

Durability of naturally aged, GFRC mixes containing Forton Polymer and SEM analysis of the failure interface

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ABSTRACT

This paper reviews the most recent durability data obtained from GFRC coupons naturally aged for up to 19 years in a climate that subjected them to freeze-thaw, rain, humidity and high temperature. It reviews the results of physical tests done on these coupons. An analysis of the aged failure interface by SEM is reviewed. Also, thermal expansion and moisture absorption of the various mix designs are reported.

KEY WORDS

Glass fiber reinforced concrete, GFRC, GRC, polymer modified, glass fiber reinforced concrete, air curing, failure interface, SEM, thermal movements, moisture absorption, fiber pullout

INTRODUCTION

The concept of polymer modification of glass fiber reinforced concrete (GFRC) was first introduced by Forton BV at the 1979 GRCA in London. Since 1983, when 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 glass fibers was a viable alternative to the then required 7 day wet curing regime to achieve maximum matrix strengths, research work has continued to characterize all the properties of this mix. Four 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 continue with reporting on the results of these test programs with a particular focus on the aged flexural strain to failure behavior of these naturally aged composites. Also data on moisture and thermal movements of aged composites will be presented. Most importantly SEM's will show the influence of the Forton polymer on aged flexural strain to failure.

HISTORY

This paper will continue the review of flexural testing results of composites reinforced with alkali resistant glass fibers and with the 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, large GFRC panels attached to a structural steel stud frame by the use of a GFRC bonding pad were being produced 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 matrix strengths. In addition, the labor to handle the panels and the amount of space to store, and maintain a 100% relative humidity for curing, would have priced the GFRC product out of the market. Yet, if the GFRC were not properly cured to achieve maximum composite strengths for design purposes, the major suppliers at the time, Cem-FIL and Owens-Corning, would not endorse the producers to architects and engineers as fabricators of quality GFRC. It made for an interesting problem in the market.

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., a division of the Portland Cement Association, with the results published in 1982 and a paper showing these results was given at the 1983 GRCA Conference.

The conclusions reached by the CTL research program was that **5 % polymer solids by volume** to 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 to 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										12.5		12.5		
Silica Fume					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 amounts 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 glass fiber 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 will be achieved.

After compaction, the material was troweled smooth before being covered with plastic for a 16-hour 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 to 98% relative humidity. After 7 days at 95-98% relative humidity, these boards were kept at ambient temperature and relative humidity for a total of 28 days.

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

TEST PROCEDURES

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

At 28 days, the testing and aging program 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, test results from 1979 to mid 1991 were obtained testing the coupons dry. After mid 1991 the procedure was changed to totally immerse the samples in water for 24 hours 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, which have been soaked in water, 24 hours prior to testing.

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 range of conditions. These ranged from freeze-thaw, during the winter months, warm and dry in the summer, with plenty of moisture year around. All these conditions are considered

harsh for GFRC. At the appropriate dates, coupons were taken from the test racks and tested according to Rilem 49 TFR. The values shown are an average of 6 flex tests.

For this round of testing, coupons of certain mix designs were no longer available.

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 Construction Technology Lab. Coupons containing no polymer have been depleted with the 16-year tests.

The drop in the 19 year LOP is not explained since there is nothing unusual that appears in the SEM's of these samples. The thinking is that it is more accurate testing software that is now available.

Otherwise, the MOR and strain are consistent with previous tests. Of particular importance is 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.

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 the 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.

Figure 4 shows the results of a test program comprised of specimens containing two levels of Forton polymer and one of both Forton polymer and metakaolin now aged to 14 years. There is a slight drop in the LOP from the 9 year results. The MOR seems to have leveled in basically a straight line for each mix from 6 years of age. The flexural strain to failure for the higher polymer loading has come back to the 6-year value.

In **Figure 5** the thirteen-year results of a mix containing only Forton polymer and a mix containing Forton polymer and metakaolin are shown. The LOP of the polymer mix

seems to have leveled after 8 years of aging. The movement in the MOR is not explained. The strain to failure of the polymer only composite seems to have leveled of, while higher polymer loading and metakaolin also stays at a higher level.

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. The significant difference between the two systems again is the maintaining of a virtually unchanged flexural strain capacity for the Forton polymer containing mix against the mix with no polymer that 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's shown in **Figure 13**. In these side-by-side shots, 90-0- is the composite without Forton polymer and 90-7.1 is with Forton polymer.

- 90-0 shows essentially a brittle break, with some fiber pullout, which registers in the value .02 percent 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 .08 percent.

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. However, the next lowest is 8.2% polymer and metakaolin (wet). That suggests the metakaolin has an influence in reducing thermal movements and the degree to which is does is influenced by the polymer content – the higher the better.

Figure 8 shows two graphs indicating the rate of absorption on a short term scale (72 hours), which would indicate a short term, real life cycle and a second run out two 650 hours. On both scales the best performing mix was Forton polymer and silica fume. This is not surprising to due the increased density that silica fume imparts to the mix. The least best 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.

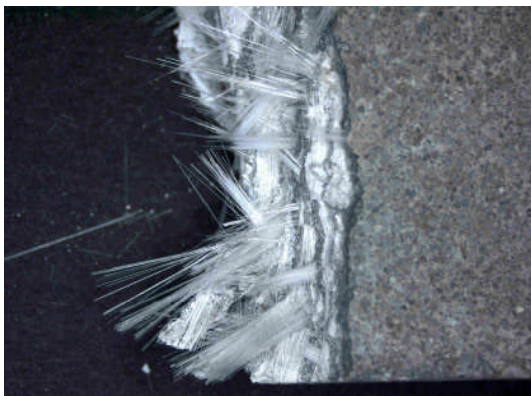
The data in **Figure 10** shows all the mixes tested having no polymer addition plotted in the natural weathering environment and correlated to the hot water and Wet/Dry accelerated aging values. It is clear from the natural weathering trend line, that the hot water and Wet/Dry accelerated aging tests 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 tests 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 accelerated aging tests are not valid as a predictor. The values in the natural aging environment remain at a much higher level.

