

Corrosion of Concrete Reinforcement Steel in Relation With W/C Ratio and Permeability

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Abstract

Study about the relationship between W/C ratio and concrete permeability and concrete reinforcement steel corrosion already done and some conclusions are drawn. The infiltration of O₂ and H₂O into concrete body is the way to bring together the corrosive components to the surface of reinforcement steel inside the concrete. Chloride and CO₂ infiltration supporting the corrosion process by chemically lowering the concrete pH. Permeability and W/C ratio became important factors beside external factors. Literature studies have shown that concrete reinforcement steel will health when the pH of steel stabilized at 12 and permeability of concrete will at best value of 0.4 and poor at 0.7

Keywords: Corrosion; Concrete steel reinforcement; W/C ratio; Permeability.

1. Introduction

Reinforcing steel is crucial for increasing the strength of concrete. Reinforcing steel is the mainstay of a construction's strength. Its presence makes a concrete structure strong enough to withstand compressive loads, tensile loads, bending moments, and shear forces. This increase in concrete strength cannot be measured qualitatively, as it depends on the size of the reinforcing steel, the binding, and other factors such as the quality of the cement, sand, and aggregates.[1]

Without reinforcing steel, concrete will only have compressive strength, while its tensile strength is very weak. The tensile strength of concrete is typically only around 7% to 10% of its compressive strength [2]. 2. Factors Causing Reinforcing Steel Corrosion divide into these factors i.e. internal factors and external factors. Internal factors include: the water/cement ratio (W/C ratio), concrete shrinkage, and the quality of materials such as sand, coral, and acidic water. [1] Concrete with a high water/cement ratio will be porous. These pores will become entry points for corrosive elements such as water and oxygen, as well as other harmful elements like chloride and sulfate. Furthermore, high concrete porosity will reduce the concrete's physical strength. The infiltration of the corrosive substances will deepen over time and potentially reach the surface of the reinforcing steel and start the corrosion process.

Furthermore, the water used should clean and neutral with a pH of 7. Non-acidic water will give positive impact to the concrete's strength. Sand and other aggregates should preferably be sourced from river rather than seawater. River sand is expected to have a low chloride content.

2. Factors of Concrete Reinforcing Steel Corrosions

To understand the corrosion of concrete reinforcement, several determining factors are discussed below, including: Internal and External Factors. Internal factors include the quality of the concrete itself. Concrete quality is greatly influenced by factors such as the W/C ratio, permeability, and microcracks. External factors include the environment and the forces acting on the structure. Concrete can be in water, soil, or other environments.

2.a. W/C ratio and Concrete Permeability

The W/C (Water-Cement) ratio is the weight of water divided by the weight of cement in a concrete mix, a crucial factor determining concrete's strength, durability, and workability; a lower W/C ratio (e.g., 0.4-0.5) yields stronger, less permeable, more durable concrete, while a higher ratio (e.g., 0.6+) increases workability but reduces strength and increases porosity, with ideal ratios balancing performance needs

Concrete with low cement content will have many pores and easily infiltrated by corrosive agents. High-quality concrete tends to be denser, less permeable, and more resistant to cracking, thus providing better protection for the reinforcing steel from corrosive agents.

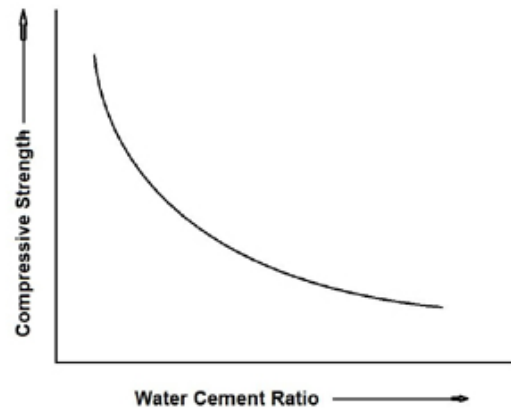


Figure 1. The relationship between W/C ratio and the strength of concrete. (Web-1)

2.b. Permeability and Microcrack

Permeability and microcrack have significant role in facilitating the corrosive agents entering into the concrete and meet the surface of reinforcing steel.

