11 25 YEARS OF FORTON POLYMER MODIFIED GRC: REASONS FOR ITS USE

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SUMMARY: This paper is a summary of the 25 years of global testing and practical use of Forton polymer modified GRC in North America. Naturally aged durability testing results and SEM views of the aged fracture interface will be shown. As well as practical production benefits, in situ performance of GRC-containing Forton polymer will be shown to further justify its use.
KEYWORDS: Air curing, color uniformity, fiber pullout, fracture interface, GRC, moisture absorption, polymer modified, SEM, thermal movements.

INTRODUCTION

The concept of polymer modification of glassfiber reinforced concrete (GFRC) was first introduced by Forton BV at the 1979 GRCA in London. In 1983 this writer presented a paper showing results that the addition of 5% polymer solids by volume to a Portland cement matrix reinforced with alkali-resistant (AR) glassfibers was a viable alternative to the then required 7-day wet curing regime to achieve maximum matrix strengths. Since then, research work has been done to characterize all the properties of this mix. Five papers have been given at earlier GRCA conferences reporting the test results of these programs and the properties of these composites as they have progressed through the various aging programs. This paper will summarize the earlier test results which show the dramatically improved aged strain to failure of the GFRC composite and then focus on the practical benefits of using Forton polymer in the GFRC composite, both in the face mix and in the back-up.

HISTORY

This paper will summarize the results of durability testing programs of composites reinforced with AR glassfibers, a matrix modified with Forton polymer and placed in a natural aging environment. In some cases, other pozzolanic materials have also been added to the matrix.

As background, in 1980, large GFRC skins (12–18mm thick) attached to a structural steel stud frame by the use of a GFRC bonding pad were being introduced in the USA. The size of these panels and the daily production output required to meet construction schedules precluded the possibility of doing the 7-day wet-curing program to develop the required matrix strengths to meet the design requirements. In addition, the labor to handle the panels and the amount of space to store and maintain a 100% relative humidity (RH) for proper curing would have priced the GFRC product out of the market, to say nothing about putting the steel frame in a rust-producing environment. Yet, if the GFRC were not properly cured to achieve maximum composite strengths for design purposes, it would not be approved by the architect and engineer.

Testing was needed to establish the amount of Forton polymer addition to the mix that would mirror the results obtained from a 7-day wet cure. This research was undertaken by the Construction Technology Lab (CTL), a division of the Portland Cement Association, with the results published in 1982; a paper showing these results was given at the 1983 GRCA conference.

The conclusions reached by the CTL research program was that including **5% polymer solids by volume** in the total mix would give composite strengths equal to or greater than those achieved with a 7-day wet cure. This amount is expressed as **6–7% polymer solids to weight of cement**. With this data the GFRC producers in the United States began using the Forton polymer to eliminate the wet cure. This also enabled them to produce larger panels utilizing the steel stud framing system.

MIX COMPOSITIONS

The mix compositions for the various programs are shown in Table 1.

Table 1 - Matrix compositions (parts by weight)

Year		**1984**		**1985**		**1986**		**1989**			**1990**		**1990**	
Pol.sol.% by weight of cement		**0**	**7.7**	**5.8**	**5.8+ SF**	**0**	**7.7**	**5.3**	**7.5**	**6.9+ MK**	**6.3**	**8.2+ MK**	**0**	**7.1**
Cement	Gray	50	50	50	50	50	50	50	50	50			50	50
	White										50	50		
Sand		50	50	25	25	50	50	25	25	25	35	35	50	50
Polymer	VF 765		8	6	6		8							
	VF 774							5.2	7.4	6.8	6.2	8.0		7.0
Metakaolinite (MK)										12.5		12.5		
Silica fume (SF)					4.8									
Water		16.7	10.2	12.0	9.2	16.3	10.5	13.5	11.5	18.0	12.1	15.7	18.9	13.6
Plasticizer		1.5	1.0	0.6	3.4	1.5	1.0			2.0		1.3	0.5	
Ratio		0.36	0.32	0.31	0.30	0.35	0.31	0.32	0.30	0.43	0.30	0.41	0.38	0.34
Pol.sol.% by total volume		**0**	**6**	**5**	**5**	**0**	**6**	**5**	**7**	**5**	**5**	**5**	**0**	**5**
No samples		x		x		x	x							

The polymer quantities (Pol.sol.%) in this chart are expressed in both 'percent polymer solids by volume of total mix' and 'percent of polymer solids to the weight of cement'. This was done to eliminate possible confusion in the producer's shop when they were developing mix designs.

FABRICATION AND CURING OF TEST BOARDS

After the slurry and glassfiber calibration tests were done, test boards were sprayed using the mixes listed in Table 1. The sprayed material was compacted using the typical GFRC compaction roller to densify the matrix and fiber so that maximum bond of the fiber would be achieved.

After compaction, the back of each test board was troweled smooth before being **covered with plastic for a 16h initial cure**. The following day the test boards were demolded. The boards containing no polymer went to a curing chamber where they were held for an additional 7 days at 95–98% RH. After 7 days at 95–98% RH, these boards were kept at ambient temperature and RH for a total of 28 days.

The boards containing Forton polymer were air cured at ambient temperature and RH (20°C and 65%).

TEST PROCEDURES

Prior to reaching a 28-day cure, test boards were cut into 50mm by 160mm coupons and the rough side ground smooth.

At 28 days, the testing and aging programs began. Coupons were tested according to Rilem Technical Committee 49 TFR to determine the 28-day LOP (Flexural Yield), MOR (Flexural Ultimate), Modulus of Elasticity (E-Mod.), Density and the Flexural Strain to Failure. It is important to note when looking at the data, that test results from 1979 to mid 1991 were obtained by testing the coupons dry. After mid 1991 the procedure was changed to totally immerse the samples in water for 24h prior to testing. This resulted in noticeably lower results, which the conservative design community was comfortable with, on the premise that the GFRC would never see the fully saturated condition in practical use.

Again, all the tests performed after 1991 were done with the GFRC coupons soaked in water 24h prior to testing according to the changes required by ASTM and GRCA standards.

The remaining coupons were installed on the test racks to begin the natural aging process. The test racks were placed facing southwest at the Intron laboratory located in Sittard, the Netherlands. The natural climate of Sittard exposed the coupons to a wide variety of conditions. These ranged from freeze–thaw, during the winter months, warm and dry in the summer, with plenty of moisture year round. All these conditions are considered harsh for GFRC. At the appropriate dates, the coupons were taken from the test racks and tested according to Rilem 49 TFR. The values shown are an average of six tests.

DISCUSSION OF RESULTS

The first group of test results shown in Figure 1 is from a program begun in 1984. This was a 1 : 1 sand : cement ratio mix containing 7.7% solids to weight of cement (6% by volume) of Forton polymer. This was considered to be the original 5-5 mix tested at the CTL. Coupons containing no polymer have been depleted with the 16-year tests.

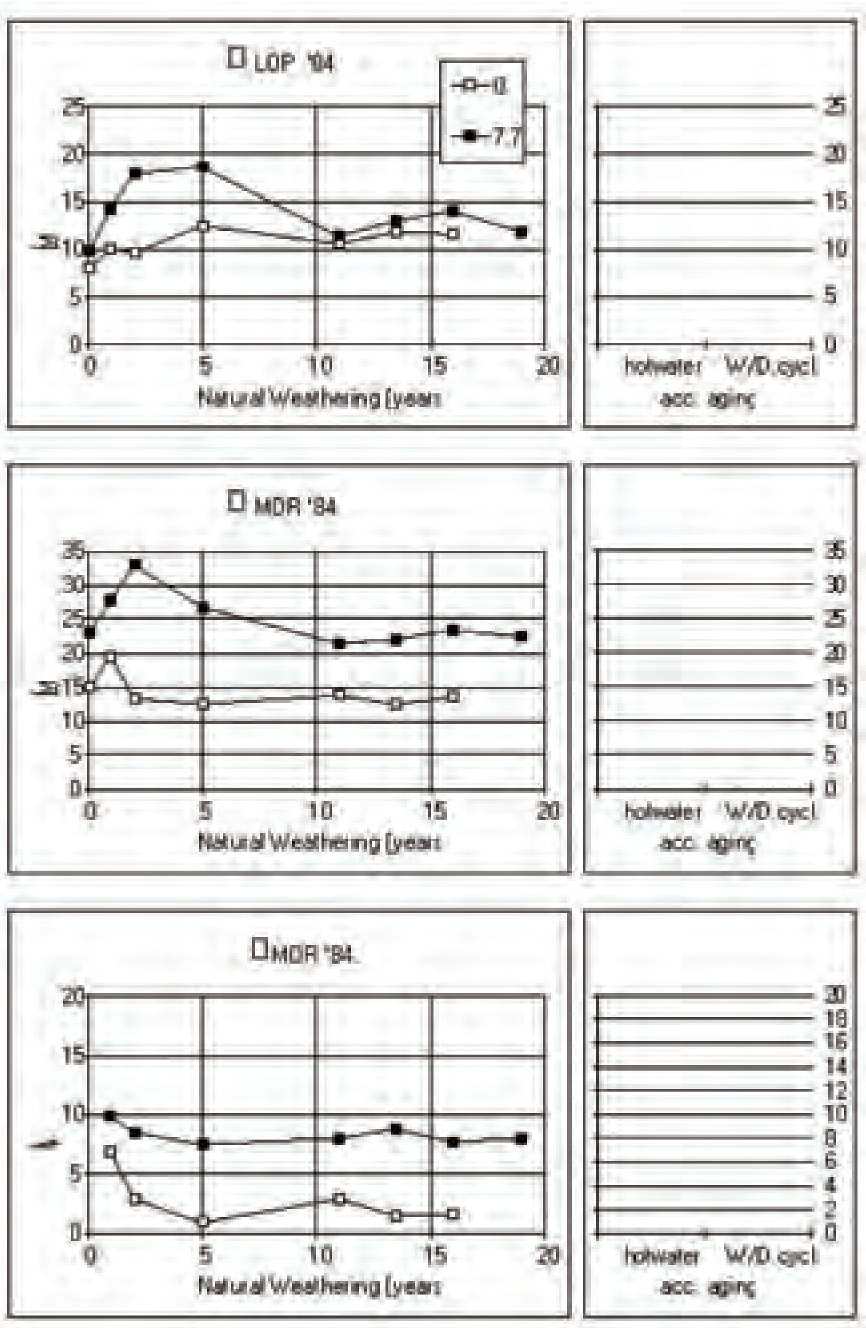


Figure 1

The drop in the 19-year LOP is not explained since there is nothing unusual that appears in the scanning electron microscope (SEM) photos of these samples. The thinking is that the newer testing software gives a more accurate reading of the first crack.

