Corrosion of Steel in Concrete

Problems and Prevention
Concrete is a marvel of modern-day engineering, a major cause of deterioration in concrete, incurring billions of dollars in repair costs annually. All too frequently, rehabilitation with conventional repair methods fail to provide a long-term solution and can contribute to the overall problem.

Corrosion of embedded reinforcing steel is a major cause of deterioration in concrete, incurring billions of dollars in repair costs annually. The Euclid Chemical Company proudly offers SENTINEL GL, SENTINEL SILVER, and SENTINEL GOLD. These galvanic anode devices are designed to combat the “anode ring effect,” thus allowing the owner to skip a repair cycle or two, which in turn saves thousands of dollars worth of repairs.

Additional Corrosion Passivation Products From Euclid Chemical Include:

DURALPREP 3202 is a water-based migrating corrosion inhibitor formulated to be typically applied to concrete. This innovative formula penetrates through the concrete and forms a monomolecular protective layer around reinforcing steel that drastically reduces corrosion.

DURALPAC A.C. easily applies to exposed steel to serve as an anti-corrosion coating and bonding agent prior to concrete repairs being made. Durapac A.C. is a water-based epoxy with a cementitious addition that is often mixed, provides a long open time for application and repairs can be made up to 26 hours later.

Baracade WB 244 is a water-based, silanesiloxane blended water repellent that is simply applied to concrete surfaces providing long lasting protection from water intrusion that may be carrying (Nordic detrimental to the concrete's reinforcement. Baracade WB 244 does not alter the appearance of concrete substrates.

EUCON CIA is a 30% calcium nitrite solution admixture. When mixed into fresh concrete, EUCON CIA inhibits the corrosion of steel reinforcement. EUCON CIA is compatible with all types of cements, pozzolans, and other admixtures.

Euclid Chemical Repair Mortars are available to complement the Sentinel Anodes. Currently there are more than 10 options to repair your next galvanic anode project. Each of these mortars has been certified to have under 15,000 ohm/cm of volumetric resistivity. For more information on how to repair your next project, please contact the Technical Services team at the phone numbers listed below.

The Anode Ring Effect

1. Chlorides begin to penetrate the concrete, usually as a result of exposure to deicing salt or sea salt. Eventually, a small amount of chloride ions move through the concrete to the reinforcing bars. As contamination progresses, chloride concentration levels at the surface eventually result in the corroded steel losing the protective oxide layer and becoming an anode. The anodic reaction is the oxidation of the steel. Electrons released at the anode move through the reinforcing bars to the cathode. The circuit is completed by chloride ions moving through the concrete toward the anode.

2. The cathodic reaction is the reduction of oxygen. Electrons released at the cathode are replenished from the reinforcing bars. The reinforcing bar becomes a cathode and the surrounding steel becomes a substitute anode.

3. Rust, the product of corrosion, occupies several times the volume of the parent steel. This volume expansion puts tremendous tensile stress on the cementitious matrix. As corrosion continues, the concrete cover breaks up further, and eventually results in the formation of a spall.

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5. The cathodic reaction is the reduction of oxygen. Electrons released at the cathode are replenished from the reinforcing bars. The reinforcing bar becomes a cathode and the surrounding steel becomes a substitute anode.

The Sentinel Solution

SENTINEL anodes are installed in the repair area on any size of reinforcing steel. This innovative formula penetrates through the concrete and forms a monomolecular protective layer around reinforcing steel that drastically reduces corrosion.
**Sentinel Galvanic Anodes**

provide state-of-the-art cathodic protection against the "anode ring effect". They are the only known powered corrosion solution of this scope and size, and they require less inspection and advanced structural tasks be cathodically protected. Unlike any innovative proprietary design, SENTINEL galvanic anodes apply cathodic protection technology to extend reinforced concrete structure to prevent rebar. 

**SENTINEL** galvanic anodes are a high-quality zinc pack that deliver long-lasting protection against corrosions. When a direct electrical connection is made between the zinc and steel, galvanic current from spontaneously or there is no need for an external power supply such as from a battery. This results in reduced installations, reduced post-maintenance costs, and improved safety. 

With a unique v-notch design, SENTINEL galvanic anodes are specifically engineered for easy, efficient placement on any type of reinforcing bar. SENTINEL galvanic anodes are placed beside the reinforcing bar in a manner that reduces the installation of the repair area, reducing labor requirements dramatically, resulting in significant cost savings.

**SENTINEL GL** has been the backbone of Euclid Chemical’s corrosion protection line for many years. Numerous projects have been and continue to be protected by the exceptional performance of the original Sentinel GL with its unique chemical composition and reinforcing design. This high performance galvanic anode has consistently outperformed competitors’ anodes in terms of corrosion in the harshest environments and will fit inside of 6” x 6” (15cm x 15cm) concrete. More current than the original Sentinel GL. This anode was designed to provide the maximum protective current for 10 to 20 years*.