When the aged MOR and flexural strain values of mixes containing polymer are compared to 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 16 MPa (2320 psi) range while the range for the mixes containing polymer is 25 MPa (3625 psi). The most notable difference is the aged flexural strain to failure. For non-polymer mixes this value is .02 while .08 is the value for aged mixes containing polymer. I think this the most important aspect of all these research and aging test 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.

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

Figure 13



90-0%



90-7,1% Forton polymer

These are examples of the fracture of 13 year old, naturally aged GFRC. 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.

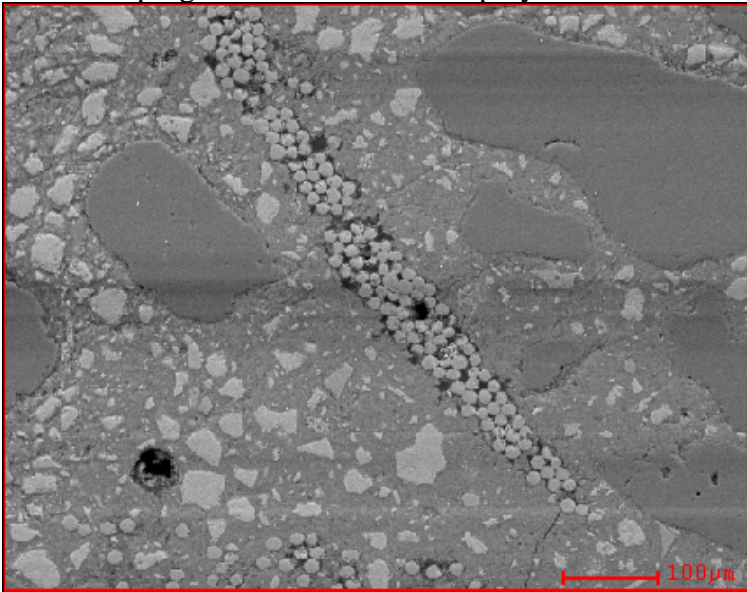
Scanning Electron Microscope Photographs

The following SEM's are taken from the coupons broken in the flexural tests to obtain the data just reported. They give a visual indication of what has happened within each composite as it has aged.

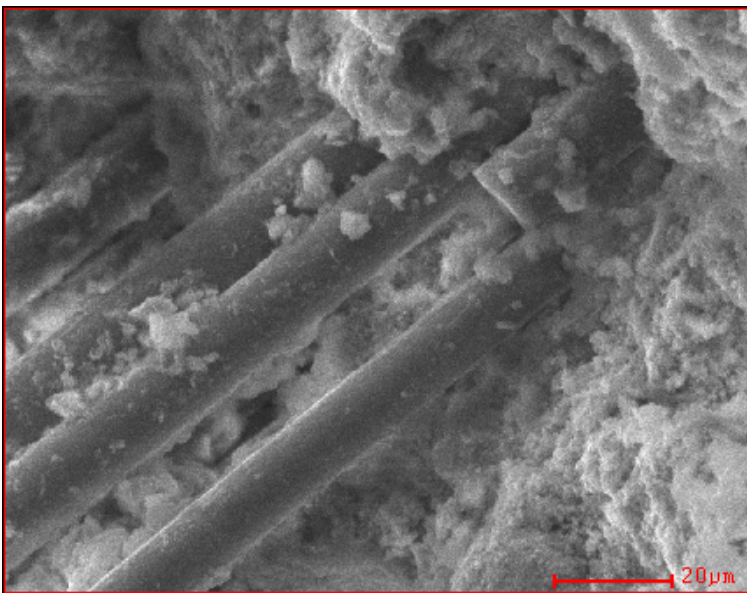
One of the most encouraging things to note is how “clean” the fibers are even after years in the cement/sand matrix. An early concern of GFRC was the “etching” of the glass fiber by the products of hydration, such as calcium hydroxide crystals. This has not occurred.

