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Electronic Properties of Carbon Fiber Reinforced Gypsum Plaster

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ABSTRACT

The electrical resistivity of carbon fiber (3 mm long, pitch-based) reinforced gypsum plaster decreased monotonically with increasing fiber content, reaching a resistivity of 600Ω cm (0·02% of the plain gypsum plaster value) at a fiber content of 2·0% by weight of the gypsum. The electromagnetic interference shielding effectiveness increased monotonically with increasing fiber content, reaching a shielding effectiveness of 22 dB at 1·5 GHz for a plaster thickness of 4·35 mm and a fiber content of 2·0% by weight of the gypsum. Even with as little as 0·3% fibers, the shielding effectiveness was 10 dB at 1·5 GHz for a plaster thickness of 3·85 mm. The additional use of chemical agents (sodium citrate, cement and aluminum sulfate 18-hydrate) increased the electrical resistivity and had little effect on the shielding effectiveness, though the chemical agents strengthened the plaster.

INTRODUCTION

Gypsum is a fast setting and light-weight building material. However, the strength of gypsum plaster is low compared to that of cement mortar. By adding short carbon fibers and chemical agents, we have previously shown that the strength of gypsum plaster can be raised to the level of cement mortar.[1] In this paper, we further show that the addition of carbon fibers serves to increase the electromagnetic interference (EMI) shielding effectiveness and decrease the electrical resistivity. As the environment is increasingly sensitive to electronic pollution owing to the increasing sensitivity and abundance of modern electronics, the ability of a building to shield electromagnetic radiation is of increasing importance.

Since both carbon fibers and steel fibers are electrically conductive, both can be added to gypsum in order to enhance the shielding effectiveness and decrease the electrical resistivity, but steel fibers are heavy and tend to rust whereas carbon fibers are light-weight and relatively inert. With the continuing drop in the price of carbon fibers, especially for short pitch-based carbon fibers, there is economic impetus for the use of carbon fibers in gypsum.

MATERIALS

The gypsum used was a dry powder, composed of calcium sulfate hemihydrate (α–$CaSO_4 . 0{\cdot}5H_2O$) 96%, calcium carbonate 3·5% and other traces 0·5%. It is known as Hydrocal B-Base, as provided by USG Corporation.

Cement powder (5% by weight of the gypsum) was used as an admixture for increasing the strength. It was Portland cement (Type III) produced by Lafarge Corporation, and was 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.

Short carbon fibers were pitch-based and unsized. They were Carboflex chopped carbon fibers kindly provided by Ashland Petroleum Company. The fibers are nominally 3·0 mm long. The fiber properties are shown in Table 1.

The chemical agents included (i) sodium citrate (0·05% by weight of the

TABLE 1
Properties of Short Carbon Fibers

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 $\mu\Omega$ m
Specific gravity	1·6
Carbon content	95 %wt

gypsum), used as a retarder, (ii) aluminum sulfate 18-hydrate crystals (0·5% by weight of the gypsum), used as an accelerating agent for increasing the strength and (iii) cement (5% by weight of the gypsum).

The water/gypsum ratio was 0·34.

The short carbon fibers and chemical agents (if used) were first mixed with water for 1 min; the hemihydrate gypsum powder was mixed with the cement powder (if used) and put into the above-mentioned suspension; the plaster was then poured into the molds. After 2–24 h (thoroughly hardened), the specimens were demolded and left in an air-conditioned room at 20–22°C and 40–50% relative humidity for 1–2 days, and then they were put into an oven provided with air circulation and adequate ventilation in order to remove the moisture. The air temperature in the oven was about 50–60°C. The specimens were thus dried to constant weight, as determined by weighing once each day up to 7 days. After that, the specimens were cooled to room temperature and tested.

Mechanical testing using standard methods showed that specimens with the same ingredients had strength values (compressive, tensile or flexural) having a scatter of ±15%.[1] Furthermore, scanning electron microscope observation of tensile fracture surfaces showed that the fibers were quite homogeneously distributed with little preferred orientation.[1]

TESTING METHODS

The shielding effectiveness was measured by 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 dB, ±0·1 dB), followed by a Hewlett Packard 423A crystal detector and then by a DC voltmeter. The crystal detector serves to convert the signal to a voltage.

The sample is 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 3·85 to 4·55 mm. Conductive silver paint is applied to the inner surface of the center hole of the sample and to the flat surfaces of the sample to a width of 5·1 mm from the inner rim of the annular disc, in order to allow a continuous metallic contact to be made between the sample and the steel tubing in the center of the tester. Moreover, silver paint is applied to the flat surfaces of the sample to a width of 3·7 mm from the outer rim of the annular disc in order to allow a continuous metallic contact to be made between the sample and the steel chamber of the tester.

