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Communication

Reduction in alkali–silica expansion due to steel microfibers

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Abstract

The alkali–silica reaction (ASR) produces an expansive gel that may cause cracking and displacement in concrete structures. Steel microfibers ranging from 1% to 7% by volume of cement mortar were incorporated to reduce the expansion and cracking. All specimens contained 5% of opal by weight of fine aggregates. The samples were cast and tested according to ASTM C-1260. A considerable reduction in expansion was observed for all steel microfiber-reinforced mortar specimens compared to the control specimens without fibers. The higher the fiber volume fraction, the lower the expansion. At constant fiber volume fraction, the expansion was further reduced when the curing time was extended from 1 day to 7 days due to an increase in the fiber-matrix interfacial bond strength. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Accelerated tests; Alkali–silica reaction; Microsteel fiber; Opal

1. Introduction

The chemical reaction involving alkali ions from Portland cement, hydroxyl ions, and certain siliceous constituents that may be present in the aggregate produces an alkali–silica gel that swells by imbibing water. The swelling causes expansion and cracking, leading to loss of strength, elasticity, and durability of concrete. The methods used to prevent expansion and cracking either control the formation of the gel or influence its expansive nature. Approaches to control the gel formation include the use of low alkali cements, nonreactive aggregates, mineral [1] and chemical admixtures [2]. The expansion associated with the gel imbibing water has been reduced by induced and applied stresses [3–5] and through the addition of steel fibers [6].

In this study steel microfibers were added to investigate their influence on expansion and cracking due to the alkali–silica reaction. Due to their small dimension (cross section 20×100 μm, length 3 mm) compared to conventional steel fibers (cross section 2.5×0.2 mm, length 32 mm) used in Ref. [6], the numerical density (number of fibers per square centimeter of any cross section) will be much higher for microfibers than it is for conventional fibers. The high density of microfibers may be more efficient in restraining the expansion due to ASR. Furthermore, due to their smaller size, they are more likely to be in close proximity to the interface of a reactive aggregate, influencing the gel expansion in its early stage.

Steel microfibers ranging from 1% to 7% by volume of cement mortar were added to specimens containing 5% opal by weight of fine aggregates. Opal was chosen for its known susceptibility to the alkali–silica reaction [7]. The specimens were cast and tested according to ASTM C-1260 [8]. For one set of the expansion experiments the ASTM C 1260 expansion test was slightly modified by allowing the specimens to be water-cured for 7 days total (i.e. extending the standard curing time by 6 days). This allowed us to investigate the influence of fiber/matrix interfacial strength on expansion.

2. Materials and experimental study

Portland cement type I/II was used to prepare mortar bars containing steel microfibers of 1, 3, 5, and 7 vol.% and control specimens with no fibers, respectively. The steel microfibers have a rectangular cross section of

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20×100 μm and are on average 3 mm long. Both the control and reinforced specimens contain opal (5% by weight of fine aggregate) as the reactive aggregate. The mortar-bar samples were cast and tested according to ASTM C-1260 [8]. ASTM C-1260 specifies the specimens to be water-cured for 1 day at 80°C and then immersed in 1 mol NaOH solution at 80°C. For one set of the expansion experiments we slightly modified the ASTM C 1260 by allowing the specimens to be water cured at 80°C for 7 days total (i.e. extending the standard curing time by 6 days). For the short and the longer curing time, three specimens were cast for each fiber volume fraction, respectively. The length change of the prisms was measured every 24 hours up to 30 days.

3. Results and discussion

The experimental results on expansion over time of the control and fiber-reinforced specimens are shown in Figs. 1 and 2. The results in Fig. 1 were obtained for the set of specimens subjected to ASTM C-1260 (i.e. 1 day water curing). Fig. 2 presents the expansion results over time for specimens where the curing time in water was extended from 1 to 7 days. The expansion data after 14 days and 30 days for the control and steel microfiber specimens are listed in Table 1. The expansion decreases with increasing steel microfiber volume fractions for both sets of curing times. The highest reduction was observed at 7 vol.% of microfibers. Most of the expansion occurred within the first 14 days after the specimens were immersed in the NaOH solution. Increasing the exposure time from 14 to 30 days enhanced the expansion of the 7 vol.% microfibers by only 17% for the specimens with the shorter curing time.

