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Recent durability studies on concrete structure

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ABSTRACT

The durability of concrete has attracted significant attention over the past several decades and is still a research hotspot until now. This paper reviews and discusses recent research activities on the durability of concrete, including: 1) major durability problems such as alkali aggregate reaction, sulfate attack, steel corrosion and freeze–thaw; 2) durability of concrete in marine environment; and 3) coupling effects of mechanical load and environmental factors on durability of concrete. Moreover, the consideration of durability in concrete structure design (DuraCrete and performance-based specifications) is also briefly reviewed.

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1. Introduction

Durability of Portland cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration to remain its original form, quality and serviceability when exposed to its intended service environment [1]. Durability problems usually appear as the materials deteriorate at the beginning. Although the material deteriorations do not have an immediate safety issue, they will progressively lead to structural damage, which puts a potential danger to the structures.

The classification of causes of concrete deterioration can be grouped into three categories, physical, chemical, and mechanical, from which

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major durability issues such as steel corrosion are initiated and developed [2]. To solve the durability problems, many researchers have conducted deep studies on these issues. The studies cover the individual topics of carbonation, alkali aggregate reaction, reinforcing bar corrosion, sulfate attack, CH leaching, and freezing–thawing. As noted by researchers, in most cases, the degradation of a concrete structure is a result of the combined effect of multi environmental factors and loading. Therefore, many researchers have extended their work from a single mechanical loading or environmental factor to the combined effects of multiple factors [3–14]. As a result of durability studies, many countries have proposed durability-based design guidelines [15–17] or durability-loading carrying ability unified service life design method [2].

This paper starts with the discussion on recent researches associated with major durability issues based on selected corresponding activities. After discussion on durability issues for concrete in marine environment, the durability based design philosophy and methodology are introduced.

2. Major durability problems

The major durability problems in concrete including alkali–aggregate reaction, sulfate attack, steel corrosion and freeze–thaw are discussed in the following subsections.

2.1. Alkali–aggregate reaction in concrete

Alkali–aggregate reaction (AAR) in concrete structure is a reaction between alkalis in pore solution and some active chemicals of aggregates. Two general types of attacks of AAR are classified as: 1) alkali–carbonate reaction (ACR) with active minerals from dolomitic limestone aggregate [18]; and 2) alkali–silica reaction (ASR) with active minerals from amorphous silica.

The commonly-used testing methods to assess the AAR are: mortar bar test (ASTM C227), rock cylinder method (ASTM C586), rapid test methods (ASTM C289), accelerated mortar bar method (ASTM C 1260), autoclave testing method [19], chemical shrinkage test [20], concrete prism test (RILEM AAR-3) [21], stiffness damage test [22], dynamic modulus and gel fluorescence test [2]. Apart from these conventional tests mentioned above, Liu and Mukhopadhyay developed a compound activation energy measurement method, as shown in Fig. 1: highly reactive borosilicate glass and/or different types of aggregates were tested with $NaOH + Ca(OH)_2$ solution. It had been proved that volume change in a closed system was in a form of chemical shrinkage as the ASR between aggregates and alkali solution proceed. There, the authors were relating the recorded change volume over time to the risk potential and actual reaction degree of ASR [23].

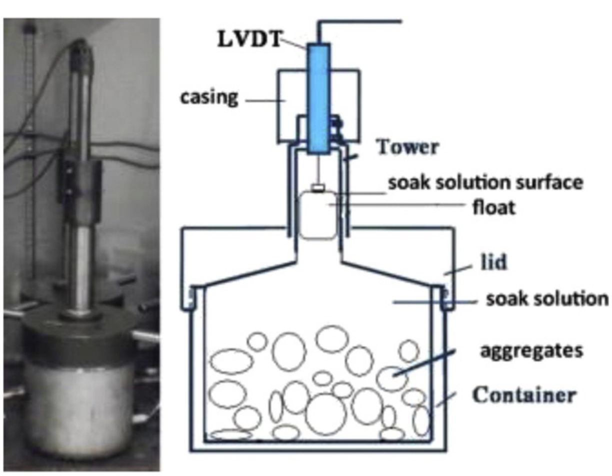

Fig. 1. The compound activation energy measurement [23].

Normally, the degree of AAR is affected by 1) presence of water, ASR only occur in high relative humidity; 2) alkali content; 3) concrete porosity and 4) temperature. Accordingly, there are some recommendations for eliminating the attack of AAR: 1) utilization of nondeleterious aggregates and/or nonreactive aggregates; 2) utilization of low-alkali Portland cement or blended cements with enough pozzolanic materials; 3) keep the concrete dry as much as possible and damage is generally not observed for RH < 80%; 4) utilization of diffusion-control coating; and 5) addition of nitrate salts. Here, the effects of pozzolanic materials and nitrate salts are selected for discussion:

1) The incorporation of sufficient reactive siliceous granular skeleton, fly ash, slag and silica-breccia [24] is beneficial to limit ASR expansion risk [25]. Wright et al. investigated that higher lime content (%CaO > 10%) fly ashes required a greater percentage of cement replacement to reduce ASR expansion to 0.08%[26]. Fly ash with CaO 27.3, 13.5 and 2.42% required 31, 18 and 13% replacement of Portland cement against ASR [26–28]. Besides, mortar and concrete with silica-breccia having a particle size less than 30 μm showed lower expansion than the control mixture in both alkali–silica reactivity and sulfate resistance tests [29,30].
2) The addition of $LiNO_3$ in cement-based materials can decrease AAR expansion, significantly influence the chemical composition and the morphology of the reaction product. Besides, dense reaction products are generated and served as the effective protective barrier to sulfate attack [31].

Interestingly, some recent researches had observed that initial ASR gel might temporarily densify the cement matrix.

1) With respect to alkali-carbonate reaction, a considerably higher increase in compressive strength was detected for the mortar with activated dolomite aggregates by Stukovnik et al., compared to the one with limestone aggregate. This phenomenon was explained as better interlocking between Portland cement binder and aggregate grains, due to the formation of a new Mg–Si–Al phase both in the ITZ and along pre-existing cracks in the aggregate grains [32].
2) Krivenko et al. also considered that alkali-susceptible aggregates could be used in the alkali activated cement concretes without any risk in spite that theory suggested the opposite. The authors suggested that the active alumina in the alkali activated cements had a favorable effect allowing to effectively controlling the structure formation process in the interfacial transition zone and to reduce expansion down to admissible levels or completely avoid it [33].
3) Bektas pointed out that the addition of alkali reactive brick aggregate did not affect engineering properties of concrete although alkali silica gel and secondary ettringite were observed by SEM [34].

2.2. Deterioration caused by sulfate attack

Sulfate attack is one of main factors causing expansion deterioration of concrete structure. Such expansion is attributed to reactions of sulfate ions with some hydration products in concrete structure.

Tests on sulfate resistance are generally conducted through storing specimens in a solution of sodium or magnesium sulfate, or a mixture of the two [2]. Currently, the effect of sulfate attack is usually assessed through several indicators: length variations, loss or increase of mass, difference of surface hardness [35], strength and elastic modulus decrease. However, these indicators do not provide sufficient information to assess chemical reactions and understand the damage mechanisms behind [36] and neither the indications can be related to performance in real conditions.

Innovative test methods are imperative to study the degradation process of concrete structure caused by sulfate attack.

1) Braganca et al. utilized electrochemical impedance to identify the sulfate attack non-destructively. The impedance tests were