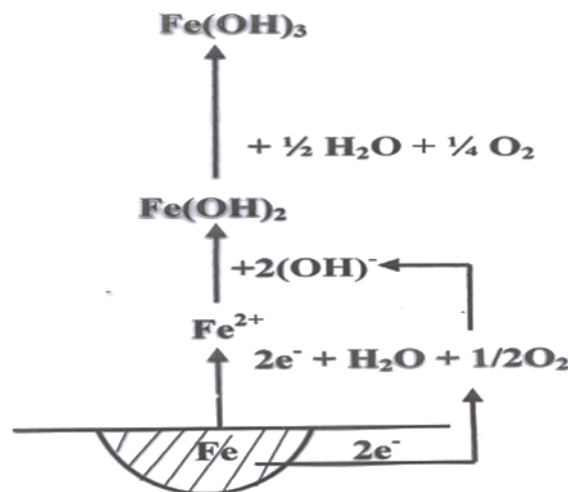
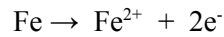
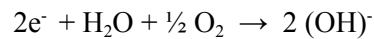


Figure 2. Corrosion of reinforcing steel by water and oxygen at the early stage.

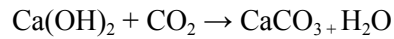
Figure 2 showing the process when the oxygen and the water reacted on the surface of the steel. The steel will undergo the oxidation reaction such as this:



The reduction process at the cathodic site:



This corrosion process will continued by the water and oxygen form ferri hydroxide ($\text{Fe}(\text{OH})_3$) and so forth. Besides, corrosion can also occur by the carbonation process i.e, the reaction between carbon dioxide (CO_2) and calcium hiroxide in concrete ($\text{Ca}(\text{OH})_2$).



Shrinkage is a cause of crack of concrete during the hardening process. [2] This shrinkage is primarily caused by the evaporation of water content in the concrete. The inhomogeneous shrinkage of concrete will cause hairline cracks (microcracks). These microcracks allow corrosive agents from the outside of the concrete to enter the concrete and reach the surface of the reinforcing steel. External factors such as soil, water, wet air and chemical atmospheric also considered as the external environment. As shown in Figure 1 , water and oxygen that enter the concrete through the pores and microcracks will reach the surface of reinforcing steel and initiate corrosion reaction. These external factors are significantly determined by the maintenance, inspection and supervision of the construction. Maintenance includes the regular inspection of the outer surface of the concrete. Supervision involves controlling the concrete pH and monitoring the interface potential of the steel to keep the reinforcing steels healthy.



Figure 3. Concrete can be in soil, water or wet air and humid environments. (Web-2)

2.c. Chloride Content

Chloride is one of the corrosive agent to the reinforcing concrete steel. Chloride could peeled off the passive film of steel and initiates corrosion by forming FeCl on the surface of steel. Many measurements have conducted, and it is recommended that the best depth of steel is 50 millimeters or more from the surface of concrete.

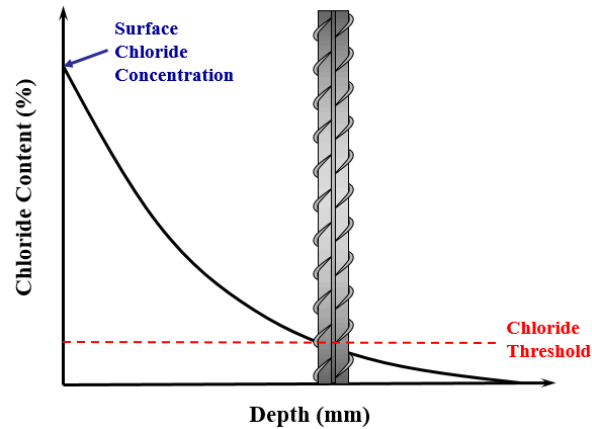


Figure 3. Chloride content and the depth of steel inside concrete. (Web-3)

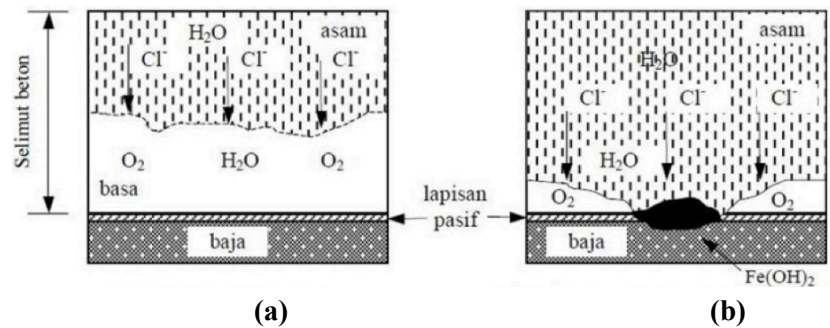


Figure 4. Chloride diffusion into concrete. (Web-4)

(a). The chloride diffusion into concrete.

(b). the steel passive film peeled off and corrosion initiated.

2.d. Concrete spalling

The oxide that forms on the surface of the reinforcing steel will enlarge and thicken over time. This oxide, in turn, will push and separate the bond between the concrete and the reinforcing steel. This pressure from the oxide, in turn, will create hairline cracks in the concrete.

