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Discussion

A discussion of the paper "Colloidal graphite as an admixture in cement and as a coating on cement for electromagnetic interference shielding" by J. Cao and D.D.L. Chung☆

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The electromagnetic shielding effectiveness for a colloidal graphite admixture incorporated into a cement paste is reported. There are a number of points that need to be reexamined:

1. "graphite is effective for shielding, presumably due to...the skin effect,"
2. "a high shielding effectiveness does not imply a high electrical conductivity,"
3. very high values for the reported resistivities.

The skin depth, δ, is the depth at which electromagnetic fields are attenuated 37% of their original value. Electromagnetic wave theory defines δ as,

$$\delta = \frac{1}{\sqrt{\pi f \mu_r \ \mu_o \sigma}} \quad (\mathrm{m}) \tag{1}$$

where, f is the frequency in Hz, μ_r is the relative permeability, μ_o is the permeability of free space given as $4\pi \times 10^{-7}$ H m^{-1} and σ is the electrical conductivity in $(\Omega\ \mathrm{m})^{-1}$. For all materials above 1 MHz, $\mu_r \rightarrow 1$. Table 1 summarizes values for δ for the cement paste and the paste–colloidal graphite systems. It can be seen from Table 1 that $\delta >> t$, where t is the sample thickness (approximately 4.4×10^{-3} m). Electromagnetic attenuation by absorption, A_{dB}, is given by,

$$A_{dB} = 8.7\left(\frac{t}{\delta}\right) \quad (\mathrm{dB}) \tag{2}$$

As expected, when $\delta >> t$, A_{dB} is negligible. Therefore, based on the experimental evidence, the skin effect contributes very little to electromagnetic attenuation regardless of whether graphite is present or not.

Shielding effectiveness (SE) is attained via three mechanisms:

$$\mathrm{SE} = R_{dB} + A_{dB} + B_{dB} \tag{3}$$

where R_{dB} is the energy reflected because of the mismatch between the impedance of the wave and the impedance of the material, A_{dB} is the energy absorbed,

Table 1
Electromagnetic attenuation parameters

Graphite (%)	σ $(\Omega\ \mathrm{m})^{-1}$	δ (m)	R_{dB} (dB)	A_{dB} (dB)	B_{dB} (dB)	SE (dB), Eq. (3)	SE (dB) reported
0	1.22×10^{-4}	1.44	− 9.1	0.03	− 44.1	− 53.2	4.0
0.46	4.34×10^{-4}	0.76	− 3.6	0.05	− 38.8	− 42.4	10.3
0.92	6.25×10^{-4}	0.63	− 2.0	0.06	− 37.1	− 39.1	22.3

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and B_{dB} refers to internal reflection. The individual terms in Eq. (3) are,

$$R_{\mathrm{dB}} = 106 + 10\log\left(\frac{\sigma}{f\mu_{\mathrm{r}}}\right) \tag{4a}$$

$$A_{\mathrm{dB}} = 8.7t\sqrt{\pi f\mu_{\mathrm{o}}\mu_{\mathrm{r}}\sigma} \tag{4b}$$

$$B_{\mathrm{dB}} = 20\log\left(1 - \exp\left(-2t\sqrt{\pi f\mu_{\mathrm{o}}\mu_{\mathrm{r}}\sigma}\right)\right) \tag{4c}$$

where the variables have been defined in Eqs. (1) and (2), and reflection in the far field is considered. Clearly, SE depends on the conductivity and thickness of the material, the frequency of the impinging wave, the distance from the source (near field/far field conditions), and the type of the source (electric or magnetic dipole, in the near field region). What is evident from Eqs. (4a) to (4c) is that material conductivity plays a very important role in SE, and SE increases directly with σ increase. In other words, when a wave is propagating through an insulating or pure dielectric material, there will be no attenuation during transmission.

With such low conductivities for the cement paste and cement–graphite paste, it is surprising that there is any appreciable electromagnetic attenuation. The reported and calculated SEs are given in Table 1. It can be seen that calculated SEs are large negative values. To this author's experience, calculated values for SE always fall within one order of magnitude compared to measured values, and certainly the odd result of a negative SE has not been seen before. It is likely that the measured resistivities are a combination of bulk material resistivity and material–electrode resistivity, wherein the latter is much larger than the former. Using the reported SE, and assuming that R_{dB} accounts for the attenuation, then the bulk material resistivities can be calculated. These values have been summarized in Table 2. The calculated resistivities for the paste samples are closer to values for paste resistivities widely reported in the literature.

Table 2
Comparison between reported and calculated resistivities

Graphite (%)	Resistivity (Ω cm) reported	Resistivity (Ω cm) calculated
0	8.2×10^5	1584
0.46	2.3×10^5	37
0.92	1.6×10^5	23