1984 Test program

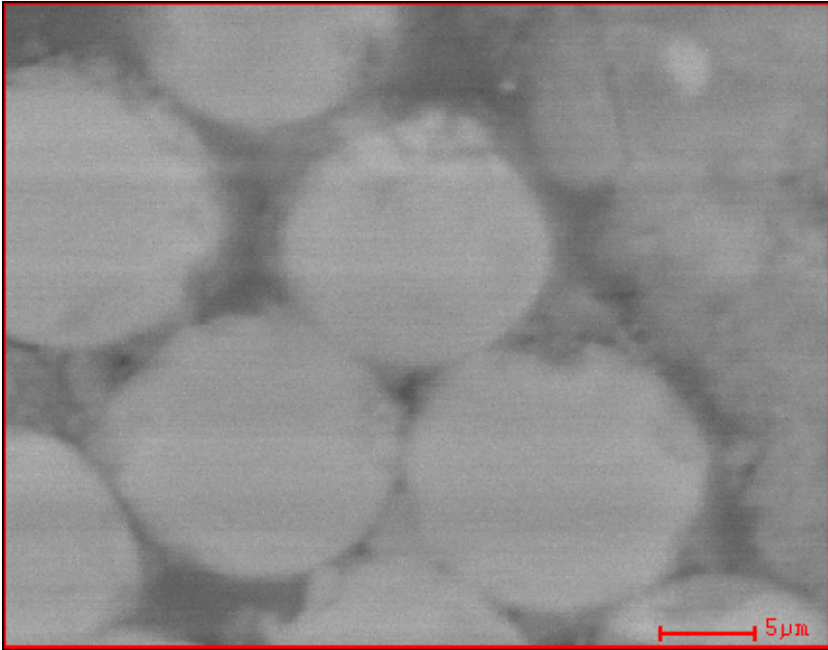
Forton polymer



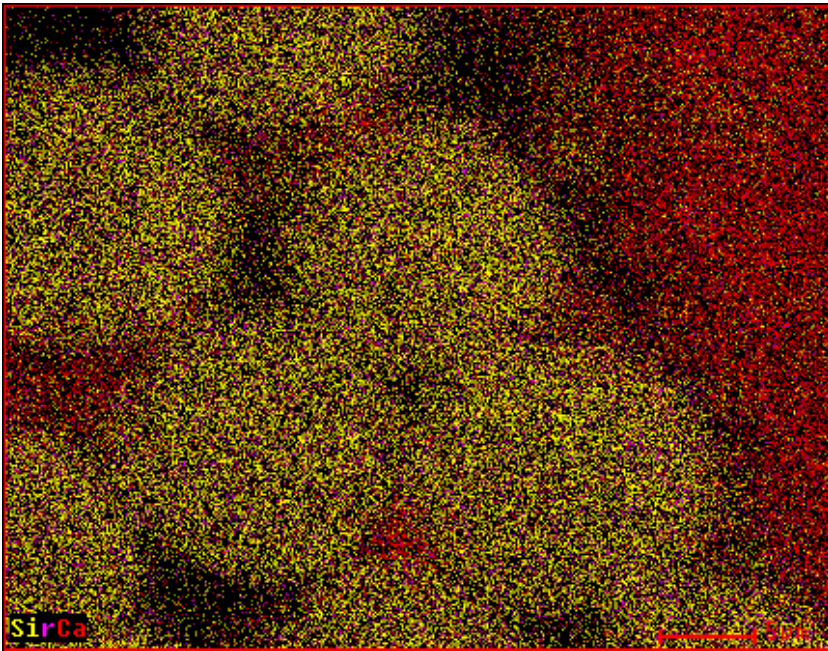
84-7,7%



84-7,7%



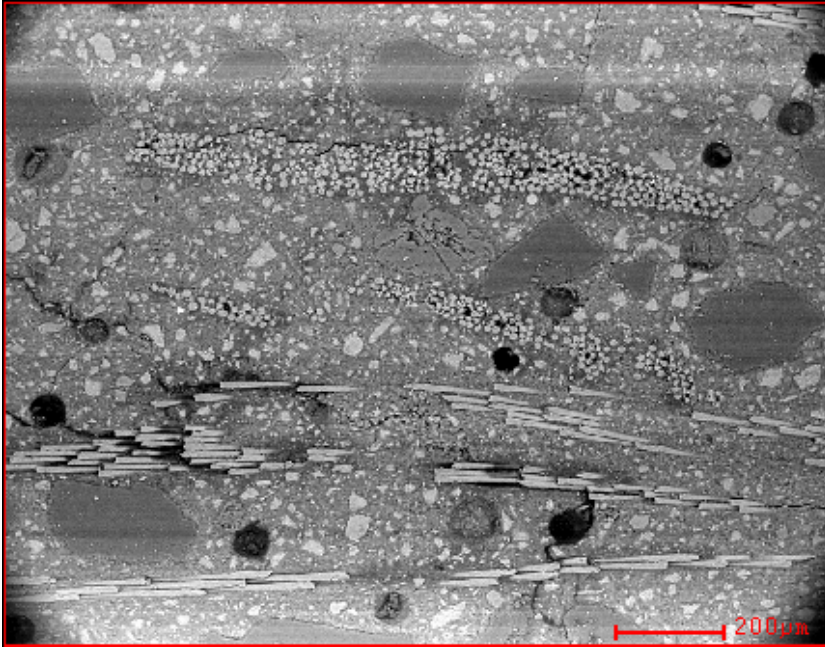
84-7,7%



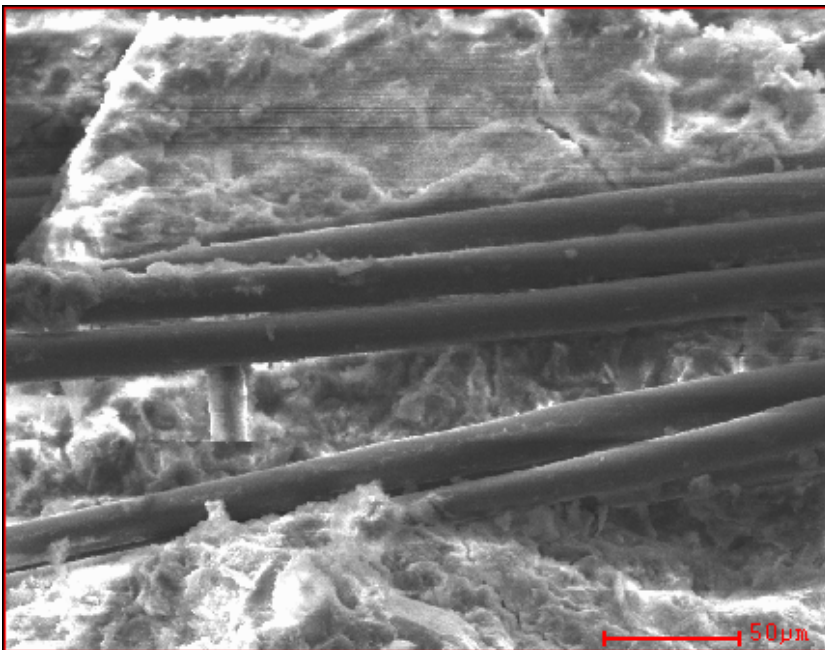
84-7,7%

yellow = silca (glass fibers)

