MECHANICAL EFFECT AND SHIELDING EFFECTIVENESS OF THE INSERTION OF METALLIC SCREEN IN GLASS AND CARBON COMPOSITE

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ABSTRACT

This paper presents the electrical and mechanical influence due to a screen insertion in a Glass Fibre Reinforced Plastics (GFRP). The objective of this research is to increase the electromagnetic shielding effectiveness, then to evaluate the effect of the metal screen insertion on the mechanical properties compared to the original structure. Results of electromagnetic wave theory and results from experimentation are compared in this work and found to provide approximately the same shielding level. Measurements have been performed on carbon samples at both L-band and S-band exhibiting shielding effectiveness greater than 45 dB.

Mechanical performances in tension and flexion of glass fibre reinforced vinyl ester composites with interlaminar metallic layer were evaluated experimentally and numerically. Compressive behaviour, before and after impact are also compared. The mechanical test results indicate that this metallic screen inserted at various levels between two layers in the thickness of the structure does not degrade significantly the composite structure.

1. INTRODUCTION

Warships are equipped with more and more electronic equipments which generate electromagnetic fields of various intensity. The superstructures support several contributors such as radar antennas, high frequency antennas and electronic warfare equipment… each being susceptible to interfere or hinder the other equipments but also perturb the operation of the equipment installed in the living spaces. It is also susceptible to impair the health of the personnel living in these spaces. In the case of Glass Fibre Reinforced Plastics (GFRP), the structure does not conduct electricity and is particularly transparent to electromagnetic radiation. Therefore one of the investigated possibilities is to insert a metallic screen in the glass composite material. In the case of Carbon Fibre Reinforced Plastics (CFRP), the structure is conductive enough by itself to obtain a good Shielding Effectiveness (SE).

This paper presents the electrical and mechanical influence due to the screen insertion in the GFRP. The objective of this study is to increase the electrical conductivity, then to evaluate the effect of the metal screen insertion on the mechanical properties compared to the original structure. Experimental and numerical effects of the position of the metallic screen in composite materials will be described.

2. EXPERIMENTS

2.1 composite material presentations

The first composite material was manufactured from a Glass/vinylester composite. The second was manufactured from Carbon/Vinylester composite. In this study the insertion of metallic screen is proposed to increase the conductivity of the GFRP. These metallic screen are made of a polyester coated copper or bronze and are inserted at various levels in the thickness of the structure as describe in the figure 1.

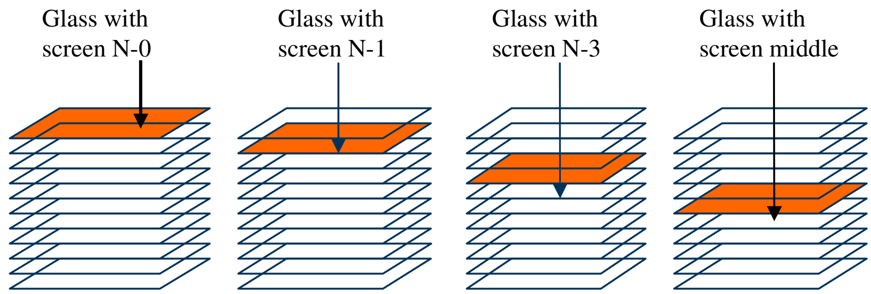

Figure 1: Insertion of metallic screen at different level of the composite structure

Figure 2 shows a screen embedded in a Glass composite.

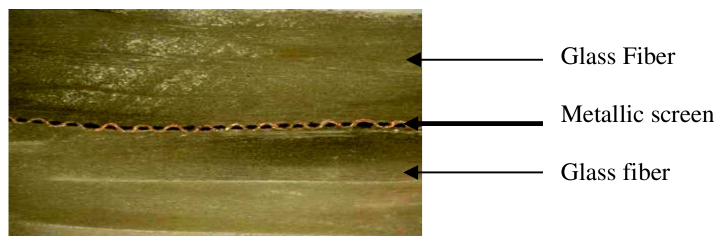

Figure 2: Metallic screen embedded in Glass composite

2.2 Shielding effectiveness

The SE is an important parameter that measures the shielding of a device from ElectroMagnetic Interference (EMI). The SE measures are the combination of the electromagnetic (EM) radiation: reflection from the material's surface, absorption of the EM energy, and multiple internal reflections of the EM radiation [1-2]. Two experimental systems are used to measure the SE of composites samples: an anechoic chamber, and a reverberation mode-stirred chamber.

