One-Step Thermoformable EMI Shielding

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INTRODUCTION

Thermoforming can be an effective alternative to traditional shielding methods.

The introduction of high-speed, more compact electronic devices into our daily lives has led to increased requirements for electromagnetic interference (EMI) shielding. Because many electronic product enclosures are now made of plastic, which has no intrinsic shielding capabilities, EMI shielding is generally accomplished by applying a conductive coating to at least one side of the plastic part. Common coating methods include copper or nickel acrylic spray paints, zinc arc spray, electroless plating, and vacuum metallization. There is a material, however, which can, in many vacuum- and pressure-forming situations, be added by the thermoformer during the thermoforming operation to eliminate the need for an added conductive coating step. Its use will result in parts that are shielded when they leave the mold.

FUNCTIONAL DESCRIPTION

The material is a one-step, self-adhering thermoformable EMI shield made from a laminate of two porous layers (Figure 1). The bottom layer consists of a mat of ethylene vinyl acetate (EVA) polymer fibers that acts as a hot melt adhesive. The top, nonwoven layer is made from a low-melting, solder-like alloy of tin and bismuth. The key to this material's functionality is that the entire structure melts at a temperature *below* the thermoforming temperature of the plastic sheet.

The thermoformer uses the material by positioning a precut piece on top of the plastic sheet, metal-fiber side up, covering the area where EMI shielding is desired. The plastic sheet with the shielding material added is then heated in the thermoforming machine's oven (Figure 2a). When the material temperature reaches 88°C, the EVA polymer softens, adhering the metal fibers to the plastic sheet. Next, at a temperature of 138°C, the metal fibers melt but retain their fibrous form. When the plastic sheet has reached its thermoforming temperature (usually in excess of 150°C), the heat-laminated composite is removed from the oven and is formed into the desired shape (Figure 2b). The metal fibers, which remain molten during the forming operation, flow and extend with the underlying plastic sheet as it conforms to the shape of the mold. The metal fibers fuse together at their intersections to form a highly conductive network across the surface of the finished part (Figure 3, inset).

SHIELDING THEORY

The shielding effectiveness (SE) of the tin/bismuth metal alloy fiber network formed by the add-on, one-step EMI shielding material is primarily the result of reflection of the EMI wave. Its performance may be described as that

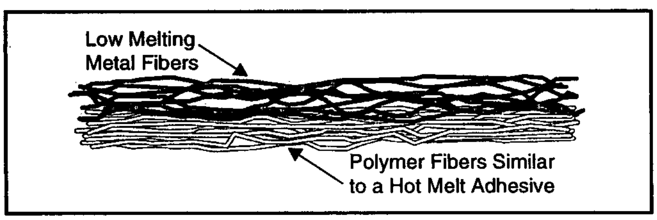

***Figure 1**. Laminate Layers.*

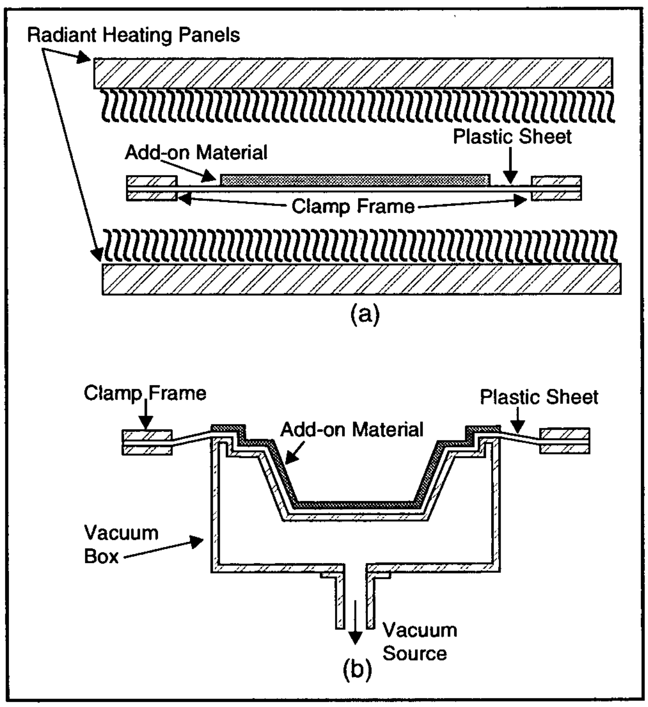

***Figure 2**. Thermoforming Layers.*

of a waveguide below cutoff with essentially no loss due to absorption.

