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***Abstract*— Conductive concrete mixture was originally developed for surface de-icing purposes but can be designed to perform as an electromagnetic shield. Testing procedures have been developed to measure the attenuation provided by conductive concrete without the cost and labor of building a large structure. This paper provides a description of the design, testing methods, and results obtained from the development of conductive concrete as an electromagnetic shielding material.**

Keywords- Conductive concrete, electromagnetic, shielding

I. INTRODUCTION

Electromagnetic (EM) shielding is a growing concern as technology progresses. Increased use of EM-sensitive equipment has led to interest in more affordable and scalable shielding materials. By mixing in several simple materials, basic concrete can be enhanced to offer protection against EM wave penetration into the structures. In this paper, we report the design, test procedures, and results conductive concrete has yielded in the area of EM shielding.

II. DESIGN APPROACH

Conductive concrete research has been towards de-icing applications for roadways and walk-ways [1]. For this purpose, a material was needed that would be robust enough to support traffic and conduct electricity as well. This has been achieved by enhancing the normal concrete mixture with steel fibers in order to create an electrically conductive network inside the concrete structure. Carbon powder is also included to increase the connectivity between individual fibers and increase the bulk conductivity. The wire mesh, created by the steel fibers and carbon powder, led to the possibility of the concrete's use as an electromagnetically reflective and absorbing material. Initial testing, discussed in a later section, had shown the concrete mixture did not perform as well at high frequencies, leading to the addition of the taconite aggregates. Taconite is an iron-bearing rock with good EM wave absorptive properties [2]. The addition of this material provides better attenuation in the higher frequency range, yielding shielding effectiveness (SE) results potentially exceeding the requirements in MIL-STD-188-125-1 [3].

III. EXPERIMENTAL APPROACH

Various conductive concrete mixtures were developed and evaluated for SE using small sample testing. The test results were analyzed to determine the best mixture that was then employed to cast larger specimens for further testing and evaluation.

A. Small Sample Testing

The first stage of testing consists of using small concrete samples of differing mixtures to determine a mixture design consisting of reflective and absorptive components that perform well together. The small sample testing is accomplished using the EM-2107A test fixture from Electro-Metrics [4] as seen in Fig. 1. The test fixture fully complies with ASTM test method D4935-10 and thus has been used to compare shielding effectiveness [5]. This fixture is designed to be an enlarged section of coaxial transmission line that can be separated to allow for the inclusion and testing of planar materials. The test fixture is connected to a network analyzer while a sample is secured between the two coaxial halves. The network analyzer is then used to measure the insertion loss, or S21, of the reference and load samples which were fabricated from the same concrete mixture. The ratio of the S21 values provides a measure of the material SE. Thus, the small sample testing can provide a rough estimate of the effect that different components may have on the shielding capabilities of conductive concrete. The results can aid in the development of an effective conductive mixture for casting large samples for further evaluation. The small sample testing therefore helps to reduce the expense and labor needed to construct and evaluate large concrete samples by limiting the sample casting to the best mixture.

Fig. 1 Small sample testing with EM-2107A fixture and network analyzer

B. RF Shelter Testing

The second stage of testing utilizes larger samples cast from the best mixture develop from the small sample tests. Large sample testing provides a more accurate representation of the attenuation effects of the conductive concrete. The test configuration involves the use of a radio-frequency (RF) shelter and conductive concrete slabs. A test port is prepared

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on the side of the RF shelter. This allows EM waves to penetrate through one opening on the shelter that can be measured with receiving antennas positioned on the inside. The test port is 4-inch in diameter, as seen in Figure 2, in order to make the size of the test slabs manageable. The conductive concrete test slabs were cast with the best mixture determined from the small sample testing. The casting was poured on a 2-foot square plate of steel pre-cut with a 4-inch aperture on center to match the test port. Steel plates are used to ensure good electrical contact between the concrete slab and RF shelter. RF copper gaskets are placed between the two surfaces to provide an RF seal between the steel plate and the shelter wall. Figure 3 shows the conductive concrete slab is affixed to the RF shelter over the test port with sufficient clamping pressure to ensure electrical continuity between the steel plate and the shelter.