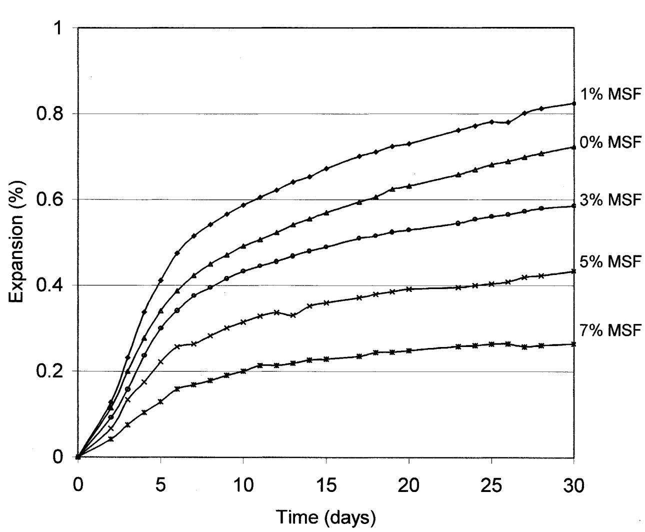

Fig. 1. Effect of the amount of microsteel fibers (MSF) on the expansion of mortar containing 5% opal (ASTM C 1260-94).

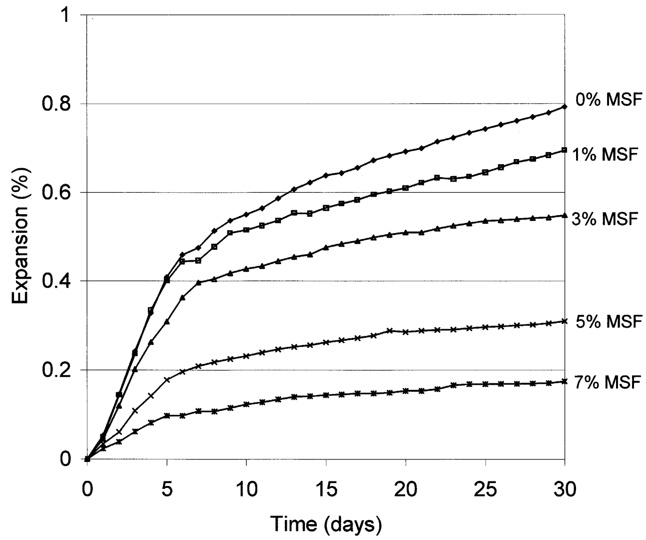

Fig. 2. Effect of the amount of microsteel fibers (MSF) on the expansion of mortar containing 5% opal after 6 days water curing at 80°C+ (ASTM C 1260-94).

The decrease in expansion due to steel microfibers is even more pronounced for specimens where the curing time was extended by 6 days. Both the initial portion and the total expansion were considerably reduced for microfiber above 3% by volume. It is interesting to note that the extended curing time did not reduce the expansion of the control specimens. The longer curing time in the microfiber-reinforced specimens enhances the fiber/matrix interfacial strength. A stronger bond between the fibers and the matrix before the expansion mechanisms are being activated reduced the expansion over the microfiber-reinforced specimens that were cured for only 1 day. The visual inspection after the accelerated tests revealed longitudinal cracks along the length of the control specimens and the specimens reinforced with 1 vol.% of microfibers, respectively, for both curing times. The first sign of visible cracking occurred after the specimens were exposed to the NaOH solution for 3 days. No visible cracks were observed along the length of specimens reinforced with 5% and 7% of microfibers over the 30 day period.

Table 1
Expansion of the mortar bars at 14 and 30 days

Addition of microsteel fiber (%)	0	1	3	5	7
ASTM 1260-94					
Expansion (%)					
14 days	0.56	0.65	0.48	0.35	0.23
30 days	0.72	0.82	0.59	0.43	0.27
6 days water curing at 80°C+ ASTM 1260-94					
Expansion (%)					
14 days	0.62	0.55	0.46	0.26	0.14
30 days	0.79	0.69	0.55	0.31	0.18

4. Summary

The effect of steel microfibers on the expansion associated with ASR was investigated. The specimens were fabricated according to the accelerated test ASTM C 1260. The effect of two different curing times were investigated. For both curing times, the steel microfibers are very effective in reducing the expansion and cracking due to ASR. The reduction in expansion was more pronounced with the longer curing time, which allowed for a stronger bond to form between the fibers and the matrix. The control specimen, however, was unaffected by the longer curing time.

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