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ArmaKap Cementitious Formulation for Protecting Spent Nuclear Fuel and Radioactive Waste

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1 Background

As the nation is waiting for a permanent solution to the storage of spent nuclear fuel and other high level radioactive waste, there is an acute need to provide cost-effective environmental barriers to prevent radioactive contamination from the hundreds of nuclear waste sites across the country. Many of these temporary sites date back to the early days of nuclear testing and reactor development, and are not designed for long-time storage. Figure 1 shows the waste disposal at a site called Material Disposal Area (MDA) A, at the Los Alamos National Laboratory (LANL) dating back to 1945, when nuclear materials development was at its infancy. Currently, the contents of that MDA are only partially known; similar waste disposal conditions and sites are known to exist at other locations across America as well.

Figure 1. A photograph of waste disposal at MDA A in 1945 (LANL photograph IM-9: 2284) [1]

Over time, waste disposal and management has become more regulated, but many such sites exist with haphazard (even undocumented) storage of potentially radioactive and chemically corrosive compounds. Thus, potential for accidents and exposure remains high at these sites, as exemplified by the recent tunnel collapse at the Hanford nuclear waste site [2]; this site lies only 200 miles from Seattle – so any potential accidents can have widespread effects. Further, there are no permanent storage sites approved for the spent nuclear fuel from the hundred odd commercial reactors. With the cessation of funding to the Yucca Mountain nuclear waste repository, nuclear reactors and sites that generate high level nuclear waste must store their spent fuel on site for many years to come potentially leaving the storage casks open to the elements (severe erosion, corrosion), seismic activity, or potential foreign or domestic attack. Unlike in countries such as France, where the high level nuclear waste is stored in permanent underground facilities, the risks of inadvertent mishaps or accidents remain rather high at the US spent fuel and nuclear waste sites.

2 Cementitious Formulation Solution from Armakap Technologies

Using a novel composition, Armakap Technologies [3] has been able to produce a formulation of cementitious formulation that achieves a high degree of radiation attenuation while offering superior mechanical and thermal properties, among other factors, relative to traditional cement composition. The elevated base mechanical strength not only indicates an improvement over the traditionally used cement, but also significantly enhances the possibility for incorporating beneficial additives that can optimize radioactive shielding, corrosion and thermal properties. In order to optimize the composition, multiple additives have been tested in various combinations and amounts. Figure 2 shows a select few of these innovative cement samples used in the tests.

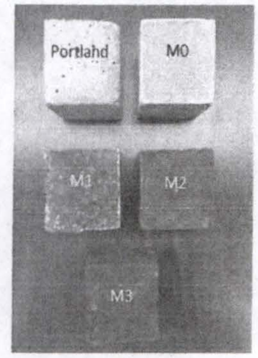


Figure 2. Select Armakap cementitious formulation samples used in testing at NC State University.

Radiation Shielding Tests: Ordinary Portland cement has been used as a control for all testing, in order to provide a direct comparison to the new Armakap samples. In Figure 2, M0 denotes the base Armakap cementitious formulation while M1, M2, and M3 are the three sample series with different additive compositions to enhance shielding and thermo-mechanical properties. Within each series, multiple concentrations of additives have been tested in order to arrive at the optimal composition.

Shielding tests have been performed using the setup shown in Figure 3, which uses a state-of-art integrated radiation detector system; these tests determine the Linear Attenuation Coefficient (LAC), which is a direct measure of the ability of a material to stop nuclear radiation over a given distance. Thus, LAC is a metric that specifies the radiation shielding performance of the samples. The results of the first of these tests can be seen in Figure 4. Compared to the control material (ordinary Portland cement), the base Armakap cementitious formulation M0 achieves a 15% increase in the LAC. Two of the samples, M3(5) and M3(9) are able achieve an impressive LAC, which are 53% and 86% higher, respectively, relative to the Portland cement. This increase in the LAC corresponds to the ability to shield the same amount of radiation with less material thickness (see Figure 5). For a radiation reduction of 99.995%, a shield using ordinary Portland cement would need to be 26.75 in thick; in contrast, shields of M0, M3(5), and M3(9) would need thicknesses of only 24.55 in, 18.59 in, and 15.16 in, respectively, signifying considerable cost saving.

