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RADIO-WAVE-REFLECTING CONCRETE FOR LATERAL GUIDANCE IN AUTOMATIC HIGHWAYS

X. Fu and D.D.L. Chung[1]
Composite Materials Research Laboratory, State University of New York at Buffalo, Buffalo, NY 14260-4400, USA

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ABSTRACT

A method for producing radio-wave-reflecting concrete, which is potentially useful for lateral guidance in automatic highways, is provided. In the form of cement paste, it contains a small amount (0.5 vol.%) of 0.1 μm diameter carbon filaments as an admixture. The radiation absorbed is negligible compared to that reflected. The reflectivity at 1 GHz is 10 dB higher for radio-wave-reflecting cement paste compared to conventional cement paste. With the filaments, the reflectivity is 29 dB higher than the transmissivity. Without the filaments, the reflectivity is 3–11 dB lower than the transmissivity. The addition of the filaments not only provides the ability to reflect electromagnetic radiation, it also reinforces the cement paste under tension, especially if the filaments have been treated with ozone prior to incorporation in the paste. *© 1998 Elsevier Science Ltd*

Introduction

The term "automatic highways" refers to highways which provide fully automated control of vehicles, so that safety and mobility are enhanced. In other words, a driver does not need to drive on an automatic highway, as the vehicle goes automatically, with both lateral control (steering to control position relatively to the center of the traffic lane) and longitudinal control (speed and headway). Current technology uses magnetic sensors together with magnetic highway markings to provide lateral guidance, and uses radar to monitor the vehicle position relative to other vehicles in its lane for the purpose of longitudinal guidance (1–3). The high cost of this technology makes it undesirable for practical use.

This paper provides an alternate lateral guidance technology, which uses concrete that reflects radio wave electromagnetic radiation as highway marking, which is either in the middle or at the two sides of each lane. The marking is sensed by radio wave electromagnetic radiation emitted by each vehicle, thereby achieving lateral guidance. In other words, the vehicle has a transmitter that emits the radiation straight down to the reflecting concrete, and the radiation is reflected by the concrete and detected by a detector in the vehicle. A vehicle

Communicated by D.M. Roy.
[1]To whom correspondence should be addressed.

can have more than one transmitter and more than one detector, such that the transmitters are in a row in the lateral direction of the vehicle (or in other configurations) for the purpose of increasing the sensitivity for the lateral position of the vehicle.

Compared to magnetic technology, the attractions of electromagnetic technology are low material cost (reflecting concrete estimated to be 30% more expensive than conventional concrete, thus much less expensive than concrete with embedded magnets or magnetic strips), low labor cost (same as conventional concrete, thus much less than concrete with embedded magnets or magnetic strips), low peripheral electronic cost (off-the-shelf oscillator and detector), good mechanical properties (reflecting concrete exhibiting better mechanical properties and lower drying shrinkage than conventional concrete, whereas embedded magnets weaken concrete), good reliability (less affected by weather, as frequency, impedance, and power selectivity provide tuning capability), and high durability (demagnetization and marking detachment not being issues). Moreover, the magnetic field from a magnetic marking can be shielded by electrical conductors (such as steel) between the marking and the vehicle, whereas the electromagnetic field cannot be easily shielded. In addition, the electromagnetic technique may be more precise than the magnetic technique.

Radio-wave-reflecting concrete is achieved in this work by using concrete containing a small amount (0.5% by weight of cement) of 0.1 μm diameter carbon filaments as an admixture (4). The radiation absorbed is negligible compared to that reflected. The reflectivity at 1 GHz is 10 dB higher for radio wave reflecting cement paste compared to conventional cement paste. With the filaments, the reflectivity is 29 dB higher than the transmissivity. Without the filaments, the reflectivity is 3–11 dB lower than the transmissivity. The carbon filaments decrease the DC electrical resistivity only slightly (from 1.62×10^5 to 1.34×10^4 Ω.cm for cement paste), because the filament volume fraction is below the percolation threshold. However, the small diameter of the filaments compared to conventional carbon fibers (10 μm diameter) or steel fibers or rebars (even larger) makes them highly effective for enhancing reflection. This is due to the skin effect, which causes electromagnetic radiation at high frequencies (such as radio wave) to interact with only the near surface region of a conductor (such as a fiber). Although steel rebars embedded in concrete can reflect electromagnetic radiation, they contribute little to the reflected signal due to their large diameter (low surface area) and their being not flat, so that the reflected ray from them would not reach the detector in the vehicle. It should be noted that "carbon filaments" are 0.1 μm in diameter, whereas "carbon fibers" are 10 μm diameter.

