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Effects of alkali-resistant glass fiber reinforcement on crack and temperature resistance of lightweight concrete

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Abstract

Effects of alkali-resistant glass fiber reinforcement on the flexural strength and ductility, restrained shrinkage cracking and temperature resistance of lightweight concrete were investigated. All these properties of lightweight concrete benefitted from the introduction of alkali-resistant glass fibers. Fiber mass fractions of 0.5–3.0% (volume fractions of 0.125–0.75%) were investigated; fiber mass fractions of 1.0–2.0% (volume fractions of 0.25–0.5%) were sufficient for control of restrained shrinkage cracks and enhancement of the flexural toughness and temperature resistance of lightweight concrete. © 2002 Published by Elsevier Science Ltd.

Keywords: Alkali-resistant glass fibers; Lightweight concrete; Shrinkage cracking; Temperature resistance

1. Introduction

The relatively low elastic modulus of lightweight aggregates and the relatively high cement content of lightweight concrete generally increase drying shrinkage movements of lightweight concrete [1–3]. The relatively high absorption capacity of lightweight aggregates increases the moisture absorption of lightweight concrete; this could yield pronounced moisture gradients during air-drying which lead to the formation of (restrained) shrinkage cracks. Fiber reinforcement provides an effective means of reducing the tendency towards (restrained) shrinkage cracking in lightweight concrete.

The research reported herein investigated glass fiber reinforcement as an effective means of controlling shrinkage cracking in lightweight concrete. The results help concrete practitioners select proper fiber dosages for shrinkage crack control in lightweight concrete construction. Test data were also produced on desirable effects of glass fibers on flexural performance and temperature resistance of lightweight concrete.

2. Experimental program

A prepackaged dry mix of (perlite) lightweight concrete was used as the matrix in this investigation. The mix proportions (by weight and volume) are presented in Table 1. The bulk specific gravity of the lightweight concrete materials considered in this investigation was 0.677.

This dry mix (incorporating water-reducer) is blended with water (at 60% by weight of the total dry mix) and air entraining agent. Alkali-resistant glass fibers were added to this mix at 0–3% weight fraction (0–0.75% volume fraction). The fibers were 12 mm (0.5 in.) long and 135 μm (0.0053 in.) in diameter, with zircon oxide content of more than 19% by weight. Fibers were added first to the mixer followed by mixing water, air entraining agent, and dry ingredients, and mixing was continued for 5 min.

The experimental program is summarized in Table 2. The effects of fiber reinforcement were investigated through the performance of restrained drying shrinkage tests [4,5] and flexure tests prior and after exposure to elevated temperatures. The restrained shrinkage test (Fig. 1) comprised a rigid steel ring against which a lightweight concrete ring was placed. The outside mold of lightweight concrete was removed at 24 h, and the specimen (restrained by the interior ring) was exposed to

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Table 1
Mix proportions by weight and volume weight

Ingredient	Weight	Volume
Type I Portland cement	1	1
Perlite	0.32	5.1
Microsilica	0.085	0.077

Table 2
Summary of the experimental program

Fiber weight fraction (volume fraction)	Tests		
	Restrained shrinkage	Flexure	High-temperature exposure
0%	×	×	×
0.5% (0.125%)	×	×	
1% (0.25%)	×	×	×
1.5% (0.375%)	×		
2% (0.5%)	×	×	
2.5% (0.625%)	×	×	×
3% (0.75%)	×	×	×

23°C (73°F) and 50% relative humidity, with the width and number of cracks monitored over a period of few months. Two restrained shrinkage specimens were prepared for each fiber volume fraction.

Flexure tests were performed through 3-points loading of $38 \times 38 \times 160$ mm^3 ($1.5 \times 1.5 \times 6.5$ in.) prismatic specimens over a 140 mm (5.5 in.) span. These specimens were demolded at 24 h and stored at 23°C (73°F) and 50% relative humidity up to the test age of 14 days.

