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Conductive Concrete: A Shielding Construction Material

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CONDUCTIVE CONCRETE: A SHIELDING CONSTRUCTION MATERIAL

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Introduction

Shielding against electromagnetic phenomenon is an increasingly important consideration on a global scale. Solar storms, privacy from electronic surveillance, and EMP weapons are just a few of the concerns that must be addressed. Current methods of protection are subject to high cost and often limited in scalability. Conductive concrete is a promising solution to both of these limitations. By adding several simple materials to traditional concrete, a new type of constructible electromagnetic shield can be produced. The following will discuss the design and testing of conductive concrete for EM shielding as well as the results of those tests.

Design

Conductive concrete was originally developed for the purpose of creating a conductive medium that could be used for deicing walkways and roadways.[1] To accomplish this, conductive fibers are mixed with traditional concrete to increase the conduction of electricity. Carbon powder is added to the mixture in order to facilitate connections between fibers and ensure good conductivity. This creates an interconnected mesh of fibers throughout the concrete. This attribute spurred the idea of using conductive concrete for shielding due to the possibility of creating an electromagnetic-reflective material. Such a reflective shielding was deemed inadequate for the range of frequencies required by MIL-STD-188-125-1.[2] For the higher frequency requirements EM absorbent aggregates, known as taconite,[3] were included in the mixture. Taconite is an iron-bearing rock that has good magnetic properties with excellent RF energy absorption. This improves the shielding performance of conductive concrete by enhancing the absorption of EM energy in the high frequency region.

Testing

Testing of the conductive concrete was accomplished in two stages. The first stage employed relatively small concrete samples and the EM-2107A test fixture from Electro-Metrics.[4] Figure 1 shows the test fixture which is an enlarged coaxial transmission line and fully complies with ATSM test method D4935-1.[5] The fixture connects to a two-port network analyzer so that the S21 measurements, used in this test to determine the relative attenuation, can be taken for test samples that have been placed between the two halves of the test fixture as shown in Figure 2. Figure 3 illustrates an example pair of samples to determine the relative attenuation of the conductive concrete. The reference set of samples consists of an outer ring that matches to the outside surface and a small disk made to fit the inner conductor. This arrangement allows EM energy to pass through the small disk as well as around it. The second load sample of the pair is a large, solid disk that covers the entirety of the test fixture. The difference of the S21 measurements for the samples determines the relative attenuation of the concrete mixture. Test samples were prepared to observe the effects of different combinations of conductive ingredients on the shielding properties of the concrete. Using this method, we were able to compare and determine the conductive concrete mixtures that would be effective in attenuating EM energy.

Figure 1. EM-2107A test fixture with conductive elastomer gasket to facilitate mounting of specimens.

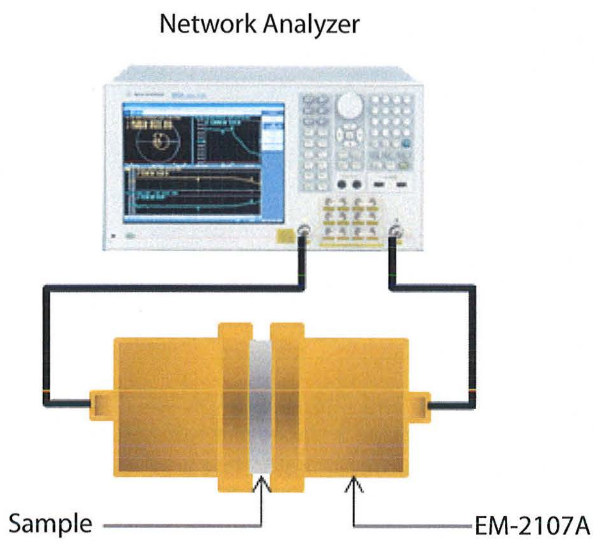

Figure 2. Test setup with sample loaded.