Otherwise, the MOR and strain are consistent with previous tests. Of particular importance is that the flexural strain to failure remains at a very high level against the non-polymer modified mix.

The second group of results shown in Figure 2 is a comparison of GFRC specimens containing Forton polymer and those containing Forton polymer plus silica fume that was started in 1985. In 1985, the addition of silica fume to concrete and cement-based mixes was a popular concept.

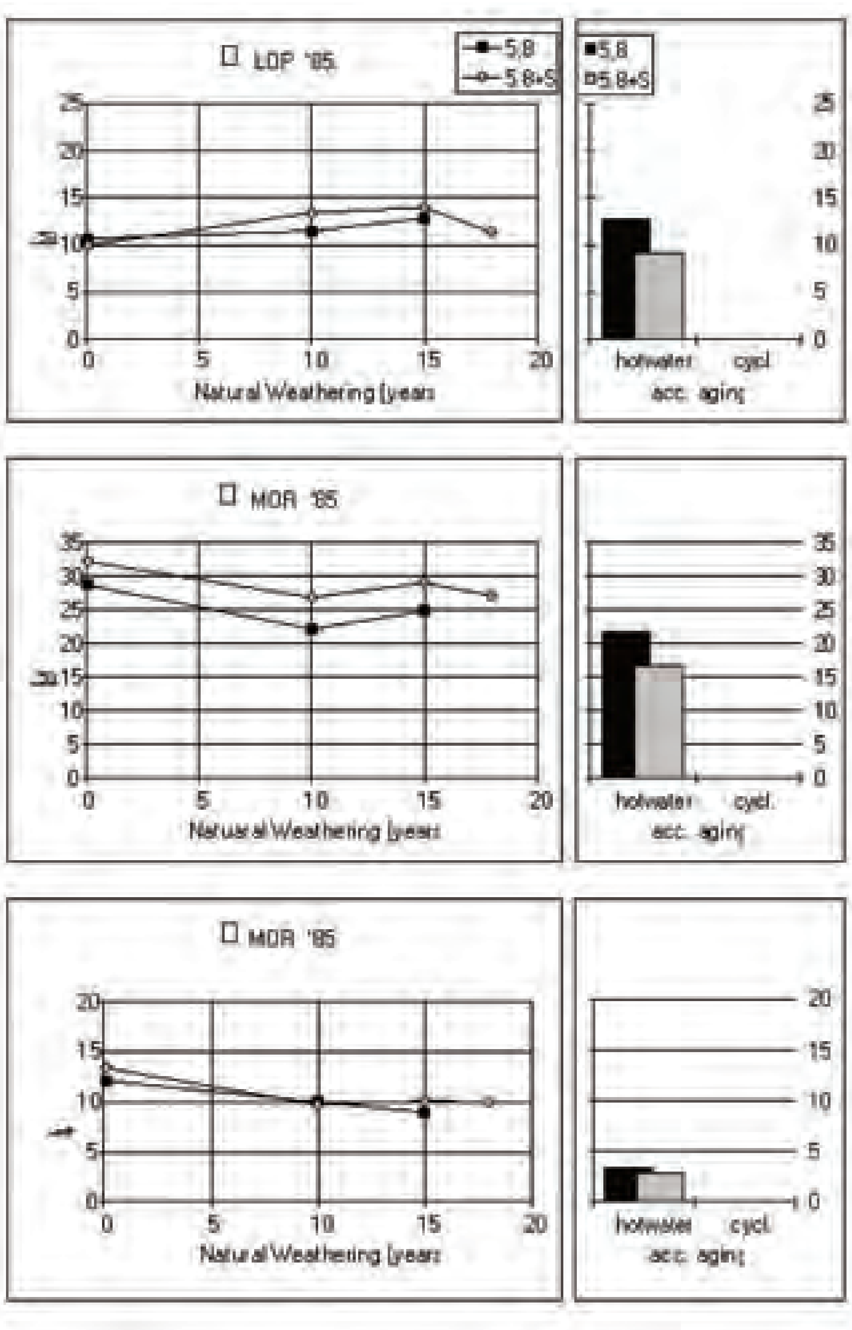


Figure 2

Also shown in Figure 2 are the results of the same mixes subjected to the hot water accelerated aging test. It becomes apparent that the hot water accelerated aging program is not predictive of the natural weathering behavior of GFRC mixes containing polymer. This is especially true with regard to the aged flexural strain capacity.

Again, the important point is that the naturally aged strain to failure remains level.

The results shown in Figure 3 are another comparison of GFRC specimens containing no polymer and specimens containing 6% by volume (7.7% polymer solids by weight) of Forton polymer. This chart has been shown before. There is no new data as the coupons are depleted, but it supports the results shown in Figure 1.

