ENHANCEMENT OF CORROSION RESISTANCE OF HEAVY CONCRETE USING LOCAL PETROLEUM-TAR-BASED ADDITIVES

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Abstract This study investigates the influence of locally available petroleum industry waste tar on the corrosion resistance of heavy concrete. Tar was incorporated into concrete mixtures in amounts ranging from 2% to 8% by cement porosity, water absorption, and sulfate-induced deterioration. The optimum performance was observed at a 5% additive content, where compressive strength increased and corrosion resistance improved considerably. The findings confirm the feasibility of utilizing industrial petroleum waste as a hydrophobic modifying additive to enhance the durability and service life of concrete structures operating in aggressive environments.

Keywords: heavy concrete, corrosion resistance, tar, sulfate attack, durability, hydrophobic additive, concrete structure.

Introduction. The reliability and long-term performance of reinforced concrete structures largely depend on the interaction between concrete and the surrounding environment. Practical observations indicate that concrete deterioration is often caused not by insufficient mechanical strength, but by incompatibility between the internal structure of concrete and aggressive environmental conditions. Heavy concrete represents a complex composite system consisting of several interacting phases:

- Gel and crystalline phases of cement stone;
- Aggregates and interfacial transition zones;
- Capillary and gel pore systems.

The pore structure is considered the weakest component of concrete because it provides pathways for the penetration of aggressive agents. Therefore, modern approaches focus not only on increasing strength, but also on controlling the transport properties of concrete. Corrosion of concrete and reinforced concrete structures remains one of the most critical issues in civil engineering, especially in hydraulic, industrial, and transportation structures exposed to aggressive environments. Sulfate and chloride ions penetrating into concrete lead to gradual structural degradation and reduced service life. Fundamental studies on concrete corrosion were extensively developed by P. K. Mehta and A. M. Neville, who established the relationship between capillary structure, water–cement ratio, and corrosion processes. Research concerning sulfate attack and pore structure modification was further expanded by Russian scientists Yu. M. Bazhenov, V. G. Batrakov, and S. N. Alekseyev, who emphasized the positive influence of hydrophobic additives on concrete impermeability. In recent years, Turkish researchers Erdoğan Özbay and Mustafa Sahmaran investigated the modification of concrete using organic and petroleum-based waste materials. Their studies reported positive effects of bituminous additives on concrete microstructure and durability. Researchers from Uzbekistan, including T. M. Mirzayev, Sh. A. Ahmedov, and A. A. Adilkhodjayev, have also conducted investigations into the utilization of local industrial waste in construction materials. However, the application of local petroleum tar to improve the corrosion resistance of heavy concrete has not yet been sufficiently studied.

Methods of Introducing Tar into Concrete. Tar is a viscous, water-insoluble petroleum residue; therefore, the method of incorporation significantly influences its distribution within the concrete matrix and the resulting mechanical properties.

Introduction in the Form of Water Emulsion. This method is considered the most effective. Tar is dispersed into water using surfactants, forming microscopic droplets. Such distribution ensures uniform dispersion throughout the cement matrix and promotes the formation of hydrophobic layers along pore walls. As a result:

- the concrete structure becomes more homogeneous;
- weak zones are minimized;
- pore connectivity decreases.

Hot Direct Introduction. In this method, tar is heated to 100–120°C and mixed with dry aggregates before adding cement and water. Although this approach improves waterproofing properties, it may negatively affect cement hydration because the tar film can coat cement particles and hinder hydration reactions. Consequently, concrete strength may decrease significantly. Therefore, this method is mainly suitable for road construction or waterproofing layers where high mechanical strength is not required. In the present study, tar was introduced into concrete in the form of an aqueous emulsion. This method ensured uniform dispersion of tar particles without negatively affecting cement hydration. It was hypothesized that microscopic hydrophobic films formed along capillary pore walls reduce moisture penetration and aggressive ion transport.

Advanced Mechanism of Concrete Corrosion. Concrete corrosion should be considered not merely as a chemical reaction process, but as a coupled system involving transport phenomena, chemical transformations, and internal stresses. Transport Stage. Aggressive ions such as sulfate (SO_4^{2-}) and chloride (Cl^-) penetrate into concrete through:

- diffusion;
- capillary suction;
- filtration under pressure.

These processes follow Fick's diffusion laws and strongly depend on concrete porosity and moisture content.

Chemical Transformations. Penetrating ions react with cement hydration products, leading to:

- dissolution and leaching of $Ca(OH)_2$;
- decomposition of C-S-H gel;
- formation of expansive products such as ettringite.