The far-field shielding effectiveness in decibels (dB) can be described in terms of the wavelength λ and the largest dimension d between fibers by the equation:[1]

$$SE = 20\log_{10}[(\lambda/2)/d] \qquad (1)$$

Because the wavelength λ is equal to the speed of light c divided by the frequency f, Equation (1) can be rewritten to describe the far-field shielding effectiveness of a mesh as follows:

$$\begin{aligned} SE &= 20\log_{10}[(c/2)/(f \cdot d)] \\ &= 104 - 20\log_{10}(f \cdot d) \end{aligned} \qquad (2)$$

where f and d are expressed in terms of MHz and mm respectively.

The validity of this relationship is based on several assumptions. First, as with all electrically thin, non-ferromagnetic paints and platings used for EMI shielding, absorption is not a factor. Second, it assumes the largest dimension d between the metal fibers is less than 100 times the thickness of the conductive fiber layer and less than $\lambda/2$ at the frequency of interest. Because the metal fiber diameter in the add-on thermoformable material is 0.076 mm and the wavelength of a 10-GHz signal is 30 mm, the largest value of d satisfying both these assumptions (for shielding EMI signals of up to 10 GHz) is 7.6 mm. Third, the metal fibers must electrically contact each other where they cross.

According to Equation (2), the SE of this material at any particular frequency is exclusively dependent on the largest dimension d between fibers. This dimension is a direct function of the spatial arrangement of the metal fibers present in the random pattern, so as more metal is applied, d decreases and the shielding effectiveness increases. During thermoforming, d becomes dependent on the draw ratio, i.e., the degree to which the material is stretched. The higher the draw ratio, the more d is increased, lowering the SE.

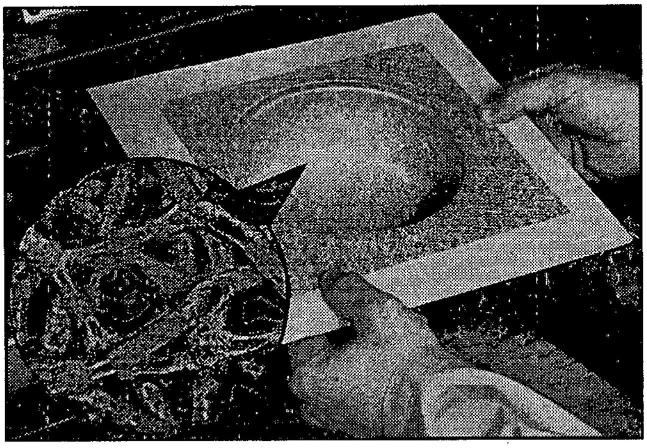

***Figure 3**. Intersection of Metal Fibers.*

By using an optical microscope, the average maximum dimension between fibers on a part with a 1:1 draw ratio (no expansion) was empirically determined to be 0.28 mm.[2] Values for d were then calculated for various draw ratios between 1:1 and 4:1. For example, to calculate the SE at a draw ratio of 2:1, the value of d, which had been empirically determined at a draw ratio of 1:1, was multiplied by 2. In other words, the 0.28-mm opening was expected to expand orthogonally to twice its size and to exhibit a diameter of 0.56 mm. The dashed line in Figure 4 represents the theoretical SE predicted by Equation (2) as a function of draw ratio. The calculations were made at a frequency of 500 MHz.

EXPERIMENT

Several samples of the add-on shielding material (each having the same metal weight per unit area) were prepared by thermoforming the material at various draw ratios onto 3.18-mm thick ABS plastic sheets. The SE was determined using a National Bureau of Standards (NBS) flanged coaxial test fixture according to the method described in ASTM D 4935 ("Standard Test Method for Measuring the Electromagnetic Shielding Effectiveness of Planar Materials"). The experimental SE of each sample at 500 MHz (circular data points) is compared to the theoretical SE (dashed line) as a function of draw ratio in Figure 4. In this graph, it can be seen that the measured SE begins to deviate from the theoretical shielding at a draw ratio of about 3:1. Microscopic examination has shown that this difference is caused by discontinuities beginning to develop within the metal fiber network. However, the EMI shielding provided by the material remains above 45 dB up to the 3:1 draw ratio.

