External and Internal Aspects on the Durability of Concrete Structures

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INTRODUCTION

Although degradation due to freeze-thaw cycles, carbonation, corrosion, sulfate attack, etc. and the corresponding mechanisms have been studied for decades, we continue to be challenged by being able to translate the kinetics of degradation reactions, rates of damage, symptoms of damage on small-scale laboratory specimens that are unreinforced, unrestrained, mechanically unloaded specimens to large-scale, real life, reinforced structural elements, subjected to restraint, and mechanically loaded. There is a need for research to relate the performance of materials tested in the laboratory to the performance of structures in the field to improve the safety, sustainability, service life of existing and new concrete structures.

Although there are several aspects that warrant attention, this presentation will address two aspects, 'external' and 'internal', pertaining to understanding laboratory concrete durability testing to structural performance in the field. The scope of this paper specifically pertains to durability associated with internal swelling of concrete. The 'external' aspect deals with concrete behavior subjected to combined exposure conditions leading to degradation. The 'internal' aspects deals with the anisotropy behavior of concrete due to element geometry, effect of confinement due to steel reinforcing steel, steel fibres, and the role of multi-axial stresses and its implications on concrete's internal swelling response.

DISCUSSION AND RESULTS

External Aspect: Combined Exposure Conditions

Several researchers [1,2] have examined the influence of freeze-thaw damage in combination with chloride ingress, sulphate attack or carbonation processes. Although some coupled deterioration processes provoke and accelerate more serious damage than single loads, this is not necessarily always the case [3,4]. One of the most common combination of concrete degradation mechanisms that has been published in the literature is: freeze thaw and chloride exposure studies. In contrast, markedly fewer studies have been conducted on the combined effect of alkali-silica reaction (ASR) and freeze-thaw or chloride exposure or carbonation or sulfate attack. In the Canadian context, this is of particular interest since ASR is infact prevalent in many structures that are in need of assessment and service life analysis. Canadian Standards Association (CSA) does allow the use of reactive aggregate in concrete with the requirement that specified supplementary cementious material (SCMs) are also used,since they are well reported to reduce ASR expansion (Figure 1), however, SCMs can also increase vulnerability to carbonation reactions. Therefore, two research questions related to the competition of the chemical reactions are: What is the resistance of concrete (with and without SCMs) to combined ASR and carbonation? And, do the CSA requirements for SCMs help or harm concrete that is subjected to combined ASR and carbonation? This presentation will discuss these aspects.

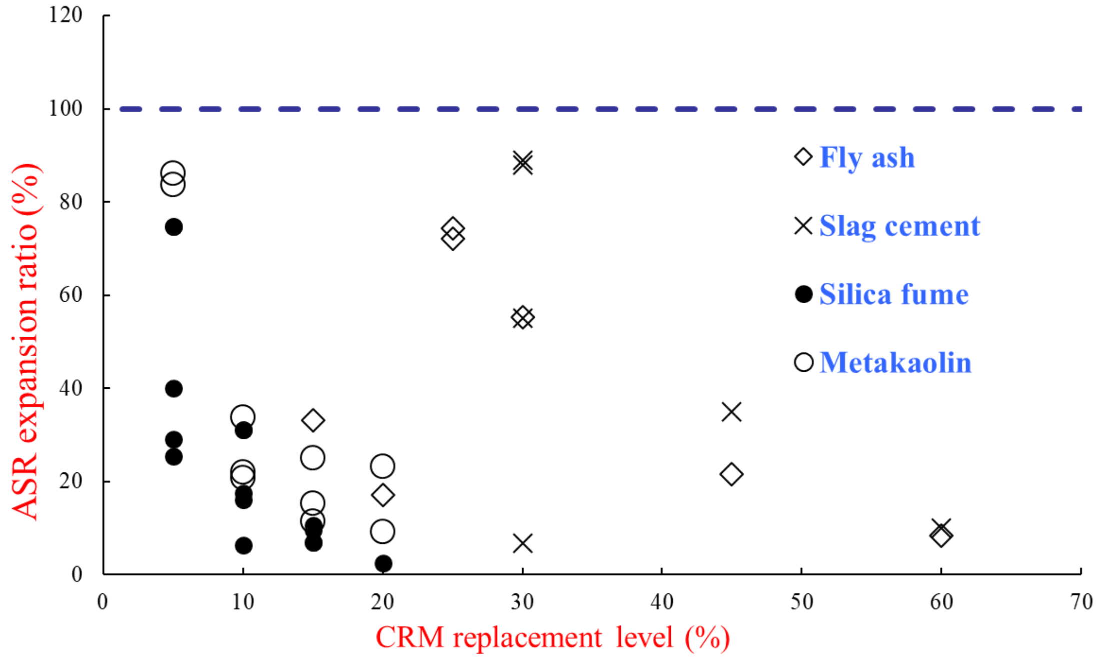
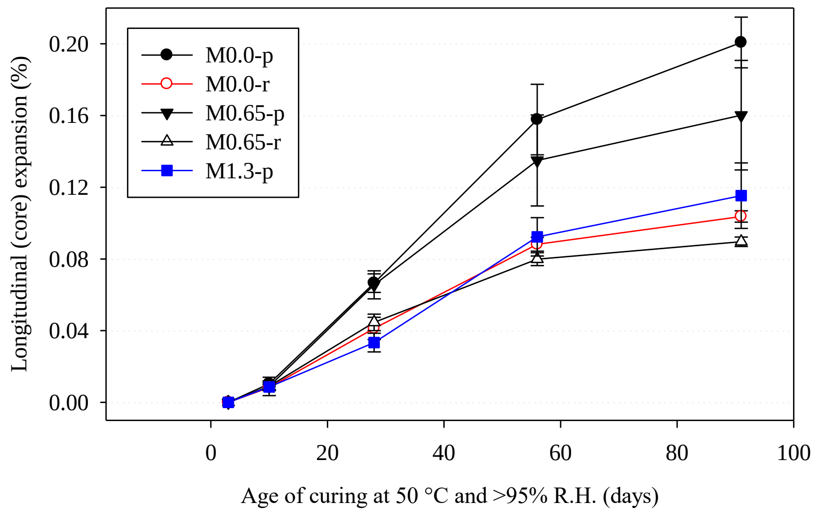


