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ScienceDirect

Ciência & Tecnologia dos Materiais 27 (2015) 108–114

Ciência & Tecnologia dos Materiais

http://ees.elsevier.com/ctmat

Special Issue IJSI 2014

Internal expansive reactions in concrete structures – deterioration of the mechanical properties

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Abstract

A significant number of problems related to concrete deterioration were detected in Portugal and worldwide due to the development of internal expansive reactions (IER). Their negative effect has important economic implications because they are the main cause of degradation of large concrete structures. In addition, the work necessary to remediate the problem involves large areas of reconstruction and complex and expensive rehabilitation techniques and materials. Moreover, IER diminishes the affected structure service life, may involve the interruption of its function and, ultimately, can lead to its decommissioning and demolishing. Therefore, a study is being conducted at LNEC to diminish their negative impact by increasing knowledge on how to reliably assess their extent and potential for future development in existing structures. To study the effect that IER have in the deterioration of concrete, the common practice is to perform tests on specimens exposed to an artificial environment that promotes IER. However, these tests take several months or years to produce results. Thus, this paper presents the preliminary work carried out to devise a method capable of producing internal damage to concrete in a short period and in a way that the produced deterioration affects the concrete mechanical properties similarly to IER.

Keywords: concrete; deterioration; internal expansive reactions; mechanical properties; internal damage; test method.

1. Introduction

In the last decade, a significant number of problems related to concrete deterioration have been detected in large concrete structures (*e.g.* dams and bridges) in Portugal and throughout the world; the leading cause being internal expansive reactions (IER), more specifically, alkali-silica reaction (ASR) and internal sulphatic reaction (ISR).

ASR is a chemical reaction between the alkali hydroxides in the concrete pore solution and some siliceous minerals present within certain aggregates. The reaction results in the formation of a calcium-rich alkali-silica gel that is hydrophilic and expands in the presence of water causing the disruption of concrete [1,2].

ISR is a chemical reaction between sulphate ions and calcium aluminates present in the hardened cement paste that results in the formation of ettringite. As the name suggests, the source of sulphate is in the concrete and can be the cement, the supplementary materials (*e.g.* fly ash), the aggregate, or the chemical admixtures. The formation of the so-called secondary or delayed ettringite has an expansive nature and can cause the disruption of concrete [2-4].

If sufficient IER occurs in the concrete, the induced pressures cause micro-cracking and then expansion of the surrounding concrete. The concrete surface does not expand to the same extent as the interior, because the conditions required for the reactions are not totally fulfilled at the concrete surface, for example, the concrete surface is subject to leaching of the alkalis

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http://dx.doi.org/10.1016/j.ctmat.2015.07.003

and to temperatures lower than those felt in the bulk of the concrete mass. This causes tensile stresses to arise in the surface and induce surface macro-cracks. The formation and orientation of both micro- and macro-cracks are affected by restraint that also reduces expansion. Generally, IER generate a very significant drop in terms of tensile strength and modulus of elasticity, whilst the compressive strength only begins to decrease significantly at high levels of expansion [4,5].

Hence, the structural integrity of large concrete structures can be severely jeopardized by both ASR and ISR evolution, which ultimately can lead to their decommissioning and demolishing. Currently, there is no effective way of stopping ASR and ISR, however, in some cases they can be slowed down through rehabilitation works.

The first reports on ASR were published in 1940 [6,7]. In the following decades the essential requirements for its occurrence were identified (sufficient moisture in concrete and appropriate relative proportions of alkali hydroxides in pore solution and reactive siliceous material in aggregate), and the first regulations to prevent ASR were created. However, the structures built according to them also developed ASR [1].

The ISR is relatively newer with respect to ASR, since it was only detected in the middle of 1980s in pre-stressed concrete railway ties [8]. The essential requirements for its occurrence consist of high temperature during concrete cure (> 65 ºC), a sufficient amount of alkali, SO_3 and C_3A in the cement, a sufficient moisture content in concrete, and an appropriate amount of calcium hydroxide in the concrete pore solution [4]. The deleterious effects of ISR may be enhanced by the initial development of cracks due to ASR or other factors, through the crystallization of ettringite in these cracks that will lead to additional expansion of the concrete.

Since then a vast amount of research has been conducted and the understanding on IER has progressed significantly. However, the problem was not totally eradicated as today numerous concrete structures still exhibit ASR and ISR. The reasoning behind the detection of an increasing number of affected structures is threefold, greater awareness of the technical and scientific community regarding IER, improvement of the methods utilized in IER diagnosis, and the fact that distress signs can appear only several years or decades after construction.

Current knowledge on IER does not allow for a complete assessment of the actual condition of an IER affected structure and an accurate prediction of the mechanical properties deterioration and, consequently, of the period during which the structure will effectively perform its function, essential for the timely and cost-effective planning of the necessary mitigation/rehabilitation/reconstruction works. This is of upmost importance in large concrete structures, where IER can have severe consequences in terms of structural safety and serviceability [9,10]. The importance of this type of structures, the number of structures in which IER was already identified or is very likely to be diagnosed in a near future, the large number of structures that are under or planned for construction, which may also come to develop IER is why, today, they are still a major concern.

Therefore, to help surpassing this situation, a research project is being conducted at LNEC to contribute to the establishment of a method for the accurate determination of the current level of IER progression and of the deterioration of the concrete mechanical properties. These are essential to the adequate overall appraisal of an affected structure, and the development of structural models that predict risks to structural integrity, potential for further deterioration due to other mechanisms, need for mitigation/remediation actions, and the remaining service life of the affected structure, as acknowledged in the "IStructE ASR Technical Guide" [11] and "IStructE Appraisal of existing structures" [12]. This paper presents the preliminary results, from the aforementioned study, concerning the assessment of the effect that internal expansion has in the deterioration of the concrete mechanical properties, more specifically in its stiffness, currently considered has being the concrete mechanical property most sensitive to deleterious expansion [5,11].

2. Experimental programme

Concrete deterioration due to IER is a very slow process and it is normally studied through the conduction of expansion tests carried out on mortar or concrete prisms exposed to an artificial environment that accelerates the reactions. For promoting ISR, the current practice is to immerse concrete specimens in water at ambient temperature. In order to promote the development of ASR, it is current practice to expose concrete specimens to high relative humidity (> 95 %) and a temperature of 38 ºC or 60 ºC. However, even with these accelerated tests, the results are obtained only after several months or years of testing. Therefore, an experimental campaign was devised to seek methods of producing internal damage to