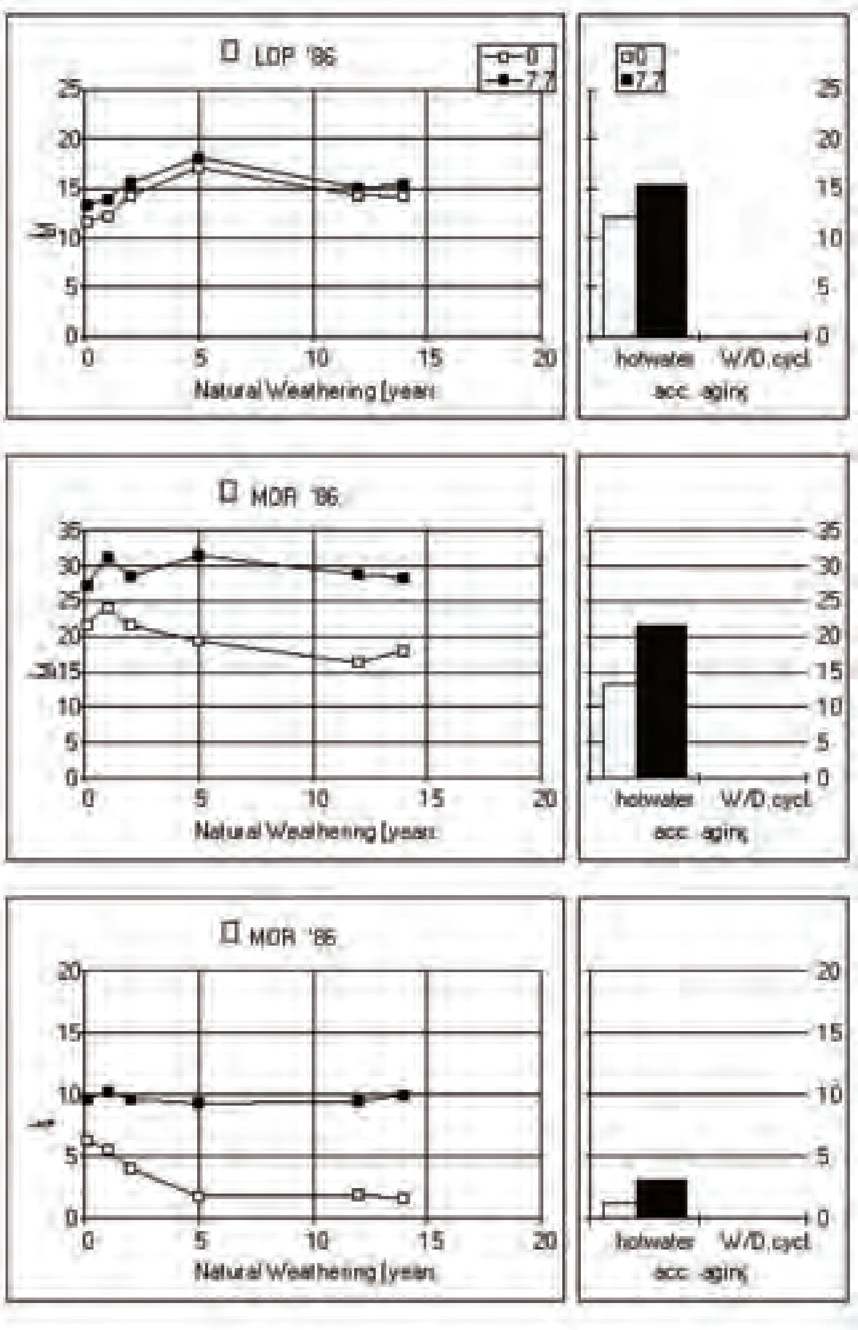


Figure 3

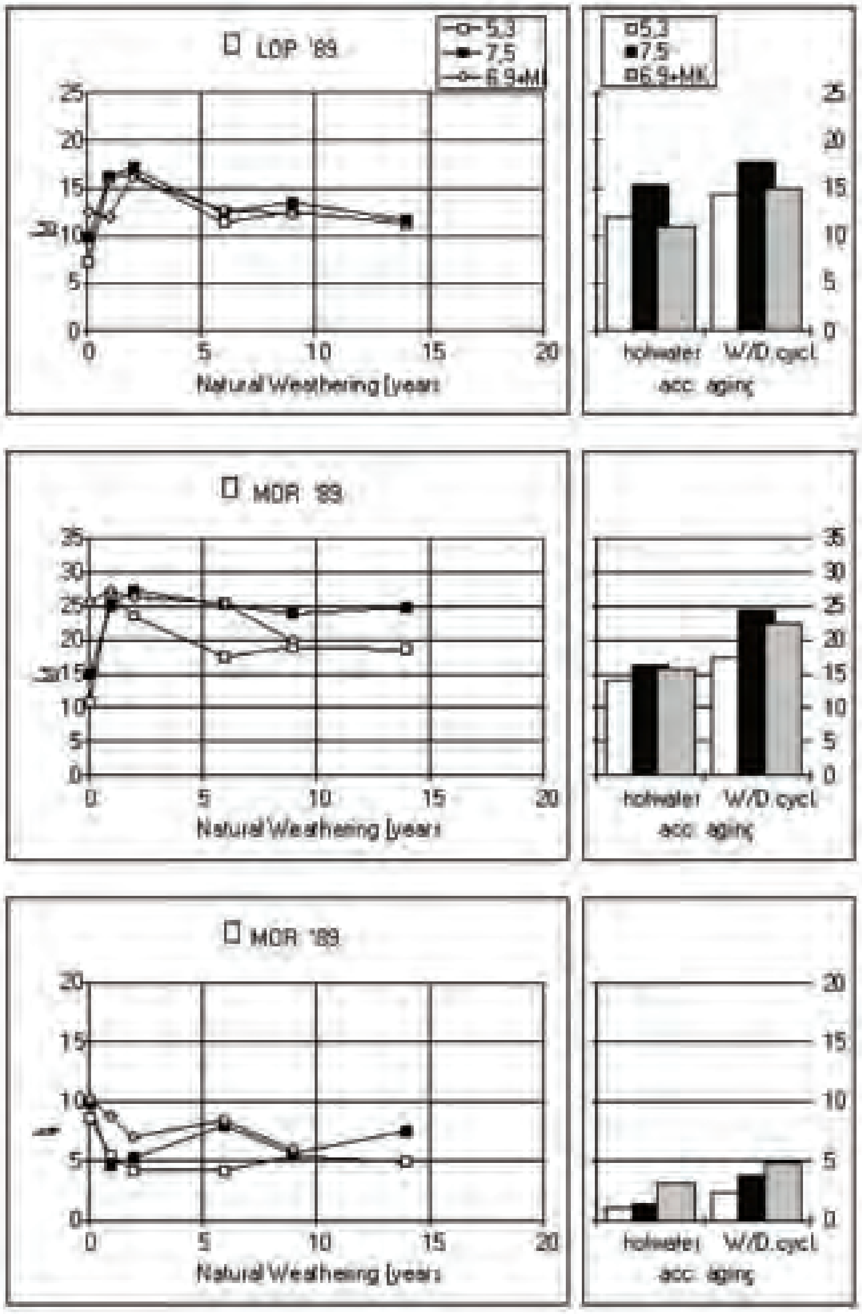

LOP '89
5.3
7.5
6.9+MK
Natural Weathering [years
hotwater W/D cycl.
acc. aging
MOR '89
MOR '89

Figure 4

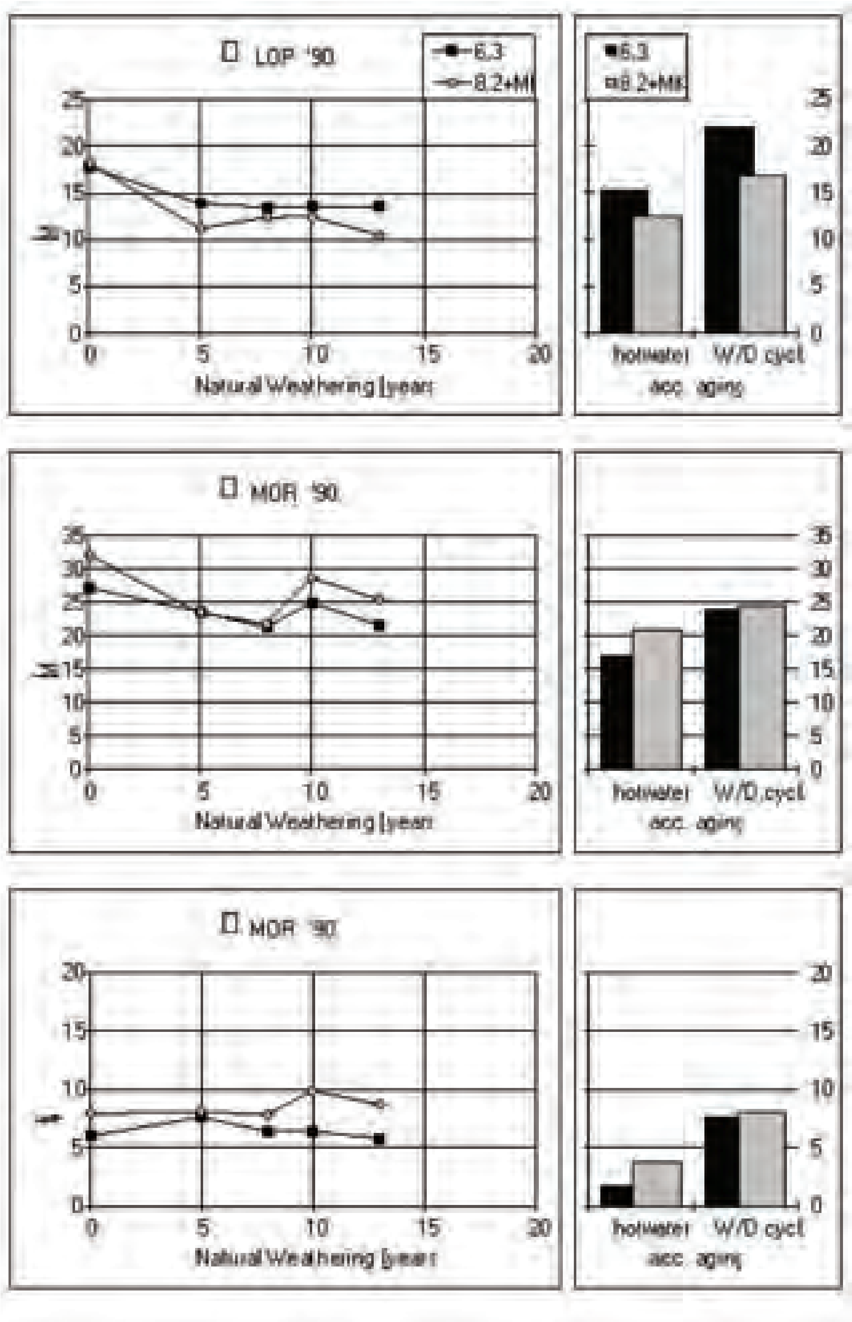

LOP '90
6,3
8.2+MI
Natural Weathering [years
hotwater
W/D cycl.
acc. aging
MOR '90
Natural Weathering [years
hotwater
W/D cycl.
acc. aging
MOR '90
Natural Weathering [years
hotwater
W/D cycl.
acc. aging

Figure 5

Figures 4 and 5 show the aging results of mixes containing Forton polymer only and metakaolin plus polymer. The aged results show the two systems giving comparable aged results, with the mix containing metakaolin having a slightly higher aged strain to failure. Where the metakaolin plus polymer has proven superior is in surface durability of form finish castings.

The results of the last program are shown in Figure 6. Again this shows the aged results of a mix containing no polymer and a mix containing Forton polymer after 13 years. The results for this program are basically the same as for similar earlier programs. Again, the significant difference between the two systems is the maintaining of a virtually unchanged flexural strain capacity for the mix containing Forton polymer against the mix with no polymer, which shows a significant drop in the strain capacity from the young condition. The high strain capacity of the naturally aged Forton mix was not predicted from the hot water accelerated aging test, nor the wet/dry cycling test, in this example. However, it is verified with the SEM photos (see Figure 13). In these side-by-side shots, 90-0 is the composite without Forton polymer and 90-7.1% is with Forton

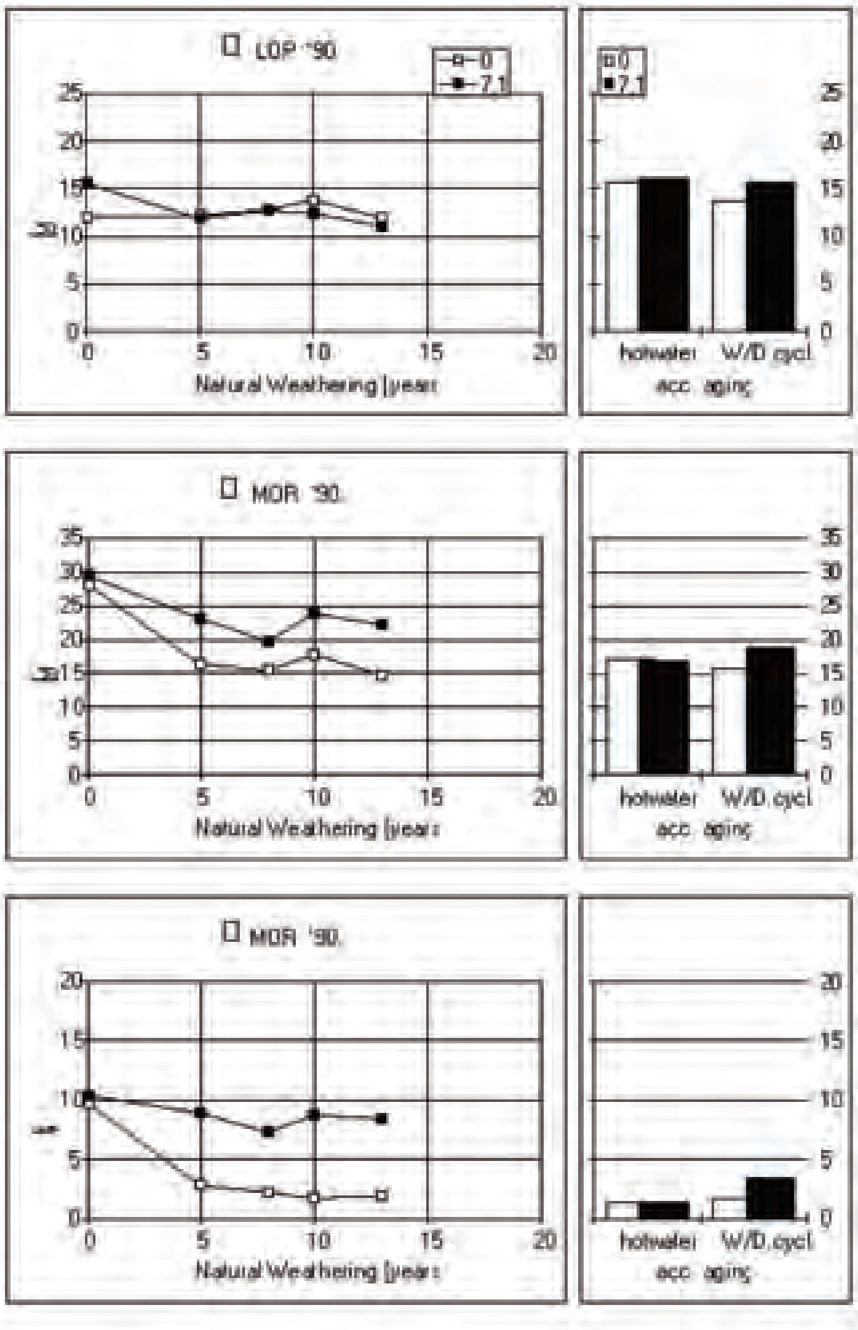


Figure 6

- 90-0 shows essentially a brittle break, with some fiber pullout, which registers in the value 0.02% in Figure 6.
- The break is very clean and straight.
- If you look past the fibers there is very little matrix.
- 90-7.1% shows a more ductile break, with many more fibers showing.
- The break is jagged and rough.
- Looking past the fibers you can see matrix, indicating micro-cracking of the matrix as the load was transferred to the fibers.
- The greater fiber pullout is shown in the test value of 0.08%.