2.2.1 Anechoic chamber

An anechoic chamber is an experimental room which walls absorb sound or electromagnetic waves. This chamber is used for the measurement of electromagnetic waves in a direct field. The anechoic chamber used for these measurements is shown in the figure 3.

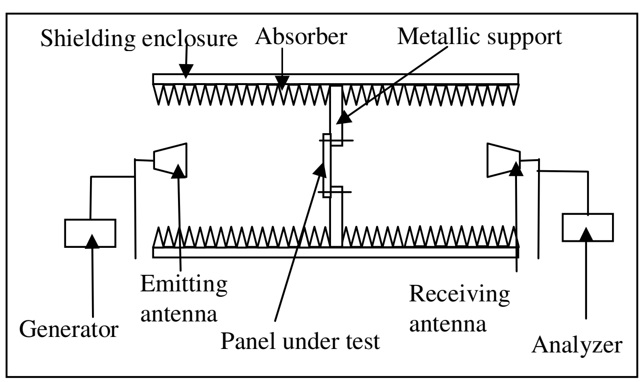

Figure 3: Anechoic room in CERPEM

2.2.2 Reverberation chamber

The type of chamber has been introduced first by H.A. Mendes in 1968. A reverberation chamber is a screened room with a minimum of absorption of electromagnetic energy.

The reverberation mode-stirred chamber consists of a metal enclosure with a metal stirrer whose role is to ensure a change in geometry of space to obtain a spatio-temporal distribution of the field. The electromagnetic field is statistically uniform and isotropic and is distributed over the entire surface. The test sample is immersed in an atmosphere of statistically homogeneous field on a stirrer tour. The method used is to measure the energy transfers by the study of transmission parameter S_{21} of the matrix of the distribution S. The reverberation chamber used for these measurements is shown in the figure 4.The shielding effectiveness (SE) is given directly by measuring transmission coefficient in decibel: $SE = 20\log\left(\frac{1}{|S_{21}|}\right)$.

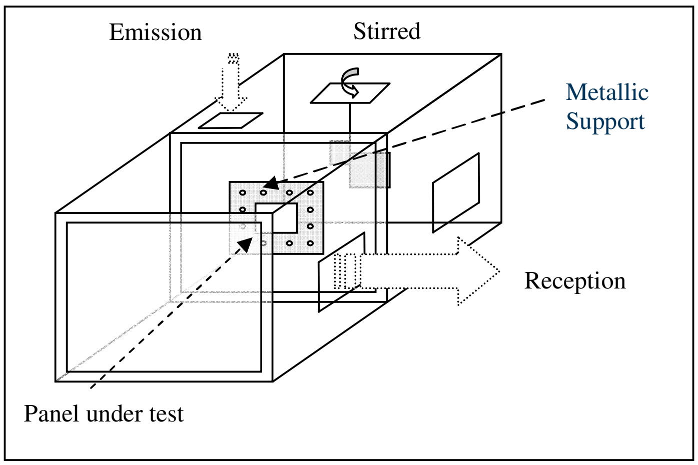

Figure 4: Reverberation chamber in ONERA

2.3 Mechanical test

The mechanical tests include: Tensile Test [3], Short Beam Bending Test [3], Impact Test and Compression after impact Test. The purpose of these tests is to evaluate the mechanical influence of the insertion of these screen compared to the host materials. Moreover, the position of the screen in the composite will be mechanically studied in order to determine the best position in the structure.

