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EFFECT OF CARBONATION, CHLORIDE AND SULPHATE ATTACKS ON REINFORCED CONCRETE: A REVIEW

Desire Ndahirwa[2], Hongxia Qiao[1] and Constant Mahame[3]

[1]Key Laboratory of Disaster Prevention and Mitigation in Civil Engineering of Gansu Province, Lanzhou University of Technology, Lanzhou 730050, China
[2]Department of Structures Analysis, School of Civil Engineering, Lanzhou University of Technology
[3]Department of Civil Engineering Construction Management, Lanzhou Jiaotong University

ABSTRACT: *Concrete is the most versatile and widely used construction material worldwide. In recent past, the durability of concrete structures has become a major concern, particularly in aggressive environments. Traditionally, a large number of natural and chemical admixtures are added to the concrete with the purpose to enhance its properties. In most cases, concrete failure occurs as a combination of errors in material design, installed workmanship, environmental impacts, usage and poor maintenance strategy. The durability of concrete can be influenced by a range of physical and chemical factors. Relevant choice of admixture can improve the strength characteristics, and therefore the durability of concrete. This paper presents a literature review of several published studies on impact of chemical aggression to reinforced concrete structures.*

KEYWORDS: Durability, Admixture, Reinforced Concrete, Chemical Aggression.

INTRODUCTION

Concrete is a durable construction material. The durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack and abrasion while maintaining its desired engineering properties. However, severe aggressive environmental conditions could lead to untimely deterioration of reinforced concrete. The durability of reinforced concrete structures is influenced by internal and external factors and damage can vary from aesthetic through to severe structural deterioration. The strength of concrete is remarkably affected when it is exposed to chemical actions such as carbonation, sulphate and chloride ions penetration.

Sulphate attack is the result of interaction between sulphate ions and hydrated cement products. Sulphate attack on concrete can appear in different forms depending on chemical form of the sulphate and atmospheric environment which the concrete is exposed to. Carbonation occurs when carbon dioxide in the environment penetrates into the concrete to react with calcium hydroxide to form calcium carbonate. Chloride ions penetration is a significant threat to reinforced concrete particularly for structures in marine environments or those that are likely exposed to high concentration salts. Carbonation and chloride attacks are main causes that initiate corrosion of steel reinforcement.

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REVIEWS OF ARTICLES

Li (1997) discussed about the theories and designs for the structural reliability and durability of reinforced concrete structure. The paper focuses on inspection of building structural performance and thus predicts the maintenance time for the building. Therefore, it also presented from a structural perspective where the maintenance of buildings depends on the deterioration condition of building structures. The failure of concrete buildings is usually caused by the deterioration of structural strength. Structural deterioration stems from two basic sources: material degradation and damage by external loads.

QCL group of companies (1999) addressed the role of sulphate attack and chloride ions penetration in concrete durability. The paper reports the recent introduction of performance tests intended to facilitate assessing concrete resistance to these chemical actions of various cementitious binder options now available for inclusion in concrete. Based on data reported from CSIRO research project, it would appear that in specifying concrete to resist sulphate attack or chloride ion penetration, a suitable approach would be as follows: f'c of 40 MPa to achieve a maximum water/cement ratio of 0.45 to reduce permeability and incorporation of at least 20% fly ash or 60% slag; either of which would also be beneficial in reducing any tendency for alkali silica reaction.

Verma et al. (2013) evaluated effect of chloride attack and concrete cover on the probability of corrosion. The authors describe chloride ions penetration in concrete structures as a significant threat to the durability of concrete structures. It has been revealed that in reinforced concrete structures corrosion takes place when passive protective layer is destroyed by chloride ingress. To model chloride ingress, most researchers use Fick's laws of diffusion. Chloride ingress in concrete structures mainly depends on diffusion coefficient. Based on several chlorination studies and from results of field survey, in order to improve chloride resistance of concrete structures it would be suggested to increase concrete cover depth, replace cement by supplementary materials, use of pozzolanic materials.