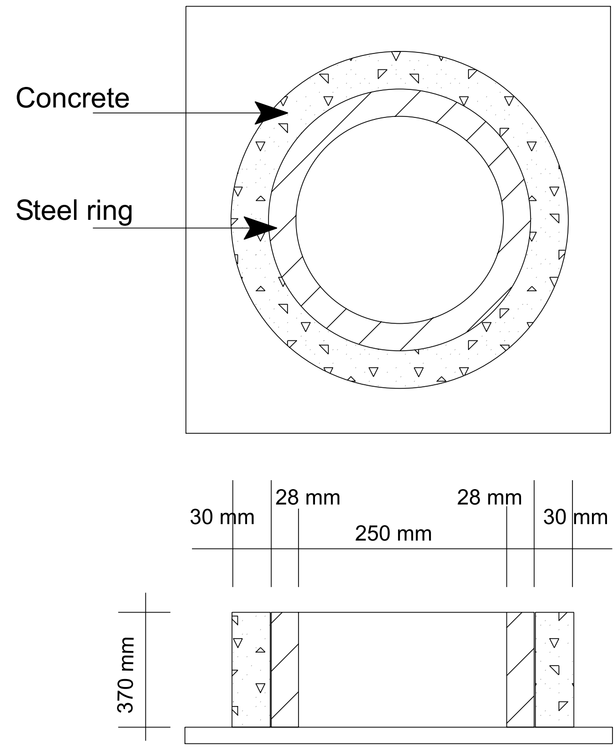

Fig. 1. Restrained shrinkage test specimen.

Given the particular application intended for the lightweight concrete mixtures considered in this investigation, that is lining of chimneys, three of the six flexure specimens were exposed to 400°C (750°F) temperature for 1 h at the age of 7 days. The heating and cooling rates were about 40°C/min (75°F/min). All specimens were tested at room temperature at the age of 14 days.

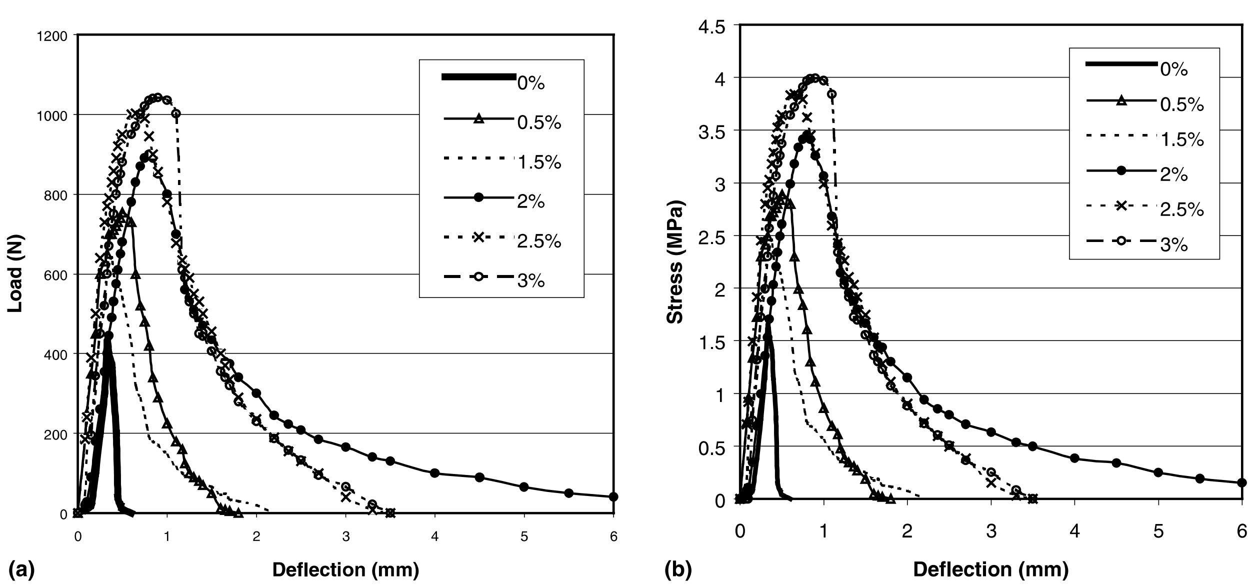

Fig. 2. Typical (a) load–deflection and (b) flexural stress–deflection curves for glass fiber reinforced concrete with different fiber mass fractions.