3. THEORICALS MODELS

3.1 Shielding effectiveness

The electromagnetic shielding efficiency is defined [4, 5] as the ratio of the incoming and outgoing waves power by the relation (1)

$$SE = 10\log\left(\frac{P_i}{P_0}\right) = 20\log\left(\frac{E_i}{E_0}\right) \qquad \text{(Expressed in dB)} \qquad (1)$$

P_i, P_0 being the electromagnetic power and E_i, E_0 the electric field of incoming and outgoing waves, respectively.

The plane wave shielding theory developed by Schelkunoff [6] and Schultz, Plantz, and Bush [7] has been used in this work. The shielding effectiveness is defined as

$$SE = A + R + B \qquad \text{(Expressed in dB)} \qquad (2)$$

Where B is the internal reflection resultant inside the shield, R is the reflection from the shield and A is the absorption. It is assumed that the shielding level from the composite is ultimately the same as the conductivity of an isotropic metal.

3.2 Mechanical theory

This theory uses a pattern of deformation of the first degree. The first step of the laminates theory is to determine the mechanical properties of a composite ply through the mechanical properties of fibres and resin. The Tsai Wu criterion is used to determine the first ply failure under the different types of stress. The first analytical results are in accordance with the experimental results later.

4. EXPERIMENTAL RESULTS

4.1 Shielding effectiveness

The surface impedance of the composite material is measured using a specific probe developed by ONERA [8]. The surface impedance is measured using a data acquisition system and ranges from 5 to $20\, m\Omega / sq$ according to various composite materials and screen.

4.1.1 Anechoic Chamber: Glass composite

The figure 5 represents the SE versus the frequency for the GFRP with the insertion of a metallic screen at various levels between two layers in the thickness of the structure (as describe in the figure 1). The specimen with the insertion to N=0 enhances the shielding effectiveness of approximately 5 dB relative to the other specimen. This can be explained by the lowest dielectric thickness between resin material and the metallic support. The SE of the best material is between 26 and 45 dB.

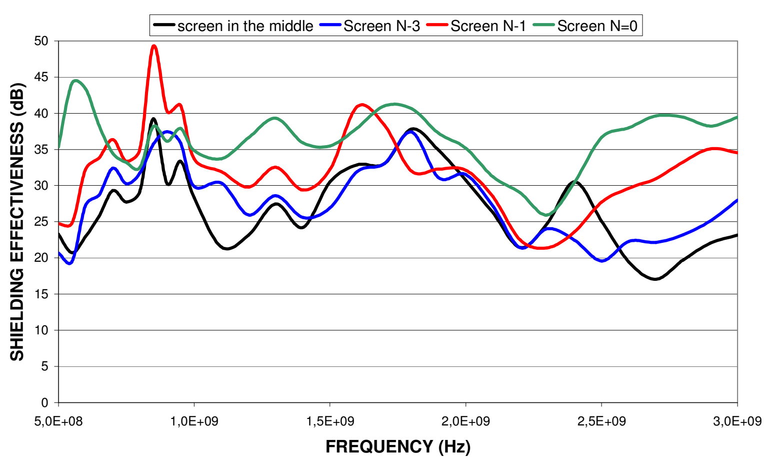

Figure 5: SE versus frequency for the GFRP with insertion of metallic screen.

In fact, an EM leakage is induced by a breach of electrical continuity as describe on the figure 6 [9].

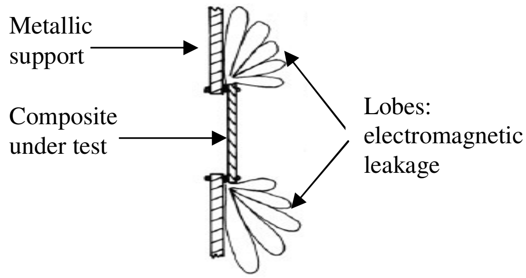

Figure 6: Lobes of High frequencies [9].

A possible improvement would be to sand the resin surface to obtain a better electrical contact between the composite and the metallic support. Figure 7 shows the shielding effectiveness of the glass composite with the metal screen located on the surface (N=0). This sample was sanded to recover a better electrical continuity. An improvement of the shielding effectiveness is seeing. This result shows the benefit of the integration of this type of screen for the electromagnetic shielding of GFRP.

