Pergamon

Cement and Concrete Research, Vol. 27, No. 12, pp. 1885–1891, 1997

0008-8846/97 $17.00 + .00

PII S0008-8846(97)00203-2

THE EFFECT OF HIGH CONTENT OF FLY ASH ON THE PROPERTIES OF GLASS FIBER REINFORCED CEMENTITIOUS COMPOSITES

Y. Zhang,[1]* W. Sun*, L. Shang,† and G. Pan*

*Department of Materials Science and Engineering, Southeast University, Nanjing, 210096, China

†Nanjing Ningyuan Science and Technology Development Company, Nanjing, China

(Refereed)

(Received July 17, 1997; in final form September 18, 1997)

ABSTRACT

The objective of this paper was to study glass fiber reinforced cementitious composites (GFRCC) with Portland cement, a high content of fly ash as matrix. The effect of fly ash content, the initial curing time, and accelerated ageing on the flexural strength of GFRCC was investigated. The suitability of the accelerated ageing method was queried by analyzing the results from SEM observation, XRD analysis, and deflection testing. © *1997 Elsevier Science Ltd*

Introduction

Glass fiber reinforced cement (GRC) has been well known for decades (1,2). In the present GRC industry, the technical method of using alkali resistant (AR) glass fiber and low alkaline special cement to produce GRC is commonly recognized. However, experts are still working hard on searching for the substitute materials for the special low alkaline cement. B. Singh and A.J. Majumdar et al. reported their results on GRC containing pulverized fuel ash (PFA) up to 50 wt% and reached the conclusion that the long-term changes in the mechanical properties of PFA containing GRC were similar to those of ordinary GRC (3,4). Relatively speaking, however, the higher the proportion of PFA in the mix, the lower is the rate of MOR reduction. In recent years, research on fly ash containing GRC has been seldom. At present, the air classified fly ash containing more fine particles is becoming commercially available increasingly, which makes us reconsider the possibility of using a high content of good quality fly ash in GRC. This paper aims at the investigation of the effect of good quality fly ash on the performance of GFRCC.

Materials and Experimentals

In all the specimens, the same 525# Portland cement was used. The chemical compositions and the physical properties of fly ash from two sources and cement are given in Table 1. The

[1]To whom correspondence should be addressed.

TABLE 1
The chemical compositions (wt%) and physical properties of fly ashes and cement

Fly ash	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	L.O.I.	Specific gravity (g/cm^3)	45-μm sieve residue
N	57.89	27.17	6.21	3.25	1.10	0.16	3.50	2.35	4.18
S	51.83	32.13	5.96	3.74	1.05	0.18	5.04	2.30	1.90
C*	21.17	4.97	5.19	64.52	1.08	2.30	1.19	3.1	9.2

*Cement

size of specimens for flexure tests was 40 × 40 × 160 mm. The water to binder ratio was 0.33, and binder to sand ratio 1/2. The content of superplasticizer was adjusted so that all the fresh specimens had similar flowability. AR glass fiber was used as reinforcement. The fiber length was 12 mm and the volume content 2%. In the process of making specimens, water containing dissolved superplasticizer was added into the dry mixture containing cement, fly ash, and sand and mixed together for 3 min, thereafter, glass fibers were scattered uniformly into the mixer and mixed for another 3 min.

Samples for SEM observations were collected from GFRCC mortars. XRD powder samples were made by grinding dried fly ash-cement pastes that was first dewatered by immersing samples in anhydrous ethanol.

The major materials applied in the test series are listed in Table 2.

Test Results and Analysis

In this study, we examined the flexural strength, the compressive strength, and the deflection at the center of two sides at the ultimate flexural strength. Because the flexural strength is much more important than the compressive strength for GFRCC, the compressive strength will not be discussed here.