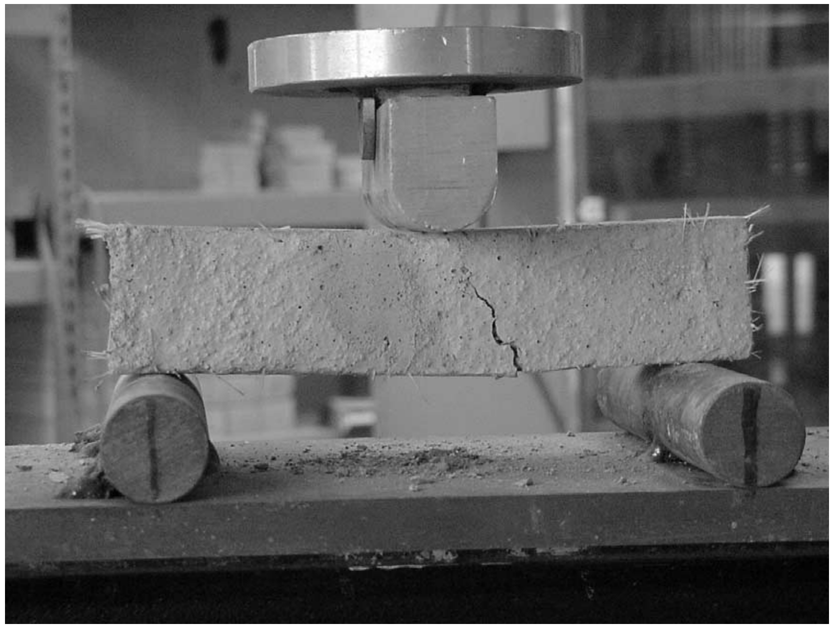

Fig. 3. A pictorial presentation of the post-cracking resistance of glass fiber reinforced lightweight concrete.

3. Test results

Typical flexural load–deflection and flexural stress–deflection curves are presented in Figs. 2(a) and (b), respectively. There are improvements in flexural strength and ductility of lightweight concrete with the introduction of alkali-resistant glass fibers. The picture presented in Fig. 3 highlights the post-cracking flexural resistance of glass fiber reinforced lightweight concrete.

The flexural strength test results are summarized in Fig. 4. Increasing fiber mass fractions are observed to increase the flexural strength of lightweight concrete; this occurs more rapidly at fiber mass fractions below 1.5%.

After exposure to elevated temperature, as shown in Fig. 5, lightweight concrete mixtures incorporating alkali-resistant glass fibers provide higher levels of residual flexural strength when compared with plain lightweight concrete. The drop in flexural strength after exposure to elevated temperature can be attributed to microcracking and cracking of concrete due to the generation of internal stream pressure at elevated temperature and also due to internally restrained thermal shrinkage effects upon cooling. Effectiveness of glass fibers in crack control explains their contributions to temperature resistance of concrete.

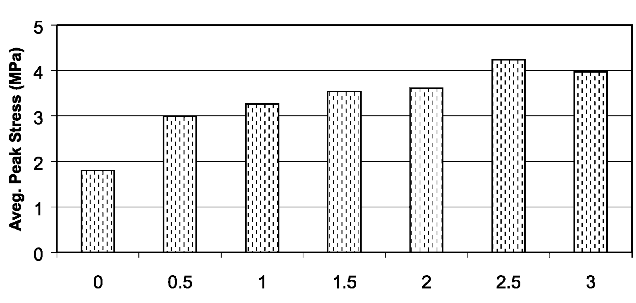

Fig. 4. Flexural strength test results.

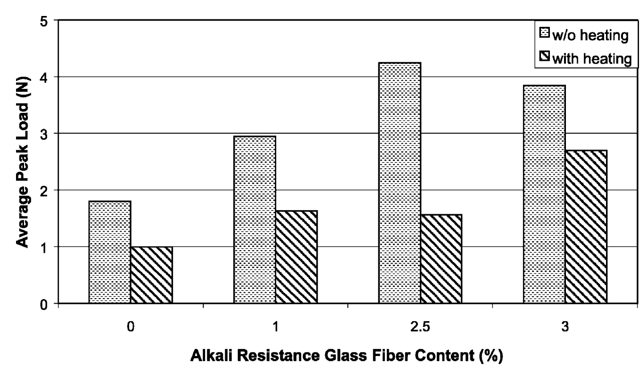

Fig. 5. Effects of exposure to elevated temperature on flexural strength.

Typical crack development patterns in restrained shrinkage tests are introduced in Fig. 6. Higher fiber contents promoted multiple cracking and reduce the maximum crack width. Only, one crack was observed in plain lightweight concrete, and three cracks were also observed at fiber weight fraction (volume fraction) of 0.5% (0.125%). Four to six cracks were observed at

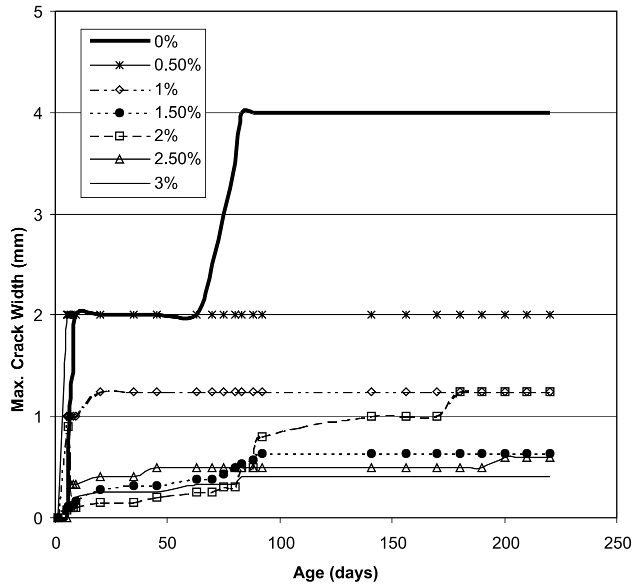

Fig. 6. Restrained shrinkage test results for lightweight concrete materials with different glass fiber mass fractions.