**SENTINEL Silver** takes the same high performance aspects of the original Sentinel GL and expands upon them. With 153% more zinc, the Sentinel Silver and fabricate with the spalled concrete, while extending the service life of the repair area in environments:

**Applications - Sentinel Anodes** are ideal when repairs are needed on larger structures, extending the service life of the repair in the following environments:

- Parking garages
- Bridge decks and structures
- For and deck supports
- Tunnels
- Parsons walls

**Anode Spacing**

Sentinel GL and Silver Features

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</table>

**The Euclid Chemical Company**

is the industry’s premier product for galvanic anodes. Containing over 200 grams of high-quality zinc, this anode is manufactured to the highest standards of corrosion resistance in its new anode form. The self-generating current to remote reinforcing bar is a continually increasing ratio that brings to the maximum protective current for more than 2 years.

**Applications - Sentinel Anodes** are ideal when repairs are needed on larger structures, extending the service life of the repair in the following environments:

- Parking garages
- Bridge decks and structures
- For and deck supports
- Tunnels
- Parsons walls

**Anode Spacing**

**The Gold (and Silver) Standard in Zinc Anode Technology**

**SPECIFYING SENTINEL ANODES** can be prevented to significantly reduce the rehabilitation of existing concrete structures. These include parking garages, bridge decks, piers and deck supports, retaining walls, concrete columns, and arches. Specifying the use of cathodic protection is more effective if it can be applied early in the process, rather than as a last resort. In the case of rebar corrosion, the specified cathodic protection product should meet the following industry standard requirements:

- A cathodic protection device should be demonstrated to deliver a protective current in a repair area greater than 5.0 mA per sq. ft. after 30 days. The test should be performed in an environment that is maintained at room temperature and about 53% relative humidity. In addition, the test should be conducted in a concrete test block containing not more than 2.7 ft³ (0.065 m³) of reinforcing steel.

In order to take full advantage of cathodic protection technology to most effectively prevent corrosion in reinforcing steel, specify a cathodic protection device in combination with low resistance repair mortar. Low volumetric resistivity is necessary for products used with cathodic protection devices in which protective current is required to pass through the repair area. As a result, cathodic protection should be specified as a system. This comprehensive approach typically yields the best results.

**A COMPLETE CORROSION PREVENTION SYSTEM**

The Euclid Chemical Company offers a complete corrosion prevention system. These repair products meet the necessity for repair materials of cathodic protection products, which require a measurement below 15,000 ohm-cm measured on one of the test coupons.

**Depending on the repair application, the Euclid Chemical Company offers the specifying community a variety of options and provides technical support on an array of specially formulated repair mortars to use with the Sentinel anodes as total corrosion inhibiting solutions.**
**Sentinel Galvanic Anodes** provide state-of-the-art cathodic protection against the “anode ring effect.” Used in reinforced concrete structures, Sentinel anodes are the preferred solution because they prevent the “anode ring effect” and the damage it causes. The anode ring effect is a condition that occurs when cathodic protection is applied to concrete structures, leading to the creation of an area of localized corrosion around the anode. Sentinel anodes are engineered to prevent this effect and enhance the structural integrity of the repair area.

**Sentinel GL** is a high-quality zinc anode that delivers long-lasting protection against corrosion. When a direct electrical connection is made between the anode and rebar, galvanic current flows from the anode to the rebar, resulting in the protection of the rebar from corrosion. Sentinel GL anodes are designed to provide a protective current to the reinforcing steel, extending the service life of the repair in various environments.

**Sentinel Silver** is an enhanced anode that offers superior performance compared to Sentinel GL. It is specifically designed to provide more current than the original Sentinel GL. Sentinel Silver provides a higher level of protection, especially in environments where the “anode ring effect” is more pronounced. With its unique chemical composition and bar hugging design, Sentinel Silver is ideal for environments where high purity zinc is required. Sentinel Silver is engineered to provide beneficial corrosion current for many years, ensuring long service life and high performance.

**Sentinel Gold** is an anode that offers the highest performance on the market. It is engineered to provide an even higher level of protection than Sentinel Silver. Sentinel Gold is designed to provide an even higher level of current, making it ideal for environments where the highest level of protection is required. Sentinel Gold is specifically engineered for easy, efficient placement, and it can be securely mounted to rebar using strong, durable tie wires.