Fig. 2 Mounted concrete slab at test port viewed from inside RF shelter


Fig. 3 Concrete slab mounted to exterior of RF shelter

RF measurements can be performed between the transmitting antennas outside the shelter and receiving antennas inside. With the shelter sealed in this manner, the relative attenuation of the concrete slab can be observed across the frequency range specified in MIL-STD-188-125-1. These measurements can be used to give useful information data on the potential of the conductive concrete to provide shielding effectiveness to the building enclosure. Slabs are constructed using selected mixtures to investigate the contribution of the different components used to make the concrete. Slab thickness from 3 inches to 12 inches was produced for each mixture in order to determine the relative attenuation improvement as the slab thickness increases. One important consideration of the testing setup is the limited aperture of the test port. Using a 4-inch port is more economical and more manageable when considering the size of slabs used for testing and the existing wall structure of the shelter. However, the 4-inch test port behaves as an aperture below cut-off attenuating lower frequency EM waves, reducing the dynamic range of the test configuration below 100 MHz significantly. The dynamic range problem was mitigated by casting the 2-foot square concrete test slabs with a 4-inch hemispherical dome cavity 6 inches in depth to match the size of the test port. As seen in Figure 4, the structure allows a small probe antenna to extend outside the shelter through the test port while still being encased in the conductive concrete dome. This configuration increases the dynamic range and permits measurements in lower frequencies range.


Fig. 4 Monopole antenna extended into concrete dome from inside the sheter

Another factor taken into consideration was the potential RF leakage from the four sides of the concrete slabs. Preferably, the EM waves would penetrate the test port only through the concrete in a direction perpendicular to the front surface. However, due to the concrete thickness, the sides of the slab are exposed and can potentially introduce RF leakage into the test port, reducing the relative attenuation provided by the slab. A mitigation measure was taken by applying conductive paint to the four sides of the slab and grounding the paint coats to the steel plate backing.

IV. EXPERIMENTAL RESULTS

Conductive concrete test slabs of various sizes were cast to determine the relative attenuation using the above test configuration. The concrete mixtures were enhanced with carbon powder, steel fibers, and taconite. Each slab was cast in the dome configuration as described above. Figures 5, 6 and 7 plot the measurement results of the 3-inch, 6-inch and 12-inch slabs over the 10 kHz to 1 GHz frequency range. Small receiving monopole and loop antennas were extended through the test port. The relative attenuation is the difference in dB between the receiving signal levels without the test slab and with the antennas enclosed by the concrete dome structure. Figure 5 shows the relative attenuation with the rubber duck (monopole) antenna nearly complies with the MIL-STD. The discrepancy between the loop and monopole antenna in the lower frequency range can be attributed to the resonance effect of the RF shelter on the loop antenna and as well as the influence of the test configuration on the magnetic fields toward frequency below 100 MHz.

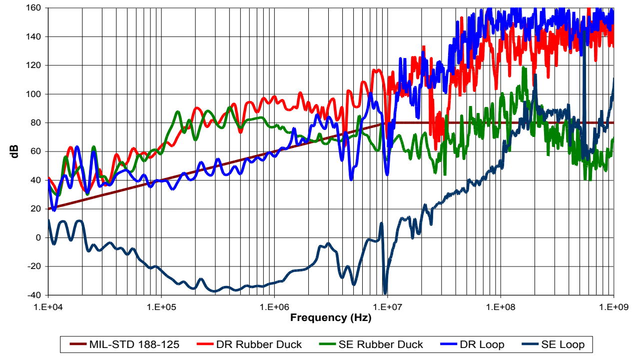

Fig. 5 Relative attenuation of 3-in. conductive concrete dome configuration

In comparison, the results in Figures 6 and 7 indicate the relative attenuation generally improves with the slab thickness. The plots show the high frequency attenuation has the 60 dB/decade absorption characteristic above 20 MHz, achieving better than 80 dB above 100 MHz. The low frequency results differ strikingly between the rubber duck and loop antennas. The loop antenna has the characteristic resonance effect that is broad and very consistent below 10 MHz. The rubber duck on the other hand was able to yield more useful information about the low frequency attenuation which exceeds the MIL-STD. In particular, the attenuation results from the rubber duck show the characteristic 20 dB per decade increase toward lower frequency, which is indicative of a reflective effect, until the dynamic range (DR) limits the measurable attenuation.