The addition of the filaments not only provides the concrete with the ability to reflect electromagnetic radiation, it also reinforces the concrete under tension (4), especially if the filaments have been treated with ozone (5) prior to incorporation in the concrete. The ozone treatment results in oxygen-containing functional groups on the surface of the filaments (6,7). These functional groups improve the wetting of the filaments with water and increase the bond strength between filaments and cement (7). The compressive strength is decreased by the filaments, although the effect of the filaments on the compressive strength is much less than that on the tensile strength (4).

The objectives of this work are 1) to investigate the radio wave reflectivity of cement pastes, 2) to develop cement pastes that strongly reflect radio waves, and 3) to investigate the mechanical properties of the radio-wave-reflecting cement pastes.

TABLE 1
Amounts of water and water reducing agent (WR) for each mix.

	Water/cement ratio	WR/cement ratio
Plain	0.45	0
+ M + SF	0.35	1%
+ L	0.23	0
+ F	0.40	0
+ M + SF + F	0.35	1%
+ L + F	0.23	0

Note: L = latex, M = methylcellulose, SF = silica fume, F = filaments.

Experimental Methods

Cement paste made from Portland cement (Type I) from Lafarge Corp. (Southfield, MI) was used for the cementitious material. The admixtures used include 1) latex, a styrene butadiene copolymer (Dow Chemical Co., Midland, MI 460NA) with the polymer making up about 48% of the solution and with styrene and butadiene in the weight ratio 66: 34, such that the latex (20% by weight of cement) was used along with an antifoam (Dow Corning Corp., Midland, MI, #2210, 0.5% by weight of latex); 2) methylcellulose (Dow Chemical Corp., A15-LV, 0.4% by weight of cement), which was used along with a defoamer (Colloids Inc., Marietta, GA, Colloids 1010, 0.13 vol.%); 3) silica fume (EMS 965, Elkem Materials Inc., Pittsburgh, PA, 15% by weight of cement); and 4) carbon filaments, which were of diameter 0.1 μm and length > 100 μm, and electrical resistivity 10^{-3} Ω.cm (estimate based on the resistivity of a filament compact, as single-filament resistivity measurement was impossible), as obtained from Applied Sciences Inc. (Cedarville, Ohio). The filaments were used in amounts of 0.5, 1.0 and 1.5% by weight of cement; these amounts corresponded to filament volume fractions of 0.51, 1.0, and 1.5% respectively. The filaments had not been surface-treated, unless noted otherwise. Surface treatment was performed by exposure to ozone (O_3) gas (0.3 vol.%, in air) for 10 min. at 160°C. Before O_3 exposure, the filaments had been dried at 110°C in air for 1 h. The water-reducing agent was a sodium salt of a condensed naphthalenesulfonic acid (TAMOL SN, Rohm and Haas Company, Philadelphia, PA) used in amounts as shown in Table 1 for various mixes. Table 1 also shows the water/cement ratio for each mix. The amounts in Table 1 were chosen in order to maintain the slump at around 170 mm. No aggregate (whether fine or coarse) was used.

A Hobart mixer with a flat beater was used. For cement pastes containing latex, the latex, antifoam and filaments were first mixed by hand for about 1 min. Then this mixture, cement, and water were mixed in the Hobart mixer for 5 min. For pastes containing methylcellulose, methylcellulose was dissolved in water and then filaments and the defoamer were added and stirred by hand for about 2 min. Then this mixture, cement, water and silica fume (if applicable) were mixed in the mixer for 5 min. After pouring the mix into oiled molds, an external vibrator was used to decrease the number of air bubbles. The specimens were

TABLE 2
Attenuation upon reflection and transmission* at 1 GHz and electrical resistivity of cement pastes. Formulation A has methylcellulose and silica fume. Formulation B has latex. Formulation C has no admixture.

Filament vol. %	Formulation	Attenuation (dB)		Sample thickness (mm)	Resistivity (Ω·cm)
		Reflection	Transmission		
0	C	11	0.4	3.6	1.62×10^5
0	A	13	1.9	4.4	2.32×10^5
0	B	7.1	4.5	3.8	2.75×10^5
0.5	C	1.8	26	4.0	1.93×10^4
0.5	A	1.3	30	3.9	1.34×10^4
0.5	B	1.3	30	4.1	8.14×10^4
1.0	A	1.1	35	3.7	1.21×10^4
1.0	B	0.9	36	3.9	7.82×10^4
1.5	A	0.8	38	3.8	1.08×10^4
1.5	B	0.7	40	4.0	7.41×10^4

*A high attenuation upon reflection means a low reflectivity. A high attenuation upon transmission means a low transmissivity.