Wu et al. (2014) conducted an experimental research to determine the corrosion and bearing capacity of a reinforced concrete (RC) slab at different ages in a marine environment. After performing several tests on corroded slab, results show that the development of corrosion-induced cracks on a slab in a marine environment can be divided into three stages according to crack morphology at the bottom of the slab. In the first stage, cracks appear. In the second stage, cracks develop from the edges to the middle of the slab. In the third stage, longitudinal and transverse corrosion-induced cracks coexist.

Trofimov et al. (2017) studied the deterioration mechanism of concrete exposed to freeze-thaw cycles. This paper reports that physical and physical-chemical effects on concrete lead to changes in the hydrated phases and the structure of hardened cement paste, which causes a decrease in strength and durability of concrete. The most aggressive effects on concrete are produced by cyclic freezing of concrete saturated with deicing salts or water and the action of aqueous solutions of certain salts, especially sulphates. Hence, the principle way to increase concrete frost resistance is to reduce the macrocapillary porosity of hardened cement paste and to form stable gel-like hydration products.

Basheer et al. (1999) described that the rate of carbonation in concrete is influenced by both its physical properties and exposure conditions. The paper presents a detailed experimental study on compressive strength, air permeability and sorptivity index. The results illustrate that the rate of carbonation of normal Portland cement concrete is primarily influenced by the water-cement ratio and other factors have only a marginal effect. Therefore, concrete can be designed to have a specific carbonation resistance based entirely on the water-cement ratio. However, this should be verified for different types of aggregate. The rate of carbonation from accelerated carbonation testing can be used for the service life design of concrete in an environment where carbonation is a probable cause of deterioration. However, there is a need to relate the results of accelerated test to those of natural exposure before this approach can be used.

Liu (1991) studied concrete structures in marine environment. Concrete structures in marine environment are exposed simultaneously to the action of number physical and chemical determination processes. Damage can vary from aesthetic through severe structural deterioration, depending on the environment in which it resides. The deterioration process may be the combined effects of chemical action of sea-water constituents on cement hydration products, crystallization of salts within concrete, alkali-aggregate expansion, corrosion of steel bars, freezing and thawing a cold climate, and physical erosion due to wave action and floating objects. When the concrete is attacked by any of these processes, the permeability tends to increase and therefore it is more susceptible to further attack by several processes.

Saeki (2002) attempted to establish models in consideration of both chloride ions ingress and carbonation, in order to predict the carbonation depth and penetration depth of chloride ions. Also, modifications in micro-structure of hardened cementitious materials due to carbonation were investigated in order to clarify the effect on chloride penetration. Chloride ions ingress and carbonation, which start from concrete surface and progress toward internal concrete, can both lead to accelerated corrosion of steel bars in concrete. When chloride ions ingress and carbonation take place simultaneously in concrete, chloride ions that have been in cement hydrates will become soluble due to the deterioration of cement hydrates caused by carbonation. When chloride ions ingress and carbonation are co-existed the prediction of the distribution of chloride ions in concrete is essential to the quantitative evaluation of concrete durability.

Neville (1995) according to the author, the chloride attack on concrete is different from other mechanisms of deterioration because the primary action of chlorides is to cause corrosion of steel reinforcement and it is only as a consequence of this corrosion that the surrounding concrete is damaged. This paper discussed the mechanism of chloride induced corrosion of steel embedded in concrete, the ingress of chlorides into the concrete, and the threshold chloride content for corrosion to occur. It also considered factors that influence the corrosion, performed tests for penetrability of concrete to chlorides; hence the approach to prevent corrosion is provided.

Zhou et al. (2015) studied the degradation mechanism of concrete strength in sulphate environment. The authors describe the corrosion of concrete by sulphates as a gradual process that starts from the surface layer to the core. In this paper, an accelerated corrosion by a sulphate solution in a dry-wet cycle was introduced to simulate the external sulphate corrosion environment. The deterioration trend of concrete strength and development law of sulphate-induced concrete corrosion depth due to sulphate attacks was experimentally studied. The accelerated corrosion test results indicated that the strength degradation of concrete by sulphate attack had a significant relation with the corrosion depth.