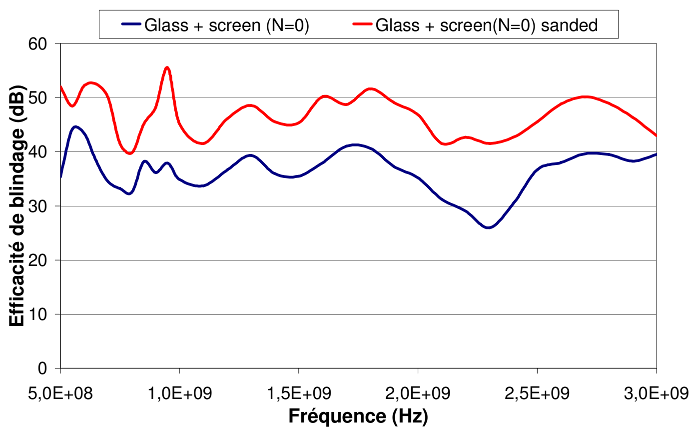

Figure 7: SE versus Frequency for the glass composite with and without sanded.

4.1.2 Anechoic Chamber: Carbon composite

The surface impedance measured for the CFRP is approximately $13m\Omega$. In theory, this material is sufficiently conductor to provide a good attenuation without the addition of a metallic screen, unlike the glass composite. Figure 8 a) shows the SE for the carbon composite material. This composite has a SE between 42 and 67 dB, which makes it a good material for electromagnetic shielding. But this result is not as good as could be expected from this type of material. As for the GFRP, this difference may be due to the electrical discontinuity between the sample and the metallic support.

As for GFRP, a possible improvement would be to sand the resin surface to obtain a better electrical contact. Figure 8 shows the difference between the SE for the carbon and sanded carbon. Carbon sanded has a shielding effectiveness between 46 and 70 dB. The SE is considered optimum for the CFRP. The attenuation provided by this material could be sufficient for an electromagnetic shielding.

a) b)

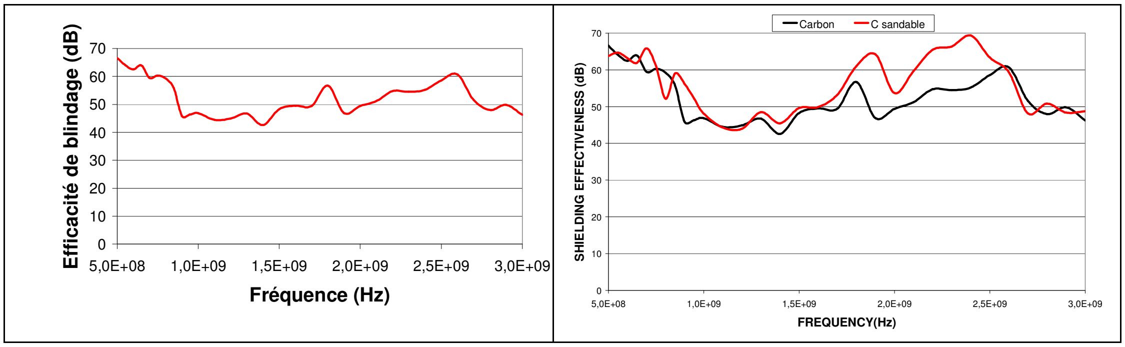

Figure 8: SE versus Frequency: a) carbon composite, b) carbon composite with and without sanded.

4.1.2 Reverberation Chamber

Figure 9.a shows the comparison SE for a CFRP in reverberation and anechoic chamber. The SE of this test, more complicated than anechoic chamber, is about 40-50 dB for frequencies between 1 and 3 GHz. So the SE in reverberation chamber is the same order of magnitude as anechoic. At high frequency (above 4 GHz) a decrease of SE is measured (Figure 9.b). This can be explained by electromagnetic leakage at the joint between the composite under test and the metallic support. For the CFRP, the theory simulates an electrical discontinuity and fits well with the level of SE measured. More details are provided about the modelling in the paragraph 5.1.