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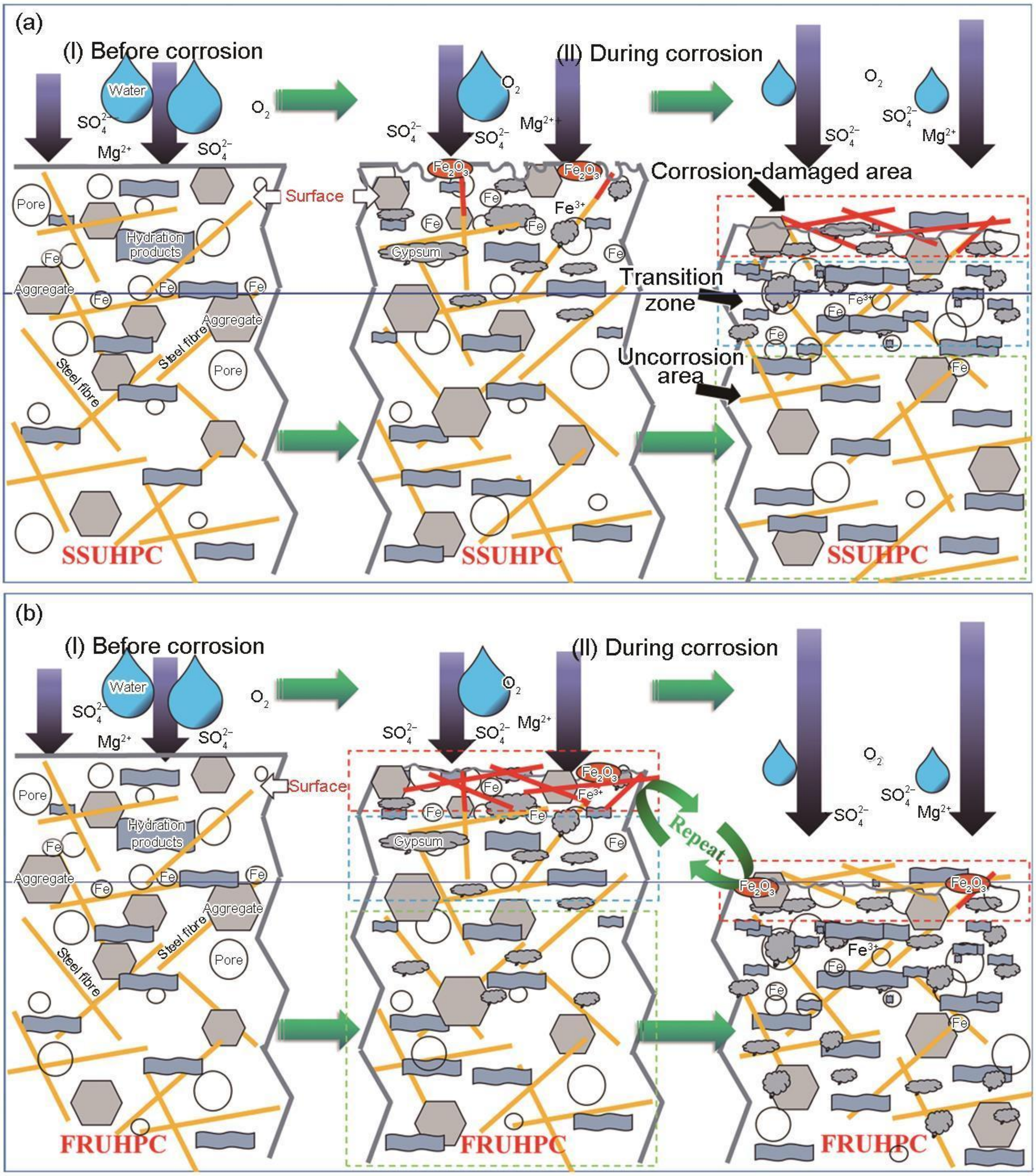
These reactions generate crystallization pressure within the concrete structure.



Structural Degradation. Internal stresses caused by expansive products result in:

- micro crack formation;
- increased porosity;
- acceleration of transport processes.

Consequently, corrosion becomes a self-accelerating degradation system.