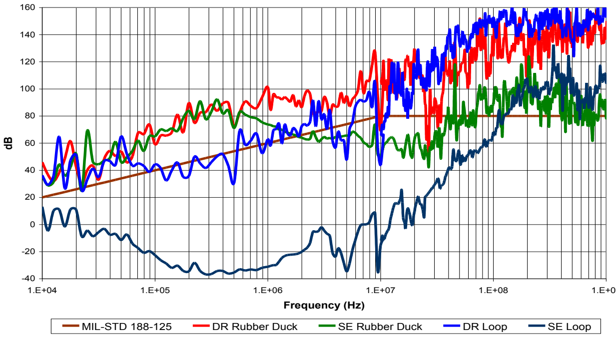

Fig. 6 Relative attenuation of 6-in. conductive concrete dome configuration

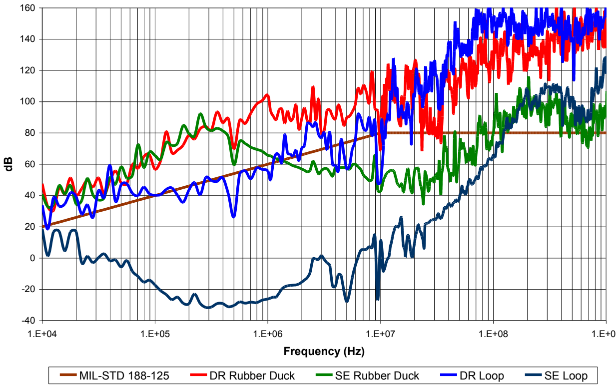

Fig. 7 Relative attenuation of 12-in. conductive concrete dome configuration

In order to evaluate the leakage effects from the four sides of the test slabs, the 3-inch concrete dome was reconfigured with conductive paint and re-tested for comparison to the results in Figure 5. The relative attenuation results are plotted in Figure 8. The re-testing was performed without the low-noise amplifier and so the DR differences are 40 dB in the low frequency and 20 dB toward the high frequency range. A comparison between Figures 5 and 8 indicates the conductive paint on the four sides evidently has mitigated the leakage as the high frequency attenuation has clearly improved by approximately 40 dB above 200 MHz. Further comparison between Figures 5 and 8 indicates the effect of the RF enclosure on the loop antenna is considerable below 10 MHz (but not so much on the rubber duck). This suggests the dome test configuration could affect the low frequency magnetic fields significantly.

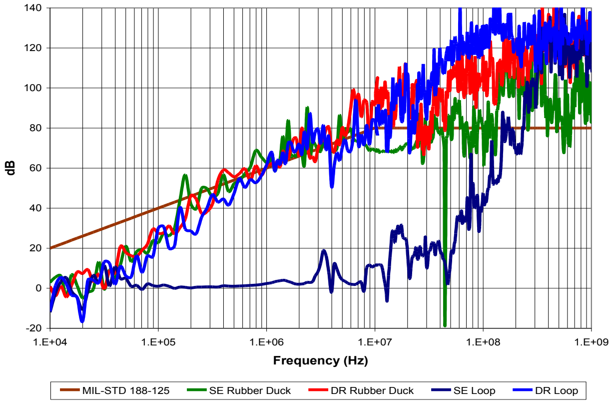

Fig. 8 Relative attenuation of 3-in. concrete dome with conductive paint

V. CONCLUSIONS

In this paper, we reported the development of conductive concrete mixture with adequate properties for use as an electromagnetic shielding material. The test results indicate that concrete mixture holds promise for providing large-scale EM shielding of building structures. EM wave measurements demonstrated that the relative attenuation of a 12in thick concrete enclosure could easily exceed 80 dB in the high frequency range. The results on the low frequency attenuation of the magnetic field remain inconclusive due to the test configuration. Efforts are underway to construct a conductive concrete shelter for MIL-STD measurements of the shielding effectiveness.

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