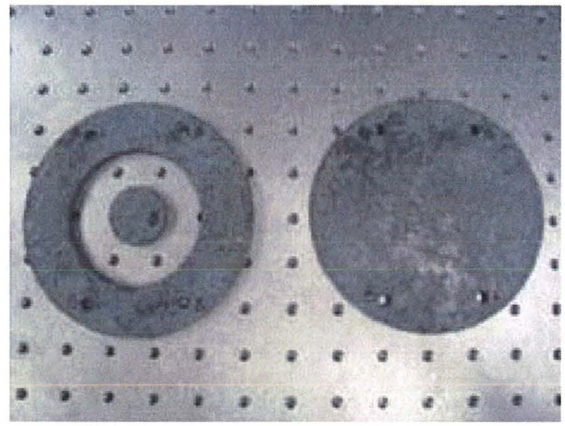

Figure 3. Example specimen set of reference and load samples.

The second stage of testing employed an RF shelter and was conducted on larger concrete test slabs of varying thicknesses. The diagram in Figure 4 shows the setup for slab testing using the RF shelter. Figure 5 shows an example test slab of 2 ft. square covering a 4 in. test port that has been cut out from the wall of the RF shelter. The RF enclosure ensures that any energy entering the inside of the shelter must pass through the test port. So by blocking the test port with the test slab, it can be determined how much energy is dissipated by the concrete slab prior to entering the structure. To ensure that adequate electrical contact was maintained between the concrete slabs and the shelter, concrete was cast directly on a 2 ft. square steel plate with a 4 in. hole centered to match the test port. Conductive gaskets made of woven copper were used to provide good contact between the RF shelter and the steel plates as shown in Figure 6. A transmitting source is placed outside of the structure and is paired with a receiver positioned inside the structure at a 10 ft. stand-off distance. To calibrate the system, a measurement is taken with no slab present over the test port to determine the nominal level of EM energy penetrating through the open test port. This establishes a baseline for comparing the levels of energy penetrating through the individual concrete slabs positioned over the test port. This is important due to the size of the test port having a large effect on the dynamic range of the system. Following a proper calibration, the slab is placed over the test port and a new measurement is taken. This measurement can be used to determine the effectiveness of the conductive concrete at blocking EM energy by comparing the amount of power received with the concrete in place to the power received with an open port. The recipes used for casting test slabs included basic concrete, the mixture that had been determined from small sample testing, as well as mixture with various construction elements including rebar.

Initial testing revealed that the small test port has a limited dynamic range for frequencies below 100 MHz. As a result, the slabs were redesigned to include a small hemispherical dome that allows small receiving antennas to extend through the test port, as seen in Figure 7. This increases the overall thickness of the slabs but maintains the appropriate thickness between the receive antenna and the environment on the opposite side of the slab, while greatly increasing the dynamic range. This configuration reduces the effect of the size of the test port on the relative attenuation measurements at lower frequencies. A second source of possible measurement interference is RF leakage through the side surfaces of the test slabs. With the addition of the dome structure to the test slabs, the overall thickness outwards is increased while the distance from the test port to the sides of the slab remained the same. This introduced the possibility of energy "leaking" through the side surfaces of the slab and into the test port as well. This effect was mitigated by coating the four sides of the test slab with electrically conductive paint, leaving only the main 2 ft. square frontal surface of the slab susceptible to EM energy.

Results and Discussion

Testing of the conductive concrete has yielded promising results. Through the small sample tests, a design mixture was chosen that has been proven to work well under RF shelter testing. Results from both methods of testing are discussed below.