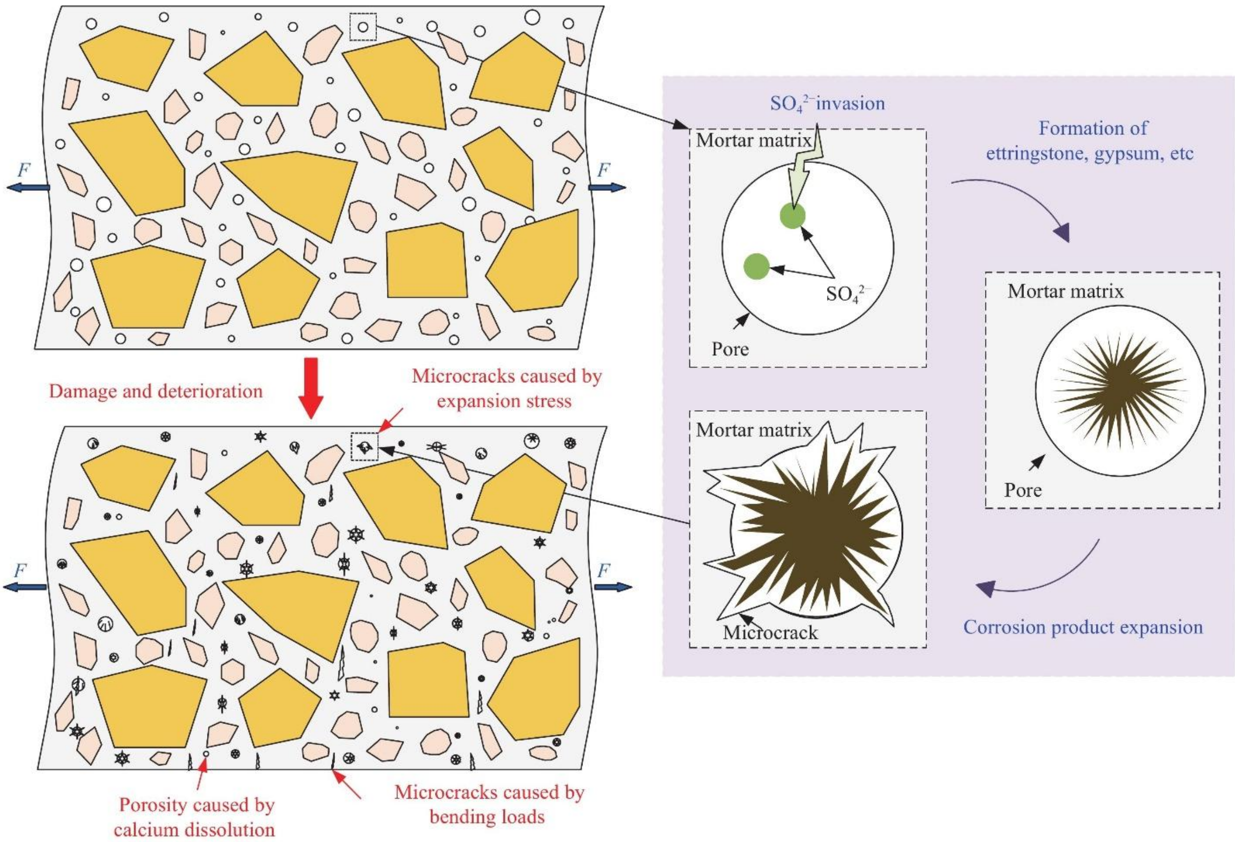


Figure 1(b). Mechanism of sulfate ion penetration into concrete structures and formation of micro cracks

Scientific Interpretation of Tar Action Mechanism. The influence of tar cannot be explained solely by its hydrophobic nature. Its effect appears at several interconnected levels.

Thermodynamic Level. Tar reduces the surface free energy of cement stone, thereby decreasing water wettability and moisture adsorption.

Structural Level. Tar partially fills macropores, interrupts capillary continuity, and destroys the percolation network inside concrete. As a result, continuous liquid transport pathways disappear.

Kinetic Level. The effective diffusion coefficient of aggressive ions decreases, while the active transport cross-section becomes smaller. Consequently, corrosion reactions proceed at a much slower rate.

Rheological Effect. Tar reduces free water mobility, improves mixture plasticity, and minimizes segregation. These effects contribute to the formation of a denser cement matrix.

Experimental Analysis and Discussion. Experimental results should be interpreted through cause-and-effect relationships rather than simple numerical increases or decreases.

Strength Development. Within the 4–6% additive range:

- concrete density increased;
- the interfacial transition zone became stronger;
- compressive strength improved.

However, at additive contents above 8%:

- the proportion of soft organic phase increased;

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- elasticity rose;
- compressive strength began to decrease.

Water Permeability. The addition of tar resulted in:

- reduced capillary radius;
- reduced number of capillary channels;
- disruption of continuous water pathways.

Therefore, concrete behavior approached that of semi-waterproof composite materials.

Corrosion Resistance. Under sulfate exposure:

- the depth of reaction zones decreased;
- formation of harmful expansive phases slowed down;
- structural stability remained higher compared to ordinary concrete.