The Flexural Strength of GFRCC Under Water at 20°C

Figure 1 showed that the incorporation of fly ash remarkably reduced the early strength of GFRCC. The higher the content of fly ash, the more the reduction of early strength. From 7 to 28 days, the flexural strength improved to a great extent, and kept on increasing after 28 days. Comparatively speaking, the flexural strength of the reference specimen without fly ash

TABLE 2
The materials and their contents of experimental series

Series	CAR	NAR 40	NAR 50	NAR 60	SAR 40	SAR 50	SAR 60
Fly ash	-	N	N	N	S	S	S
Content of fly ash	0	40	50	60	40	50	60

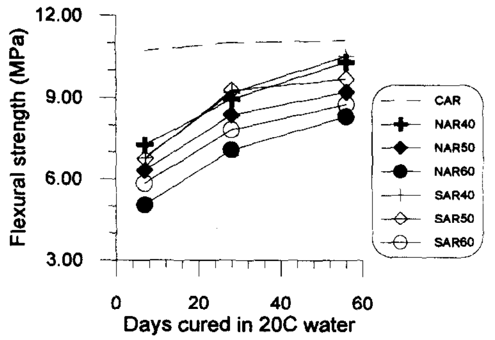


FIG. 1.
The flexural strength of GFRCC cured in 20°C water.

changed a little after 28 days. This result was similar to that of the high content of fly ash Portland cement mortars without reinforcement (5).

The Effect of Accelerated Ageing on the Flexural Strength of GFRCC

The accelerated ageing method adopted was as follows: immersing specimens under water at 80°C up to 11 days after all the specimens were pre-cured in 20°C water for 7 days.

Figure 2 shows the test results of accelerated ageing at 80°C. It can be seen that, within the initial 4 days of accelerated ageing, the flexural strength increased continuously; 4 days later, however, the changes of flexural strength of different series were different. Further accelerated ageing reduced the flexural strength of GFRCC containing 40% or 50% fly ash. The flexural strength of GFRCC containing 60% fly ash increased during the 11-day accelerated ageing period. For reference specimens, the flexural strength dropped sharply at the initial period of accelerated ageing.

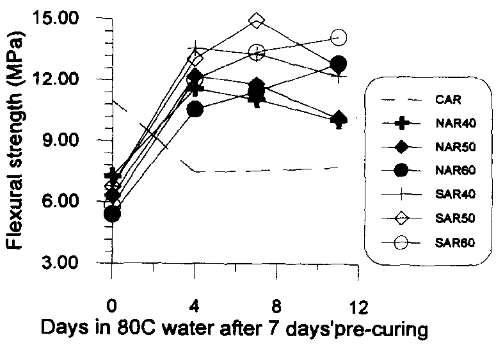


FIG. 2.
The flexural strength of GFRCC after accelerated ageing.

TABLE 3
The effect of initial curing time on the results of accelerated ageing

	3-day initial curing		7-day initial curing		28-day initial curing	
Series	Ageing time (day)	Flexural strength (MPa)	Ageing time (day)	Flexural strength (MPa)	Ageing time (day)	Flexural strength (MPa)
NAR43	4	11.08	4	11.56	4	11.92
	7	11.53	7	11.41	7	11.31
	11	10.55	11	10.70	11	11.14
NAR53	4	11.20	4	12.20	4	11.70
	7	11.34	7	11.79	7	10.83
	11	11.89	11	10.12	11	10.04
NAR63	4	9.95	4	10.54	4	9.29
	7	12.67	7	11.42	7	9.73
	11	12.87	11	12.82	11	10.68

