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SHIELDING EFFECTIVENESS PERFORMANCE OF CONDUCTIVE CONCRETE STRUCTURES

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SHIELDING EFFECTIVENESS PERFORMANCE OF CONDUCTIVE CONCRETE STRUCTURES

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Abstract— Conductive concrete mixtures have been designed and demonstrated to perform electromagnetic shielding. This paper describes the design, testing methods, and results obtained from the development of conductive concrete construction for structured electromagnetic shielding.

Keywords- *Conductive concrete, electromagnetic shielding*

I. INTRODUCTION

Electromagnetic (EM) shielding is imperative in protecting electronic assets from both natural and man-made EM threats. The wide range of threats, including solar storms, electromagnetic pulse (EMP), and electronic eavesdropping, requires versatile methods for protection and security. Traditional methods of shielding include steel panel enclosures and wire mesh Faraday cages which can be costly in construction and maintenance. In previous work, we developed conductive concrete mixture as an EM shielding material [1, 2, 3]. In this paper, we describe the development of conductive concrete construction as an electromagnetic shielding structure and explore new design and shielding effectiveness (SE) performance. The results demonstrate that the concept of using conductive concrete for building shielded structures is feasible with standard construction practices and should lead to a cost-effective construction material and construction method for structured shielding.

II. CONSTRUCTION DESCRIPTION

Previous research into using conductive concrete as an EM shield yielded a mixture of traditional concrete with steel fibres, carbon powder, and taconite. This high-performance mixture began with the goal of creating a concrete mixture for melting ice on surfaces [4], and then was enhanced using taconite to increase EM absorption property of the material at higher frequencies [5]. The mixture evaluation was focused on low-cost, experimental methods based on standard tests which produced very promising results [2, 3]. These tests employed small samples, and 2-foot by 2-foot test slabs not more than 1-foot thick, to gauge the effectiveness of the mixture.

In order to evaluate SE on a larger concrete structure, 5-sided conductive concrete cubes with open bottoms were built that has a thickness of 12 inches and inside dimension of either 2.5 feet or 5 feet. Figure 1 compares the two cube sizes. The walls of each cube are poured on the steel C-channel, sealing the cube bottom that is positioned on a steel baseplate for testing as shown in Fig. 2. The conduit for the fiber optic cable as well as the layer of steel powder that is used as an RF gasket material above the baseplate can be seen in Figs. 2 and 3. The steel powder creates an amorphous seal between two incongruous

steel surfaces and seal against RF leakage. As reinforced concrete with rebar has been shown to attenuate EM waves [6], the cubes enable evaluation of different wire mesh and rebar configurations embedded inside the concrete to enhance SE.

Figure 1. 2.5-foot cube (left), and 5-foot cube (right).

Figure 2. Steel powder seals on steel baseplate.

Figure 3. Concrete cube sealed to steel baseplate.

Five test cubes were cast and evaluated for SE. Table 1 summarizes the dimensions and description of the cubes. As mentioned, the cubes have open bottom and were made to be

lowered over the receiving test antennas positioned on the steel base plate. It was determined that the standard RX antennas that fit inside the larger cube 1 could be replaced with smaller antenna probes without significantly changing the results. Thus, test cubes 2 to 5 were cast with reduced dimensions, yielding significant savings in terms of sizes, materials and construction cost.

Table 1. Summary of 12-in thick test cubes

Test Cube	Overall Height (ft)	Footprint (ft ²)	Embedded Steel Reinforcement
1	6	7 × 7	None
2	3.5	4.5 × 4.5	2 layers of 2-in welded wire fabrics (WWF)
3	3.5	4.5 × 4.5	2 layers of 2-in welded wire rebar (WWR)
4	3.5	4.5 × 4.5	3 layers of 2-in WWF
5	3.5	4.5 × 4.5	2 layers of 0.125-in wire mesh

Test cube 1 had an inside dimension of 5 feet and is composed of only the conductive concrete mixture that had been evaluated and selected using the slab method [2]. The next four test cubes were built with smaller inner dimensions of 2.5 feet and incorporated variations of multi-layer embedded wire mesh structures as illustrated in Fig. 4 for cube 4. Cube 2 included two layers of welded wire mesh or fabrics (WWF) with 2-in square openings spaced 6-in apart and positioned 3-in from the inner and outer surfaces. Cube 3 was cast with the WWF replaced by two welded wire rebar (WWR) mesh with 2-in square openings. Cube 4 incorporated three layers of WWF with 2-in openings spaced 6-in apart with the outer two layers close to the inner and outer surfaces. The last cube 5 was cast with very fine wire mesh affixed to the inner and outer surfaces.

Figure 4. Cube 4 with 3 layers of welded wire mesh.

III. EXPERIMENTAL DESCRIPTION

SE testing of the concrete cubes was initially configured to follow the procedure in mil-std-188-125-1 Appendix A. Figure 5 depicts the test setup. The Agilent network analyzer E5061B performs sweep frequency measurement with the fiber optic RX inside a shielded enclosure for isolation. The RF output is amplified and transmitted with the TX antennas outside the test cube. A fiber optic TX inside the cube sends the received signal via the fiber optic cable through the conduit on the base plate back to the network analyzer. The resonant and plane wave measurement from 25 MHz to 1 GHz was performed with the BiConiLog TX antenna model 3142D from ETS-Lindgren, and the biconical and log periodic RX antennas models SAS-542 and SAS-510-2 from A. H. Systems. ETS-Lindgren loop antennas model 6512 were used in the magnetic field frequency range from 10 kHz to 25 MHz.

Figure 5. Shielding effectiveness test setup.