Figure 7 shows in graph form, the rate of expansion of the aged GFRC mixes when the temperature is increased from 20°C to 60°C and if the specimens are wet or dry. The lowest rate of expansion is for the 6.9% Forton polymer and metakaolin mix (dry) and the worst is for the lower polymer content and silica fume. The next lowest is 8.2% polymer and metakaolin (dry). This suggests the metakaolin has an influence in reducing thermal movements.

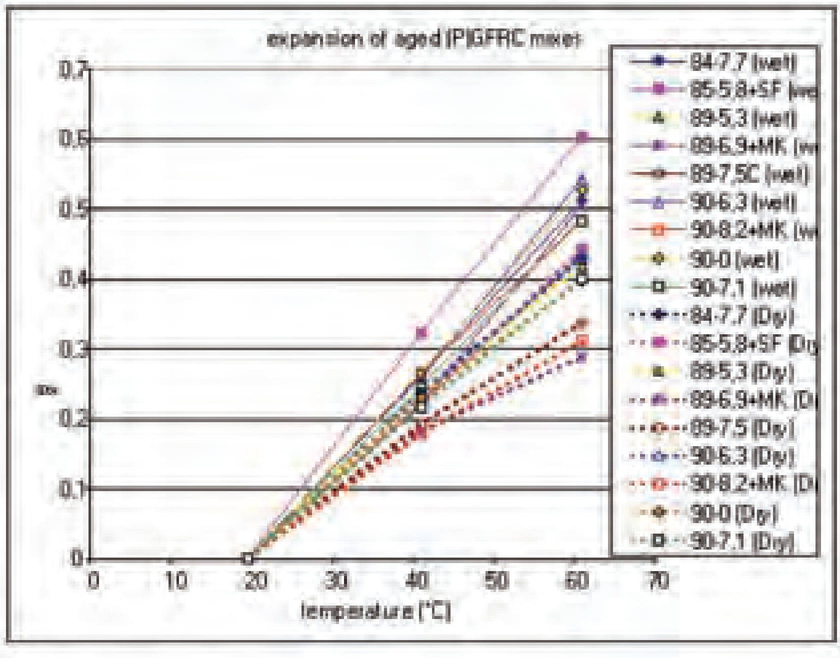


Figure 7

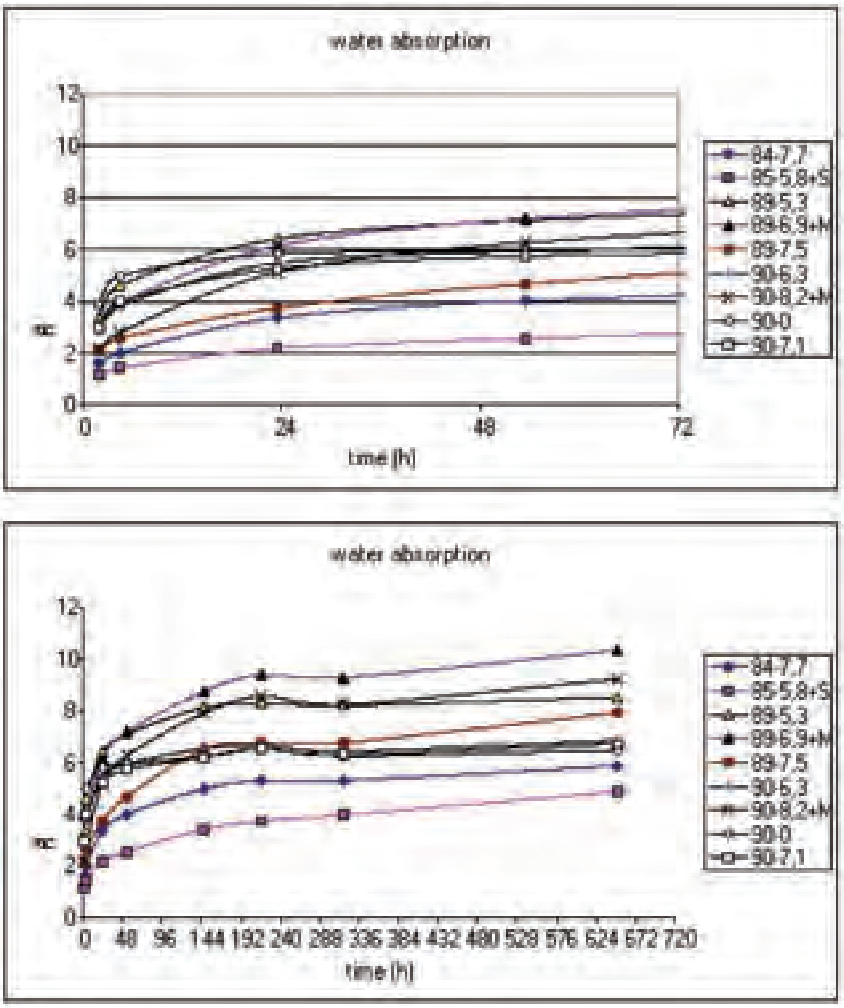


Figure 8

Figure 8 shows two graphs indicating the rate of absorption on a short-term scale (72h), which would indicate a short-term, real-life cycle and a second run out to 650h. On both scales the best performing mix was Forton polymer and silica fume. This is not surprising due to the increased density that silica fume imparts to the mix. The worst was metakaolin at a lower polymer loading. The typical GFRC mix composition (7.7% polymer solids by weight of cement) had a very low rate of absorption in both time frames.

The results shown in the two graphs in Figure 9 indicate the expansion of each mix design due to water absorption as a function of time. The mix containing 7.7% Forton polymer by weight of cement had the lowest expansion over time. The next best was polymer and metakaolin.

Taken together, the mix containing 7.7% polymer solids by weight of cement does the best in reducing moisture absorption and expansion due to moisture absorption so the composite has reduced internal stresses.

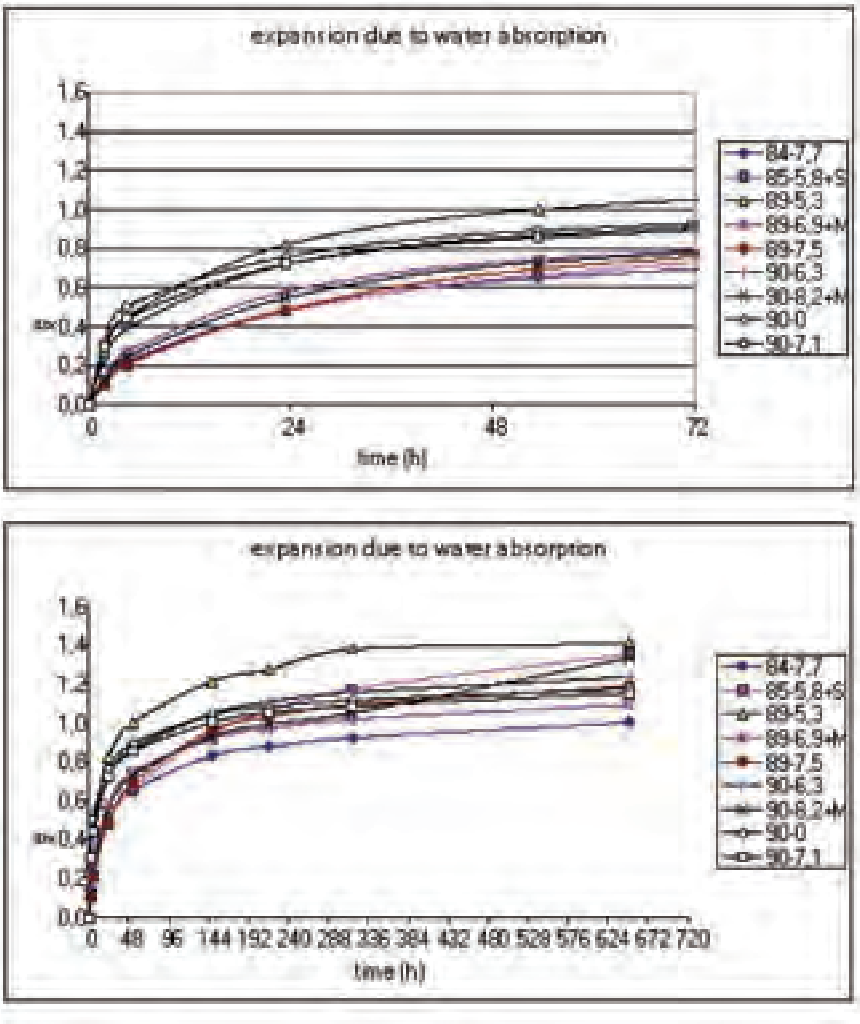

expansion due to water absorption
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
0
24
48
72
time (h)
84-7,7
85-5,8+S
89-5,3
89-6,9+M
89-7,5
90-6,3
90-8,2+M
90-0
90-7,1
expansion due to water absorption
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
0 48 96 144 192 240 288 336 384 432 480 528 576 624 672 720
time (h)
84-7,7
85-5,8+S
89-5,3
89-6,9+M
89-7,5
90-6,3
90-8,2+M
90-0
90-7,1

