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2008

https://hdl.handle.net/10356/79881

https://doi.org/10.1109/APEMC.2008.4559909

Feasibility Study of Using Porous Metal as Practical Shielding Material

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Abstract − This paper presents the feasibility study of using porous metal for electromagnetic shielding purposes. Using the highly porous aluminum (close to 90% porosity) as the material under study, its shielding effectiveness (SE) was studied systematically. A preliminary measurement was carried out to evaluate the SE of porous aluminum sample. This was followed by a full-wave EM modeling of the porous aluminum shielded box. Finally, a shielded enclosure was assembled using porous aluminum panels and the overall SE of this enclosure was measured. With the conventional installation method, the enclosure has been found to provide at least 60 dB shielding effectiveness in the frequency range of 250 kHz to 1 GHz.

I. INTRODUCTION

Conventional methods for architectural shielding use either welded solid metal pieces or modular sandwiched steel-wood-steel panels. The welded solid metallic shielded enclosure provides excellent shielding performance but requires skilled welders and takes a longer construction time, and therefore, can be very expensive. The modular sandwiched panel shielded enclosure is easy to construct but the overall SE is always limited by the electromagnetic field leakage through the panel joints. There is one thing in common for both methods; they are heavy and pose structural loadings to existing buildings.

In the past decade, the interest in porous metals, also commonly know as metallic foams, has increased considerably. The main reason for this development is the lightweight and reasonable mechanically properties. Porous metals, particularly aluminum [1, 2], offer a great potential for many engineering applications, where weight is a major concern, particularly in the construction, automotive and aerospace industries. Besides its lightweight property, the porous aluminum also has other interesting features, such as incombustibility and sound absorption ability.

There is no reported work on using porous metal as an alternative for architectural electromagnetic shielding applications. Due to its highly porous nature, porous metal with 90% porosity only weighs one tenth of the weight of solid metal. The ultra lightweight property makes porous aluminum panels very attractive as an alternative architectural shielding material for buildings that have structural loading constraints.

II. SHIELDING EFFECTIVENESS

The shielding effectiveness of a shielded enclosure is defined as:

$$SE = 10\log\frac{P_1}{P_2} \text{ (decibels, dB)}$$

Where:
P_1 is the received power without shielding enclosure present,
P_2 is the received power with shielding enclosure preset

If the receiver readout is in unit of voltage, the following equation is used:

$$SE = 20\log\frac{V_1}{V_2} \text{ (decibels, dB)}$$

Where:
V_1 and V_2 are the received voltage levels without and with shielding enclosure present,

To measure the SE of porous aluminum, the IEEE STD 299 was adopted [3]. This method provides the measurement procedures and techniques to assess the SE of a room-type shielded enclosure at frequencies from 14 kHz to 18 GHz.

III. EXPERIMENTAL AND SIMULATION RESULTS

A. SE measurement of porous aluminum samples

The shielding effectiveness of porous aluminum samples with three different thicknesses was measured following the IEEE standard method. The sample size is 24 cm × 24 cm.

An existing shielded room with a feed-through panel was used for the measurement. A mounting test fixture was designed to hold the sample under test, as shown in Fig. 1. Fig. 2 shows the sample under test mounted onto the fixture.
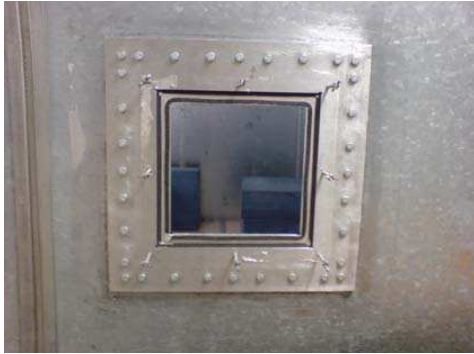

Fig. 1 Mounting fixture of the shielded room

Fig. 2 Porous aluminum sample mounted on the fixture

The mounting fixture consists of a piece of solid aluminum frame with a square opening of 21 cm × 21 cm, and an edge cover plate made of stainless steel. The sample under test will be clamped between the frame and the cover plate and tightened by the screws. Shielding gasket is added between the frame and the cover plate to ensure good electrical contact along the edges. To determine the SE of the porous aluminum sample, the received signal from the transmitting antenna was first recorded without the sample mounted and then another reading was recorded again with the presence of porous aluminum sample. The difference of the two readings is the SE of the sample. The measured SE of the porous aluminum samples with three different thicknesses 0.6 cm, 1 cm and 2 cm, are plotted in Fig 3.