**Applications - Sentinel Anodes** can be specified for a wide range of applications, including:

- **Parking garages**
- **Bridge decks & structures**
- **Pier and dock supports**
- **Retaining walls**
- **Parking garages**
- **Concrete structures**
- **Ambient electrical conditions**
- **Cathodic protection devices**
- **Repair mortar materials**
- **Concrete repair materials**
- **Cathodic protection systems**
- **Reinforcing steel**
- **Concrete structures**
- **Wet environments**
- **Steel density - ft²/ft²**

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**Specifying Sentinel Anodes**:

Sentinel anodes can be specified for protection in reinforced concrete structures. They provide targeted performance benefits and are effective in both pre-cast and field-constructed concrete. Sentinel anodes are specifically designed to protect reinforcing steel in concrete structures while minimizing the risk of the “anode ring effect.”

**Anode Spacing**:

- **Very Corrosive**
- **Moderately Corrosive**

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**The Gold (and Silver) Standard in Zinc Anode Technology**

The Euclid Chemical Company offers the highest performance and most cost-effective cathodic protection solutions on the market. Sentinel Gold and Sentinel Silver are the gold and silver standards in zinc anode technology, providing the highest level of protection and the best cost-benefit advantage. Sentinel Gold and Sentinel Silver are specifically engineered to provide superior performance and reliability, ensuring long service life and high performance in the most challenging environments.

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**The Test**:

A cathodic protection device should be demonstrated to deliver a protective current in excess of 1.0 milliamps after 90 days. The test is used to verify that the specified cathodic protection device will meet the industry standard requirements. It is essential to specify a cathodic protection device that will deliver the required protective current to provide long-term protection against corrosion.

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**Technical Support**:

The Euclid Chemical Company offers expert technical support on a wide range of specially formulated repair mortars to use with the Sentinel anodes as a total corrosion inhibiting solution. Technical support is available to ensure that the anodes are installed correctly and that the repair work is performed to the highest standards.
**SENTINEL Galvanic Anodes**

**Applications**
- Parking garages
- Bridge decks & structures
- Tunnels
- Drainage structures
- Apartments & condominiums
- Pier and dock supports
- Retaining walls
- Tunnels
- Piers and bridge decks

**Sentinel GL, Silver and Gold Features**

*Current required to completely prevent corrosion of steel in concrete will vary with conditions, as will effective service life.*

When a direct electrical connection is made between the zinc and steel, galvanic current flows spontaneously so there is no need for an external power supply, DC, or contact. This results in reduced installation, maintenance and materials costs.

**Unique v-notch design**
- SENTINEL galvanic anodes are specifically engineered for easy, efficient placement on embedded rebar corrosion.
- With a unique v-notch configuration, SENTINEL galvanic anodes are specifically engineered for easy, efficient placement on electrical connection is made between the zinc and steel, galvanic current flows spontaneously so there is no need for an external power supply, DC, or contact. This results in reduced installation, maintenance and materials costs.

**SENTINEL GL**

**Cathodic Protection**
- SENTINEL GL galvanic anodes use a high quality zinc pack to deliver long-lasting protection against corrosion. When a direct electrical connection is made between the zinc and steel, galvanic current flows spontaneously so there is no need for an external power supply, DC, or contact. This results in reduced installation, maintenance and materials costs.

**Applications**
- Apartments & condominiums
- Parking garages
- Tunnels
- Retaining walls
- Pier and dock supports
- Piers and bridge decks

**Specifying Sentinel Anodes**

**Cathodic Protection**
- The Euclid Chemical Company recommends that its specially formulated line of patching mortar materials be used with SENTINEL, SENTINEL GL and SENTINEL silver as a corrosion control system. These repair products meet the necessity requirements demanded of both effective cathodic products necessary to prevent corrosion, thus requiring a measurement below 15,000 ohm-cm when measured after 28 days.

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**Cost Considerations**
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Corrosion of Steel in Concrete

Problems and Prevention
Concrete is one of the most widely used materials in the world, but it is a reactive material that can be susceptible to corrosion. Corrosion of embedded reinforcing steel is a major cause of deterioration in concrete, incurring billions of dollars in repair costs annually. All too frequently, rehabilitation with conventional repair methods fail to provide a long-term solution and can contribute to the overall problem.

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The Euclid Chemical Company proudly offers SENTINEL GL, SENTINEL SILVER and SENTINEL GOLD. These galvanic anode devices are designed to combat the “anode ring effect,” thus allowing the owner to skip a repair cycle or two, which in turn saves thousands of dollars worth of repairs.

**The Anode Ring Effect**

- Anodes begin to penetrate the concrete, usually as a result of exposure to seawater, deicing salts or the presence of chlorides in the concrete mix.
- As corrosion continues, chloride concentration levels at the surface of the reinforcing steel may exceed the critical pH level (at about 2 pH) for corrosion of steel (C = 1.0 lb/yd^3). The protection cathodic on the steel is decreased, allowing the anodic reaction to proceed. In other words, the corrosion cell is driven by the concentration of the anode material, which is usually a more concentrated chloride source.
- Anodes move through the reinforcing bars to the cathode. The circuit is completed by chloride ions moving through the concrete toward the anode.
- The conventional repair requires removal of the concrete patch. A new concrete patch is formed. The reinforcing bars are coated with a cathodic agent prior to concrete repairs being made. The corrosion of steel surrounding the patch becomes anodic, and a new corrosion cell is formed. The concrete cover limits the oxidation of iron to iron oxide, or rust.