Also, as shown in Figure 4, the measured SE of the unstretched material (draw ratio of 1:1) is almost 10 dB lower than that theoretically predicted. The reason for this is that the metal fibers had not fused together at all of their intersections even though they had melted. The best performance of the metal gridwork is achieved when, in addition to melting, there has been some disturbance of the fibers such as the stretching that occurs

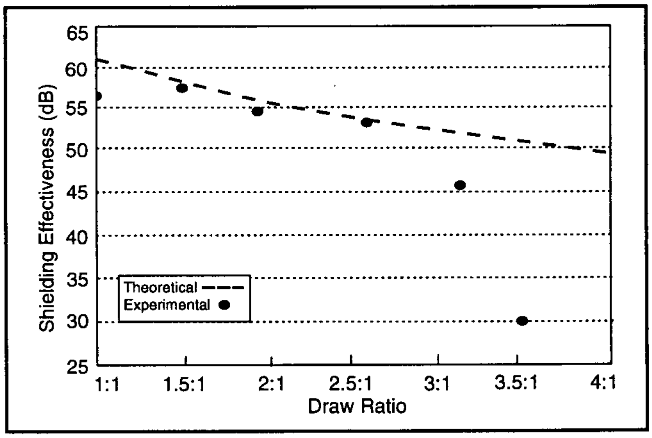

***Figure 4**. Add-on Shielding Material Performance at 500 MHz.*

during thermoforming. The result is the optimization of fiber-to-fiber contact at the intersections as required in the assumptions for Equation (2). Nevertheless, the shielding performance of the material in the unstretched condition was still in excess of 55 dB.

COST AND PERFORMANCE

The cost of using the new add-on EMI shielding material at the "front end" (i.e., during thermoforming) is quite competitive with, and in some cases significantly less expensive than, application of conductive paint or plating in secondary operations. With the add-on EMI shielding material, the entire application occurs in the thermoforming shop with negligible process adjustment. Therefore, the cost of shielding increases or decreases strictly in proportion to part size.

In the case of painting and other off-site shielding methods, however, there are significant costs to be considered other than the cost of the coating process alone. For example, there are added packaging and shipping costs for sending the parts to the shielding vendor. There are added administrative costs, such as outgoing and incoming inventory control and reinspection on return. In addition, the basic costs of the shielding operation alone can increase rapidly depending on the size and complexity of the part because of the masking and other preparation work required.

An evaluation was made of the costs for various shielding techniques (excluding the aforementioned additional secondary processing costs). The subject of this comparison was a relatively simple part made from a 27-cm square blank of ABS, formed into a flanged bowl as pictured in Figure 5. The costs for shielding this part using each of the described technologies, based on actual quotations for a quantity of 1000 units, are summarized in Figure 6.

Figure 7 shows a comparison of the SE of the in-mold, add-on shielding material with some of the more commonly used post-mold shielding techniques. All of the products referred to were applied either by the manufacturer or by a recommended distributor onto parts configured in the same way as those on which the add-on thermoformable material was tested. The one-step shielding technology proved to be comparable in SE to most of these traditional methods.

LIMITATIONS

One important limitation of this material is that it does not appear to be usable on parts which require over 3:1 draw ratio. Not only does metal separation begin to occur at this point, but these parts generally require a wooden block called a "pusher" or "plug assist" to help force the plastic sheet uniformly into the deeper mold cavities. While in the softened forming state, the add-on shielding material can be dislodged from the plastic surface if it is contacted by any object, such as a "pusher." Similarly, mold design must be such that the add-on shielding material is always applied on the side of the plastic away from the mold surface.

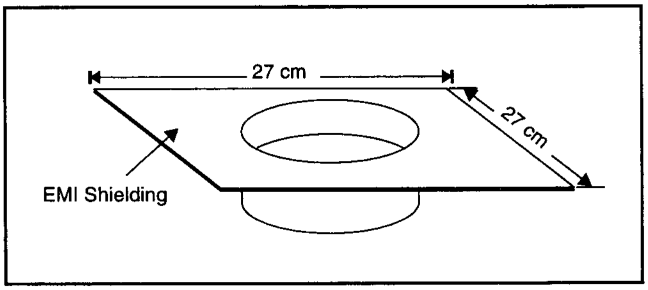

Figure 5. Sample Used for Cost Evaluation.