Improved Scientific Approach**.** The study proposes a multi-component modification system rather than the use of a single additive:

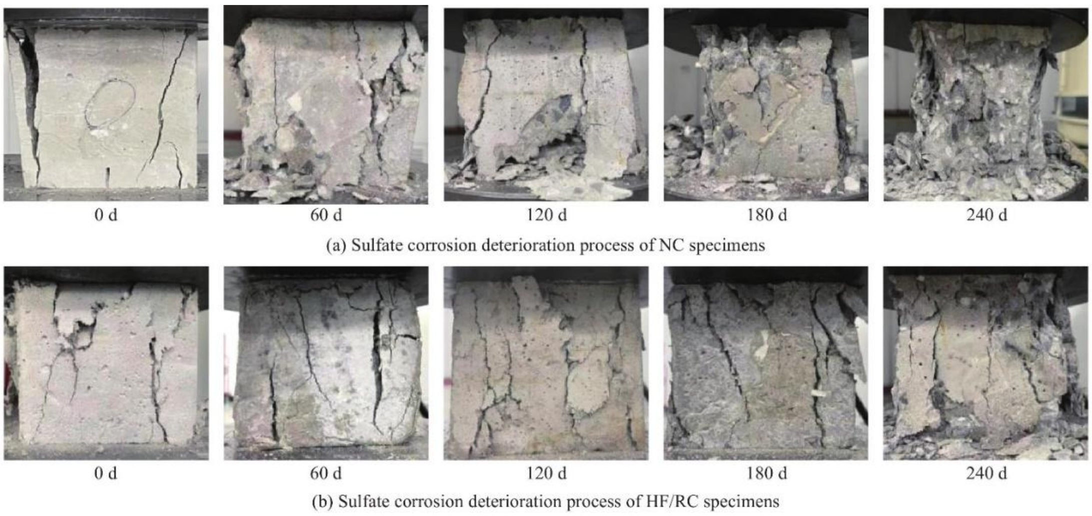
- Tar (hydrophobic phase);
- Mineral additives (microsilica or fly ash);
- Plasticizer.

This combined system:

- reduces porosity;
- densifies the structure;
- minimizes transport properties of aggressive media.

Scientific Novelty. The scientific novelty of this research can be summarized as follows:

- concrete corrosion was interpreted as a transport-limited process;
- the influence of tar was explained using a multi-level physicochemical model;
- the optimal additive content was justified from physicochemical and structural viewpoints.



(a) Sulfate corrosion deterioration process of NC specimens

(b) Sulfate corrosion deterioration process of HF/RC specimens

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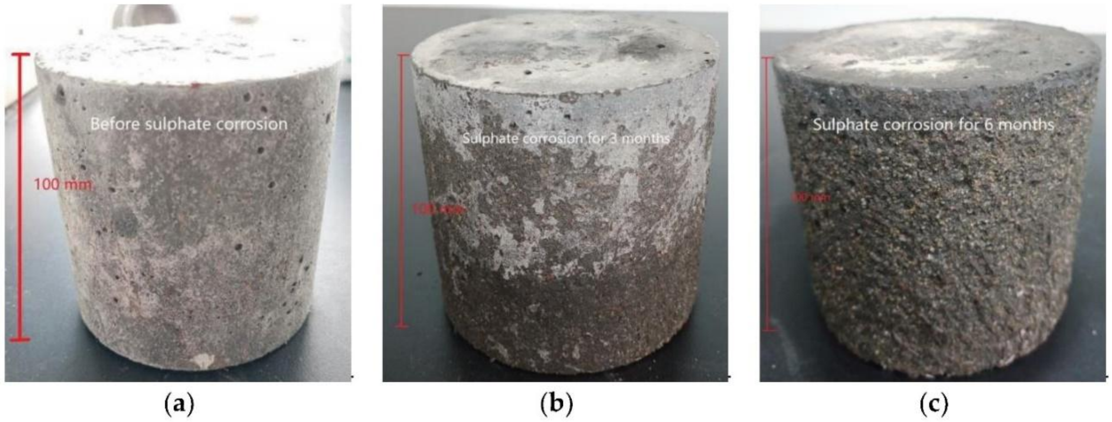

Figure 2. External deterioration process of concrete samples under the influence of a sulfate environment

Conclusion. Concrete modified with petroleum tar should be regarded not merely as an improved construction material, but as a transport-controlled composite system. The principal outcome is that aggressive media penetration into concrete is significantly reduced; therefore, corrosion reactions either do not occur or proceed much more slowly. As a consequence:

- the service life of concrete structures increases;
- operational reliability improves;
- industrial petroleum waste is transformed into a high-value construction material.

The results demonstrate that locally available petroleum tar waste can be effectively utilized as a hydrophobic modifying additive for enhancing the durability and corrosion resistance of heavy concrete exposed to aggressive environments.

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