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Discussion

Reply to discussion by Peter J. Tumidajski of the paper "Colloidal graphite as an admixture in cement and as a coating on cement for electromagnetic interference shielding"☆

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The electrical conductivity is one of the main parameters that affect the shielding effectiveness. However, a material that exhibits low electrical conductivity does not necessarily exhibit poor shielding effectiveness, even in the case that reflection is the dominant mechanism of shielding.

For example, cement paste containing 0.1 μm diameter carbon filament exhibits much lower conductivity but much higher shielding effectiveness than cement paste containing 15 μm diameter carbon fiber at the same volume fraction [1,2]. Reflection is the dominant mechanism of shielding for both cements. Cement paste containing 0.1 μm diameter carbon filament is more reflective and thus more effective in shielding than that containing 15 μm diameter carbon fiber.

The high reflectivity of cement containing 0.1 μm carbon filament is due to the small diameter of the component of high reflectivity and the consequent large interface area per unit volume. Because of the skin effect, a large area of the component of high reflectivity helps the shielding.

Therefore, in case of a composite material that contains components that are very different in reflectivity, the application of Eq. (4a) of the Discussion by Tumidajski to the overall composite can be misleading. The more relevant skin depth is that of the component of high reflectivity rather than that of the overall composite. Furthermore, the surface area of the reflective component needs to be included in the consideration.

The low conductivity of cement paste containing 0.1 μm carbon filament is due to the small diameter of the filament and the consequent large number of filament–filament contact points per unit volume. Due to the electrical resistance associated with each contact point, the conductivity of the composite is low.

The importance of a large surface area for reflectivity is also supported by the high reflectivity of flexible graphite (skin depth = 44 μm at 1 GHz) compared to polycrystalline graphite (skin depth = 62 μm at 1 GHz) [3]. Flexible graphite exhibits a large surface area. The importance of a large interface area is also supported by the high reflectivity of a polymer–matrix composite containing 0.4 μm diameter nickel (skin depth = 0.47 μm at 1 GHz) filament compared to that containing 2 μm diameter nickel fiber at the same volume fraction and the high reflectivity of the composite containing 2 μm diameter nickel fiber compared to that containing 20 μm diameter nickel fiber at the same volume fraction [4].

In the case of a cement–matrix composite containing graphite particles (the material of the paper under discussion), the electromagnetic radiation interacts with each graphite particle while the interaction with the cement matrix is little. Thus, the skin depth for a graphite particle is relevant to the understanding of the effectiveness of the graphite particles in enhancing the shielding of the cement–matrix composite. Even if the skin depth is considerably larger than the size of a graphite particle, it is still relevant, because the interaction of the electromagnetic radiation with a conductor decreases exponentially as it penetrates into the depth of the conductor and the skin depth is the depth for decay by a factor of $1/e$.

The larger are the conductive particles used in a composite material for shielding, the less is the effectiveness of the particles at a fixed volume fraction and a fixed composition of the particles. This is due to the skin effect, which makes the inner part of a particle contribute less to shielding than the outer part of the particle. This notion is supported by experimental results in a comparative study of a considerable variety of cement–matrix and polymer–matrix composites [1,2].

The measured resistivity values reported in the paper under discussion were obtained using the four-probe meth-

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od. As a result, the contribution of the resistance of the electrical contacts to the measured resistance was negligible.

The high resistivity values (10^5 Ω cm) obtained are reasonable, because the graphite particles are much lower in aspect ratio than carbon fibers and the percolation threshold has not been reached, even for the highest graphite particle content of 0.92 vol.%. In contrast, for carbon fibers, the percolation threshold is low (between 0.5 and 1.0 vol.%) [5,6]. Resistivity values that are almost as high as those in the paper under discussion have been reported for cement pastes containing coke powder, the percolation threshold of which is beyond 9.2 vol.% coke [7].

The calculated resistivity values shown in Table 2 of the Discussion by Tumidajski are unreasonably low, in view of previous work on related materials [6,7], as well as the measured values in the paper under discussion. The calculated shielding effectiveness values shown in Table 1 of the Discussion by Tumidajski are also unreasonable, in view of the measured values reported in the paper under discussion.

References

[1] D.D.L. Chung, Comparison of submicron diameter carbon filaments and conventional carbon fibers as fillers in composite materials, Carbon 39 (8) (2001) 1119–1125.

[2] D.D.L. Chung, Electromagnetic interference shielding effectiveness of carbon materials, Carbon 39 (2) (2001) 279–285.

[3] X. Luo, D.D.L. Chung, Electromagnetic interference shielding reaching 130 dB using flexible graphite, Carbon 34 (10) (1996) 1293–1294.

[4] X. Shui, D.D.L. Chung, Nickel filament polymer–matrix composites with low surface impedance and high electromagnetic interference shielding effectiveness, J. Electron. Mater. 26 (8) (1997) 928–934.

[5] P.W. Chen, D.D.L. Chung, Improving the electrical conductivity of composites comprised of short conducting fibers in a non-conducting matrix: the addition of a non-conducting particulate filler, J. Electron. Mater. 24 (1) (1995) 47–51.

[6] D.D.L. Chung, Electrical conduction behavior of cement–matrix composites, J. Mater. Eng. Perform. 11 (2) (2002) 194–204.

[7] J. Cao, D.D.L. Chung, Coke powder as an admixture in cement for electromagnetic interference shielding, Carbon 41 (12) (2003) 2433–2436.