Figure 9

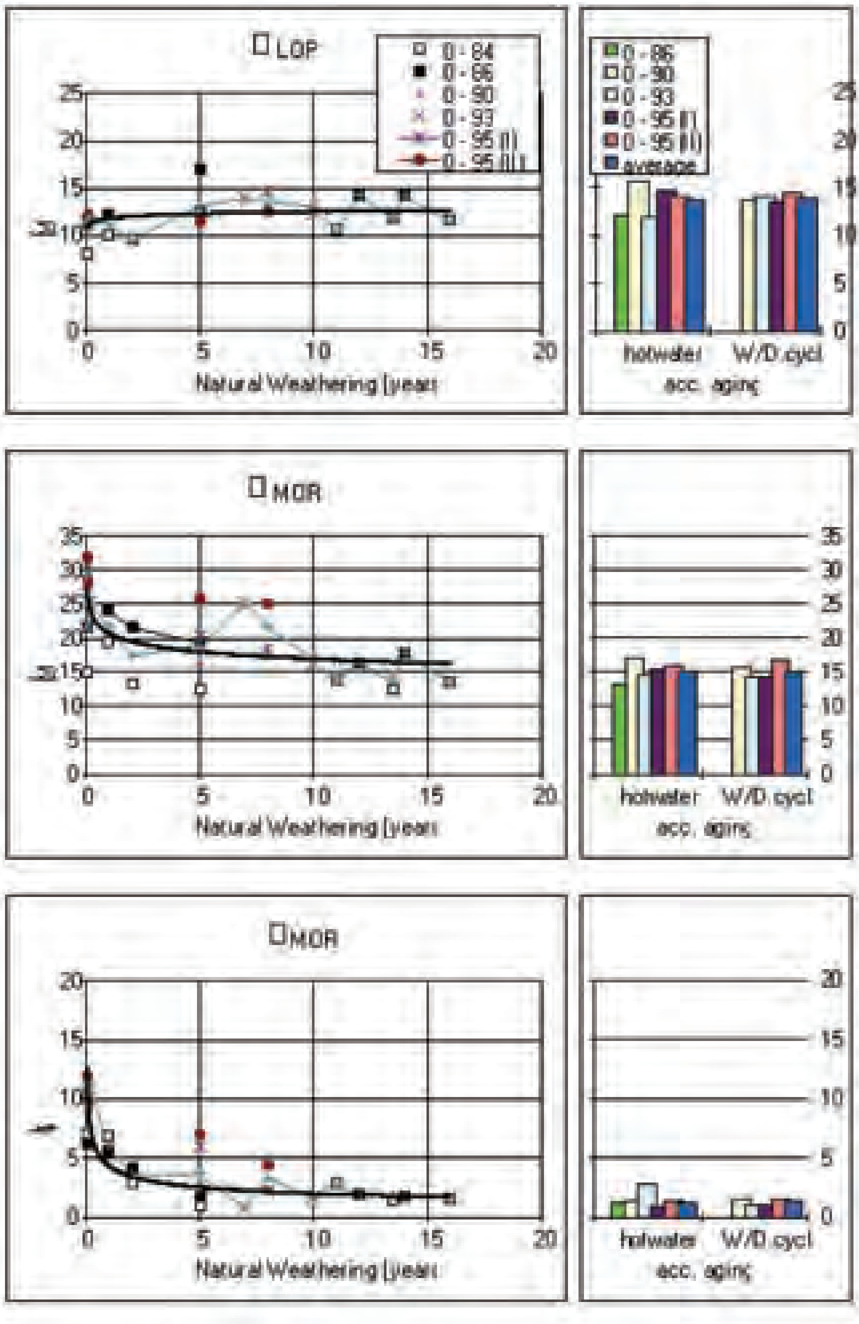


Figure 10

The data in Figure 10 shows all the mixes tested having no polymer addition plotted in the natural weathering environment and correlated to the hot water and wet/dry accelerated aging values. It is clear from the natural weathering trend line, that the hot water and wet/dry accelerated aging tests are very predictive of the long-term behavior of this mix design, especially, the low strain to failure values.

Figure 11 plots all the data from the same test series as in Figure 10, except these mixes contain polymer. For the LOP, the natural weathering, hot water and wet/dry cycling are virtually the same and the accelerated aging tests would be a good predictor. For the MOR and flexural strain values the hot water accelerated aging tests are not valid as a predictor. The values in the natural aging environment remain at a much higher level.

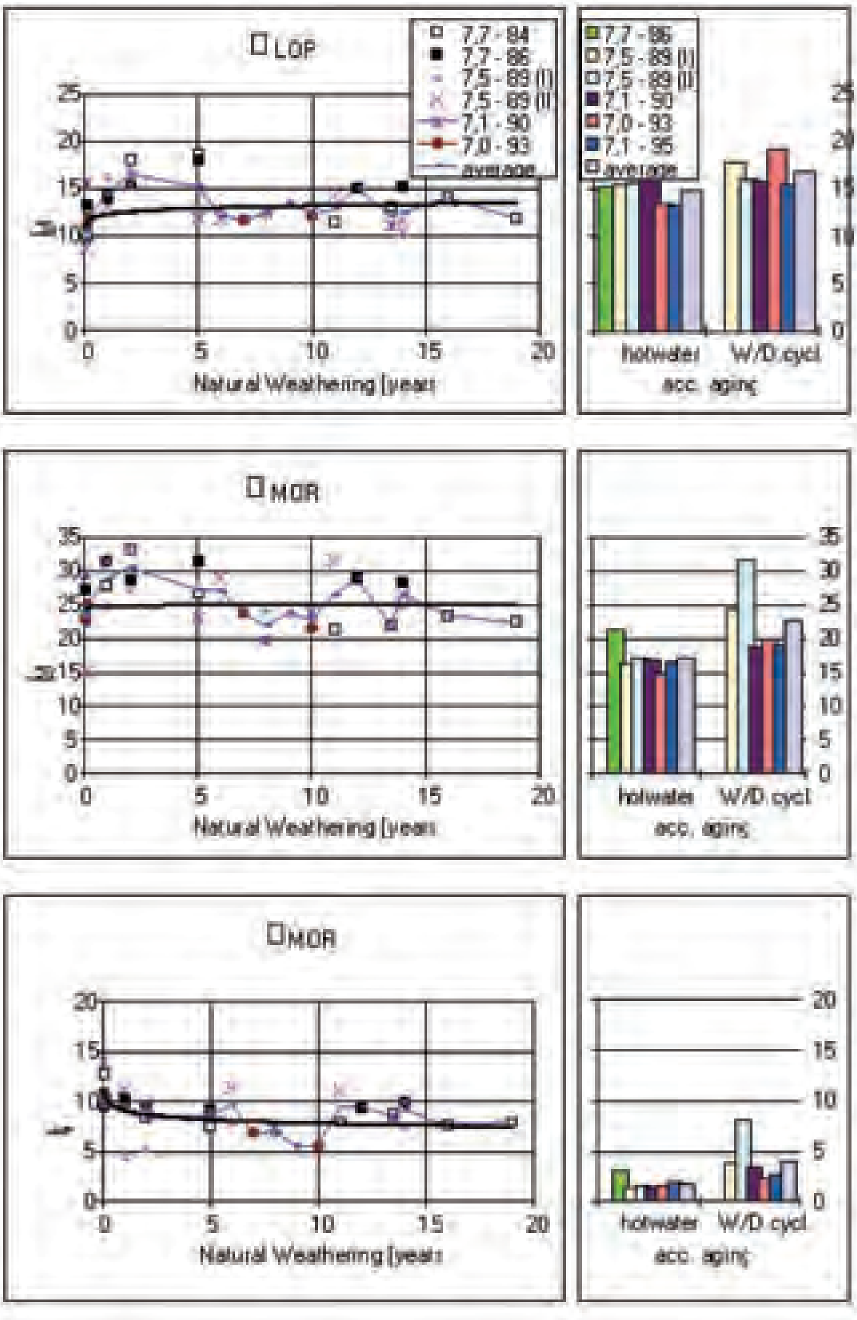


Figure 11

When the aged MOR and flexural strain values of mixes containing polymer are compared with mixes not containing polymer a significant difference is seen. Graphically this is shown in Figure 12. For the aged MOR, the non-polymer mixes are in the 16MPa (2320psi) range while the range for the mixes containing polymer is 25MPa (3625psi). The most notable difference is the aged flexural strain to failure. For non-polymer mixes this value is 0.02 while 0.08 is the value for aged mixes containing polymer. I think this is the most important aspect of all the research and aging programs. We can see that Forton polymer modified GFRC maintains a high strain to failure and therefore remains a relatively ductile composite after aging in a natural environment.