The Effect of Initial Curing Time on the Results of the Accelerated Test

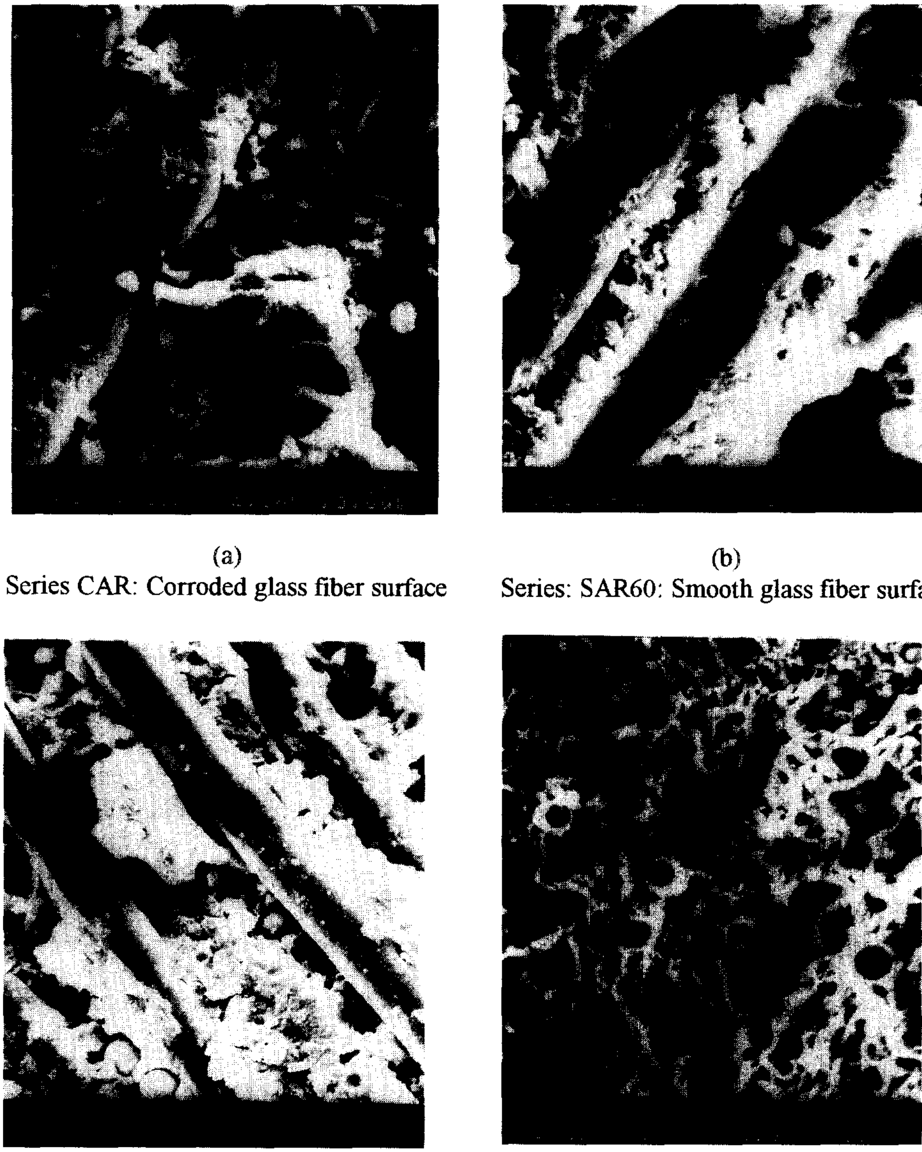
The influence of initial curing time on the results of the accelerated ageing test was investigated owing to the consideration of the high content of fly ash in GFRCC. The initial curing time in water at 20°C before accelerated test was 3, 7, and 28 days, respectively. The results can be seen in Table 3. It can be concluded that a short initial curing time delayed the presence of the worsening of properties of GFRCC under accelerated ageing. Take series NAR43 for example, the reduction of flexural strength took place at the 11th day and the 7th day for the initial curing time being 3 days and 7 or 28 days respectively. For series NAR63, the flexural strength developed continuously under the accelerated test no matter how long the initial curing was. Therefore, we should prolong the initial curing time as long as possible, in particular for GFRCC containing large amounts of fly ash, so as to make the results from accelerated ageing reflect the real development of GFRCC under natural condition.

Results of SEM Observation

Figure 3 shows the micromorphology of the matrix and fibers in GFRCC. From (*a*) we can see the severely corroded AR glass fiber surface in pure Portland cement matrix without fly ash after 11-day accelerated ageing in 80°C water. Panels (*b*) and (*c*) showed the smooth surface of AR glass fibers from matrix with 60% fly ash S and N respectively after 11-day accelerated ageing. Panel (*d*) showed the glass fiber fracture surface and the dense matrix of GFRCC with 60% fly ash N.

Results of XRD Analysis

Although we cannot examine the content of calcium hydroxide quantitatively from the results of XRD analysis, we can compare the relative amount of CH crystals from XRD diagrams.



(a)
Series CAR: Corroded glass fiber surface

(b)
Series: SAR60: Smooth glass fiber surface

(c)
Series NAR60: Smooth glass fiber surface

(d)
Series NAR60: Fractured fibers and dense matrix

FIG. 3.
SEM photos of GFRCC after 11-Day accelerated ageing.

