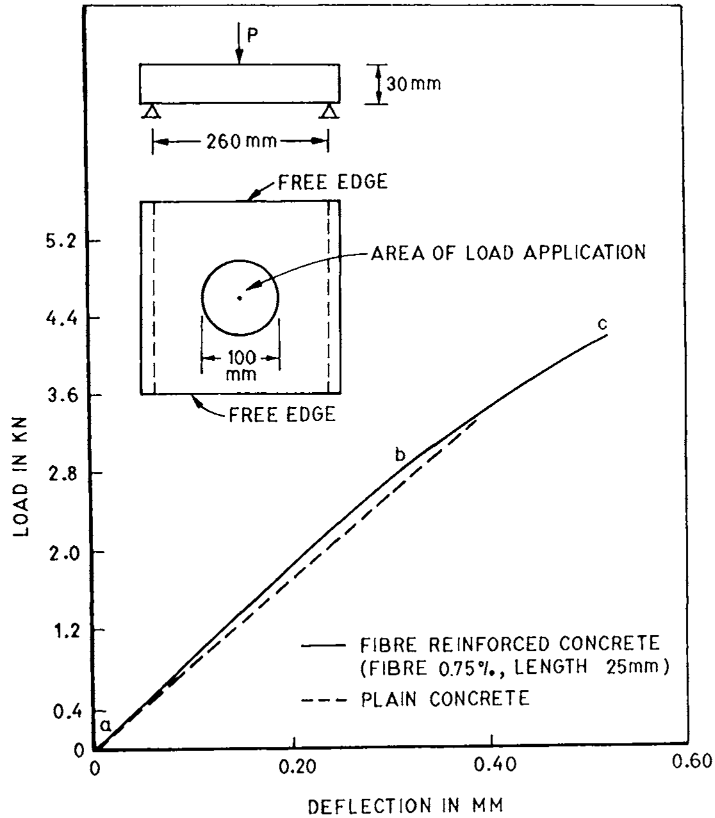
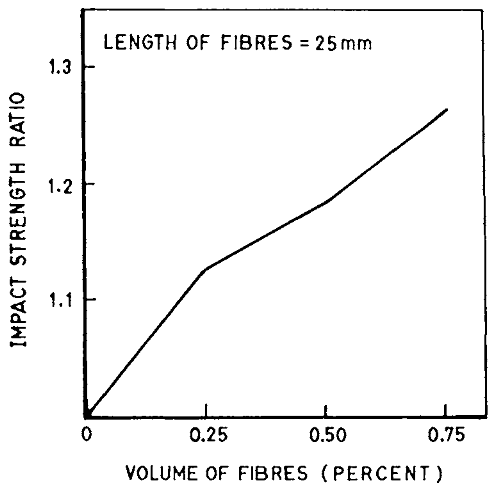


Fig. 2—Load-deflection curve for sheets under static loading



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Glass Fiber Reinforced Concrete with Improved Ductility and Long Term Properties

by H.J. Molloy, J. Jones, and T.G. Harmon

"Synopsis": This paper presents results of a development program to improve the properties of glass fiber reinforced concrete (GFRC). The current system is composed of portland cement, silica sand, five percent alkali resistant glass, curing agent,(5% acrylic copolymer solids by weight of cement), and a water cement ratio of 0.32. Historically this system has resulted in the loss of some ductility due to the development of calcium hydroxide which bonds the individual filaments together in the strand reducing their reinforcing efficiency.(1)

A new system was developed to improve the performance of the composite. This system is composed of rapid hardening hydraulic cement, silica sand, and additives to combine with any free lime, provide enhanced workability and a degree of retardation, using a water cement ratio of 0.45(5), and 5% alkali resistant glass containing 20% Zirconia. Polymer curing agents are not recommended.

The durability of the system was tested using the glass industry test of immersing the product in hot water, (60°C), for up to 100 days and periodically measuring the flexural strength and strain capacity using ASTM C947-89.(6). Analysis of the results indicates a very high retention of both flexural strength and strain capacity for the new system, after being exposed to the hot water aging test. To differentiate between the two systems, the new system will be identified as Zircrete GFRC.

Keywords: Cement additives; ductility; durability; flexural strength; glass fibers; hydraulic cements; reinforced concrete; strains

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INTRODUCTION

Since the introduction of glass fiber reinforced concrete in the USA by Owens Corning Fiberglas during 1974, there has been an effort to improve the long term properties of the matrix. Specifically, the flexural strength, strain capacity , and ductility of the material is reduced as the material is exposed to conditions of high humidity. The measured value of the reduced flexural strength approaches the value of the proportional elastic limit, (PEL).(2)

This feature of the material is caused by the development of calcium hydroxide as the cement hydrates. The calcium hydroxide fills the interstices of the strand of glass, bonding the individual filaments together and reducing their ability to accept a bending strain. The result is a loss of ductility. Although this feature of the material is well understood and accommodated for in the design of products manufactured with GFRC, it has been a challenge to the industry to improve these properties.