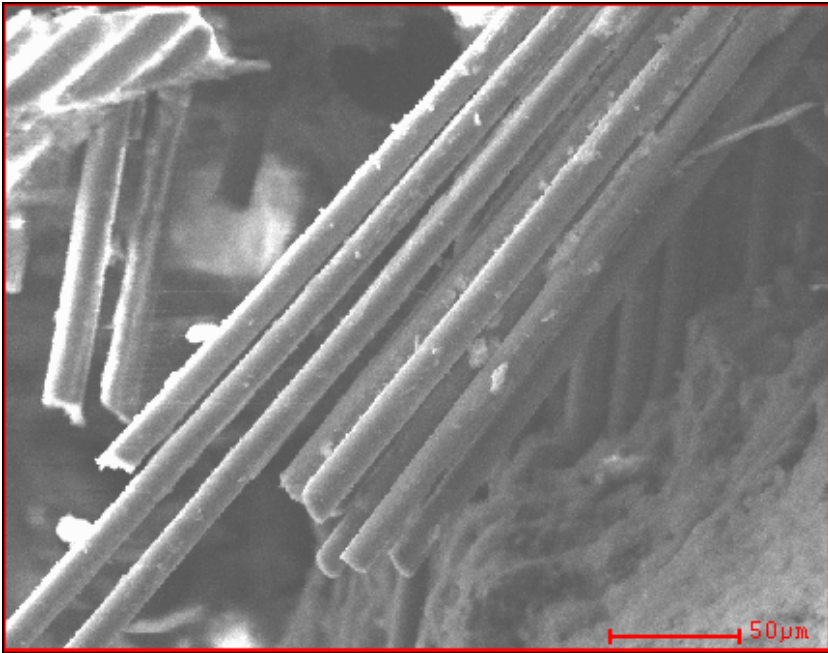
red = calcium (cement matrix)



