THIS MONTH: **IMPACT OF CORROSION ON THE ENVIRONMENT**

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CORROSION PREVENTION AND CONTROL WORLDWIDE

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AMPP

Zirconia Inc. is Ending Concrete Corrosion

Figure 1 The Pantheon, Rome, Italy.

Concrete is an amazingly versatile material, and easily the most widely used structural building material on earth. From the 1840s, conventional hydrating cement (Portland cement) became widely used to make concrete and build the modern world. Since that time, the surface corrosion of concrete from carbonation, salts, and weathering has been the nemesis of concrete asset owners. All concrete structures big and small corrode from various forms of chemical erosion. This includes bridges, dams, condominiums, as well as simple sidewalks. In most environments, the horizontal surfaces of major concrete structures like dams are corroded within only 20 years. In my Seattle neighborhood, most sidewalks have long since lost their surface cement binder due to carbonation, leaving only a slippery aggregate, and encouraging slip-fall accidents that are common. But, well, it's just considered normal. Before now, there has been no answer to the surface vulnerability of concrete to corrosion.

In my recent tour of several Los Angeles County dams at the Dam Safety 2023 event, most of the horizontal surfaces had long since corroded away, leaving exposed aggregate, and the dam spillways surfaces were severely corroded to the point of structural decay. After chatting with many dam engineers at the event, it was obvious that the lack of technology to stop corrosion, much less technology to efficiently repair corrosion, has led to relative ambivalence to the problem. In the case of America's dams, the backlog of corroded concrete repair remains in the billions of dollars. Bridges and other major assets are also corroding away leaving the USA increasingly vulnerable to bridge failures, as well as catastrophically expensive repairs. Remember the 2017 Orville dam failure in northern California, USA? The whole dam cost $123 million to build, opening in 1968, and $1.1 billion to fix the spillway section alone, after the spillway corroded and cracked, leading to its collapse. Imagine that many of the USA's largest dams were built between 1920 and 1950, giving them decades longer to corrode. No surprise then, that the famous ASCE Infrastructure Report Card 2021 gives dams a D grade. This is of course just one example, and dams are big, often displaying concrete corrosion more readily. Certainly, we could discuss bridges, wastewater infrastructure or the other types of concrete assets. Overall, America's infrastructure gets a C- from ASCE, and much of the age-related degradation in this report's discussion on "aging" infrastructure is related to concrete corrosion.

Relatively young concrete-made assets corrode away here in the USA, while in old Europe, grand churches and famous structures like the Pantheon (Figure 1) and Colosseum (Figure 2) remain standing after several thousand years. The surfaces of these structures appear preserved over time, and carbonation damage does not appear present, despite their advanced age. Why?

In 1998 Dr. Perumalsamy Balaguru, a professor at Rutgers University's Engineering Department, decided to research what made old Roman cements last so long. This led him to the study of alumina-silicate polymers called "geopolymers." Geopolymers are "inorganic, typically ceramic, alumina-silicate forming long-range, covalently bonded, non-crystalline (amorphous) networks." What Balaguru discovered is that the Romans had invented a way to create man-made stone, similar to granite. Feldspar, to be precise (alumina-silicate polymer balance by potassium ions), which is a main mineral in granite—but let's just say granite for now. Intriguingly, the geopolymer manufacturing technology goes back in time to ancient Egypt, to a priest named Imhotep in 2600 B.C. Geopolymers, like their granite analogue, are incredibly durable. One important thing about geopolymers is that they are not affected by carbonation or salts in the same way as hydrated cements, meaning they don't corrode. Instead, they self-seal.

Balaguru decided to develop a coating that chemically bonds to and preserves concrete and steel surfaces, rather than replicate a bulk Roman mortar. Twenty-five years ago, he made the first version of a geopolymer coating, which we now call a Ceramic Surface Treatment (CST). Since Balaguru had no desire to make the product commercially available, it was many years later that his son, Muralee Balaguru, decided to assist in its commercialization and formed Zirconia Inc. in 2017.

This is where the history of ancient geopolymers and modern nano-ceramic technology really become relevant with regards to preserving modern hydrating concrete surfaces from corrosion. Our modern story begins here: All concrete corrosion happens from the surface inward, which is the primary way concrete assets age/corrode. As surface corrosion grows, the depth and erosive nature of corrosion gets worse. So, the more corrosion you have, the more you will have. This is corrosion escalation, and it's a big problem for asset owners. But what if it wasn't?

If you can significantly reduce concrete asset corrosion rates to near zero, this will extend asset life by many times its engineered lifespan. This is what geopolymers can do because of their unique chemical bonding behavior and extreme resistance to carbonation, salt corrosion, weathering, and wear abrasion. Additionally, geopolymer coatings increase in density and strength when exposed to environmental factors, including UV light, humidity, heat, and salt, which increase the self-sealing property of this technology. These environmental exposures are curing agents for inorganic geopolymer coatings. So, the same environmental factors that destroy organic paints, make geopolymer coatings virtually immortal.