Figure 3. Radiation shielding test setup at NC State University.

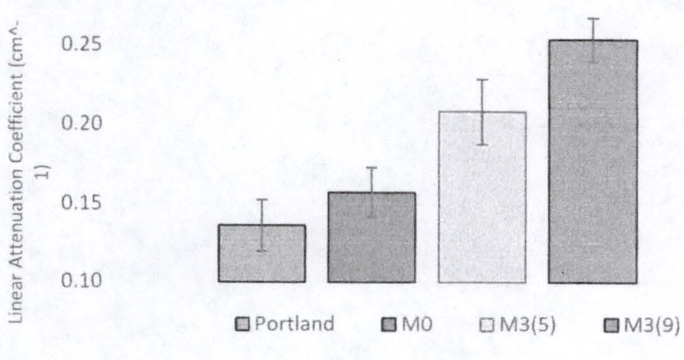


Figure 4. The average linear attenuation coefficients (LAC) of three Armakap cementitious formulation compositions, along with that of Portland cement.

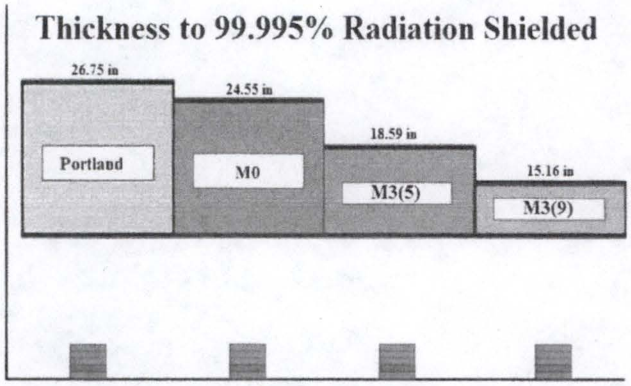


Figure 5. A graphic depicting the sample thickness to shield 99.995% of the gamma rays. As evident, M3(9) needs a significantly lower thickness to shield the same level of nuclear radiation; this directly correlates to lower materials cost.

Mechanical Tests: Mechanical tests have been performed on site at the Armakap Technologies manufacturing facility, using a Forney compression machine, and the results are shown in Figure 6. These tests provide a quantitative metric for the mechanical strength when the samples are subjected to a compressive stress. The lowest displayed compression stress (2000 psi) is that of Portland, so any increase that is visible represents an increase over the Portland composition.

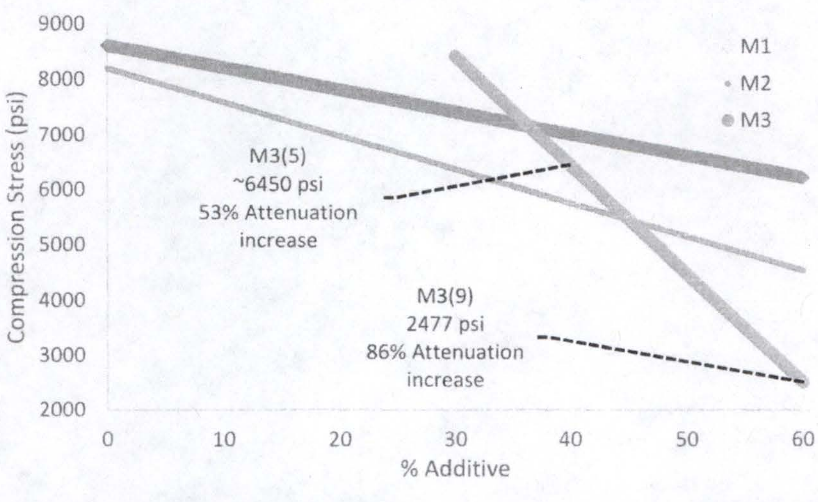
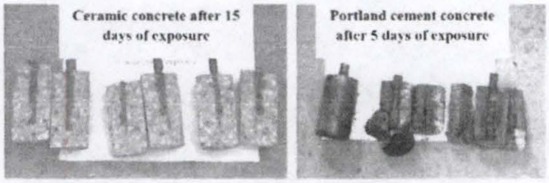