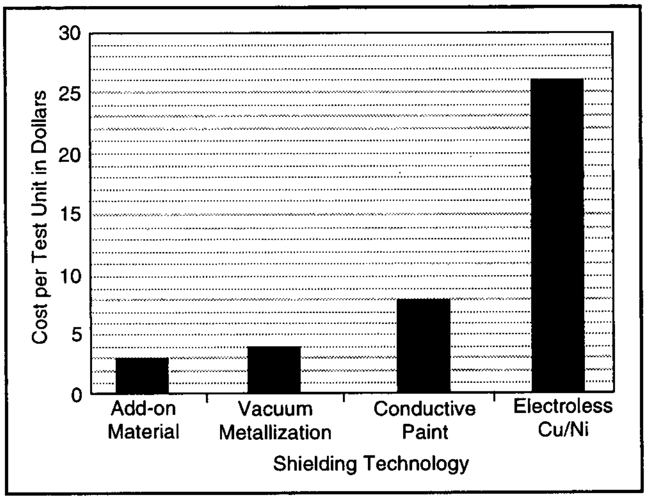

Figure 6. Comparative Costs for Conductive Coatings.

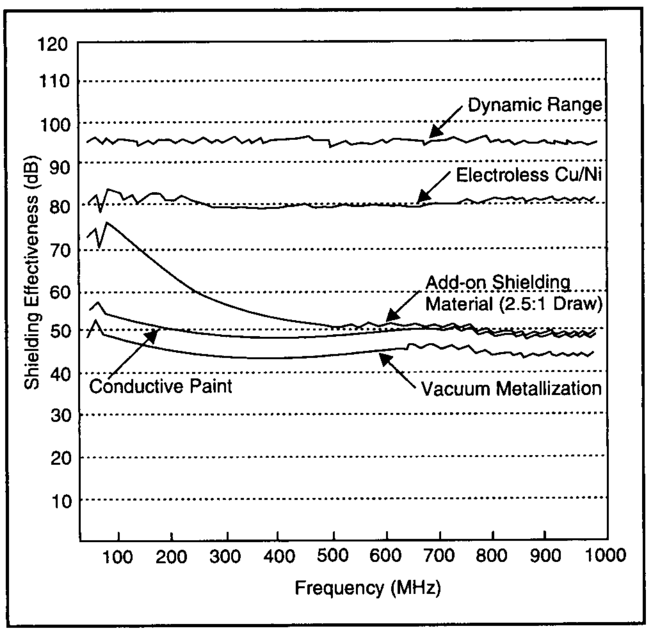

Figure 7. Performance of Shielding Technologies in Use Today.

MATERIAL COMPATIBILITY

ADHESION

An important property of any shielding coating is its adhesion to the plastic part. The adhesion of the new shielding material to a variety of plastics was evaluated quantitatively by the method described in ASTM D 5179 ("Standard Test Method For Measuring Adhesion of Organic Coatings to Plastic Substrates by Direct Tensile Testing"), which has been suggested for use in evaluating EMI shielding coating adhesion to plastic substrates.[3] Using this method, the face of an aluminum stud is adhered to the surface of the coating using cyanoacrylate adhesive, and the tensile force required to pull the coating from the substrate is measured. Figure 8 shows that the add-on material is adhesively compatible with a large number of plastics. To put the magnitude of these values in perspective, comparative data for the adhesion to ABS of some common shielding materials is reported in Figure 9.

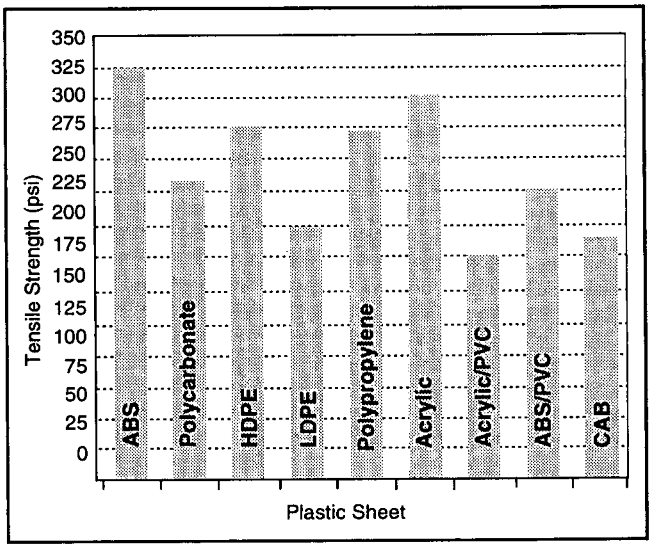

***Figure 8.** Adhesion of Add-on Material to Common Plastics.*

FLAMMABILITY

The EVA hot melt backing material, like many polymers of its type, is not inherently flame retardant. The shielding material relies on its lamination to a flame retardant plastic sheet for its overall flame resistance performance. Therefore, the flammability rating changes with the type and thickness of the plastic to which it is laminated.