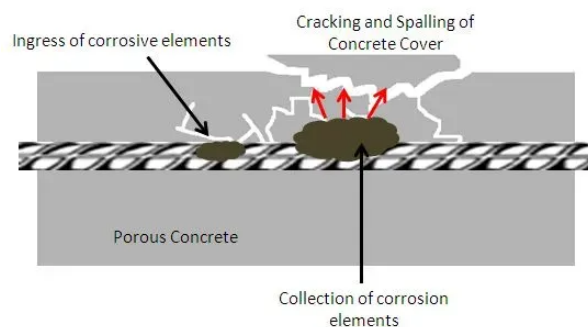


Figure 5. Hairline cracks are created due to the pressure of oxides that form on the surface of the reinforcing steel. (Web-5)



Gambar 6. Concrete collapses due to the pressure exerted by oxides on the surface of the reinforcing steel, which enlarge and thicken over time. (Web-6)

3. The Phases of Concrete Failure

Reinforcing steel corrosion is a process of damage to concrete reinforcement that occurs due to the infiltration of harmful elements from outside the concrete, and the process is a function of time. The process of damage to concrete structures due to corrosion of reinforcing steel can be divided into four stages: the incubation stage, the development stage, the acceleration stage, and the catastrophic stage. The progression from the initial phase to the subsequent phase is characterized by an increasing rate of corrosion in the reinforcing steel. The initial phase begins with the appearance of surface defects in the concrete, such as pitting or microcracks, which allow harmful elements from outside the concrete to penetrate and reach the surface. The most harmful elements to reinforcing steel are water and oxygen. Chloride and sulfate are also present. When chloride reaches the steel surface, it flakes off the passive layer and forms FeCl_2 with the steel. Sulfate can also originate from acid rain, where 2H^+ ions react with Fe^{2+} to form Fe^{2+} and free hydrogen.

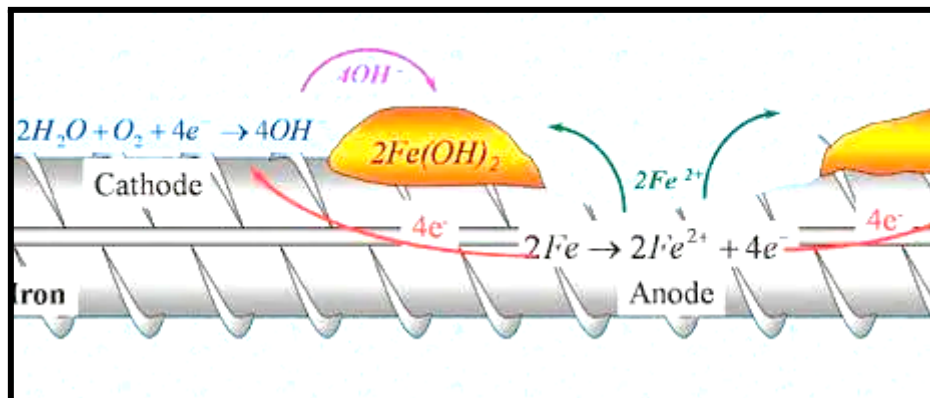


Figure 7. Corrosion process by moisture and oxygen on the surface of reinforcing steel (Web-7)

The initiation phase begins when reinforcing steel is embedded in concrete, where a passive layer forms on the steel surface. This passive layer will then peel off if corrosive elements that penetrate the concrete reach the steel surface. This passive layer will peel off, and the corrosion process will begin. The propagation phase begins when corrosion of the reinforcing steel has already occurred, causing an increase in the corrosion rate and resulting in a reduction in the cross-sectional area of the reinforcing steel, thus reducing its strength. This reduction in the steel's cross-sectional area will impact the steel's ability to support construction loads. This will ultimately lead to structural damage, where the

structure is no longer able to support the loads it carries. This can occur before the structure reaches its intended operational life.



Fig 8. Corroded of reinforcing steels in open atmosphere before constructed (Web-8)

The image above shows reinforcing steel that has been corroded before construction. Based on SNI 2052:2017, only mild corrosion is permitted on reinforcing steel during construction. Severe corrosion, as shown in the image above, is not recommended, because the oxide layer on the steel surface will weaken or even eliminate the bond between the steel and concrete.

4. Conclusions

- a. The corrosion on the surface of concrete reinforcing steel could happen by internal factor of concrete such as W/C ratio, permeability dan hairline crack.
- b. External factor such as environment, chloride content of the surrounding and maintenance is important factor for the construction.
- c. Regular monitoring of the metal interface potential is recommended to ensure the health of the reinforcing steel.

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