In the warm, humid, sunny weather of South Florida's Miami-Dade County, the salty air corrodes the concrete away, exposing the reinforcing steel rebar, which also corrodes to dust. This led to the extraordinarily tragic condominium collapse that you have heard about, while also leading to bridge failures that require full demolition and reconstruction every 20 to 30 years due to salt spalling. You don't see this bridge issue in the news much, but it remains an economic disaster. A bridge should really last 100 years minimum to be a sustainable public investment. Zirconia's CeramycGuard can stop salt corrosion indefinitely, at a cost that might be less than \$0.01 on the dollar to major demolition and reconstruction, so we are hoping to save the bridges and condominiums starting in January 2024. Zirconia is expected to get material approval by Miami-Dade County by late December 2023, making Zirconia the first to bring a durable salt-corrosion-prevention coating past regulatory approval in the USA.

Zirconia came up with the term CST, because (a) we are not making paint like folks think of paint commonly, and (b) it describes what we are actually doing, which is forming a ceramic glass composite layer at the surface of concrete by using the special quantum properties of nanoparticles that can polymerize at room temperature due to their low energy of reaction—without a kiln.

Figure 2 The Colosseum, Rome, Italy.

Our CST coating, CeramycGuard, mixes as a three-part system, and applies like paint, with brush and roller. It applies as a thin, creamy exterior paint, but is actually a water-borne slurry of nanoparticles and micronized ceramics in a silicate binder solution (pH 14). This "green" coating technology is water-borne, and non-toxic to workers or the environment. It is thermally compatible with concrete, and immune to heat and cold, and weathering in general.

Getting back to the issue of bonding behavior, Zirconia's CeramycGuard coating has a few key traits that create aggressive chemical bonding with the concrete surface. The main driver is the reactive ceramic nanoparticle slurry that contains highly catalyzed oxygen atoms, which will bond with calcium, iron, silica, and other cations (positively charged ions). The inorganic polymerization is accelerated by this trait. Also, the CeramycGuard captures anions like oxygen to itself in a trade-secret manner, which binds all atoms with a negative charge. In short, this coating technology bonds all the elements in concrete together in a covalent and ionically bonded ceramic composite. It cannot be separated once cured, as there are no layers, just on composite system that is permanent.

CeramycGuard nano-ceramic technology heals and seals concrete, improving its physical structure and chemical stability, while reversing the damage done by decades of corrosion. In the process, it fills in pores, capillaries, as well as microscopic and macroscopic cracks, making the surface structure more resilient to chemical ingress and wear stress. With larger cracks, up to 0.25 in (6.35 mm), CeramycGuard acts like an inorganic glue and bonds the concrete back together.

At Rutgers University, Balaguru decided to test just how tough this technology is, compared with plastic coatings. Attempting to mimic a full range of climates, he created an accelerated weathering test, which went on for three months, and rotated though harsh environmental factors within each 24-h cycle, including:

- 8 h of salt spray with a 5% sodium chloride (NaCl) concentration
- 4 h of UVA/UVB and infrared heating to 140 °F
- 12 h of freezing down to –10 °F

In this case, the plastics were destroyed within a few weeks, but the CeramycGuard suffered no degradation, and only became denser. Funded with over \$2 million from

New Jersey DOT and U.S. DOT, Balaguru did multiple trials in the mid-2000s around the New Jersey area, which have survived freeze-thaw cycles, road salt, and UV for over a decade and still look like the day they were coated. This is in part due to the oxidative (antimicrobial) and photocatalytic nature of this technology, which has self-cleaning properties that inhibit biological life, allowing the concrete surface to remain looking clean.

Creating CeramycGuard could not have been possible prior to 2017, because the next generation of nano-ceramic particles had not become commercially available. We have been fortunate to be able to evolve the technology and subsequent patents for room temperature-cured CSTs within this current era of manufacturing. Zirconia has invented CST for concrete, steel, and galvanized steel, but due to the widespread issue of concrete corrosion, we decided to launch our CST for concrete first.

Zirconia's CeramycGuard coating technology can end the concrete corrosion cycle: corrode, demolish, rebuild, repeat. But, even with this amazing coating technology, it will take education, and consultants, specifiers, coatings experts, and applicators to accomplish our goals for more sustainable infrastructure. This is where AMPP guidelines for concrete preparation are incredibly beneficial to establish surface evaluation and preparation standards. In addition, project oversight by AMPP-certified inspectors will prove critical to our success.

New technology also creates new opportunities. Carbon credits may soon be coming to concrete asset owners helping to pay for infrastructure restoration with Zirconia's technology. Because Zirconia's coatings can save concrete and steel from being destroyed by corrosion, we feel it will be possible in the future to create carbon credits for preserving high-CO_2 concrete and steel assets from demolition and the need for reconstruction. After all, the "greenest" concrete infrastructure is one that does not need rebuilding. And, this prevention strategy avoids the manufacture of massive volumes of new concrete and steel, which account for 18% of global CO_2 emissions.

Zirconia's CST coatings will preserve the infrastructure that society relies on globally to thrive, protect commerce, our lifestyles, and our health. Zirconia is happy to save concrete from corroding, while encouraging the renovation of global infrastructure, preserving our climate from carbon emissions, and dramatically reducing the cost of concrete infrastructure ownership and maintenance. Zirconia is now working around the world to bring more sustainability to the built environment. Everybody wins. *MP*

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