a) b)

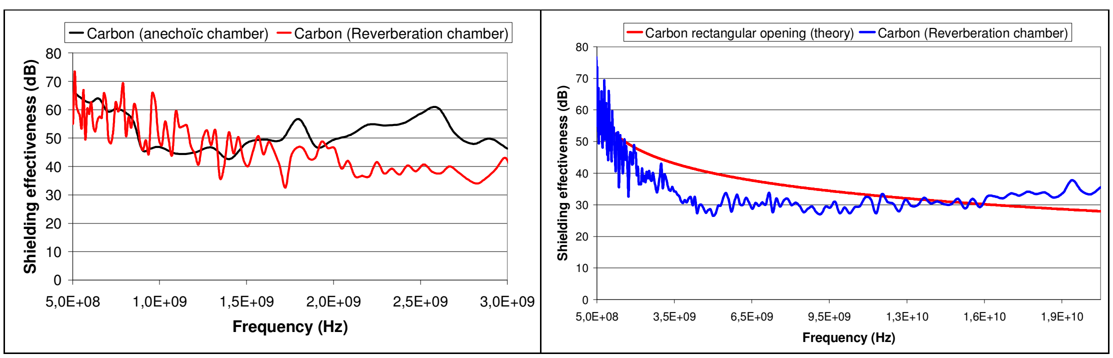

Figure 9: SE for the composite carbon; a) comparison between anechoic and reverberation chamber; b) comparison between reverberation and theory.

4.2 Mechanical performance

4.2.1 Tensile Test

Tensile test specimens were prepared as in accordance with ASTM D3039-76.The tensile test can be used to define the mechanical properties of composites materials. It can determine the law of stress-strain behaviour in a given direction. The characteristics which are deducted are the longitudinal module, the maximum stress and the elongation break. The results, strength and elastic modulus were compared between the embedded and the non-embedded cases as shown in the figure 10. The value of Young modulus is influenced by the presence of the metallic screen but the position in the laminate has not importance. Moreover, the maximal strength decreases approximately 20 %

compared to the host composite. We can imagine that the metallic screen destabilizes the structure and promote the spread of damage.

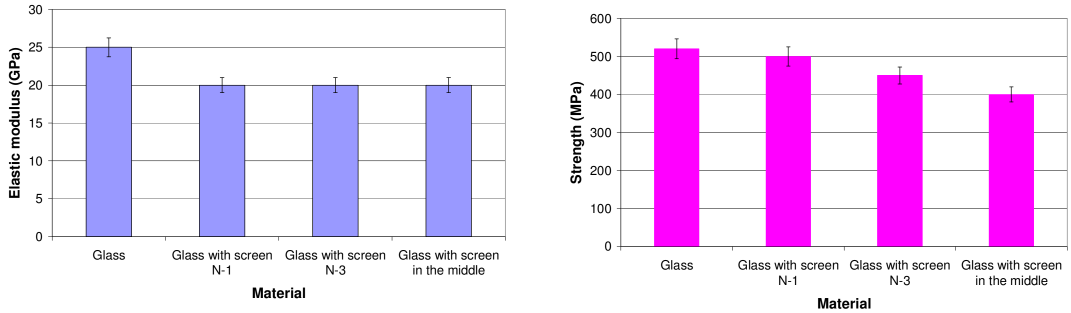

Figure 10: Tensile test result: a) Elastic modulus, b) Strength

4.2.2 Short Beam Shear Test

Short Beam Shear Test was used to determine the effect of embedding a metallic screen on the interlaminar shear strength of composites laminates. The test was done according to EN ISO 14130.

The maximum loads were recorded and converted into the maximum shear stress inside the specimens. The results are represented in figure 11.