In the measurement, after inserting the sample in the tester, the variable

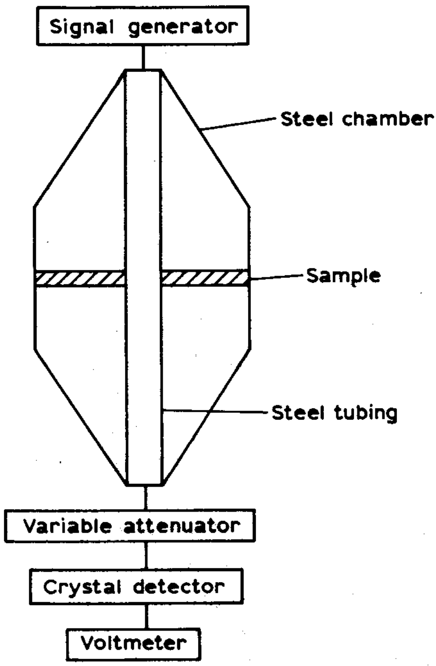

Fig. 1. Set-up for measuring the EMI shielding effectiveness.

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.

Because the shielding effectiveness increases with increasing sample thickness, comparison of the shielding effectiveness of samples of various types should be made for samples of essentially the same thickness.

The electrical resistivity was measured by the four-probe method. The electrical contacts were made using silver paint, which was applied around the whole perimeter of each of four parallel cross sections of a sample in order to assure an equipotential condition within each cross section.

RESULTS

Table 2 gives the electrical resistivity of ten types of gypsum plasters. The carbon fibers greatly decrease the electrical resistivity, especially for fiber contents beyond 0·5% by weight of the gypsum. On the other hand, the chemical agents increase the electrical resistivity, probably because of the

TABLE 2
Electrical Resistivity of Gypsum Plasters

No.	*Material*	*Electrical resistivity* (Ω *cm*)
1	PGP[a]	3.4×10^6
2	PGP + 0·3%[b] fibers	3.4×10^6
3	PGP + 0·5% fibers	3.2×10^4
4	PGP + 1·0% fibers	7.6×10^3
5	PGP + 2·0% fibers	6.0×10^2
6	PGP + chemical agents	7.1×10^6
7	PGP + chemical agents + 0·3% fibers	4.5×10^6
8	PGP + chemical agents + 0·5% fibers	4.4×10^6
9	PGP + chemical agents + 1·0% fibers	1.4×10^5
10	PGP + chemical agents + 2·0% fibers	8.0×10^3

[a] PGP = plain gypsum.
[b] 0·3% by weight of the gypsum, or 0·26 %vol of the gypsum plaster, or 4·1 kg fibers/m³ gypsum plaster.

poor electrical conductivity of the compounds formed from the chemical agents. Thus, although the chemical agents are useful for strengthening the gypsum plaster, they degrade the electrical conductivity of the plaster.

Table 3 gives the shielding effectiveness at 1·0, 1·5 and 2·0 GHz for the same ten types of gypsum plasters. At any of the frequencies, the shielding effectiveness increases significantly with increasing carbon fiber content,

TABLE 3
Shielding Effectiveness of Gypsum Plasters

No.	*Material*	*Attenuation (dB)*			*Thickness (mm)*
		1·0 GHz	*1·5 GHz*	*2·0 GHz*	
1	PGP[a]	0·2	1·4	0·0	3·90
2	PGP + 0·3%[b] fibers	7·4	10·1	9·9	3·85
3	PGP + 0·5% fibers	9·0	11·9	10·6	3·90
4	PGP + 1·0% fibers	15·4	18·6	16·0	4·50
5	PGP + 2·0% fibers	18·0	21·7	19·5	4·35
6	PGP + chemical agents	0·3	2·3	0·2	4·00
7	PGP + chemical agents + 0·3% fibers	7·2	9·5	8·7	4·30
8	PGP + chemical agents + 0·5% fibers	11·1	13·3	11·7	4·40
9	PGP + chemical agents + 1·0% fibers	15·2	17·9	15·6	4·35
10	PGP + chemical agents + 2·0% fibers	17·0	19·7	17·8	4·55

[a] PGP = plain gypsum plaster.
[b] 0·3% by weight of the gypsum, or 0·26 %vol of the gypsum plaster, or 4·1 kg fibers/m³ gypsum plaster.

whether with or without chemical agents. In particular, increasing the fiber content from zero to 0·3% (by weight of the gypsum) increases the shielding effectiveness at 1·0 GHz from 0·2 to 7·4 dB for the case without chemical agents. On the other hand, the presence of the chemical agents has little effect on the shielding effectiveness.

CONCLUSION

Short carbon fibers (as little as 0·3% by weight of the gypsum, or 0·26% vol of the gypsum plaster, or 4·1 kg fibers/m^3 gypsum plaster) are effective in increasing the EMI shielding of gypsum plaster to 7 dB or more in the frequency range from 1·0 to 2·0 GHz for a plaster thickness of about 4 mm. The shielding effectiveness increases monotonically with increasing fiber content. Similarly, short carbon fibers are effective in decreasing the electrical resistivity of gypsum plaster, especially for fiber contents of 0·5% (by weight of gypsum) or more. On the other hand, the use of chemical agents (sodium citrate, cement and aluminium sulfate 18-hydrate crystals) increases the electrical resistivity and has little effect on the EMI shielding effectiveness, even though the chemical agents are useful for strengthening the gypsum plaster.

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