TABLE 3
Effect of ozone treatment on the tensile and compressive properties of cement paste.

	P	+F
Tensile strength (MPa)		
Untreated	0.91 (±2.7%)	1.23 (±1.9%)
Treated	0.91 (±2.7%)	1.37 (±2.2%)
Tensile modulus (GPa)		
Untreated	11.2 (±2.1%)	12.4 (±1.9%)
Treated	11.2 (±2.1%)	13.8 (±2.0%)
Tensile ductility (%)		
Untreated	0.0041 (±1.9%)	0.0090 (±2.5%)
Treated	0.0041 (±1.9%)	0.0120 (±1.8%)
Compressive strength (MPa)		
Untreated	57.9 (±3.2%)	40.9 (±2.1%)
Treated	57.9 (±3.2%)	42.5 (±1.5%)
Compressive modulus (GPa)		
Untreated	2.92 (±2.3%)	5.75 (±1.2%)
Treated	2.92 (±2.3%)	6.47 (±2.2%)
Compressive ductility (%)		
Untreated	1.72 (±2.2%)	1.12 (±2.1%)
Treated	1.72 (±2.2%)	1.20 (±2.1%)

Note: P = plain (no admixture), F = filament (0.5% by weight of cement, or 0.51 vol.%), M = methylcellulose (0.4% by weight of cement), SF = silica fume (15% by weight of cement), and L = latex (20% by weight of cement).

demolded after 1 day and then allowed to cure at room temperature in air (relative humidity = 40%) for 28 days. All testing was performed at 28 days.

The attenuations upon reflection and transmission were measured using the coaxial cable method. The setup consisted of an Elgal SET 19A shielding effectiveness tester with its input and output connected to a Hewlett-Packard (HP) 8510A network analyzer. An HP APC-7 calibration kit was used to calibrate the system. The frequency was 1 GHz. The sample placed in the center plane of the tester (with the input and output of the tester on the two sides of the sample) was in the form of an annular ring of outer diameter 97 mm and inner diameter 32 mm. The sample thickness ranged from 3.6 to 4.4 mm.

The DC volume electrical resistivity was measured by the four-probe method (outer two probes for passing current and inner two probes for voltage measurement), using silver paint for the electrical contacts, which were applied around the perimeter of the specimen (160 × 40 × 40 mm) in four parallel planes perpendicular to the current direction (along the longest dimension of the specimen).

Tensile testing was performed on dogbone-shaped specimens. The specimen cross section was 30 × 20 mm in the narrow part of the dogbone shape. The Sintech 2/D screw action mechanical testing system was used at a cross head speed of 1.27 mm/min. The strain was measured by using a strain gage attached to the narrow part of the dogbone-shaped specimen. The strain allowed determination of the tensile modulus and ductility.

For compressive testing according to ASTM C109–80, specimens were prepared by using a 2 × 2 × 2 in (5.1 × 5.1 × 5.1 cm) mold. Compression testing was performed

TABLE 3
Continued.

+F+M	+F+M+SF	+F+L
1.52 (±2.5%)	1.67 (±3.1%)	2.86 (±3.2%)
1.73 (±2.4%)	1.83 (±2.7%)	2.98 (±2.1%)
8.7 (±2.3%)	12.8 (±1.2%)	6.8 (±1.2%)
10.8 (±1.7%)	15.2 (±2.8%)	10.6 (±2.8%)
0.0160 (±2.1%)	0.0140 (±1.8%)	0.0360 (±2.2%)
0.0201 (±3.2%)	0.0210 (±3.0%)	0.0425 (±1.9%)
41.6 (±2.8%)	47.2 (±2.8%)	43.3 (±2.0%)
43.5 (±2.0%)	48.6 (±3.0%)	45.1 (±2.8%)
3.52 (±1.8%)	3.55 (±1.4%)	3.72 (±2.3%)
4.12 (±3.1%)	4.16 (±2.6%)	4.46 (±1.6%)
1.23 (±1.7%)	1.29 (±2.2%)	1.33 (±1.5%)
1.27 (±2.2%)	1.31 (±2.7%)	1.45 (±2.3%)

using a hydraulic material testing system (MTS). The cross head speed was 1.27 mm/min.

