Durability of Cement Based Building Materials

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ABSRACT

Cement based building materials undergo destructive chemical reactions. Some of the reactions involve water as the reactant. However in the majority of the reactions water acts as a carrier and the reaction medium. These materials can be protected from intrusion of water by various waterproofing technologies. Selection of the technology that provides long term protection is essential. Film former or barrier technology (coating) has been used very widely. Due to weathering and UV exposure the coating has limited life (3-5 years) and periodic reparative applications are required. Only organo silane based technology is appropriate for long term protection.

INTRODUCTION

Building materials are mostly based on cement. These include Reinforced Concrete, Mortar, Cement Plaster, Cement Building Blocks, Cement Roofing Sheets, Cement Pipes, etc. Durability of these materials depends on weathering and environmental factors. Field experience with deterioration suggests that the major cause for deterioration is chemical in nature. Cementitious material undergoes chemical reactions due to weathering and environmental factors. These can be summarized as follow:

ASR (Alkali-Silica-Reaction)

Normal cement based building materials are very basic in nature (pH over 13). This is due to presence of Ca(OH)₂. The major component of the concrete structure is Silicate bond (Si-O-Si). Silicate bond can undergo chemical reaction with water in highly basic environment. As a result, Si-O-Si bond converts into two Silanol groups (Si-OH). The silica containing Si-OH is known as Silica Gel. Silica Gel has four times more volume than normal Si-O-Si containing material, and imparts additional pressure. As a result, concrete develops cracks. Additionally silica gel absorbs more water than the parent materials and accelerates ASR reactions.

\[ =\text{Si-O-Si}_\text{Silicate} + H_2O \rightarrow =\text{Si-OH}_{\text{Silica Gel}} \]

ASR Cracks Formation
Carbonation

Carbonation is considered the natural decaying process of the cementitious material. Air contains carbon dioxide. When water dissolves carbon dioxide, it becomes acidic because of the formation of Carbonic acid (H$_2$CO$_3$). Carbonic acid can react with Ca(OH)$_2$ in the cementitious material and generates CaCO$_3$. This reaction decreases pH of the material. When pH reaches close to 8, then almost all Ca(OH)$_2$ is replaced with CaCO$_3$. Ca(OH)$_2$ is a crystalline, strong material and it is replaced by amorphorous CaCO$_3$. The life expectancy of any concrete structure is determined by the carbonation reaction rates.

\[
\text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{H}_2\text{CO}_3
\]

\[
\text{Ca(OH)}_2 + \text{H}_2\text{CO}_3 \rightarrow \text{CaCO}_3 + 2\text{H}_2\text{O}
\]

Concrete Aging (Carbonation)

Acid Rain

Most acid rain is caused by environmental factors. Burning of fossil fuel (natural oil based fuel used by automobiles and power plants) can generate sulfur oxides and nitrogen oxides. These oxides combine with water (during rain) to form sulfuric and nitric acid. These are two very strong acids that can react with any basic material including all cementitious materials, sand stone, brick etc. For concrete material, the reaction with Ca(OH)$_2$ can form Ca(NO$_3$)$_2$ and CaSO$_4$. These are salts and much weaker material then crystalline Ca(OH)$_2$. Acid rain has special effects in certain areas, especially in India. In India the monsoon season appears once a year (lasts for 3-4 months), the rest of the year is completely dry. Pollutants accumulate in the atmosphere, and therefore the first rain shower water is most acidic and most damaging to the building materials.

\[
\text{S} + n\text{O}_2 \rightarrow \text{SO}_x \quad \text{(Sulfur Oxides)}
\]

\[
\text{SO}_x + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4 + \text{H}_2\text{SO}_3 + \ldots
\]

\[
\text{Strong Sulfur Acids}
\]

\[
\text{N}_2 + \text{O}_2 \rightarrow \text{NO}_x \quad \text{(Nitrogen Oxides)}
\]

\[
\text{NO}_x + \text{H}_2\text{O} \rightarrow \text{HNO}_3 + \text{HNO}_2 + \ldots
\]
Strong Nitrogen Acids

\[
\begin{align*}
\text{Ca(OH)}_2 + \text{H}_2\text{SO}_4 & \rightarrow \text{CaSO}_4 + 2\text{H}_2\text{O} \\
\text{Ca(OH)}_2 + 2\text{HNO}_3 & \rightarrow \text{Ca(NO}_3)_2 + 2\text{H}_2\text{O}
\end{align*}
\]
Calcium sulfate
Calcium Nitrate