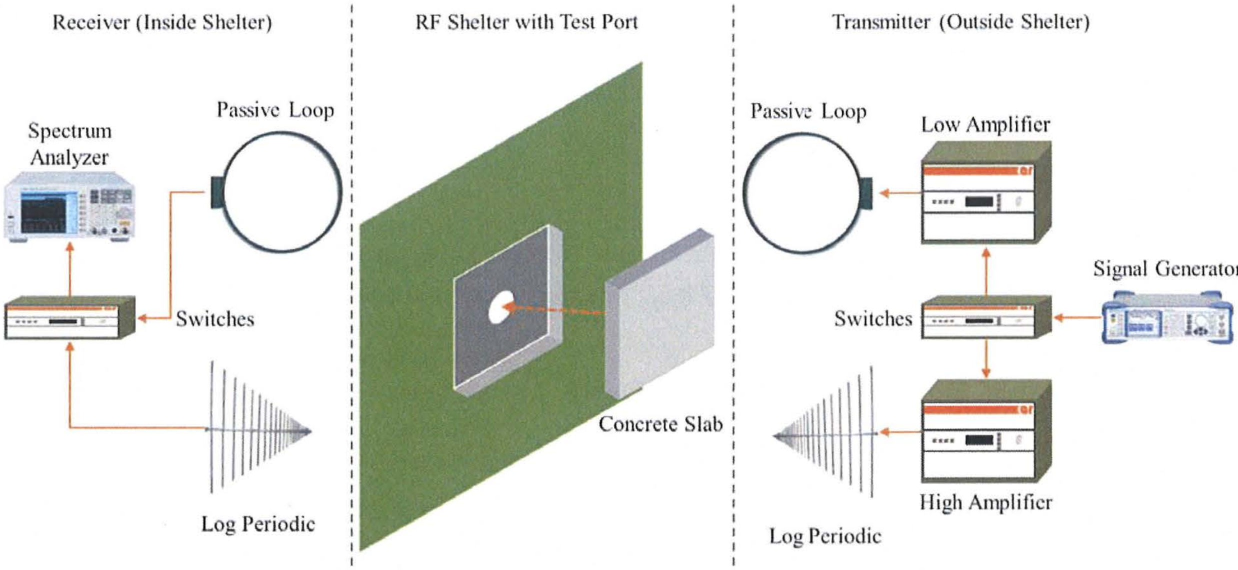

Figure 4. Test setup for large concrete slab testing.

Figure 5. Concrete slab mounted on the outside wall of RF shelter.

Figure 7. Test port with small antenna inserted within the slab using the dome configuration.

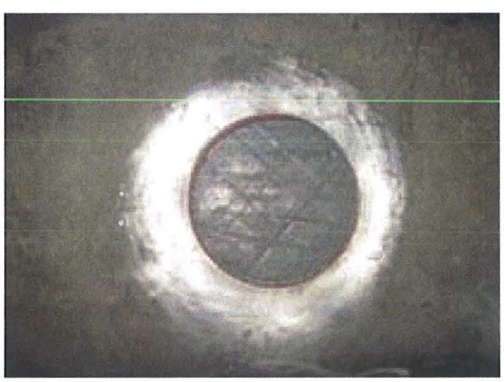

Figure 6. Test port of RF shelter seen from the inside with concrete slab and copper gasket.

Test Fixture

The results for small samples were produced using the EM-2107A test fixture. Figure 8 shows the relative attenuation, or S21, of a mixture comprised of carbon powder and steel fibers. It can be seen that the mixture performs well at the lower frequencies but loses some effectiveness in the higher frequency range. This effect led to the inclusion of taconites as the EM absorptive aggregates. Notice that the relative attenuation measured using this method is relative to the sample size and not indicative of the attenuation for larger samples.

Figure 9 plots the relative attenuation of a conductive concrete mixture comprised of carbon powder, steel fibers, and taconites. Compared to the mixture in Figure 8 ~~7~~, there is significant attenuation above 1 GHz that can be attributed to the taconite aggregates in the concrete mixture. The difference in the low frequency range for the

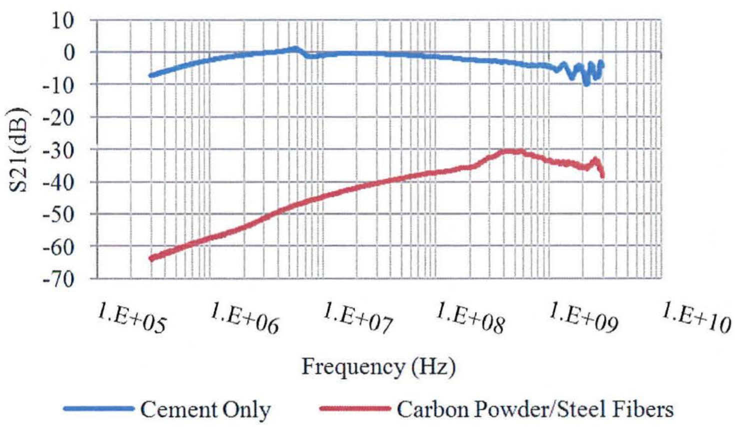

Figure 8. S21 of 0.25 in. samples.