For cube 1 with the inner dimension of 5 feet, this method proved to be applicable using full-size RX antennas as shown in Fig. 6, consisting of the loop, biconical, and log periodic antennas, which would fit inside the cube. However, to enable testing of a wider variety of test cube constructions, casting smaller cubes would be less costly and more desirable experimentally. In order to test smaller cubes with inner dimensions of just 2.5 feet, a small receiving antenna set was employed as shown in Fig. 7, consisting of a monopole and a small passive loop from the Electro-Metrics EM-6992 probe set. To verify the efficacy of this antenna setup, measurements of cube 1 (whose interior surface had been affixed with aluminum foil as discussed in Section IV) were taken with both the full-size and small antenna sets and comparable results were obtained, as shown in Fig. 8. Note that the SE results with the large antenna set is about 5 dB better up to 10 MHz, which can be attributed largely to the coupling effect between the larger antenna and the cube.

Figure 6. Full-size RX antenna set for mil-std testing.

Figure 7. Small RX antenna set.

Figure 8. Performance of small antenna set versus full-size antenna set.

IV. EXPERIMENTAL RESULTS

Cube 1 was initially evaluated for comparison against the results that have been obtained with the small concrete samples and test slabs from previous work [1 - 3]. Figure 9 compares the attenuation between the cube testing method and the previous slab evaluation that had yielded a good estimation for the SE of conductive concrete. The poor dynamic range (DR) of the slab in the low frequency below 1 MHz was due to the configuration of the test port as reported previously in [2]. The results in Fig. 9 validate previous methods for testing the small samples and test slabs for conductive concrete mixture evaluation.

Figure 9. Attenuation comparison of slab and cube testing methods.

The plots in Fig. 9 show that the cube has better absorption characteristics from about 20 MHz to 300 MHz, meeting the 80 dB SE requirement above 100 MHz and reaching a dynamic range limited maximum of about 120 dB. The results also reveal that cube 1 failed the SE requirements below 100 MHz. In particular, the lack of meaningful attenuation below 25 MHz shows that the concrete mixture does not perform well in the magnetic field regime.

In order to explore low frequency magnetic shielding, household aluminium foil of about 1-mil thick was affixed over the interior surface of the cube. Figure 10 below shows the cube with the facing aluminium foil being lowered by the overhead crane onto the steel base plate for testing. The plots demonstrate that incorporating the aluminium foil to the cube has improved the low frequency SE significantly, by as much as 50 dB below 25 MHz, and the high frequency shielding was also enhanced.

Figure 10. Test cube 1 with aluminum foil.

While affixing a metallic foil to the concrete surface is impractical in terms of constructability with concrete materials, the results in Fig. 10 have motivated a number of practical construction options that include inserting a wire mesh inside

the concrete structure. Various construction methods were investigated for embedding the wire mesh configuration in the concrete and the four small test cubes were cast for evaluation.

Cube 2 was cast with two embedded layers of wire mesh having 2-in opening. Figure 11 shows significant improvement compared to cube 1 in the low frequency SE below 25 MHz, with cube 2 attenuation reaching as much as 40 dB better at 10 MHz and being within 10 dB of the requirement at 10 kHz. The plots show that the embedded wire mesh would also contribute to enhancing the high frequency attenuation.

Figure 11. SE comparison for cubes 1 through 4.

The wire mesh in cube 2 was replaced with two layers of welded rebar in cube 3 to assess the rebar thickness. The results from cube 3 were mixed as evidenced in Fig. 11. It largely underperforms compared to cubes 2, but still has better low frequency attenuation than cube 1 below 25 MHz. The spacing of the rebar mesh may have had the effect of allowing the two layers to be shorted together, creating an equivalent single mesh layer that is less effective compared to the two individual layers in cube 2.

Based on the results from cubes 1 to 3, cube 4 was cast with a three wire mesh layer configuration embedded in the concrete. The results in Fig. 11 demonstrate clearly that cube 4 has the better performance that is within 20 dB of the SE requirement below 25 MHz, reaching less than 5 dB at 10 kHz. For frequencies above 25 MHz, cube 4 performs exceedingly well, achieving about 120 dB of attenuation at 300 MHz, and is largely limited by the dynamic range of the test setup.

Finally, in order to evaluate the effect of incorporating very fine wire mesh in the concrete structure, cube 5 was cast with two wire mesh having 0.125-in opening affixed to the inner and outer surfaces of the cube. The SE plot in Fig. 12 clearly demonstrates, in comparison to Fig. 11, that this configuration has the best performance, particularly relative to the mil-std requirements. The measurements were performed with larger RX loop and monopole antennas in order to improve the dynamic range as can be seen in Fig. 12. The results from the test cubes indicate that the conductive concrete together with the wire mesh can provide structured SE over a broad frequency range, from the low frequency magnetic regime to the high frequency plane wave range.

Figure 12. SE of cube 5 with two very fine wire mesh.

V. CONCLUSIONS

In this work, we demonstrated that the concept of using conductive concrete for building shielded structures is feasible with standard construction practices. Embedding wire mesh structures in concrete is not a new construction concept and would need to be considered in the design of conductive concrete building for EM shielding. The conductive concrete mixture must employ additive conductive materials and incorporate embedded structures to achieve SE over a broad frequency range. We demonstrated that embedding a multi-layer, 2-in welded wire mesh configuration in the conductive concrete would increase the SE in the magnetic field regime to within 20 dB of the mil-std requirements and exceed the SE requirements in the resonant and plane wave regime by 20 dB above 100 MHz. The results provide a basis for further modifications, for example using 1-in or very fine wire mesh, and should lead to a cost-effective shielding material and construction method for structured shielding that would meet the mil-std SE requirements.

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