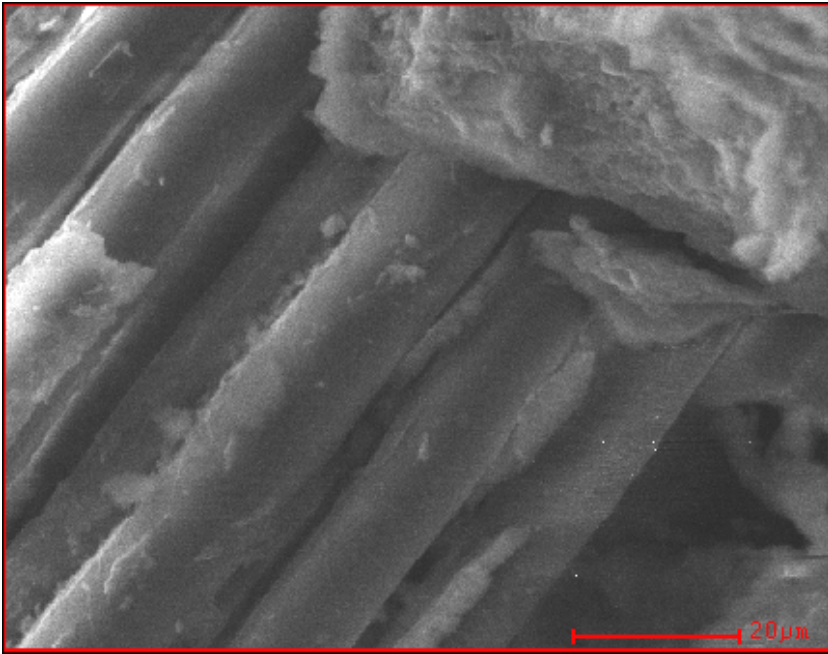
85-5,8+SF



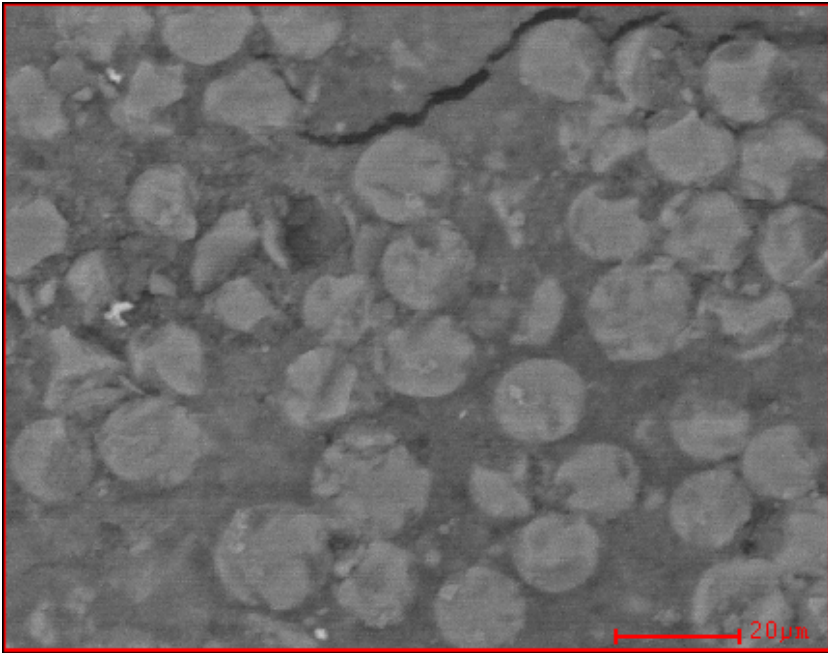
85-5,8+SF



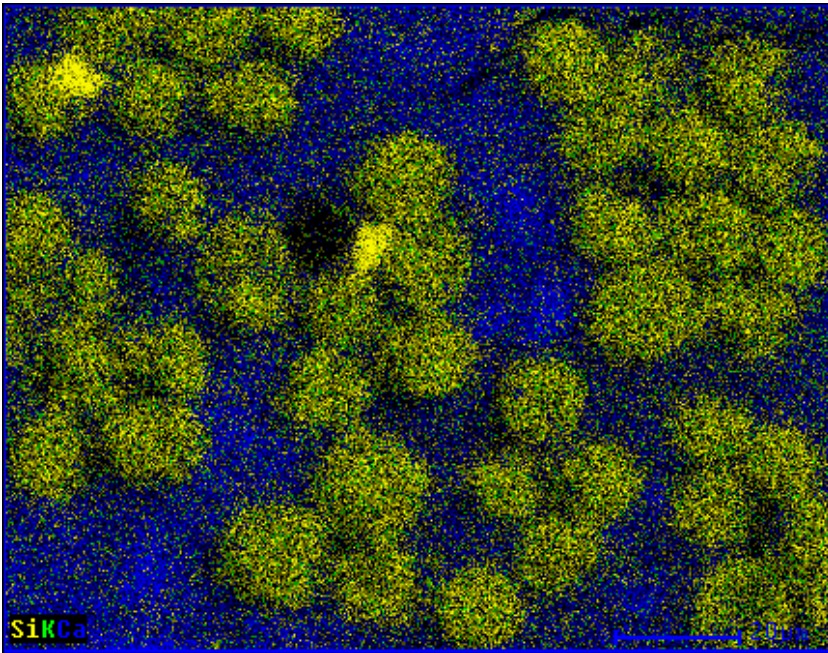
85-5,8+SF



85-5,8+SF

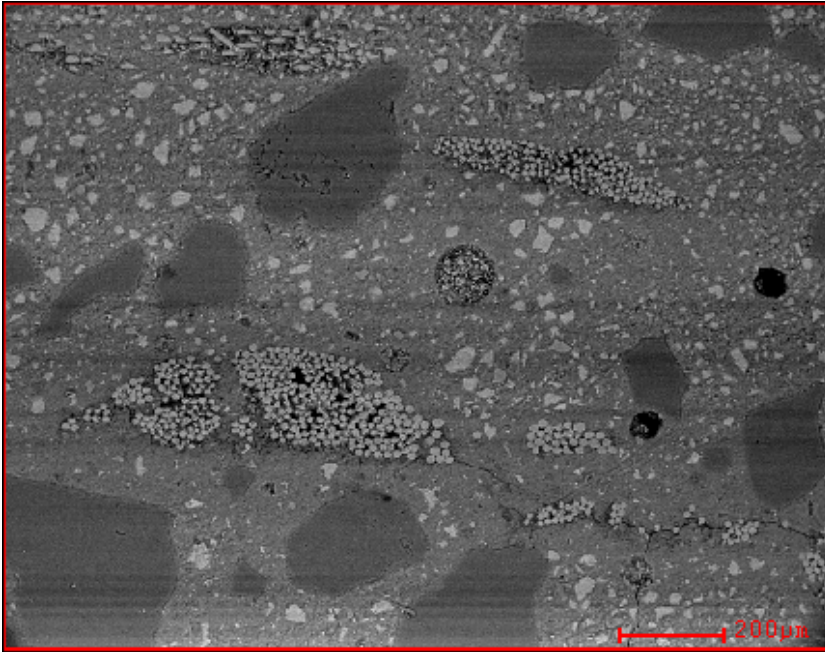


85-5,8+SF

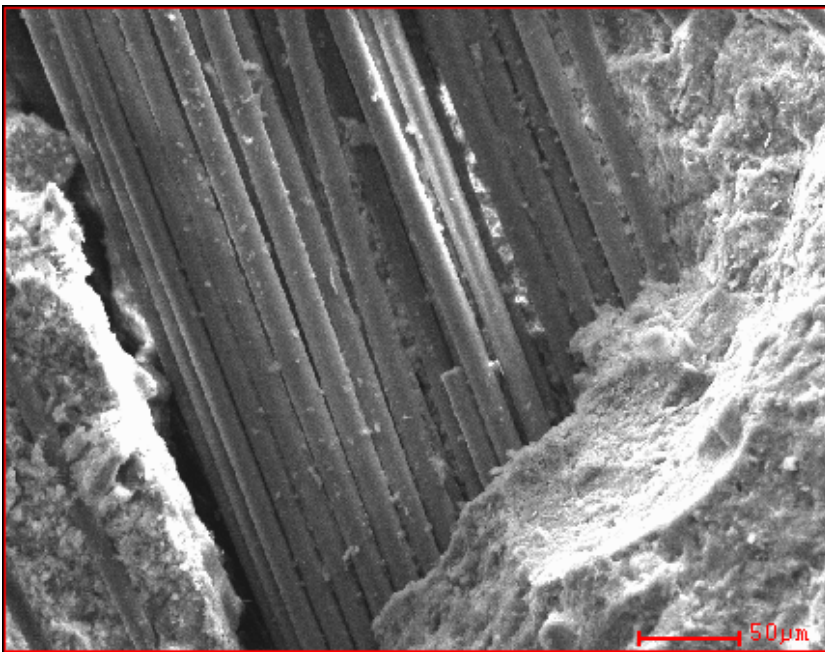


85-5,8+SF

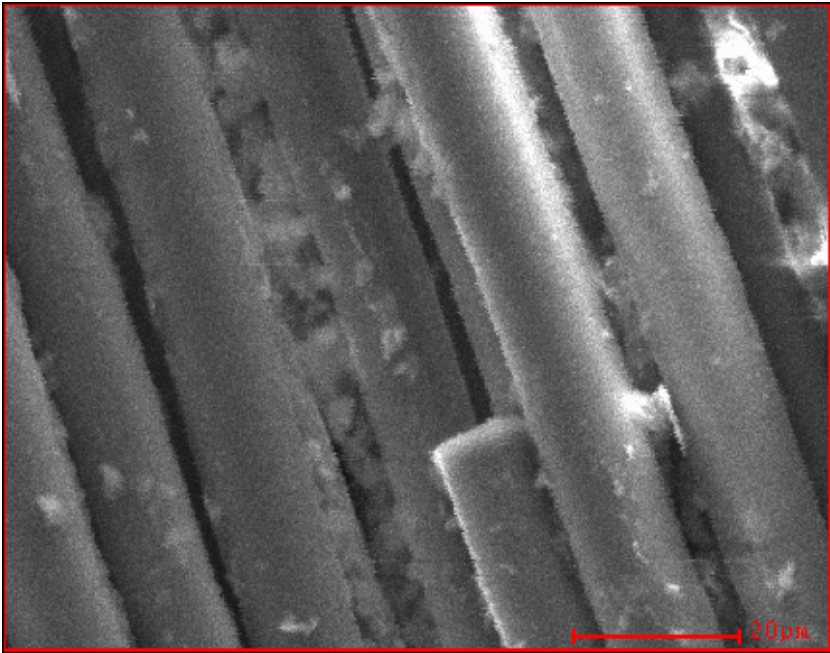
blue = Calcium (cement matrix) yellow = silica (glass fibers)