It is clearly observed that the SE for the three different thicknesses exhibit similar value and trend. Theoretically, one would expect thicker sample to give higher SE due to increase in absorption loss. It is suspected that the SE of the sample is much higher than the SE of the shielded enclosure and the measured SE is practically the SE of the enclosure itself. To verify our suspicion, the sample was replaced with

a 1 cm thick solid aluminum as a reference for comparison. The measured SE of 1 cm thick solid aluminum is also plotted in Fig. 3. Interestingly, it resembles all the SE curves of the three porous aluminum samples. Hence, it has confirmed our earlier suspicion. It is obvious that the actual SE of the porous aluminum samples is expected to be much higher than those measured in Fig. 3.
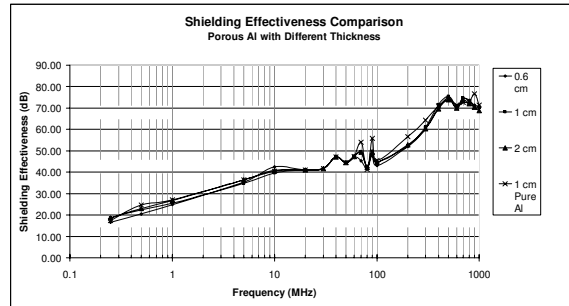

Fig 3. SE of samples with different thicknesses

B. Full-wave simulation results

To provide some kinds of indication of the intrinsic SE of the porous aluminum, it is impossible to measure it experimentally due to limitation of the measurement system's dynamic range. To investigate the shielding performance of the porous aluminum, full-wave electromagnetic simulation was carried out using the CST MICROWAVE STUDIO [4].

To carry out simulation, the conductivity of porous aluminum must be provided. Ma and Peyton have developed an equation that describes the relationship between porosity and electrical conductivity of porous metal [5]. The equation is given below:

$$\sigma_s = \frac{0.6806(1-\xi)}{0.6806+\xi} \times \sigma$$

where σ is the electrical conductivity of solid metal (3.767 × 10^7 S/m for solid aluminum) and ξ is the mean porosity of the porous metal (91.48% for our samples).

Using this equation, the equivalent electrical conductivity of the porous aluminum sample is estimated to be 1.3692 × 10^6 S/m.

In the simulation, a fully enclosed shielded box with external dimensions 40 cm × 40 cm × 40 cm was modeled. The wall thickness is specified at 1 cm. The material of the box was defined to be porous aluminum by specifying σ = 1.3692 × 10^7 S/m and μ = 4π × 10^{-7} H/m. Three electrical field probes are specified at the center of the shielded box, as shown in Fig. 4. An incident plane wave approaching the box was then defined as the external field source. The SE is the difference between field strengths with and without the shielded box. Fig. 5 shows the simulated SE for the shielded