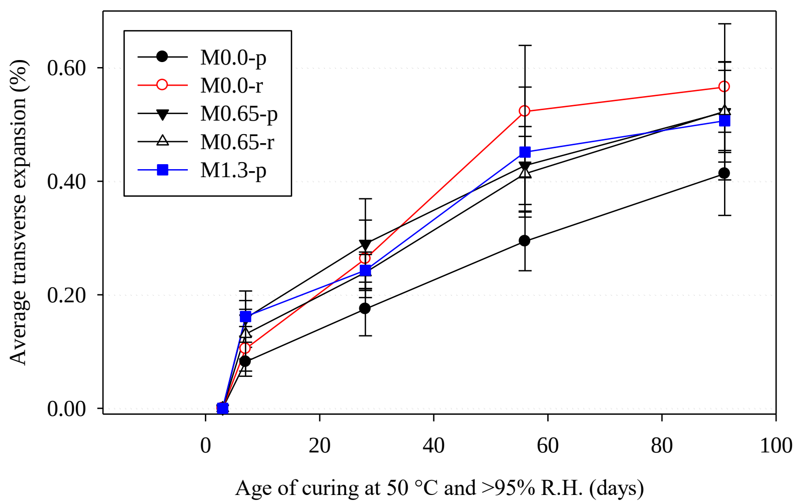
Figure 1: Effect of cement replacement material (CRM) on ASR expansion

Internal Aspect: Anisotropic Behavior and Confinement of Concrete Due to Reinforcement

Although the direction of casting induces anisotropic behavior of concrete, the influence of this factor on the anisotropy of internal swelling behavior are inconclusive. This study has examined the multi-axial expansion and the damage rating index (DRI) of concrete that is: unreinforced; reinforced with one steel bar; steel fibre reinforcement; multi-axially loaded in compression. The concrete is designed in accordance with ASTM 1260 with reactive Spratt aggregate. For unreinforced concrete, the expansion in the transverse directions was markedly greater (3.72 times) than in the longitudinal direction. In the literature, relatively fewer studies have focused on the anistropic behavior of internal swelling of ASR-affected fibre-reinforced concrete. Although some studies indicate that fibers reduce ASR damage of concrete, other sources indicate that longitudinal expansion was larger compared to the expansion of specimens without fibres [5].This behavior was attributed to the greater ductility of fibre-reinforced concrete, which allowed less cracking and more expansion [5]. Part of the conflicting observations may be associated with the fact that fibres are oriented in three-dimensional space, and their effect on the ASR performance of concrete cannot be understood by measuring axial expansion alone. Figure 2 highlights the differences in longitudinal, and transverse expansion of ASR-affected unreinforced concrete (M0.0-p), reinforced concrete with one bar (M0.0-r) as well as plain and reinforced concrete with 0.65% steel fibre (M0.65-p and M0.65-r) and plain concrete with 1.3% steel fibres (M1.3-p).



a)



b)

Figure 2: Expansion of ASR affected specimens (a) longitudinal and (b) transverse

CONCLUSION

There is a need to translate results from laboratory studies of concrete durability to field durability of concrete structures which could lead to the development of: new protocols for the inspection, testing, and prognosis of existing structures that account for the anisotropic behavior; new laboratory test specifications to evaluate concrete exposed to coupled durability mechanisms; and more accurate service life predictions of concrete structures based the performance and properties of reinforced, mechanically loaded concrete specimens. With a strong effort by researchers from a collaborative materials and structural perspective, there is potential to bridge the disconnect between the interpretation of laboratory concrete durability tests and the field performance of structures.

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