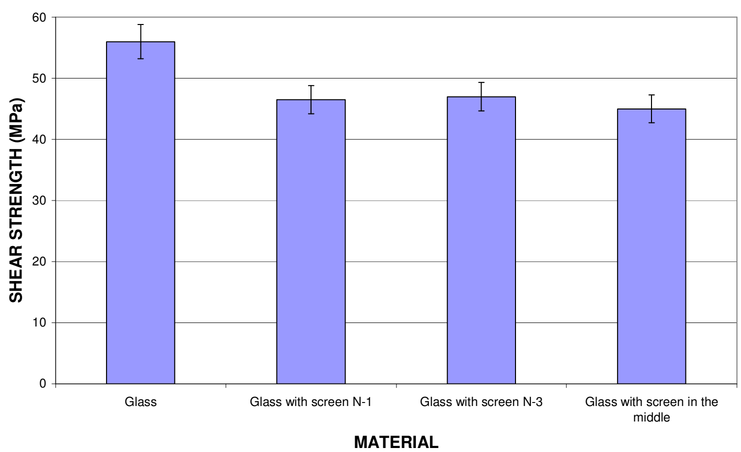

Figure 11: Short beam shear test result

It can be seen, there is 17 % difference between the Short Beam Shear Strength of composite with and without a metallic screen embedded inside. The different types of specimens failed in similar fashion-multiple simultaneous shear cracks between the plies (i.e. delamination). The presence of metallic screen promotes delamination between the plies. By contrast, the position does not affect the decohesion.

4.2.3 Impact Test

Impact test specimens were prepared as in accordance with ISO 6603. The general principle of this test is to drop a striker from a given height perpendicular to a plate and to characterize the type of failure or behaviour for a kinetic energy applied. Modification mechanical performance will be measured by a compression test after impact.

4.2.4 Compression Test

The compression test, Boeing type, has been used before and after impact. The main advantage of the Boeing test is the ability to use of test specimen of a large area (150*100 mm²): this allows, for example, to measure the compressive residual strength after impact. Plate compression test was used to examine the effects on the strength of composite laminates when there are metallic screen embedded. Compression loading was chosen because it is expected to have the most prominent effect. Four types of specimens were tested: Composite laminate with and without impact of 20 J and composite laminates embedded with a metallic screen with and without impact of 20 J. The results were compared between the embedded and the non-embedded and with and without impact cases as shown in the figure 12.

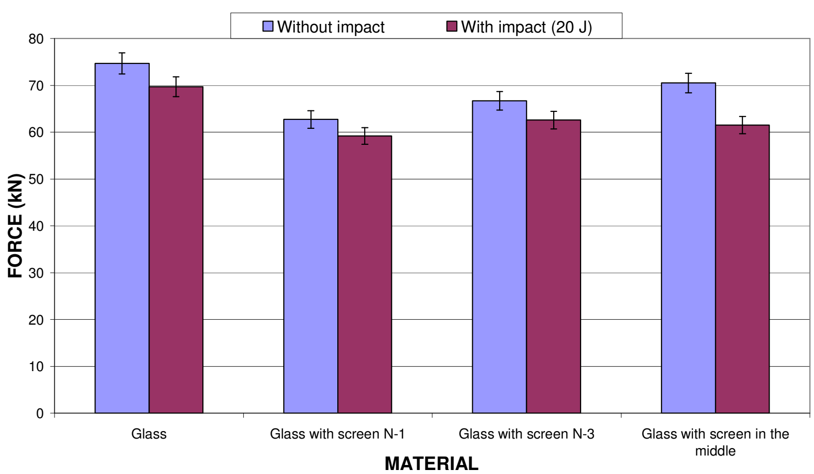

Figure 12: Plate compression test result

The residual strenght varies few compared with the material without insertion, except for the case where the metal screen located in N-1, down about 15%. Buckling (Euler Theory) will be promoted by decenter insertion before impact, which is no more measured after impact. This is due to the fact that the metal screen absorbs impact energy and stops matrix cracking.

5. COMPARISON BETWEEN MODEL PREDICTIONS AND EXPERIMENTS

5.1 Shielding effectiveness

Equations of GAMT-20 suitable for composite materials [10-11] are used to simulate the shielding effectiveness of our materials. The first hypothesis is developed considering an homogeneous material of infinite dimension according to 2 dimensions which simplifies the modelization. Figure 13 shows the comparison of the SE between the experience (glass with metallic screen in anechoic chamber) and model. The model takes into account an electrical discontinuity between the composite material and the metallic support. This electrical discontinuity is modellized by a slot hole. This simulate of a thick low dielectric layer (resin) of approximately 150µm.

