Electromagnetic interference shielding by carbon fibre reinforced cement

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The addition of short carbon fibres and chemical agents (triethanolamine, sodium sulphate and potassium aluminium sulphate) to Portland cement greatly increased the electromagnetic interference shielding effectiveness of the cement. For example, the attenuation of electromagnetic radiation of a frequency of 1.5 GHz increased from 0.5 dB for plain cement mortar (3.6 mm thick) to 10.2 dB for the same thickness of cement mortar containing chemical agents and 3 mm long carbon fibres (in the amount of 0.5% by weight of the cement or 0.21% by volume of cement mortar).

Key words: *concrete; cement; carbon fibre; electromagnetic shielding*

Cement is a widely used building material, but it lacks the ability to shield electromagnetic radiation. As the environment is increasingly sensitive to electronic pollution, the ability of a building to shield electromagnetic radiation is of increasing importance.[1] This paper demonstrates that the addition of chemical agents and carbon fibres to cement can greatly enhance the shielding effectiveness. In addition to improving the shielding effectiveness, carbon fibres and chemical agents enhance the tensile and flexural strengths significantly.[2] As both carbon fibres and steel fibres are electrically conductive, both can be added to cement to enhance the shielding effectiveness, but steel fibres tend to rust whereas carbon fibres are chemically stable and inert.

Materials

The cement powder used was Portland cement (Type III) produced by the Lafarge Corporation. It is composed chiefly of $3CaO.SiO_2$ (47.1 wt %), $2CaO.SiO_2$ (26.9 wt %), $3CaO.Al_2O_3$ (9.0 wt %), $4CaO.Al_2O_3.Fe_2O_3$ (4.8 wt %), together with several minor oxides such as SO_3 (3.80 wt %), MgO (3.28 wt %), *etc.*

The short carbon fibres used were pitch-based and unsized (Carboflex chopped carbon fibres provided by Ashland Petroleum Company), and were among the cheapest carbon fibres available. The fibre properties are shown in Table 1.

The sand used was crystalline silica (quartz), middle grade. The sand/cement ratio was 1.0 by weight and the water/cement ratio was 0.5 by weight.

The chemical agents used were of triethanolamine (0.06% by weight of cement), sodium sulphate (0.5 wt %) and potassium aluminium sulphate (0.5 wt %). The chemical agents served as an accelerating admixture to make the cement particles disperse in water more easily, solutize the cement particles to form hydrolysed calcium silicate gel, make the cement hydrate faster and generate crystalline compounds which fill the voids caused by the presence of the fibres.

The short carbon fibres were first mixed with the cement powder and sand, then water and the chemical agents were put together and stirred with a mixer for 2 to 3 min. The mortar was then poured into a mould.

Table 1. Properties of short carbon fibres

Filament length	3.0 mm
Filament diameter	12 μm
Tensile strength	690 MPa
Tensile modulus	48 GPa
Elongation at break	1.6%
Electrical resistivity	30 μΩm
Specific gravity	1.6
Carbon content	95 wt %

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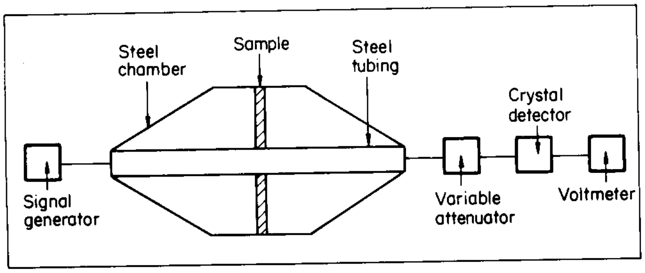

Fig. 1 Set-up for measuring the electromagntic interference shielding effectiveness

After 24 h the specimens were demoulded and left to cure in an air-conditioned room at 20–22°C and 50–70% relative humidity for 1 day. Longer curing times up to 7 days did not change the results of shielding effectiveness.

Testing method

The shielding effectiveness of specimens was measured using the coaxial cable method. The set-up, as illustrated in Fig. 1, consists of an Elgal SET 19A shielding effectiveness tester, which is connected with a coaxial cable to a Wavetek 2002A sweep signal generator (10–2500 MHz) on one side and on the other side to an Alfred Electronics E101 variable attenuator (0–50 ± 0.1 dB), a Hewlett Packard 423A crystal detector and a DC voltmeter. The crystal detector serves to convert the signal to a voltage.

The sample is tested in the form of an annular disc, with an outside diameter of 97.4 mm and an inside diameter of 28.8 mm. Its thickness ranges from 3.6 to 4.1 mm. Silver conductive paint is applied to the surface of the centre hole of the sample and to the flat surfaces of the sample for 5.1 mm from the inner rim of the annular disc to allow a continuous metallic contact to be made between the sample and the steel tubing in the centre of the tester. Silver paint is also applied to the flat surfaces of the sample for 3.7 mm from the outer rim of the annular disc to allow a continuous metallic contact between the sample and the steel chamber of the tester.

After inserting the sample in the tester, the variable attenuator is set to zero and the voltmeter is read. Then the sample is removed from the tester and the variable attenuator is adjusted until the voltmeter has the same value as the case with the sample in the tester. The reading of the adjusted attenuator gives the attenuation, which describes the shielding effectiveness.

RESULTS

Table 2 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 fibres in the amount of 0.5% by weight of the cement). Comparison of Rows 1 and 2 of Table 2 shows that the use of chemical agents (even without carbon fibres) 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.[2] However, an even larger enhancement can be obtained by the further addition of carbon fibres, as shown by the comparison of Rows 1, 2 and 3. The use of chemical agents and 0.5% fibres gives a shielding effectiveness comparable to that obtained by the use of no chemical agents and 1% fibres, 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 fibre content. The trends are similar for all three frequencies.

CONCLUSIONS

Short carbon fibres (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 fibres.

Table 2. Shielding effectiveness of cement mortars

No.	Material	Attenuation (dB)			Thickness (mm)
		1.0 GHz	1.5 GHz	2.0 GHz	
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	16.5	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

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