mixtures in Figures 7 and 8 can be attributed to the variation in the casting of the specimens.

Figure 10 compares the conductive concrete samples of varying thicknesses using the test fixture. For each measurement, the sample thickness is increase by a quarter of an inch from 0.25 in. to 0.75 in. The results clearly show that the attenuation increases as the concrete becomes thicker. The increase, however, is not uniform with thicknesses and across the frequency range. This can be attributed to a number of factors that include non-linear response of the test fixture, effects of the specimens not being electrically thin, variation in the casting of the specimens, and the variable attenuation of the conductive ingredients themselves.

RF Shelter

Figures 11 through 13 present the large scale test results using the RF shelter for the conductive concrete slabs in the dome configuration. The test slabs were cast with a mixture composed of carbon powder, steel fibers, and taconites. Figure 10 plots the relative attenuations of a 3 in. thick test slab and also the dynamic ranges (DR) of the test configuration with the small rubber duck and loop receiving antennas positioned through the test port and inside the concrete domes. The plots show that the relative attenuation of the test slab above 100 MHz is in near compliance with the HEMP standard for shielding effectiveness. The difference between the rubber duck and the loop antenna in the lower frequency range is due to the effect of the dome configuration on the decoupled EM fields below 100 MHz. Notice that the broad loop antenna resonance through the test port also affects the results below 10 MHz.

In order to investigate the relation between the slab thickness and the relative attenuation, we also tested additional conductive concrete slabs with increased thicknesses. The results for the 6 in. and 12 in. slabs that were cast with the same mixture in the 3 in. slab are plotted in Figures 11 and 12, respectively. The higher frequency attenuation improves with thickness as expected, while the lower frequency attenuation decreases marginally. The improvement can be attributed to increase in the penetration depth especially through the taconite aggregates in the slab. The marginal reduction can be attributed to the increased leakage along the edges of the thicker concrete slabs. This effect is expected to diminish with a fully enclosed concrete structure.

To investigate the effect of RF leakage around the sides of the test slabs, the side surfaces of the 3 in. slab with the dome configuration was coated with conductive paint. The paint was added in several coats to ensure a highly conductive coating on four of the five exposed sides. The slab was then retested for comparison of the original test documented in Figure 11. The results in Figure 14 demonstrate that the conductive paint had a large effect on mitigating the RF leakage through the side surfaces above 200 MHz.

Conclusion

We have conducted a preliminary study to develop the conductive concrete mixture for EM shielding applications. The results that have been obtained through testing of the small concrete samples and the large-scale test slabs demonstrate that conductive concrete has the potential to provide EM shielding for large building structures. The concrete performs extremely well in the higher frequency ranges that exceed 80 dB of attenuation for a 6 in test slab. The performance in the lower frequency range is limited by the test configuration and the size of the test slabs. Further study is currently underway that will provide more evidence for the application of conductive concrete to provide shielding against electromagnetic energy.[6]

