Composite Materials for Electromagnetic Interference Shielding

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Abstract. This paper demonstrates that the addition of chemical agents and carbon fibers to cement can greatly enhance the shielding effectiveness of the concrete. In addition to improving the shielding effectiveness, carbon fibers and chemical agents enhance the tensile and flexural strengths significantly. As both carbon fibers and steel fibers are electrically conductive, both can be added to cement to enhance the shielding effectiveness, but steel fibers tend to rust whereas carbon fibers are chemically stable and inert.

1 Introduction

Electromagnetic interference (EMI) shielding refers to the reflection and/or absorption of electromagnetic radiation by a material, which thereby acts as a shield against the penetration of the radiation through the shield. As electromagnetic radiation, particularly that at high frequencies (e.g. radio waves, such as those emanating from cellular phones) tend to interfere with electronics (e.g. computers), EMI shielding of both electronics and radiation source is needed and is increasingly required around the world. The importance of EMI shielding relates to the high demand of today's society on the reliability of electronics and the rapid growth of radio frequency radiation sources [1].

EMI shielding is to be distinguished from magnetic shielding, which refers to the shielding of magnetic fields at low frequencies (e.g. 50 Hz). Materials for EMI shielding are different from those for magnetic shielding. EMI shielding is a rapidly growing application of carbon materials, especially discontinuous carbon fibers. This review addresses carbon materials for EMI shielding, including non-structural and structural composites, colloidal graphite, as well as EMI gasket materials.

2 Mechanisms of shielding

The primary mechanism of EMI shielding is usually reflection. For reflection of the radiation by the shield, the shield must have mobile charge carriers (electrons or holes) which interact with the electromagnetic fields in the radiation. As a result, the shield tends to be electrically conducting, although a high conductivity is not required. For example, a volume resistivity of the order of 1 [Ωcm] is typically sufficient. However, electrical conductivity is not the scientific criterion for shielding, as conduction requires connectivity in the conduction path (percolation in case of a composite material containing a conductive filler), whereas shielding does not. Although shielding does not require connectivity, it is enhanced by connectivity. Metals are by far the most common materials for EMI shielding. They function mainly by reflection due to the free electrons in them. Metal sheets are bulky, so metal coatings made by electroplating, electroless plating or vacuum deposition are commonly used for shielding. The coating may be on bulk materials, fibers or particles. Coatings tend to suffer from their poor wear or scratch resistance [1].

A secondary mechanism of EMI shielding is usually absorption. For significant absorption of the radiation by the shield, the shield should have electric and/or magnetic dipoles which interact with the electromagnetic fields in the radiation. The electric dipoles may be provided by $BaTiO_3$ or other materials having a high value of dielectric constant. The magnetic dipoles may be provided by Fe_3O_4 or other materials having a high value of the magnetic permeability, which may be enhanced by reducing the number of magnetic domain walls through the use of a multilayer of magnetic films. The absorption loss is a function of the product $\sigma_r\mu_r$, whereas the reflection loss is a function of the ratio σ_r/μ_r, where σ_r is the electrical conductivity relative to copper and μ_r is the relative magnetic permeability. Silver, copper, gold and aluminum are excellent for reflection, due their high conductivity. Superpermalloy and mumetal are excellent for absorption, due to their high magnetic permeability. The reflection loss decreases with increasing frequency, whereas the absorption loss increases with increasing frequency [1].

3 Composite materials for shielding

Due to the skin effect, a composite material having conductive filler with a small unit size of the filler is more effective than one having conductive filler with a large unit size of the filler. For effective use of the entire cross-section of a filler unit for shielding, the unit size of the filler should be comparable to or less than the skin depth. Therefore, a filler of unit size 1 µm or less is typically preferred, though such a small unit size is not commonly available for most fillers and the dispersion of the filler is more difficult when the filler unit size decreases.

Electrically conducting polymers [2] are becoming increasingly available, but they are not common and tend to be poor in the process ability and mechanical properties. Nevertheless, electrically conducting polymers do not require conductive filler in order to provide shielding, so that they may be used with or without filler. In the presence of conductive filler, an electrically conducting polymer matrix has the added advantage of being able to electrically connect the filler units that do not touch one another, thereby enhancing the connectivity. Cement is slightly conducting, so the use of a cement matrix also allows the conductive filler units in the composite to be electrically connected, even when the filler units do not touch one another. Thus, cement–matrix composites have higher shielding effectiveness than corresponding polymer–matrix composites in which the polymer matrix is insulating. A shielding effectiveness of 40 dB at 1 GHz has been attained in a cement–matrix composite containing just 1.5 vol. % discontinuous 0.1 µm diameter carbon filaments. Moreover, cement is less expensive than polymers and cement–matrix composites are useful for the shielding of rooms in a building [3]. Similarly, carbon is a superior matrix than polymers for shielding due to its conductivity, but carbon matrix composites are expensive [1].

4 Results

Tab. 1 gives the shielding effectiveness at 1.0, 1.5, and 2.0 GHz for nine types of cement mortars (for example, electromagnetic attenuation at 1.5 GHz frequency increased from 0.5 dB for plain cement to 10.2 dB for the same thickness of disc (3.6 mm) with chemical agents and short carbon fibers in the amount of 0.5 % by weight of the cement). Comparison of Rows 1 and 2 of Tab. 2 shows that the use of chemical agents (even without carbon fibers) enhances the shielding effectiveness substantially. This is consistent with the fact that the presence of these chemical agents reduces the electrical resistivity of the cement. However, an even larger enhancement can be obtained by the further addition of carbon fibers, as shown by the comparison of Rows 1, 2 and 3. The use of chemical agents and 0.5 % fibers gives a shielding effectiveness comparable to that obtained by the use of no chemical agents and 1 % fibers, as shown by comparing Rows 3 and 4. Furthermore, comparison of Rows 4, 6, 8 and 9 and of Rows 3, 5 and 7 shows that the shielding effectiveness increases monotonically with increasing fiber content. The trends are similar for all three frequencies [4].

Tab. 1.: Shielding effectiveness of cement mortars [3]

		Attenuation [dB]			**Thickness**
No.	**Material**	1.0 GHz	1.5 GHz	2.0 GHz	[mm]
1.	Plain cement	0.4	0.5	1.5	3.6
2.	Cement + chemical agents	3.7	3.7	7.3	4.0
3.	Cement + chemical agents +0.5 % fibres	9.4	10.2	11.7	3.6
4.	Cement + 1 % fibres	10.2	9.8	15.8	3.8
5.	Cement + chemical agents + 1 % fibres	14.8	12.3	18.5	3.8
6.	Cement + 2 % fibres	1.5	15.2	21.8	3.9
7.	Cement + chemical agents + 2 % fibres	15.6	13.7	19.6	3.9
8.	Cement + 3 % fibres	19.2	16.8	23.8	4.1
9.	Cement + 4 % fibres	21.1	18.6	25.1	3.9

5 Conclusions

Short carbon fibers (as low as 0.5% by weight of cement or 0.21% by volume of cement mortar) and chemical agents (triethanolamine, sodium sulphate and potassium aluminium sulphate) are effective in increasing the electromagnetic interference shielding effectiveness of cement mortar to about 10 dB or more in the frequency range 1.0 to 2.0 GHz for a mortar thickness of 4 mm. This degree of shielding effectiveness is sufficient for the construction of electromagnetic interference shielded structures. A small carbon fibre content is desirable for material cost saving and ease of dispersing the fibers.

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