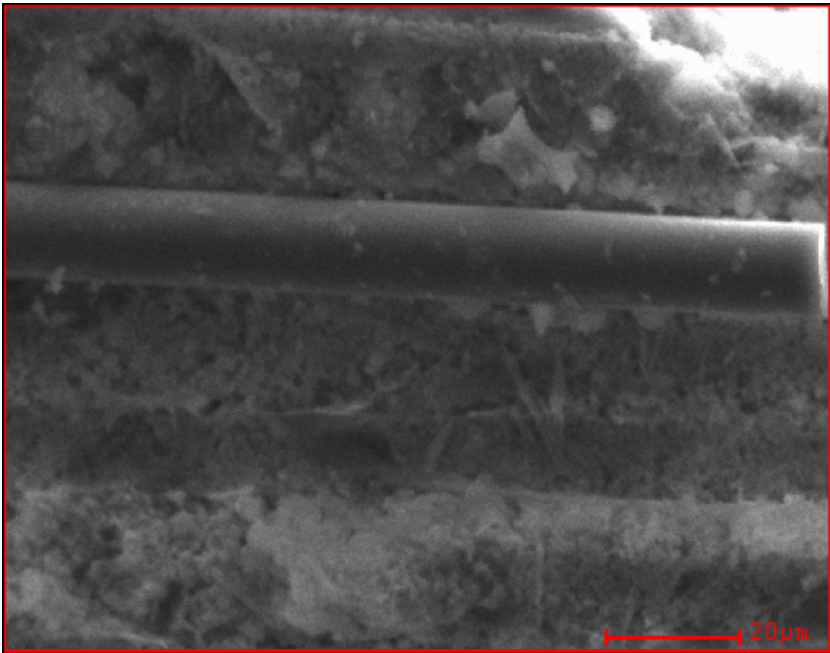
89-5,3



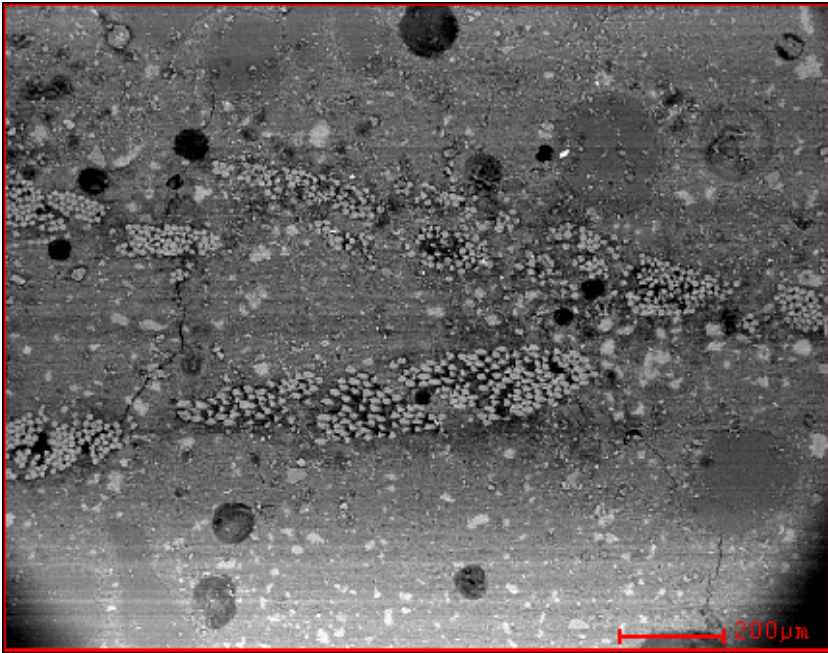
89-5,3



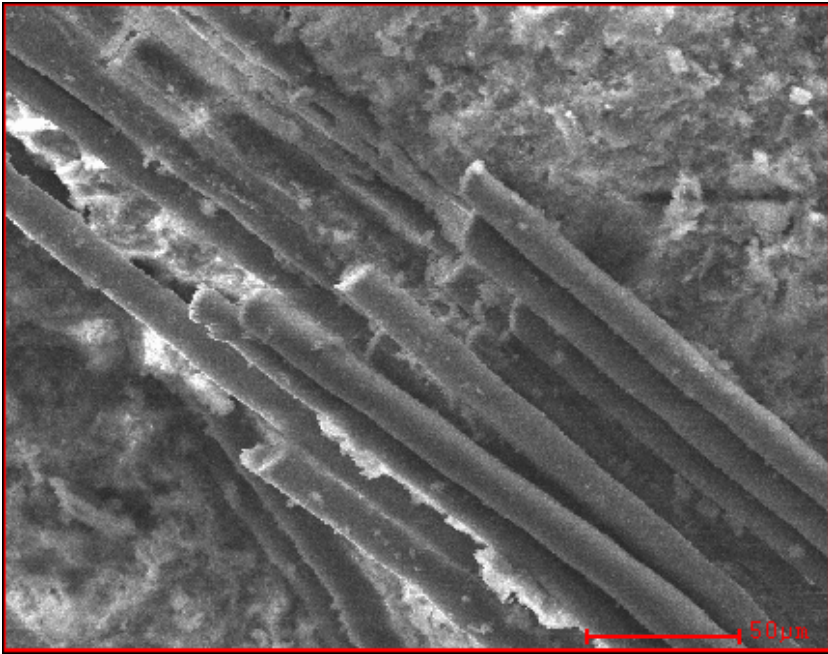
89-5,3



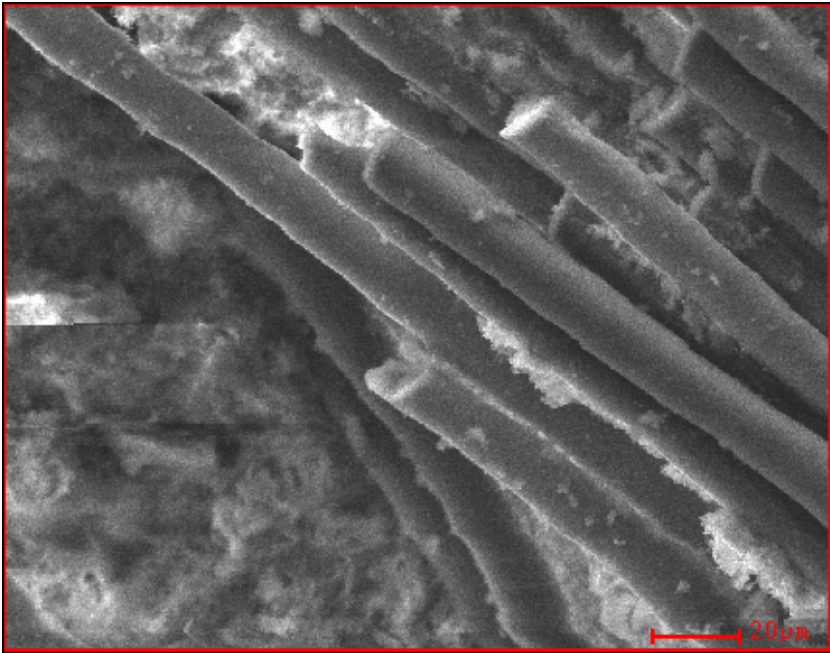