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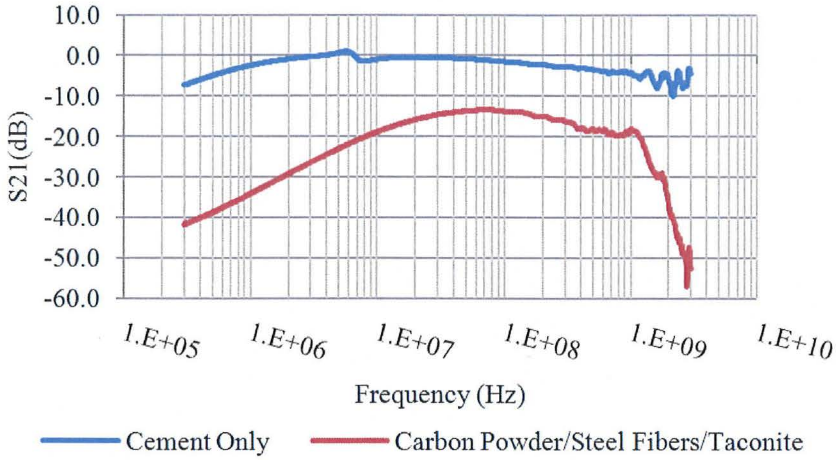

Figure 9. S21 of 0.25 in. samples.

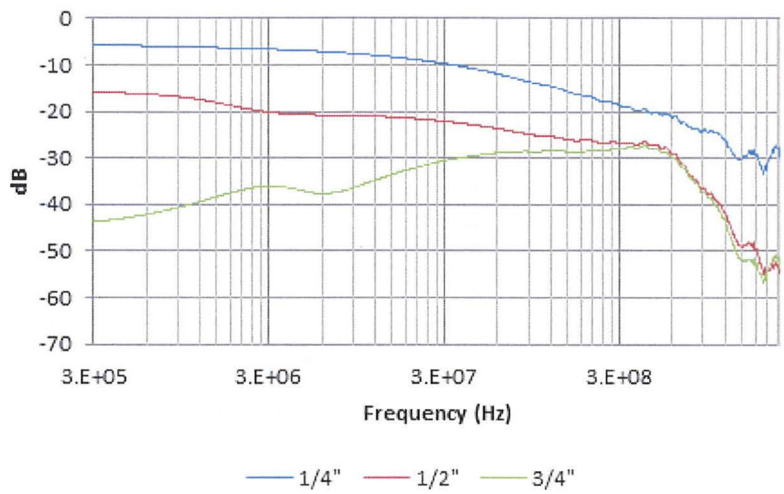

Figure 10. S21 of different thicknesses for cement, carbon powder, steel fibers, and taconite mixture.

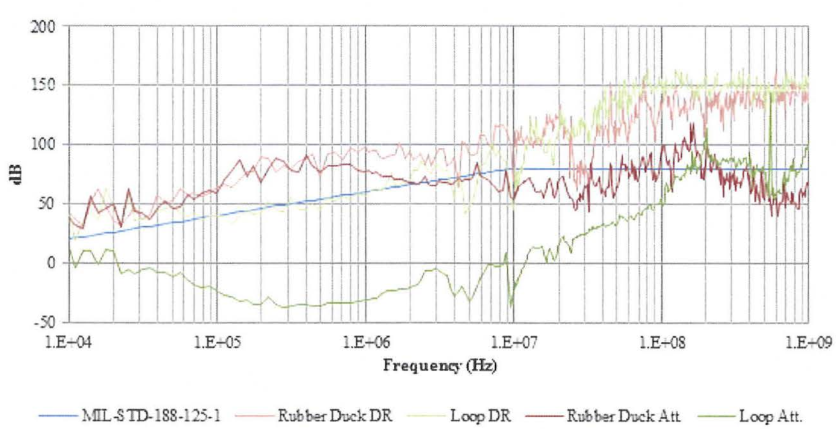

Figure 11. Relative attenuation of 3 in. conductive concrete dome configuration.