For samples cured in 20°C water for 56 days, the one with fly ash N showed much more CH than that with fly ash S, which explained the relatively superior properties of GFRCC containing fly ash S to fly ash N. For samples submitted to accelerated ageing, the CH decreased with accelerated ageing time.

TABLE 4
Deflection at ultimate flexural strength

Series	20°C water, 28 days	80°C water, 7 days
NAR43	0.124	0.082
NAR53	0.181	0.124
NAR63	0.206	0.134

Deflection at Ultimate Flexural Strength

Table 4 showed the deflection of GFRCC specimens before and after accelerated ageing. Before accelerated ageing, GFRCC exhibited excellent toughness with fiber pull out at failure. However, the process of accelerated ageing makes GFRCC lose most of its toughness with deflection significantly reduced.

Discussion

We can now make a conclusion that the addition of 60% fly ash replacing Portland cement to GFRCC successfully prevented AR glass fibers from chemical attack originated from the matrix. However, the loss of toughness occurred in the course of accelerated ageing.

The role of fly ash in cement matrix has been studied for many years. But little is known about the effect of large amounts of fly ash on the long-term properties of GFRCC. The microstructure, both the pore structure and the composition of hydrates, of cement matrix containing 60% fly ash is quite different from that of the pure cement matrix or cementitious matrix with small amounts of fly ash. At early ages, cementitious matrix with large amounts of fly ash showed much greater porosity than cement matrix without fly ash, and the porosity increased with fly ash content (5). As curing time progresssed, the cement hydration product CH was gradually consumed due to the pozzolanic reaction of fly ash. At present, we still lack the quantitative understanding of the effect of fly ash on the microstructure.

From the comparison of SEM microphotos of GFRCC with 60% fly ash and that without fly ash, we may infer that AR glass fiber will not be attacked not only at early ages, but also at prolonged ages for GFRCC containing fly ash. As far as the micromechanical mechanism is concerned, it is difficult to predict the long-term toughness of GFRCC from the results of the accelerated ageing tests, because the microstructure at high temperature differs from that at low temperature, in particular for GFRCC containing high content of fly ash, and we are short of quantitative understanding of these GFRCCs. Therefore, we need further investigation on GFRCC under normal conditions.

Conclusion

The flexural strength of GFRCC containing 60% fly ash N or S kept on increasing during the 11 days under accelerated ageing test in water at 80°C. XRD analysis showed that the peak value of CH crystals declined with age, and that of fly ash-cement paste samples containing fly ash S was much smaller than that containing fly ash N, which obviously marked the importance of the fineness of fly ash on the properties of GFRCC. SEM observation revealed that AR glass fibers in GFRCC containing 60% fly ash were not corroded after 11-day accelerated ageing in water at 80°C. This study also showed that prolonging the initial curing time was necessary for accurately predicting the long-term properties of GFRCC.

Although the investigation showed no chemical attack for GFRCC containing AR glass fiber and 60% fly ash, the fracture surface and the deflection results demonstrated the embrittlement of GFRCC under accelerated ageing. Due to the large amounts of fly ash contained in the matrix, one should not predict the long-term toughness from the present data. Extensive research on the long-term properties of GFRCC containing large amounts of fly ash under natural conditions is necessary for examining the validity of the accelerated ageing method.

Acknowledgment

The authors are grateful to the National Building Materials Bureau of China for the kind financial support.

References

1. A. Bentur and S. Minds, Fiber Reinforced Cementitious Composites, p. 449, Elsevier Applied Science, London, 1990.
2. A.J. Majumdar and V. Laws, Glass Fiber Reinforced Cement, p. 192, BSP Professional Books, Oxford, 1991.
3. B. Singh, A.J. Majumdar, and M.A. Ali, Int. J. Cem. Compos. Lightweight Concr. 6, 65 (1984).
4. B. Singh and A.J. Majumdar, Int. J. Cem. Compos. Lightweight Concr. 7, 3 (1985).
5. Y. Zhang, W. Sun, and L. Shang, Cem. Concr. Res. 27, 1093 (1997).