89-5,3



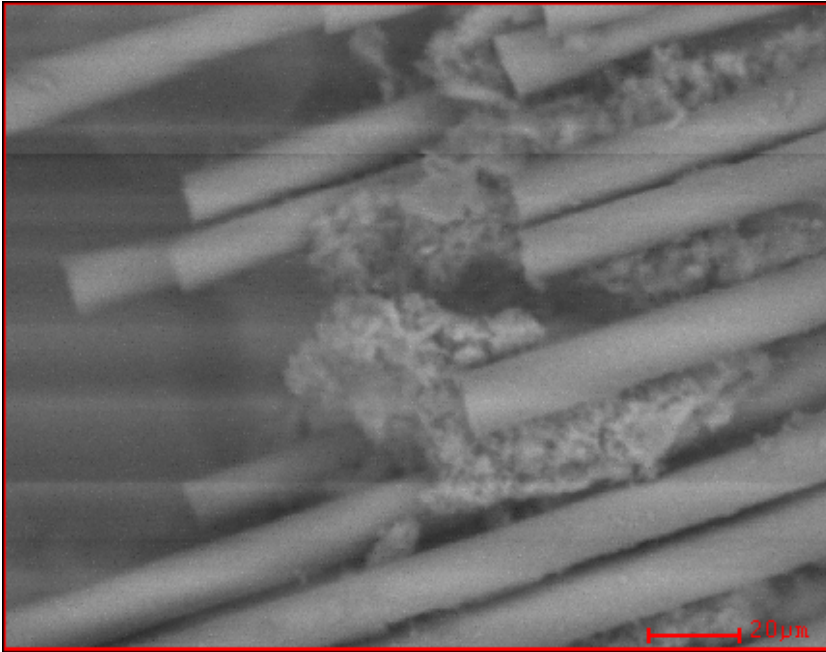
89 6,9 + MK



89-6,9 + MK



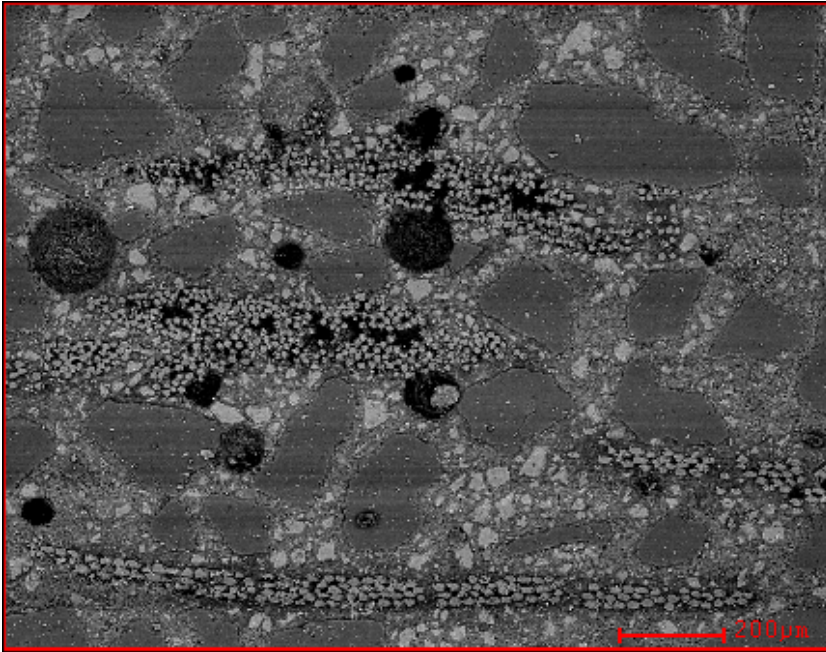
89-6,9 + MK



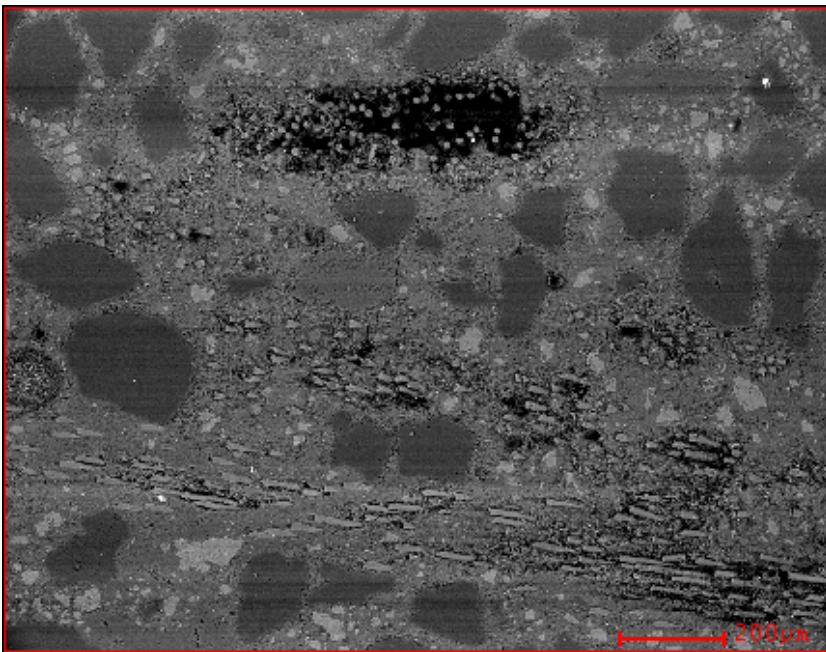