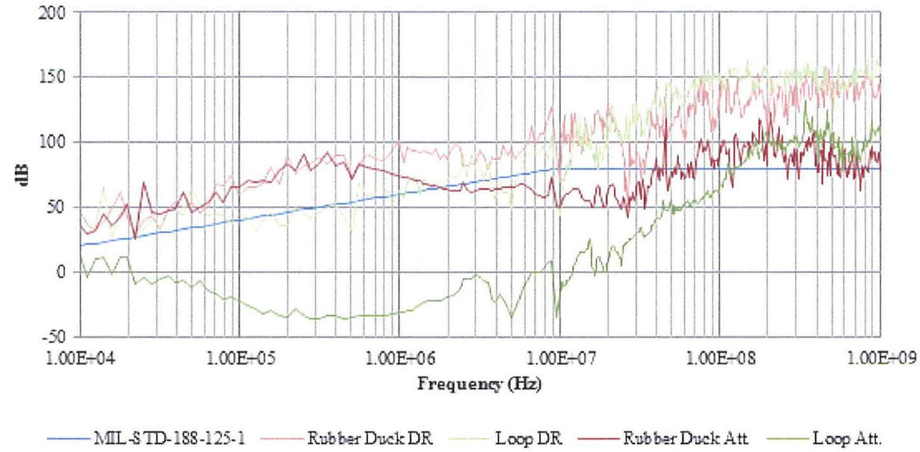

Figure 12. Relative attenuation of 6 in. conductive concrete dome configuration.

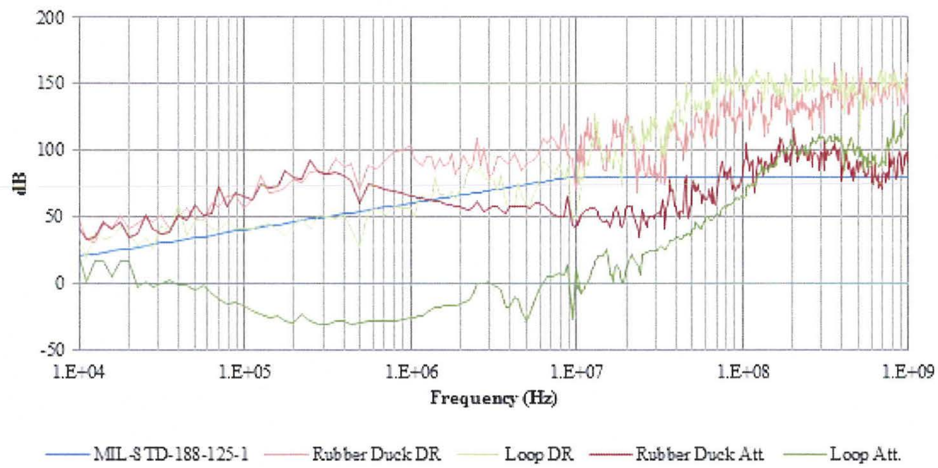

Figure 13. Relative attenuation of 12 in. conductive concrete dome configuration.

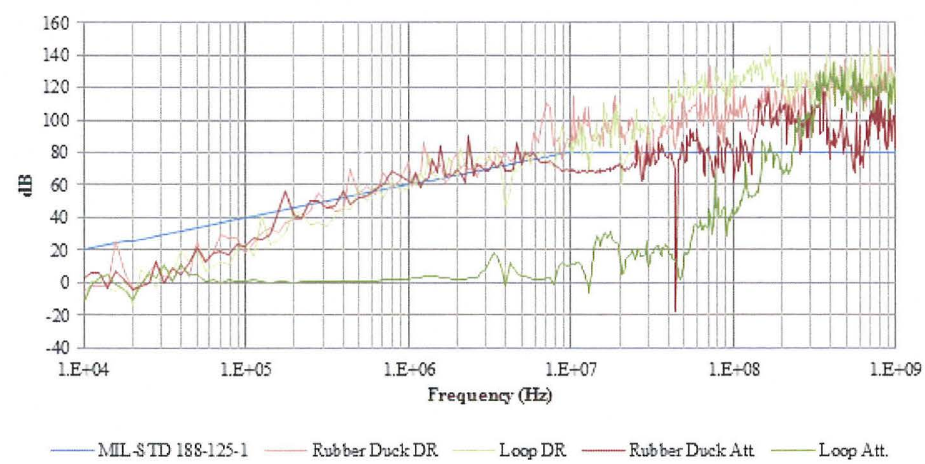

Figure 14. Relative attenuation of 3 in. concrete dome configuration with conductive paint.

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