Results and Discussion

When 0.1 μm diameter carbon filaments (0.5–1.5 vol.%) are used as an admixture in cement paste, the reflectivity is 24–37 dB higher than the transmissivity, and reflectivity 10 dB higher than conventional cement paste (without admixture) has been attained (Table 2). The reflectivity is mostly due to the filaments, which strongly reflect. The intensity absorbed is negligible compared to that reflected. In contrast, without the filaments, the reflectivity is 3–11 dB lower than the transmissivity. As shown in Table 2, the attenuation upon reflection decreases (i.e., the reflectivity increases), the attenuation upon transmission (due to both reflection and absorption) increases (i.e., the transmissivity decreases), and the DC electrical resistivity decreases with increasing filament volume fraction. For Formula A (with methylcellulose and silica fume) or B (with latex), even at a filament volume fraction of just 0.5% (corresponding to 0.5% by weight of cement), the reflectivity is 29 dB higher than the transmissivity and the reflectivity is 10 dB higher than conventional cement paste. When both cost and performance are considered, a carbon filament volume fraction of 0.5% is recommended. When a conventional isotropic-pitch-based 10 μm diameter carbon fiber (4 vol.%) is used instead of the carbon filaments, the reflectivity is even less than that of the cement paste with 0.5 vol.% carbon filaments. Thus, the carbon filaments of diameter 0.1 μm are much more effective than the carbon fibers of diameter 10 μm in providing radio-wave-reflecting concrete.

Admixtures such as methycellulose (0.4% by weight of cement) together with silica fume (15% by weight of cement), or latex (20% by weight of cement) are needed to help the dispersion of the filaments. As shown in Table 2, when filaments are present, both formulae A and B give similar attenuation, though Formula A gives lower resistivity than Formula B for the same filament volume fraction. The higher resistivity for Formula B is partly due to the higher filament/cement contact resistivity (6). This contact resistivity affects the volume resistivity more than the attenuation, because connectivity is more important for conduction than for attenuation. The higher resistivity for Formula B is also partly due to the lower degree of fiber dispersion (8). The slightly higher reflectivity for Formula B compared to Formula A is at least partly due to the larger sample thickness for Formula B at each filament volume fraction. Formula C is less attractive than Formula A or B, as shown by the low reflectivity and high transmissivity compared to Formula A or B at the same filament volume fraction. Because latex (20% by weight of cement) is expensive, Formula A is recommended.

Surface treatment of the carbon filaments with ozone prior to incorporation of the filaments in concrete increases the surface oxygen concentration, thereby improving wettability by water and increasing the bond strength between filament and cement paste, as shown for the case of conventional carbon fibers (5,6). As a result, the tensile strength, modulus and ductility and the compressive strength, modulus and ductility of cement paste are all increased by the ozone treatment of the carbon filaments, as shown in Table 3. Although the carbon filaments are not as effective as the conventional carbon fibers as a reinforcement (5), they still reinforce, as shown by the low values of the tensile strength, tensile ductility and compressive modulus of the plain cement paste compared to the pastes with filaments in Table 3.

Conclusion

This paper provides methods for producing radio-wave-reflecting concrete, which is potentially useful for lateral guidance in automatic highway technology. In the form of cement paste, it contains a small amount (0.5 vol.%) of 0.1 μm diameter carbon filaments as an admixture. The radiation absorbed is negligible compared to that reflected. The reflectivity at 1 GHz is 10 dB higher for radio wave reflecting cement paste compared to conventional cement paste. With the filaments, the reflectivity is 29 dB higher than the transmissivity. Without the filaments, the reflectivity is 3–11 dB lower than the transmissivity.

The addition of the filaments not only provides the cement paste with the ability to reflect electromagnetic radiation, it also reinforces the cement paste under tension, especially if the filaments have been treated with ozone prior to incorporation in the concrete. For example, the tensile strength is 0.91 MPa for plain cement paste, 1.67 MPa for cement paste with untreated filaments and 1.83 MPa for cement paste with treated filaments. the compressive strength is decreased by the filaments, although the effect of the filaments on the compressive strength is much less than that on the tensile strength. For example, the compressive strength is 57.9 MPa for plain cement paste, 47.2 MPa for cement paste with untreated filaments and 48.6 MPa for cement paste with treated filaments.

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