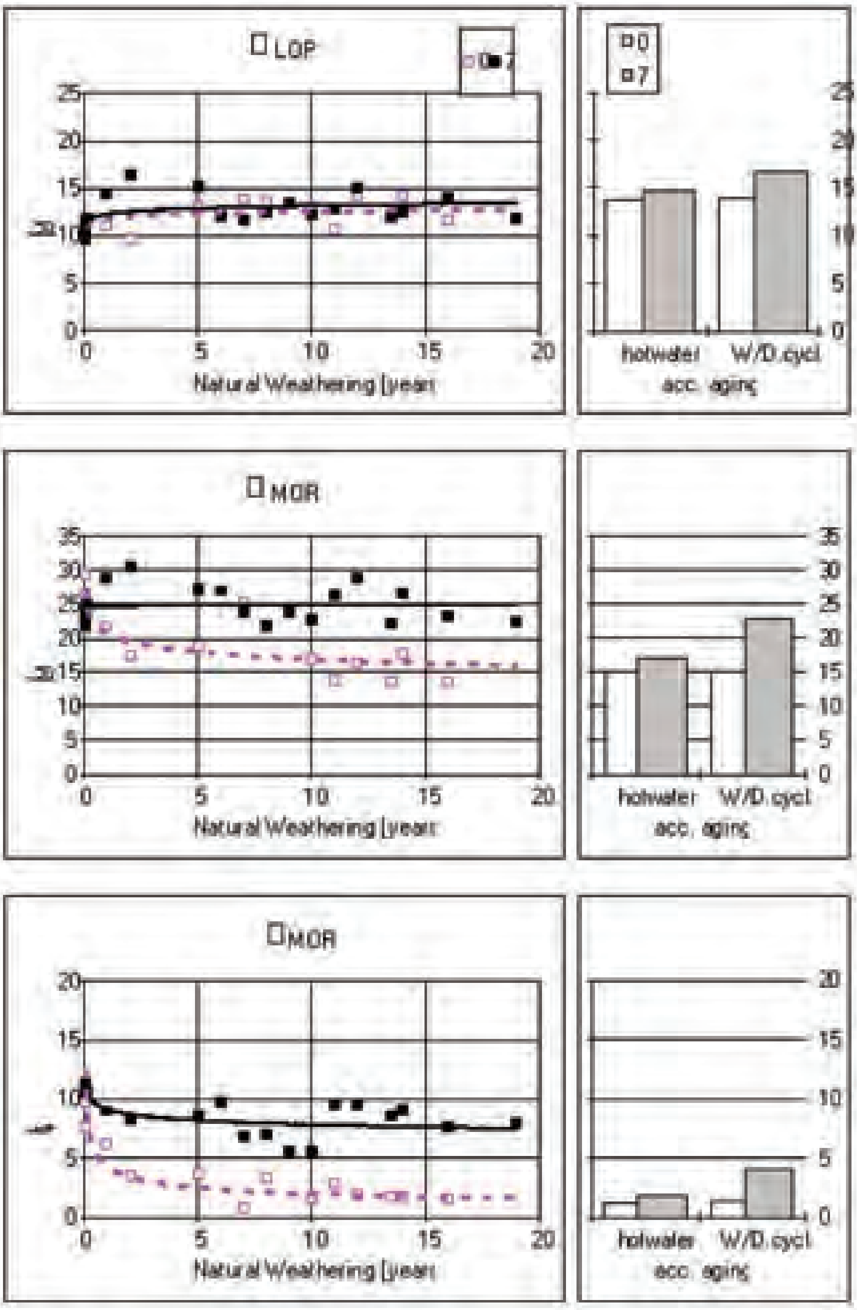
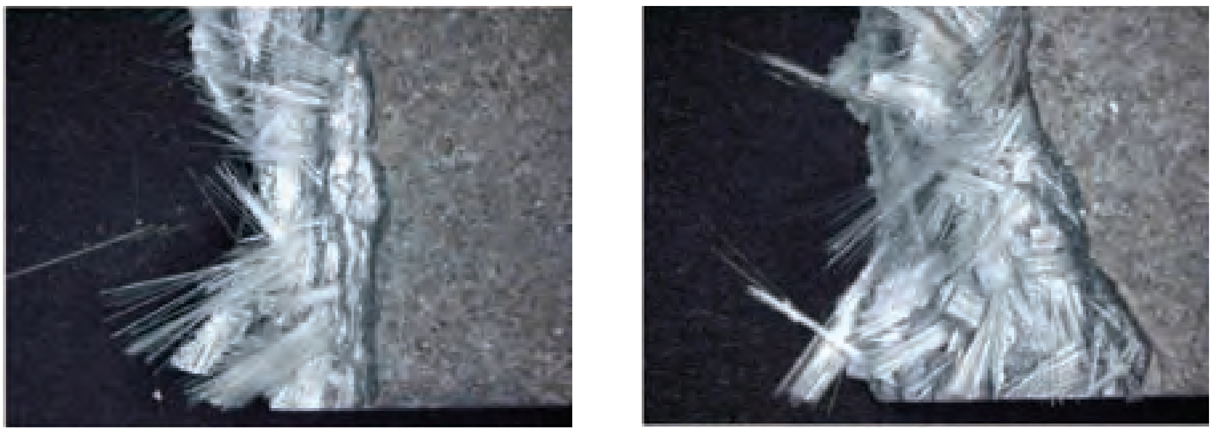


Figure 12

The visual proof of the effect of Forton polymer on the long durability of GFRC is seen in Figure 13 below.



90-0% (non-polymer) 90-7.1% (polymer modified)

Figure 13

These are examples of the fracture of 13-year-old, naturally aged GRC. Non-polymer modified is on the left and Forton polymer modified is on the right.

Figure 14 adds the current data points to the typical graph shown in the PCI Recommended Practice. This gives validity to the PCI design philosophy.

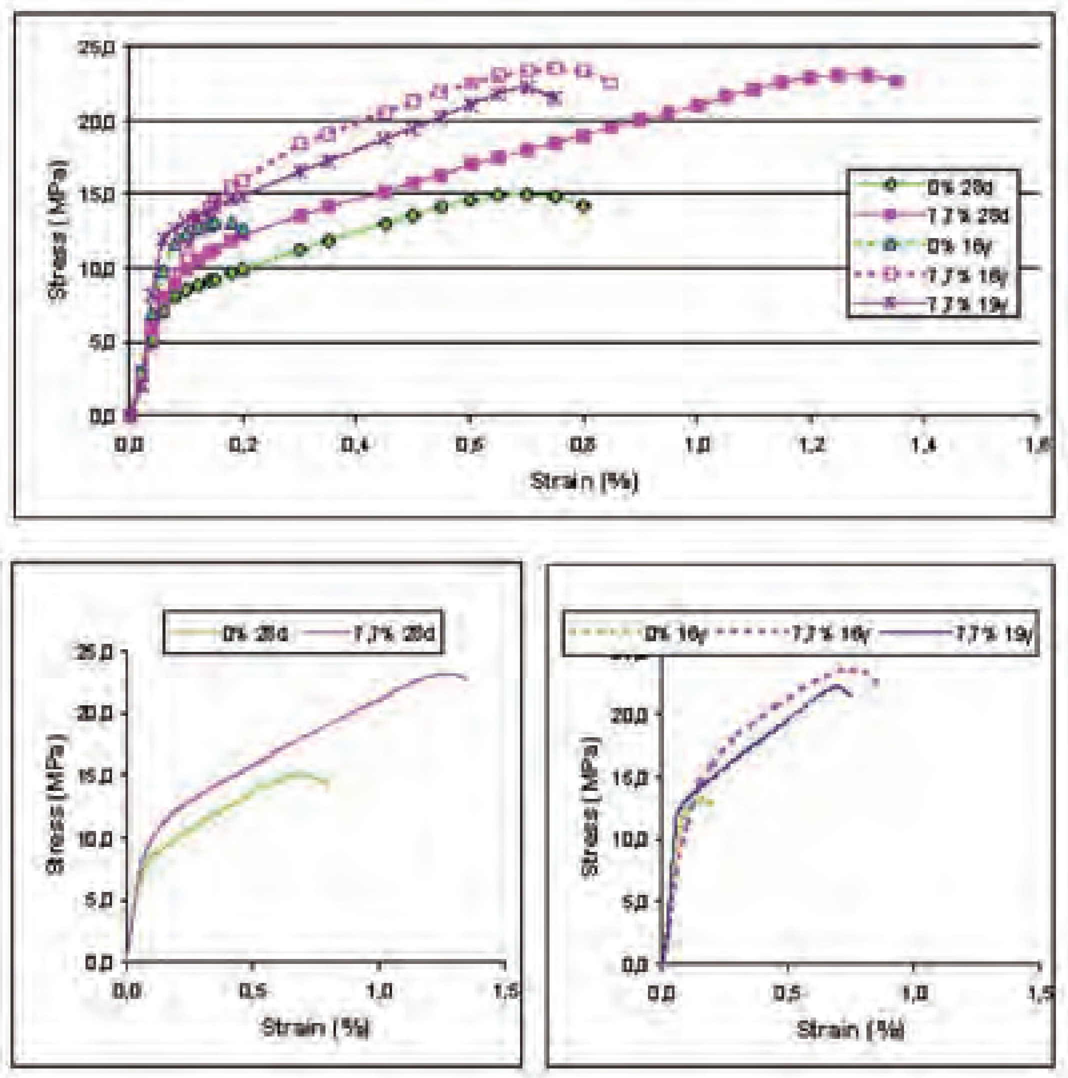


Figure 14

CONCLUSIONS

The conclusions that can be drawn from a review of this data are very clear and straightforward.

- A sand and cement mixture, with the addition of at least 6–7% Forton polymer solids to the weight of cement of Forton polymer, and reinforced with AR glassfiber containing a minimum of 16% zirconia oxide, results in a composite that maintains a stabile LOP, and a high MOR in a natural weathering environment.
- The composite containing Forton polymer also maintains a high, and stabile, flexural strain to failure in a natural weathering environment, therefore remaining ductile.
- The aged MOR of composites containing no polymer is lower than the aged MOR of composites containing Forton polymer.
- The aged flexural strain of composites not containing Forton polymer drops significantly below the young values, and results in a brittle composite.
- The hot water accelerated aging test is not a valid predictor of the aged properties of a composite containing Forton polymer.
- The wet/dry cycling test is a more accurate procedure to predict the aged values for all GFRC composites.
- The addition of other pozzolanic materials to mixes containing Forton polymer do not result in any significant increase in aged properties over mixes containing only Forton polymer.
- SEM photos indicate the fiber is still in excellent condition in the aged composite.
- Via the SEM we can see the influence of the Forton polymer on the fiber pull-out and micro-cracking in the aged composite. It is not a brittle failure.

The importance of this data to the design engineer, GFRC producer and building owner is that now they should have a high degree of confidence in the performance of properly made Forton polymer modified GFRC reinforced with AR glassfibers.

The SEM images (Figures 15–24) that follow show the fiber to matrix relation of the various mix designs at the end of the natural weathering aging tests. Most importantly they show that the glassfiber has not been etched or eroded in any way so that the tensile properties of the individual filaments remains at its highest level. This is a very important point when compared with the data that was reported to be the condition of the aged filaments 25 years ago at papers presented at this conference. Some of those data came from the Strand in Cement test which appears to have given an erroneous prediction as to the characteristics of the aged filament.