- Cracking soon develops outside the patch, and repairing becomes a never-ending cycle. This opens another concrete patch, which is repaired in the same manner. This cycle continues, eventually resulting in the formation of a spall.

**The SENTINEL Solution**

- SENTINEL GL is a 30% calcium nitrite solution admixture. This high performance, low viscosity solution is designed to be added directly to concrete and fills the hole with a repair material or regular concrete. The steel surrounding the patch becomes anodic, thus passivating the corrosion of the steel.
- EUCON CIA inhibits the corrosion of steel reinforcement. It is a 10% solution of calcium nitrite and is simply applied to concrete surfaces providing long lasting protection from water intrusion that may be carried by chlorides detrimental to the concrete’s reinforcement. EUCON CIA is compatible with all types of cements, pozolans, and other admixtures.

**Additional Corrosion Passivation Products From Euclid Chemical Include:**

**DURALPREP 2020**: This water-based migrating corrosion inhibitor formulated to be topically applied to concrete. This innovative formula penetrates through the concrete and forms a monocellular protective layer around reinforcing steel that drastically reduces corrosion.

**DURALPREP A.C.**: Easily applied to exposed steel to serve as an anti-corrosion coating and bonding agent prior to concrete repairs being made. DURALPREP A.C. is a water-based epoxy with a cementitious addition that, when mixed, provides a long open time for application and repairs can be made up to 24 hours later.

**BARACADE WB 244**: A water-based, silicone-siloxane blended water repellent that is simply applied to concrete surfaces providing long lasting protection from water intrusion that may be carried by chlorides detrimental to the concrete’s reinforcement. BARACADE WB 244 does not alter the appearance of concrete substrates.

**EUCON CIA**: A 30% calcium nitrite solution admixture. When mixed into fresh concrete, EUCON CIA inhibits the corrosion of steel reinforcement. EUCON CIA is compatible with all types of cements, pozolans, and other admixtures.

**EUCLID CHEMICAL REPAIR MORTARS** are available to complement the SENTINEL Anodes. Currently there are more than 10 options to repair your next galvanic anode project. Each of these mortars has been certified to have under 15,000 ohm/cm of volumetric resistivity. For more information on how to repair your next project, please contact the Technical Services team at the phone numbers listed below.

**SENTINEL GL**
**SENTINEL SILVER**
**SENTINEL GOLD**

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**“NEGLIGENCE IS THE RUST OF THE SOUL THAT CORRODES THROUGH ALL HER BEST RESOLVES”**

- OWEN FELTHAM
Corrosion of Steel in Concrete

Problems and Prevention
Concrete is a versatile and durable material, yet it is a major cause of deterioration in concrete, incurring billions of dollars in repair costs annually. All too frequently, rehabilitation with conventional repair methods fail to provide a long-term solution and can contribute to the overall problem.

Corrosion of embedded reinforcing steel is a major cause of deterioration in concrete, incurring billions of dollars in repair costs annually. Problems and Prevention

The Euclid Chemical Company proudly offers SENTINEL GL, SENTINEL SILVER and SENTINEL GOLD. Three galvanic anode devices can be designed to combat the “anode ring effect,” thus allowing the owner to skip a repair cycle or two, which in turn saves thousands of dollars worth of repairs.

**The Anode Ring Effect**
- Chlorides begin to penetrate the concrete, usually as a result of exposure to seawater or deicing salt. The concrete becomes more permeable, allowing for the movement of ions, including chloride ions.
- As the chloride content rises, the concrete becomes more conductive, allowing for the formation of an “anode ring.” This effect can lead to the formation of a corrosion cell, with the reinforcing steel acting as the anode and the surrounding concrete acting as the cathode.
- The cathodic reaction is the reduction of oxygen. Electrons released at the cathode are used to drive the corrosion process, leading to the formation of rust and the subsequent weakening of the steel.

**The Sentinel Solution**
- The Sentinel Solution is designed to combat the “anode ring effect,” allowing the owner to skip a repair cycle or two, which saves thousands of dollars worth of repairs.
- The anode devices are designed to provide a long-term solution to the anode ring effect, preventing the formation of corrosion cells and reducing the risk of further deterioration.

**Additional Corrosion Passivation Products From Euclid Chemical Include:**

- **Duralprep 2020** is a water-based migrating corrosion inhibitor formulated to be typically applied to concrete. This innovative formula penetrates through the concrete and forms a monomolecular protective layer around reinforcing steel that dramatically reduces corrosion.
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