An Exact Numerical Approach to Determine the Effective Permittivity of a Wire Medium

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Steel fiber reinforced concrete (SFRC) exhibits excellent isotropic mechanical properties and is typically being used for slabs on grade, such as pavements, industrial oors and airport runways. When mixing the fibers with the fresh concrete in a truck mixer, care needs to be taken to obtain a uniform distribution and a random orientation of the fibers. At present the concentration and uniformity of the fibers in the hardened slab only can be checked in a destructive manner. We have developed a non-destructive microwave measurement technique to measure the steel fiber volume fraction of a dry hardened slab (S. Van Damme *et al.*, IEEE Trans. Geosci. Remote Sens., 42, 2511-2521, 2004). In this measurement method, we made use of a classical homogenization formula (Maxwell-Garnett) for the inversion of the measured permittivity to a volume fraction (A. H. Sihvola, and J.A. Kong, IEEE Trans. Geosci. Remote Sens., 26, 420-429, 1988). Although classical mixing formulas have their merits, their applicability in terms of volume fractions, inclusion geometry and frequency is limited.

In this paper, a full-wave homogenization technique is developed to study the relationship between the effective permittivity and the fiber content in an exact way. The SFRC is considered as a uniform distribution of identical perfectly electrically conducting wires, which are randomly oriented in a dielectric host. The effective permittivity of this wire medium is obtained by first computing the scattered field for a volume of wire medium surrounded with the homogeneous dielectric host and next by fitting to these data the permittivitty of a homogeneous volume with the same shape and dimensions and surrounded with the same dielectric host. In this paper cylindrically and spherically shaped volumes are considered. Similar approaches have been proposed by (K. Sarabandi, and P.R. Siqueira, IEEE Trans. Antennas Propagat., 45, 858-867, 1997).

For the computation of the field scattered by the PEC wire medium volume, an electric field integral equation formulation is applied. The field scattered by a homogeneous cylinder of finite length is approximated by the analytical solution for the two dimensional infinitely long cylinder. For a homogeneous dielectric sphere, an exact expression for the scattered field is used. The homogenization approach is tested with numerical examples and the in uence of various parameter choices on the fitted effective permittivity is illustrated, such as the dimensions of the wire medium, the illumination frequency, and the radius of the observation circle. These values also show a satisfactory agreement with a Maxwell-Garnett mixing rule for randomly oriented perfectly conducting prolate spheroids.

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