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Zhou et al. (2014) conducted an experimental study on carbonation-induced and chloride-induced corrosion in reinforced concrete structures. this review paper introduces the two principal degradation mechanisms associated with corrosion, discusses different forms of corrosion-induced mechanical degradation, summarizes analytical methods for predicting the basic corrosion mechanisms, and compares and contrasts several corrosion measurement and detection techniques. Carbonation takes place as a result of the interaction of carbon dioxide with the calcium hydroxide in concrete. It reveals that both carbonation-induced and chloride-induced corrosion widely prevail in reinforced concrete structures. The environmental conditions influence the carbonation depth and chloride concentration. The concrete with higher compressive strength has a great resistance to carbonation and chloride attacks on reinforced concrete.

Li et al. (2011) studied the effect of stress on the resistance of concrete to chloride ion penetration, tests of stressed specimens exposed to salt solution immersion and salt spray. The authors analyzed the chloride contents in uncracked concrete specimens with different water-cement ratios, states and levels of stress, and environmental. The results show that the resistance of concrete to chloride ion penetration can be improved by reduction of the water-cement ratio. The content of chloride ion is higher in concrete stressed in tension than in unstressed concrete. For concrete stressed in compression, chloride content depends on stress level. Salt solution immersion is more severe than salt spray.

Huang et al. (2015) carried out the rapid chloride penetrating test of ordinary Portland concrete (OPC), glass fiber reinforced concrete (GFRC) and basalt fiber reinforced concrete (BFRC) under the environment of carbonation in order to observe the influence of fiber on the resistance to chloride-ion penetration of concrete under the environment of carbonation. This study investigates the differences of carbonization depth, porosity and permeability with the increase of carbonation ages comparing the effect of fiber on chloride penetration resistance of concrete, and observing the microstructure through scanning electron microscope (SEM). The results show that the glass and basalt fiber increases the porosity of concrete, but the carbonization depth at the beginning of carbonation was reduced, so as to improve carbonation resistance. Carbonation resistance of basalt reinforced concrete is better. Carbonation reaction would enhance the resistance to chloride ion penetration of concrete, which glass fiber performs better than basalt fiber does.

Zhang et al. (2015) studied the influence of carbonation on sulphate attack of concrete materials. Several experiments have been carried out to determine the effect of carbonation on the resistance of sulphate attack of concrete materials. The accelerated carbonate testing was used to prepare the carbonate specimens, and wetting-drying cycles were used to evaluate the resistance of sulphate attack. Results show that longer carbonate time leads to greater depth of carbonation, and fly ash may accelerate the carbonation of concrete materials. There is a decrease of flexural and compressive strength. Carbonation is detrimental to the resistance of sulphate attack of concrete materials.

Zhu et al. (2016) studied the combined effect of carbonation and chloride ingress in concrete. Carbonation influences the transport of chloride ions in concrete significantly. The influence of carbonation on the diffusion coefficient of chloride ions depends on the types and mix proportions of concrete considered experimentally. Although, carbonation and chloride ingress take place simultaneously, it should be noted that the diffusion of chloride ions is much faster than the rate of carbonation. The purpose of the study was to develop a

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comprehensive model for the combined effect of carbonation and chloride ingress in concrete structures.

CONCLUSION

Based on reviewed studies related to deterioration of reinforced concrete due to chemical aggression, there is a major change in strength properties and therefore the durability of exposed concrete structures. The deterioration mechanism depends on material constituents and exposure conditions. In most concrete structures, chemical attacks are initiated by diverse causes such as inappropriate choice of cement type for the conditions of exposure, high concrete porosity and permeability, cement content, type and quality of constituent materials. The results from summarized studies show that increase in compressive strength and incorporation of supplementary cementitious materials can enhance the resistance of concrete to aggressive chemical actions.

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