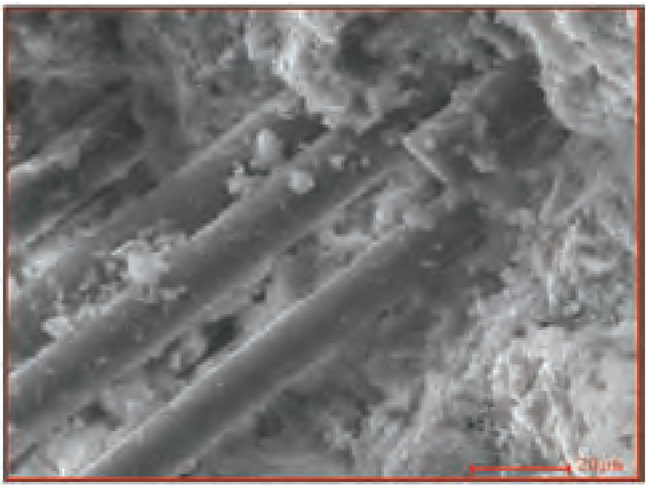


Figure 15 - 84-7.7%

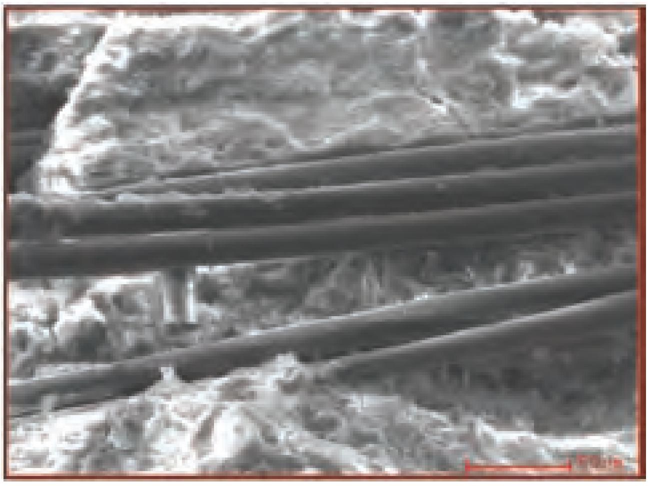


Figure 16 - 85-5.8%+SF

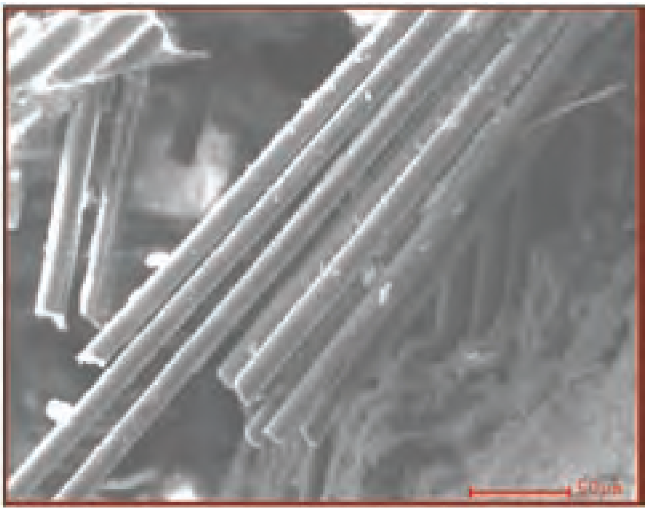


Figure 17 - 85-5.8%+SF

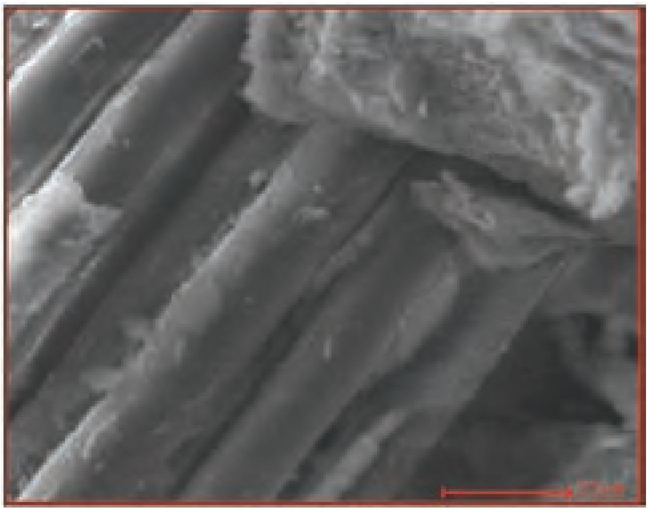


Figure 18 - 85-5.8%+SF

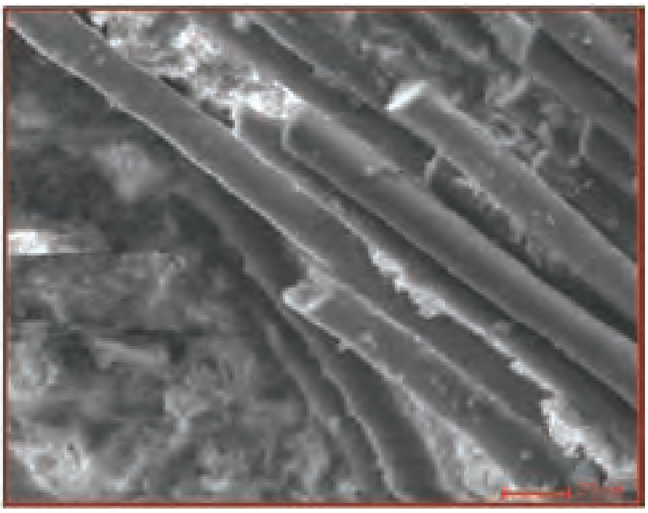


Figure 19 - 89-6.9%+MK

Figure 20 - 90-0% BS

Figure 21 - 90-7.1% BS

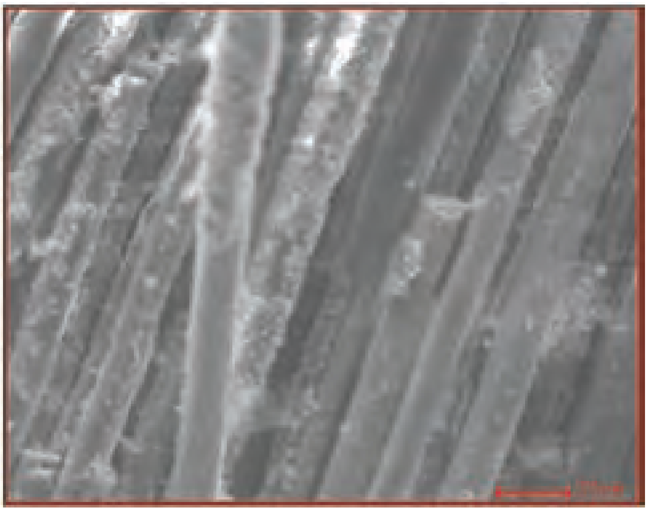


Figure 22 - 90-7.1% SE

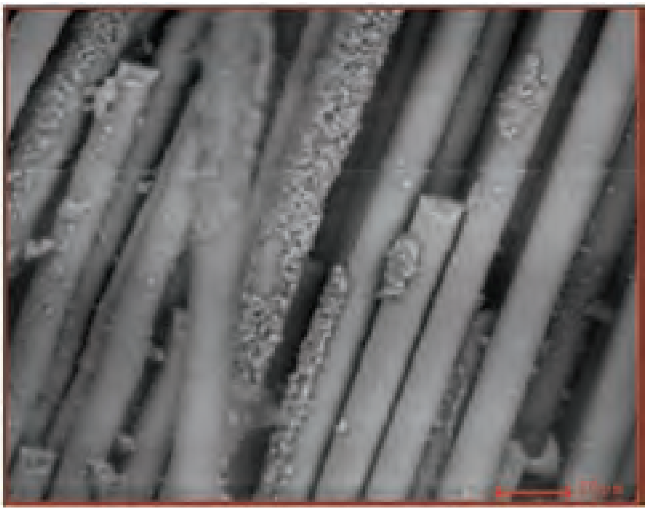


Figure 23 - 90-7.1% BS

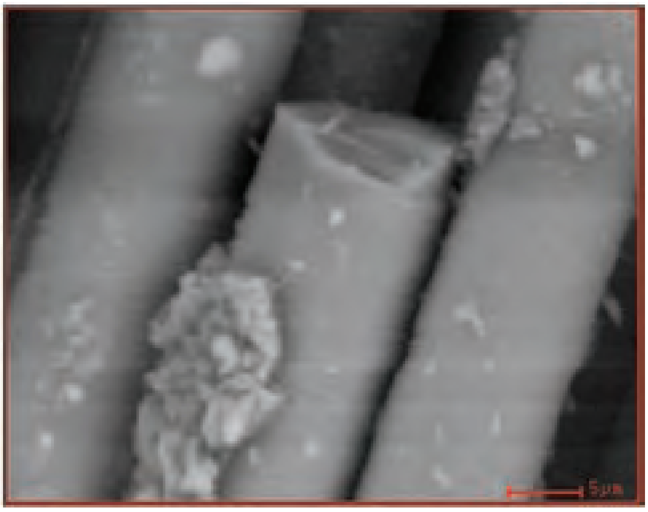


Figure 24 - 90-7.1% BS

PRACTICAL, REAL WORLD REASONS FOR USING FORTON POLYMER (VF-774) IN GFRC MIXES

The data shown in prior reports has shown the two primary technical reasons for using Forton polymer in GFRC composites. Once these data were accepted in the North American market and Forton started to be used in GFRC architectural panel production a number of other 'real world benefits' started to become known. Individually, perhaps, they do not seem important, but collectively they have made a dramatic improvement in product quality and the in-situ performance and life cycling of the product on buildings.

All North American GFRC has an integrally pigmented face mix which is sandblasted to expose the aggregate to give the desired architectural finish. Using this technique GFRC can replicate many naturally occurring finishes such as limestone, cast stone and granite.

The GFRC skin is 12–18mm thick, following the profile of the mold and bonded to a structural, but light-gauge steel frame designed to carry all the loads appropriate for the panel location on the building and building codes.

A very important point is that Forton VF-774 is put in the face mix and back-up mix to bond one to another and to minimize differential thermal stresses.