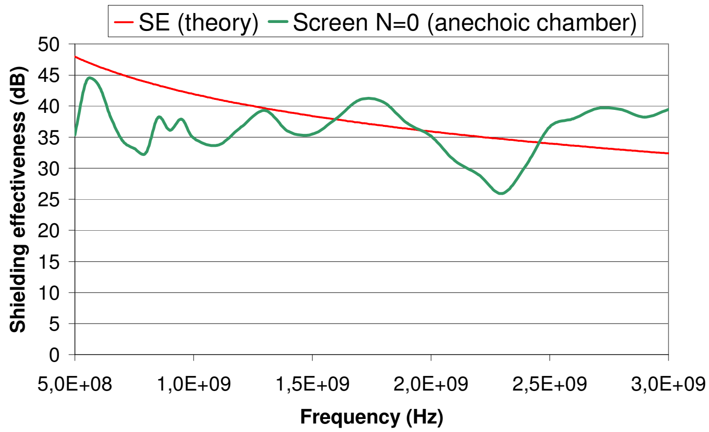

Figure 13: SE vs Frequency of glass with metallic screen, comparison model and experiments.

Figure 14 shows the comparison between the experience (carbon in anechoic chamber and reverberation chamber) and model (carbon and 1 carbon ply) of the shielding effectiveness. Large similarity between experiments and model is observed for carbon with a rectangular opening simulating an electrical discontinuity. Moreover, the shielding effectiveness for a carbon ply was simulated to demonstrate the maximum SE, i.e. with a perfect electrical contact.

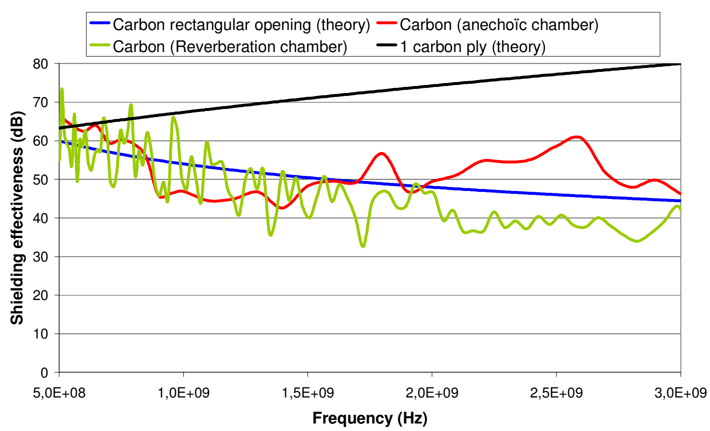

Figure 14: SE vs Frequency of carbon, comparison model and experiments.

This confirms that the thin layer of dielectric resin greatly reduces the effectiveness of electromagnetic shielding. In addition, a carbon ply, with a perfect electrical continuity, allows sufficient electromagnetic shielding (>60dB).

6. CONCLUSIONS

In this study, the shielding effectiveness for carbon or glass with insertion of metallic screen is measured in anechoic and reverberation chamber. We have shown the importance of continuity on the outskirts of electrical material on performance measured. By doing a neat sanding, it is possible to reduce electromagnetic leakage.

For Glass Fibre Reinforced Plastics (GFRP), the best performances were achieved with the metallic insert on the surface. The attenuation level shows it is possible to obtain an interesting level shielding, even for dielectric materials.
Nevertheless, it was shown that the inclusion in a glass of a composite metal screen slightly degrade the mechanical behaviour of the composite. But this slight mechanical damage is not catastrophic, and therefore this technique can be used for electromagnetic shielding.
For the CFRP, the intrinsically conductivity is sufficient to provide adequate shielding for our application. The SE of this material is greater than 46 dB.
The model used in this study shows us a good similarity with the experiments. Furthermore, a break in the electrical continuity can be simulated by a slot hole.

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