Several methods have been evaluated including coating the glass fiber strand to prevent the calcium hydroxide from entering the strand, introducing pozzolans, adding polymer up to 15%, and changing glass formulations. None have been commercially acceptable for various reasons, including cost and handleability.

It was concluded that the only way to successfully improve the properties was to develop a new cement.

OBJECTIVES

The objectives of the program were as follows:

1- Improve the ductility and provide stable physical properties in the composite.
2- Reduce the shrinkage to less than ordinary portland cement.
3- Develop a non-combustible composite which will pass ASTM E-136 and E-84 tests.
4- Formulate a system which will be easy to use in manufacturing.
5- Provide a composite that is easily cured.
6- Provide a composite that is competitive with the current GFRC system.
7- Use only commercially available materials for the system.

DEVELOPMENT PROGRAM

This phase of the program started in 1985 and involved an evaluation of existing cements to determine the degree of calcium hydroxide generation. As a result of this evaluation it was decided that a new cement would have to be developed. The first such cement was introduced by Chichibu Cement company of Japan.(2) The results indicated that most objectives were met, however costs for the material, and curing requirements precluded its introduction in the USA .

Rapid hardening hydraulic cements produced by CTS Cement company and Blue Circle Cement company both of the USA, also demonstrated improved results.(5) The additive produced by M&J Inc. in combination with the rapid hardening cements improved the results by further reducing or eliminating the calcium hydroxide. Mix designs and test coupons were produced by Molloy and Associates Inc., and durability tests were accomplished by Washington University, of St. Louis, Mo..

MATERIALS, MIX DESIGNS AND TEST METHODS

Materials: (new mix Zircrete)

Cements: Rapid hardening hydraulic cements.
Sand: Silica Sand
Additive: Pozzolan, and workability aids . M&J Sales Co., Hutchins TX.

The new cements were evaluated using mix designs similar to the current industry standard, of 1-1 sand-cement. However, since the new cement package is 88 pounds, (40kg), mixes with 1:0.88 sand-cement ratio were included to evaluate the effect on strength using the higher sand contents.

The control composite was standard GFRC using ordinary portland cement with a 1-1 sand- cement ratio and a water to cement ratio of about 0.32. Curing is accomplished by keeping the product wet for seven days, or with the addition of 5% percent acrylic co-polymer solids by weight of cement. (4)

The new rapid hardening hydraulic cement requires a higher water cement ratio of about 0.45. Retarders to control set time, plasticizers to enhance workability, and specific pozzolans to combine with the un-reacted free lime are required. Curing is accomplished by keeping the product wet from initial set through exotherm. After the product begins to cool, no further water addition is necessary. No curing polymer is used or recommended.

Test methods used included the glass industry hot water immersion test for accelerated aging, at temperatures from 50°C to 60°C for periods up to 110 days. Coupons were tested periodically using ASTM C947-89 to measure flexural strength and strain capacity. Other ASTM tests were used to measure physical properties.

Test Specimens

For each test series a test board was produced using standard GFRC production spray up equipment. Some pre-mix samples were produced to compare developed and retained strength values.
Test specimens were cut to conform with ASTM C947-89 flexural strength test. All specimens for the durability program were tested wet

per ASTM C947-89 which results in about a twenty percent reduction in measured strength as compared to dry testing . (table 1)

ANALYSIS AND DISCUSSIONS OF TEST RESULTS

Durability

Figures 1 and 2 show the change in the materials performance due to aging in 60°C hot water. Both figures show results for Glass Fiber Reinforced Concrete made with (1) Ordinary Portland Cement (OPC), and rapid hardening hydraulic cement with specific additives, Zircrete. In figure1, the MOR for each type of cement is plotted versus time aged in hot water. There is very little reduction in MOR for Zircrete while the MOR for GFRC made with OPC reduces substantially and approaches the 28 day Proportional Elastic Limit, (PEL). Figure 2 , shows the change in strain at failure at specific days aged in hot water. Zircrete shows significant improvement over composites produced with OPC. This improvement is critical since strain capacity is an important parameter in the materials ability to resist volume changes due to temperature and moisture changes. In order to achieve this improvement, it is necessary to include specific pozzolans to combine with the residual free lime thereby eliminating as much calcium hydroxide as possible. Figures 4 and 5 show typical stress/strain plots before and after 100 days accelerated aging.

Shrinkage and Moisture Induced Movement

Initial drying shrinkage of Zircrete is less than portland cement. However, if excess water or too little water is used in the mix then the cement will not hydrate properly and drying shrinkage could occur with values similar to portland cement. For this reason it is recommended that the water -cement ratio be kept in the range of 0.43 to 0.50. Also it is recommended that the composite be kept wet during the initial set, particularly at the onset of the exotherm. This will ensure that the rise in temperature of the curing cement does not drive off water to such an extent that there is not sufficient moisture to properly hydrate the cement.

After the exothermic reaction has occured and the composite starts to cool the shrinkage compensating reaction is largely complete and there should not be any further related dimensional changes.