box with wall subdivided into 3 equal mesh cells. The result shows that more than 300 dB of SE is achievable. Of course higher SE is expected with finer mesh cells, it is impractical to carry out the simulation with more than 3 cells because of prohibitive simulation time. With the given simulation result, it can be concluded that the intrinsic SE of the porous aluminum, even with more than 90% porosity, is sufficiently high enough for practical shielding applications.
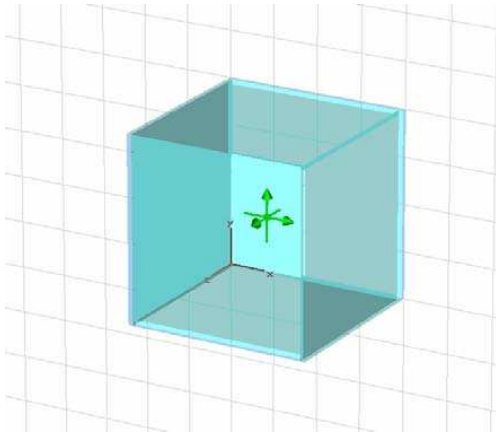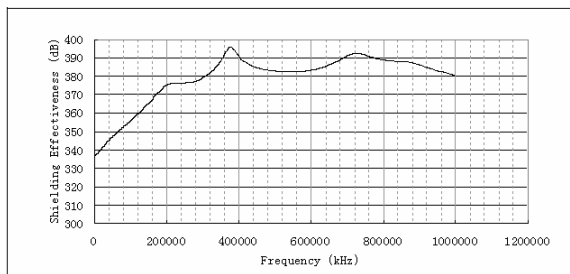

Fig. 4 The model of the shielded box

Fig. 5 Simulated SE of the shielded box

IV. POROUS ALUMINUM SHIELDED ENCLOSURE

Table 1 compares the mechanical properties of porous aluminum (90% porosity) with typical wood [6]. It shows that even with 90% porosity, the mechanical properties are comparable to wood. Hence, porous aluminum is rugged enough for normal mechanical installation purposes.

Table 1 Comparison of key mechanical properties

Parameter	Porous Al	Wood
Density (g/cm^3)	0.23	0.4 to 0.8
Young's Modulus	1.1 (Mpa)	7 to 11 (Mpa)
Shear Modulus	0.3 (Mpa)	0.5 to 1.1(Mpa)
Shear Strength	1.2 (Mpa)	4 to 8 (Mpa)
Tensile Strength	1.6 (Mpa)	1.5 to 3 (Mpa)

To demonstrate the feasibility of using porous metal for practical shielding applications, a shielded room was designed and constructed using the porous aluminum panels. Fig. 6 shows the final installed shielded enclosure. It has a size of 1.4 m (L) × 1.4 m (W) × 2.4 m (H). A total of eight pieces of 2.4 m × 0.7 m and four pieces of 1.5 m × 0.7 m porous aluminum panels were used. All the panels have the same thickness of 2 cm. The mechanical clamping method is adopted for the installation of shielded room. The door size is 1.8 m × 0.9 m with the usual fingers along the edges to ensure good electrical contact with the door frame.

Fig. 6 Porous aluminum shielded room

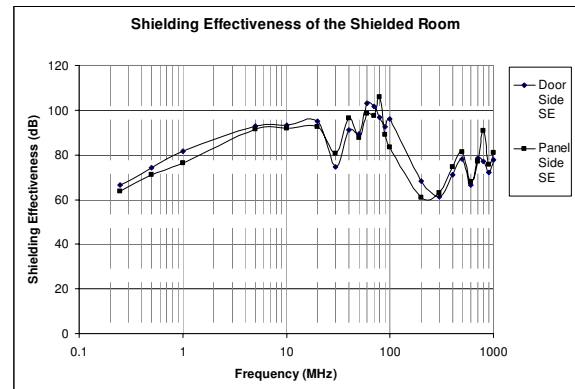The measured SE of the shielded enclosure using IEEE STD is presented in Fig. 7.

Fig. 7 Measured SE of the shielded enclosure

Fig. 7 shows that the shielded room can achieve SE of between 60 dB and 100 dB. It has demonstrated that with the simple clamping method, shielded room constructed using the porous aluminum panel is as effective as the conventional metal-wood-metal double shield.

V. CONCLUSIONS

A comprehensive study has been carried out to evaluate the feasibility of using porous aluminum as an alternative for practical shielding applications. The study has demonstrated that even with close to 90% porosity, the effective conductivity of the porous aluminum is still high enough to provide excellent intrinsic electromagnetic shielding. A shielded room constructed using porous aluminum panels with the conventional claming installation method has exhibited SE between 60 and 100 dB up to 1 GHz. The most attractive feature of using porous metal as shield is the ultra lightweight property of the material.

Acknowledgements

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