Figure 6. Compressive stress of various compositions of Armakap cementitious formulation as a function of additive proportion. With 40% additives, the M3(5) formulation has a compressive strength of ~6450 psi which is 325 % above Portland cement. At the same time, the radiation shielding efficiency increases by 53%.

As evident from Figure 6, all of the Armakap samples have significantly superior compressive strengths relative to the Portland cement (2000 psi). We note here that M3(5) has a 53% increase in the radiation shielding performance while having a compressive strength of ~6450 psi, which is 325% more than that of Portland cement. When the proportion of the additives is increased to 60%, the radiation attenuation increases to 86% however compressive strength is reduced (although still higher than Portland cement).

Thus M3(9) is clearly superior with regards to radiation attenuation, but the tradeoff comes with a reduction in the mechanical strength. Based on several tests, we have identified that M3(5), which demonstrates a 53% increase in linear attenuation coefficient for radiation shielding, as well as a 340% increase in the compressive stress, is a superior formulation of Armakap cementitious formulation for the proposed radiation shielding and nuclear waste protection application.

Fire Tests: ASTM E-119 (at Armakap): Fire tests were conducted at 1950 F for 3 hours followed by pressurized cold water quenching with 12 ft x 8 ft x 1 inch samples (see left). While Armakap cement lasted the test conditions without any structural damage, samples with traditional concrete disintegrated. These tests again show how Armakap cement formulation is superior to conventional cement for protecting nuclear waste materials from potential fires or thermal reactions, which already occur in multiple situations, such as the Waste Isolation Pilot Plan (WIPP).



Corrosion Tests: Several nuclear waste sites are located near the oceans, so protective structures should be built withstand a saline environment for long periods of time. Armakap has conducted several limited-time tests in sodium chloride solutions and all the samples lasted without any noticeable damage. These accelerated corrosion tests in very high salt concentrations again showed the durability of Armakap cement in extreme environments; in contrast, traditional cement formulations quickly corroded that resulted in precipitous reduction in thermo-mechanical-chemical properties.

3 Summary: This is a brief summary based on several tests that have been performed with Armakap cement products. Based on true acid-base reactions, Armakap cementitious formulation, once catalyzed, will go to completion without the addition of plasticizers or superplasticizers or any other chemical additives. It is both self-firing and rapid-curing, with high bond strengths, compression strength, tensile strength, and impact strength. It is also highly impervious to external elements, like water and heat. Our tests show that Armakap cement has a high tolerance to heat with a temperature range that extends from -275 F to over 2000 F; the heat tolerance can be increased by a variety of natural aggregates. Radiation and mechanical tests further demonstrate that Armakap cementitious formulation can effectively protect nuclear waste with optimized properties to reduce materials costs. The application of cementitious formulation is fast and can be tailored to a wide variety of applications; in addition, repair work, if needed, is simple assuring fast return to service conditions with minimal downtime.

4 References:

[1] Los Alamos National Laboratory Newsroom: www.lanl.gov/newsroom/photo/index.php
[2] Bever, Lindsey, and Steven Mufson. "Tunnel Collapses at Hanford Nuclear Waste Site in Washington State." The Washington Post, WP Company, 9 May 2017.
[3] ARMAKAP - https://armakap.com/