Hardened Zircrete does have moisture induced dimensional effects in that soaking will cause expansion and drying will cause contraction. Figure 3 shows how Zircrete expands and contracts when subjected to wetting and drying cycles. The extent of moisture induced movement decreases with time and is less than that exhibited by portland cement-sand mixes of the same ratio. Freshly cured Zircrete can demonstrate a fully saturated to totally dry moisture induced movement of 0.23%, but this total movement quickly reduces and stabilizes in less that ten wet/dry cycles to a total wet to dry movement of less than 0.05%, which is about half the movement exhibited by standard GFRC.

Rate of Gain of Strength

Zircrete gains strength very rapidly once the initial set has started. Table 2 shows how the flexural and compressive properties develop over the first 24 hours and up to 28 days. The composite develops over 65% of its final strength within 2 hours of initial set, (onset exotherm), and 80% of its final strength within 24 hours of initial set. This allows for much faster stripping or demolding than the standard portland cement composite. Demold or stripping times can be between 30 minutes to 4 hours.

It is important to note that the retarders used in the additive only delay the initial set time, or the onset of the exotherm. Once the composite reaches initial set and it becomes hard the retarders have no effect on the rate of gain of strength.

CONCLUSIONS

Rapid hardening hydraulic cements in combination with additives to control curing and eliminate calcium hydroxide, have been shown to significantly improve the performance of Glass Fiber Reinforced Concrete. Rapid hardening hydraulic cement by itself is shown to improve retention of strength and strain to failure in Glass Fiber Reinforced Concrete subject to accelerated aging in hot water. This improves the ductility of Glass Fiber Reinforced Concrete, however significant additional improvement can be obtained by the addition of specific compounds to further reduce the amount of free lime in the hardened Fiber Concrete and control set time. The increase in retained strength and ductility is significant in terms of the increased factor of safety available to the designer of Glass Fiber Reinforced Concrete and the reduced probability of serviceability problems such as cracking. Curing of the composite is accomplished in a short time which appeals to manufacturers. Shrinkage and moisture movement values are less than OPC. None of the ingredients used in the new system are combustible, the economics indicate that the new system is competitive with the standard product, and all materials are commercially available.

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TABLE 1 — TYPICAL PROPERTIES OF ZIRCRETE

Property **28 day air cured** **Aged - 100 days 60 0C hot water**

Density		120-140 pcf	120-140 pcf
Compressive Strength		7000-10000 psi	7000-10000 psi
Flexural	Yield	900-1300 psi	900-1400 psi
	Ultimate	2700-3500 psi	2600-3300 psi
	Mod of elast.	3.0 X 10 psi	3.0 X 10 psi
Thermal Conductivity		3.5 to 7.0 (Btu/in/hr/ft/F)	3.5 to 7.0 (btu/in/hr/ft/F)

Note:
1pcf = 16.02 kg/m
1 psi = 6.895 kPA
145 psi = 1N/mm = 1MPa
1 in. lb/in = 0.175 N.mm/mm

*These are typical values and are not to be used for design or control purposes. Each manufacturer must test production composites to establish physical properties for design. The values achieved in practice will be dependent on mix design , quality control of materials, fabrication process and curing.

** Developed from accelerated testing programs on GFRC specimens immersed in 50 to 80 deg C (122 and 176 deg F) water. on the basis of comparisons between behavior in real weather and accelerated tests, predictions can be made of properties for 50+ years in different climates.(8)

Tests on rapid hardening hydraulic cement have shown that it has equivalent performance to OPC in freeze/thaw, (ASTM C-666), and exposure to sea water and has superior resistance to sulfate attack.

Curing Test: (7 days) One set of test coupons were immediately after stripping, (demold), immersed in water at 60 degrees F and stored for seven days. Another set of test coupons cut from the same board, were stored in air at 60 degrees F, and 60% RH for seven days.

Results:	CURE @ 60°F.	MOR	PEL
	7 days wet cure	2450 psi	963 psi
	7 days dry cure	2574 psi	836 psi

Note: samples tested using ASTM C947-89 at seven days.

Conclusion: There does not appear to be any statistically significant difference between the two curing conditions.

Other tests on curing conditions have identified a difference of approximately 20% between testing wet according to ASTM 947 and using the same procedure, but testing without the pre-soak.

TABLE 2 — RATE OF GAIN OF STRENGTH

Time	Compressive Strength psi	**Flexural Strength psi	P.E.L. psi
0 hrs		1458	506
.5 hrs		2050	650
1.0 hrs	4500	2175	710
1.5 hrs.		2258	775
2.0 hrs		2270	800
3.0 hrs.	6000	2340	860
5.0 hrs		2420	900
8.0 hrs		2510	930
24.0 hrs	6500	2803	994
3 days	6960		
7 days	7830	3193	1053
14 days		3434	1053
28 days	8990	3234	1064

Notes:

a-- Coupons wetted for 15 minutes when exotherm started
b-- Air cured with average temperature 70F at 60-% RH
c-- Mix water temperature 65F
d-- Flexural testing according to ASTM C947-89 **(wet soak not possible)
e-- Mixing began at 09:00
Finished spraying at 09:25
Exotherm noted 12:20
Age zero (0) 12:30

MODULUS OF RUPTURE
ACCELERATED AGING IN 140° F (60° C) HOT WATER