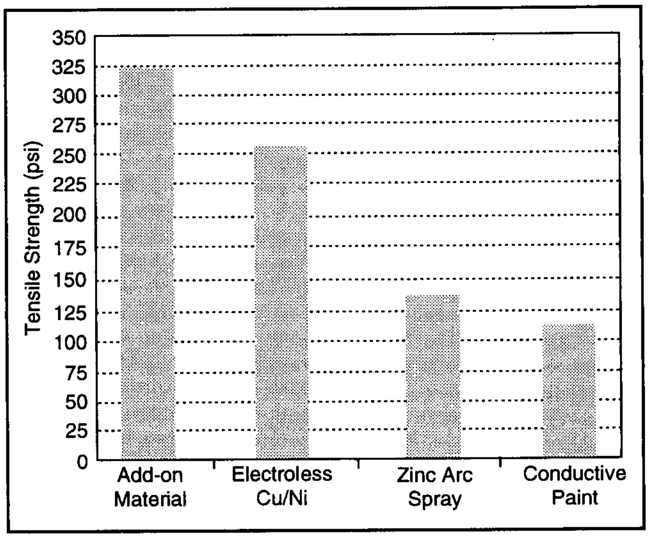

***Figure 9.** Adhesion of Shielding Materials to ABS Plastic.*

OTHER CONSIDERATIONS

The add-on thermoformable EMI shielding material can be used to shield large surface areas by overlapping two pieces of the material along the edges. As the material is heated and stretched, the lapped seam fuses together to become electrically continuous. In a similar manner, the material can be "patched" onto itself during thermoforming to help shield localized deeper-draw areas.

The ease of use of the add-on material in a variety of thermoforming situations makes it a convenient solution to a number of current shielding application problems. For example, it is useful for making small localized shields over particularly noisy or susceptible components within an electronics enclosure. This allows the designer the economy of applying shielding only where necessary rather than shielding an entire enclosure. The major portion of the housing can then be recycled, which is becoming a necessity for companies doing business in Europe. The metal fiber-covered surface of these localized shields has been successfully bonded over components using conductive adhesive. Also it has been found that the hot melt characteristics of the EVA polymer will allow the shields to be heat staked in some applications (Figure 10). The add-on material is also useful for forming snap-in shields or liners from thin gauge material, resulting in simplified assembly of the final equipment housing.

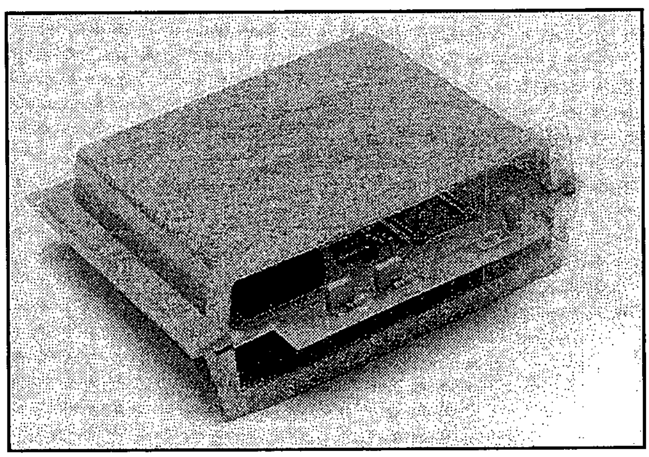

***Figure 10**. Heat Staked Shield Application.*

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CONCLUSION

The add-on thermoformable material provides a new and useful technology for applying EMI shielding to plastic parts during the forming operation. The shielding provided, up to a draw ratio of nearly 3:1, is comparable to most post-molding techniques in use today. Its use helps avoid some of the pitfalls of the shielding process: the need for an outside vendor, spray painting, volatile/toxic compounds, environmental restrictions, and additional handling (masking, packaging, shipping, invoicing, quality control, and so on). The material also adheres very well to a variety of plastic substrates.

REFERENCES

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3. G.L. Nelson, "Testing of EMI/RFI Coating Adhesion to Plastics by a Tensile Test Method," Final Report of Computer and Business Manufacturers' Association and Society of the Plastics Industry, University of Southern Mississippi, June 1989.

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