The practical reasons to use Forton polymer are as follows:

- The specific polymer chemistry of Forton VF-774 gives improved workability to the GFRC mix at lower water/cement ratios. This further enhances the concrete strength.
- The ability to spray vertical mold surfaces without having the face mix sag.
- Complete dispersion of dry iron oxide pigments for batch-to-batch color consistency of face mixes.
- Face mixes cure harder for better sandblasting uniformity.
- Produces a tighter, denser cured product which reduces absolute moisture absorption and vapor permeability while at the same time significantly reducing the rate of absorption as a function of time. This is very important to reduce internal stresses due to daily thermal cycling
- Eliminates crazing and spider-cracking in the face mix due to the soft polymer particles in between the cement particle and sand grain.
- Reduces drying shrinkage and reversible shrinkage in the GFRC skin, therefore reducing internal stresses in the skin.
- UV stability of the Forton polymer permits architectural finishes to maintain their as-produced colors.

Figures 25–32 give an indication of the size of GFRC architectural panels produced and the steel stud frame that is attached to the frame by means of the bonding paddy. Figures 33–37 show those panels installed and the color uniformity of the panels containing polymer in the face mix. These panels were sandblasted to expose the aggregate in the face mix.

Figure 25

Figure 26

Figure 27

Figure 28


Figure 29


Figure 30


Figure 31


Figure 32


Figure 33


Figure 34

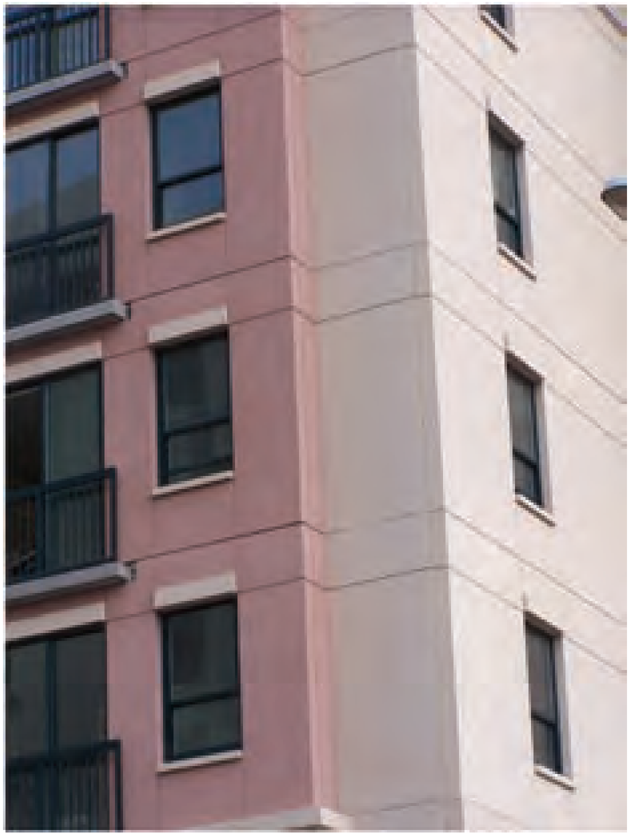


Figure 35

Figure 36

Figure 37

Figures 38 and 39 are of a restoration project in Buffalo, NY where three different colors of face mix were sprayed into the mold to achieve a multi-colored, glazed terra-cotta effect in the cast pieces.

Figure 38

Figure 39

Figure 40 is of Shepherd Hall at City College in New York City. GFRC was used to replace the original light-colored terra-cotta after the effects of freeze–thaw and acid rain had taken its toll on this very high-profile building. The face mix used the Cemstar system with Forton polymer to maintain the as-demolded surface. The major concern of the architect was the aged surface of the GFRC as well as the durability of the GFRC material. He conducted specific aging and weathering tests, especially focusing on acid rain prior to choosing the CemStar system.

Figure 41 is of San Francisco Towers, a retirement facility in downtown San Francisco. It is 16,000m^2 (160,000sq. ft.) of GFRC panels, many having two or three colors of face mix on each panel.

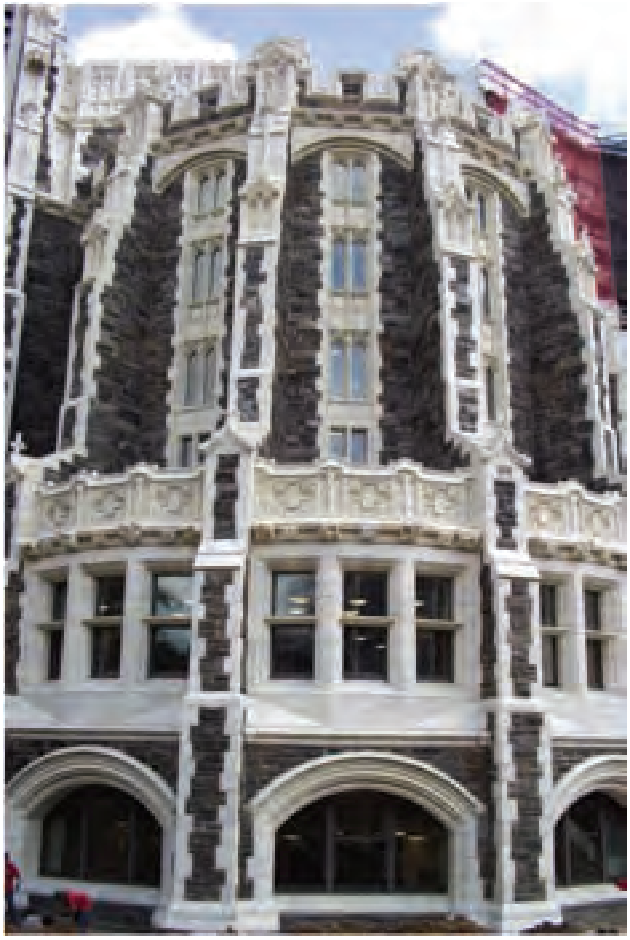


Figure 40

Figure 41

A recent approach to keeping the color intensity even stronger and keeping the sandblasted surface cleaner is the use of the Forton VF-774 diluted either 10 : 1 or 15 : 1 with water as a surface sealer. Real-world aging tests have shown this to be a very effective way to keep the surface clean and the color true. Figures 42 and 43 show a mock-up of a GFRC mullion and sill as it would be installed on the building. Figure 42 shows the pieces sealed with the Forton VF-774 diluted 15 : 1 and Figure 43 shows with no sealer. Figures 44 and 45 are of a mix containing polymer and metakaolin and sandblasted. The mix in Figure 44 has been sealed with the Forton sealer while Figure 45 shows the castings not sealed. All the pieces were placed outside in Pittsburgh, PA on 20 December 2004. These photos were taken on 15 August 2005. You can see how clean the sealed pieces are and the streaking on the unsealed pieces. Another test that has been running for two years shows a dramatic reduction in the fading of darkly pigmented face mixes when sealed with the Forton sealer over non-sealer and commercial siloxane sealers.

Figure 42

Figure 43

Figure 44

Figure 45

SPRAYED PREMIX

The technique of spraying a 3% fiber-loading GFRC premix has been well established in the North American market over the last 10 years. Forton polymer has played a very important role in this production technique by enabling the premix to be pumped and sprayed via a peristaltic pump without the fibers clumping and balling in the mixer or in the hose, all while keeping a low water to cement ratio so that matrix strengths remain high. In addition to all the other benefits listed, the Forton VF-774 polymer has a greater lubrication impact on the mix than other polymers in the market.

It also enables us to spray blends of different fiber lengths, such as 12mm and 40mm, or 18mm and 40mm, so that we get the longer fiber in the composite to improve the flexural and impact properties.

Figure 46 shows a typical high shear mixer set-up for mixing premix. It is a two-step procedure. First the polymer, water, pigment, sand, cement and plasticizer are mixed with the mixer set at 1000–1100rpm. Then the mixer is stopped to allow for false set and to reduce the rpm to 350 for the introduction of the glassfiber. Figure 47 shows the premix slurry being pumped by the peristaltic pump. This mix contains a blend of 12mm and 40mm AR fibers for improved flexural properties. It is a 3% by weight fiber loading.

Figure 46

Figure 47

Figure 48 shows the premix being sprayed into the mold and compacted in Figure 49. The demolded panel is shown in Figure 50. Figure 51 shows the premix exiting the pump line. It shows no signs of clumping or segregation. Figures 52 and 53 show additional finished products done with sprayed premix. Sprayed premix is viable for pieces 10m^2 (100sq. ft.) and under that tend to fall into the standard product category, such as the column covers shown in Figure 53. Larger pieces must be done with the spray chop method.

Figure 48

Figure 49

Figure 50

Figure 51

Figure 52

Figure 53

WHY FORTON POLYMER?

The Forton polymer is specifically formulated for the GFRC production process and all aspects of the performance of GFRC architectural panels. It is the only polymer designed for use in the GFRC market with 25 years of research and data to support its use.

There are a number of white milky liquids available as cement or concrete modifiers or bonding agents. They are good products designed for that application and should stay specific for those uses. They are not formulated for the specifics of GFRC production like the high shear mixer, open time and spraying characteristics.

The specific points appropriate to the Forton polymer are:

- Polymer chemistry: not all white, milky liquids are equal. Many are not UV stabile, nor are they alkali stabile in the high pH cement matrix. Some will in fact re-emulsify after curing if they get wet.
- UV stability is an especially important requirement for the architectural market. If the wrong polymer is used it can break down with UV degradation.
- Particle size is very important because it controls the effect of the pigmentation and color uniformity batch to batch. If it varies, the same amount of pigment will show a different color in the panel.
- Molecular weight and Tg influences the durability of the polymer in the matrix.
- Polymer solids: water-based polymer emulsions comprise a certain number of polymer particles suspended in water. You are paying for the quantity of polymer solids in the liquid. The higher the polymer solids the better value for money. Forton is 51% polymer solids.
- The Forton polymer (all acrylic co-polymer) is the only polymer chemically engineered for the rigors of the GFRC production process and the specific issues such as uniform pigment dispersion, minimum film forming temperature, density and life cycle properties of GFRC composites. Other polymers do not measure up in one or more of these very important points.

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