\[
A = 0.1285 \sqrt{\mu_r (\varepsilon_r - \varepsilon_r^*)} \text{ dB} \tag{7}
\]

\[
R = 20 \cdot \log_{10} \left( \frac{|\varepsilon_r|}{4} \right) \text{ dB} \tag{8}
\]

\[
B = 20 \cdot \log |1 - e^{-j\gamma}|, \gamma = j0.021f \cdot \sqrt{\varepsilon_r} \text{ dB} \tag{9}
\]
The re-reflection loss \( B \) corrects for the multiple reflections inside the barrier and is always a negative value since re-reflections degrade SE. This term is very small and have been neglected in the calculations.

**III. RESULTS**

Data from the three methods were collected and are here shown for the three sample materials in Fig. 11, 12 and 13.

In Fig. 11, 12 and 13 the stars shows near field shielding effectiveness of an electric field source. In the figures, the stars indicates the insertion loss at frequencies where peaks were present in the transmitter free-space signal spectra (Fig. 2). The repeatability for these measurements are very good and the results presented are from one measurement occasion but the results must of course be regarded as unique to this test set-up. This is because the shielding material is in close proximity of the transmitting antenna so that the input impedance of the transmitting antenna may change when changing material. Also the near field impedance, that is the relation of electric field strength to magnetic field strength is unknown.

The results for the far field shielding effectiveness measurements are presented as solid lines in Fig. 11, 12 and 13 for the different thermoplastic materials. The results are for 3 mm thick sample plates and are averaged results for 4 measurement occasions performed over a period of 2 weeks.

The dotted lines in Fig. 11, 12 and 13 shows the calculated shielding effectiveness values based on measured permittivity and permeability for the different thermoplastic materials.

For the materials used in Fig. 11 and Fig. 12 the measured imaginary part of the permittivity is shown in Fig. 13 and Fig. 14, respectively.
IV. DISCUSSION

Measured shielding effectiveness with the far field method show the same trend in frequency response as the near field method but with an offset in some cases.

When studying a larger number of different materials than presented in this paper, materials that performs well in the plane wave case usually also offers good shielding in the near field case. The largest deviation found in this comparison is about 20 dB (Fig. 11). This could indicate the effect of the incident field impedance on SE. However the deviation would then be expected to be in the opposite, that is a larger value of SE were expected for near field SE than for far field SE indicating expected good electric field shielding. Calculated shielding effectiveness based on measured material properties does not agree well with measured near field shielding effectiveness. The largest deviation found in this comparison is almost 20 dB (Fig. 12).

In conclusion the measurement of material properties does not give good information on near field shielding effectiveness (SE). Further the approach of far field measurement agrees well in most cases but deviations with no reasonable explanation are found.

The base PC/ABS offers 8 dB to 10 dB better far field SE than the pure ABS base with vol. 1% stainless steel fibre as the additive. This is also supported by calculated shielding effectiveness for an infinite flat shield based on the measured electrical properties. For the near field case, no noticeable difference can be seen.

The difference in calculated shielding effectiveness (dotted lines) between Fig. 11 and Fig. 12 can be explained by studying the properties of the materials. By analyzing the measured permittivity and permeability further a large difference is found in imaginary permittivity, see Fig. 14 and Fig. 15, for the materials. The imaginary part of the permittivity includes the effect of conductivity in the material. The cause of the losses in a dielectric material is usually that the conductivity is large [7].

In conclusion the thermoplastic materials with high imaginary part of the permittivity seem to give an improved shielding effectiveness compared to materials with small imaginary part of permittivity. The real part of the permittivity can not alone be correlated to a good SE.

V. REFERENCES