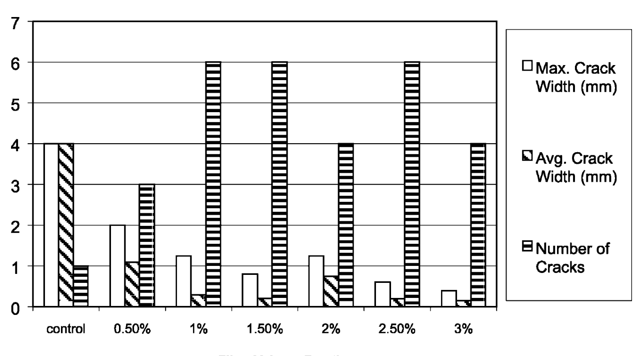

Fig. 7. Data on crack conditions of restrained shrinkage specimens after 220 days of drying versus fiber volume fraction.

higher fiber contents. Fig. 7 summarizes data on cracking conditions versus glass fiber volume fraction after 220 days of drying. The effectiveness of glass fibers in promoting multiple cracking and controlling crack width is apparent in this figure. Glass fibers thus benefit the serviceability and durability characteristics of lightweight concrete, which are greatly influenced by maximum crack width. The picture presented in Fig. 8 compares typical crack patterns of plain (left) and glass fiber reinforced (right) lightweight concrete materials. In general, glass fibers significantly reduce restrained shrinkage crack widths, and fiber mass fractions equal to or greater than 1.0% were sufficient to effectively reduce restrained shrinkage crack widths in lightweight concrete.

4. Conclusions

The effects of alkali-resistance glass fiber at mass (volume) fractions up to 3% (0.75%) on the restrained shrinkage cracking attributes, flexural performance and temperature resistance of lightweight concrete were investigated. Alkali-resistant glass fibers were found to be highly effective in controlling restrained shrinkage cracking of lightweight concrete. Alkali-resistant glass fibers promote multiple cracking and reduce crack widths. Introduction of glass fibers also improves the flexural strength and ductility of lightweight concrete, and controls the negative impacts of exposure to elevated temperatures. Alkali-resistant glass fibers at about 1% mass fraction (0.25% volume fraction) are quite effective in enhancing the material properties of the lightweight concrete mixtures investigated in this project.

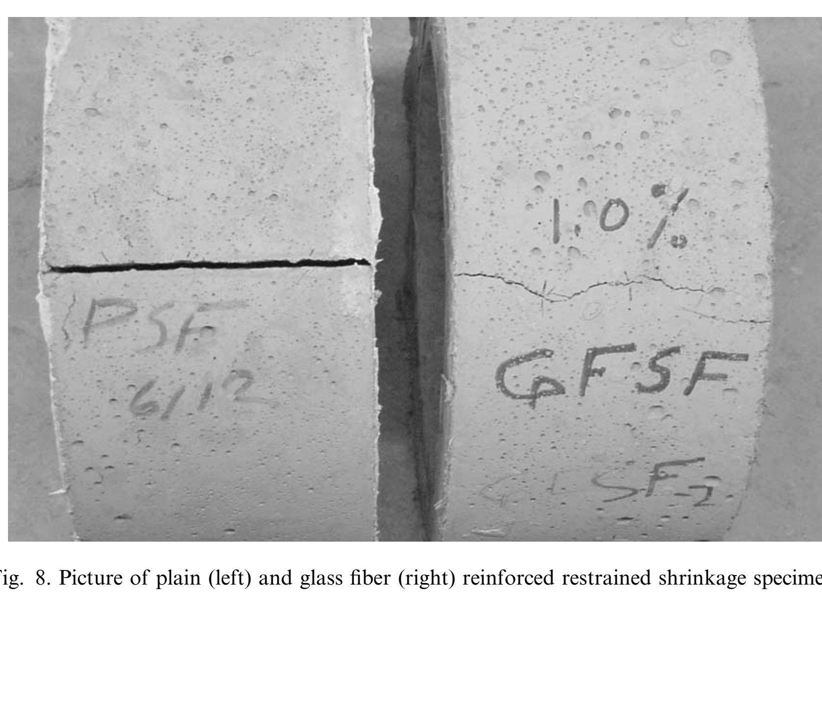

Fig. 8. Picture of plain (left) and glass fiber (right) reinforced restrained shrinkage specimens.

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