Acid Rain Corrosion Building Materials

**Corrosion of Steel in Reinforced Concrete**

Corrosion of steel in reinforced concrete creates serious structural problems. Corrosion of steel is an electrochemical process. In this reaction, Fe (steel) loses electrons and Oxygen (O\(_2\)) gains these electrons. Fe is oxidized and Oxygen is reduced. These reactions require an electron transport medium. If concrete is wet, water provides the required electron transport medium. Therefore water is essential for corrosion to start. The other important factor is the presence of chloride. Chloride is always present in concrete. Additional chloride is induced by rain water particularly in coastal areas. Steel bar in the concrete has iron oxide layer which is known as the passivation layer. This layer protects steel from further corrosion. However if this layer gets wet, the oxide becomes hydrated iron oxide which is chemically more reactive. Water intrusion into concrete also provides migration of chloride to steel rebar. These chlorides react with hydrated iron oxide and subject the steel to further corrosion. The overall reaction does not involve chloride, therefore chloride acts as a catalyst. Free chlorides continue promoting corrosion until the steel structure is converted to rust.

\[
4 \text{Fe} \rightarrow 4 \text{Fe}^{2+} + 8 \text{e}^- \quad \text{(Cathodic Reaction)}
\]

\[
4 \text{Fe}^{2+} + \text{O}_2 + 8\text{OH}^- \rightarrow 4 \text{FeOOH} + 2 \text{H}_2\text{O} \quad \text{(Anodic Reaction)}
\]

Corrosion Electro-Chemical Process
Conclusion

The durability of concrete structures depends on the extent of destructive reactions occurring during the life cycle of the structure. All these reactions require water as a reactant or as the reaction medium. If intrusion of water is reduced then these reactions can be minimized, and durability of the structure can be increased. Therefore it is important to protect cementitious material from water.

Solution

The technology that provides long lasting protection from water and salt is based on organosilane chemistry. Organosilane compounds are the only reactive and penetrative material that provides longevity to these structures. The silane molecule reacts with surface –OH groups and alters surface property from hydrophilic (water loving) to hydrophobic (water repellent). This technology has been known and used for over 40 years. However, because it is a solvent based technology and relatively expensive, wide spread use did not materialize.

Zycosil developed by Zydex Industries is an organosilane water soluble product. This product is reactive to cementitious surface, similar to solvent based organo silane products. Because of its nano size molecules (3-6 nM), it penetrates inside the pores of the substrates. The longevity of the product performance is due to reactivity with the substrate and the depth of penetration.
Zycosil Product

Zycosil is a new generation of nano technology, which has been developed for waterproofing and has UV resistance, thermal resistance, and an ability to withstand the wind erosion due to its nano-size and penetrative power. Zycosil development has kept ecological issues in mind. This is the first water based nano technology, which means it meets all the toughest VOC standards. Zycosil is diluted in water and forms a water clear solution which can be applied to both new and existing concrete and masonry structure by simple spray, brush or roll application. Zycosil chemically binds to the concrete and masonry surface, and once dried orient itself to give superior barrier properties against incoming water. The conventional coating based film forming chemistry tends to trap moisture inside the substrate which leads to the failure of paint films inside the building. Zycosil chemical bonding allows the structure to breathe, thus you would not expect the paint to peel off, maintaining the building appearance for a longer time. Zycosil, being chemically reactive to mineral based building materials, will not leach out due to repeated rains. It has a unique composition, which is resistant to UV degradation and penetrates deep enough at low concentration to give economical & effective protection for cementitious material.

Test Results

(1) ACCELERATED WEATHERING

The samples were treated with Zycosil (1part Zycosil with 10 part water). The weathering test was carried out using a UV chamber.

Weathering Cycle: UV exposure according to ASTM G-154 (21 hours), followed by rain showers (for 1 hour) and drying at 110 °C (230F) for 2 hours.

The samples, Concrete blocks, Bricks, Plaster, Sand stone, and Cement Sheet have undergone over 90 cycles.

All the Samples retained over 98 % of water repellency, after 90 cycles. This is equivalent to over 20+ years’ performance.

(2) Water absorption rate

The samples were treated with Zycosil (1part Zycosil with 10 part water).

These tests were carried out using RILEM Test Method II.4. The RILEM tube was affixed on the substrate surface. Then water is filled to 5-ml mark. The rate of water absorption is measured. Hydraulic pressure generated on the substrate surface is equivalent to 87 MPH wind driven rain.
(3) Water immersion Test

The 24 and 48 hours immersion test (ASTM D6489) for concrete (M-35) showed over 90% reduction on absorption of water.

APPLICATIONS

- New Buildings
- Existing / Old Buildings
- Coastal Areas
- Concrete Roofing Tiles
- Concrete Parking Decks
- Concrete Pavers
- Clay Articles / Tiles / Pots
- Stones of all Types in Construction and Decorative Applications
- Exposed Bricks Including Mortar

COMMERCIAL APPLICATION AREA

- Concrete Cooling Towers
- Waste Water Treatment Facilities
- Concrete Pipes
- Concrete Bridges
- Re-Bar Protection in Concrete
- Tunnel Walls
- Marine Piers
- Docks