90-0 BS



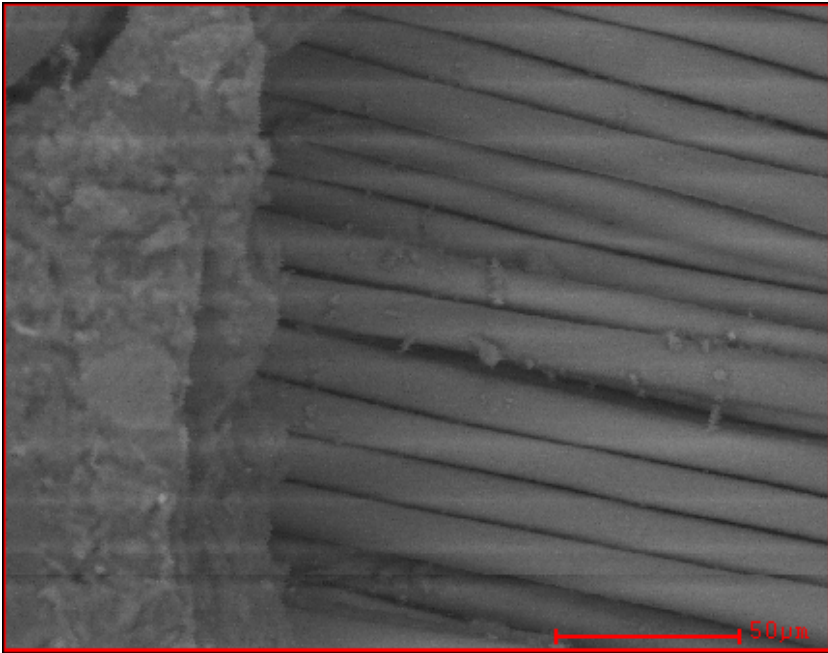
90-0 SE



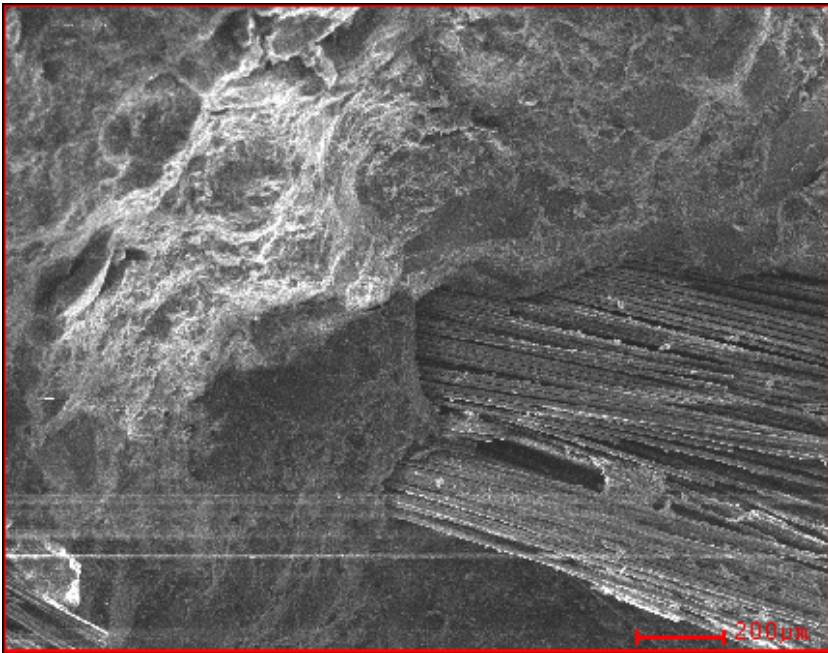
90-7,1%



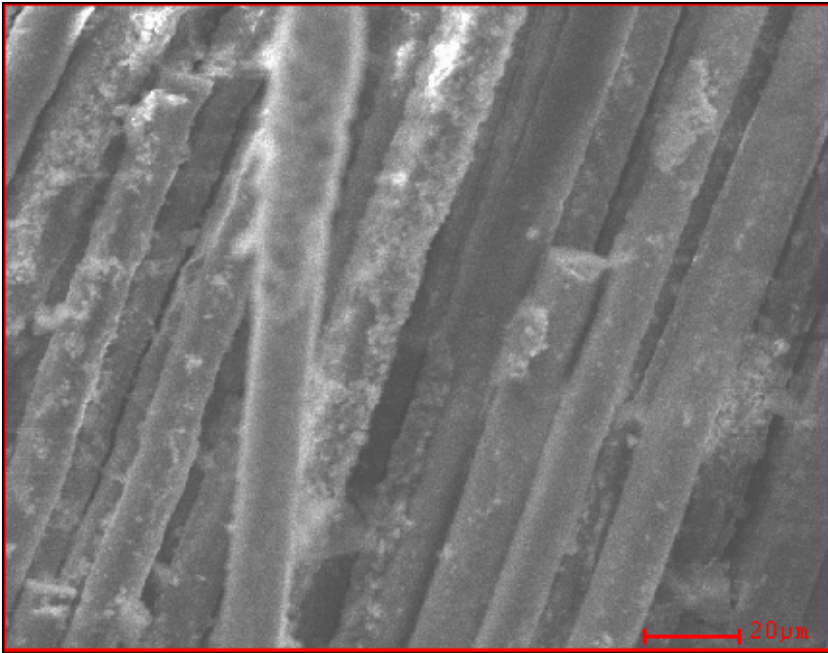
90-7,1%



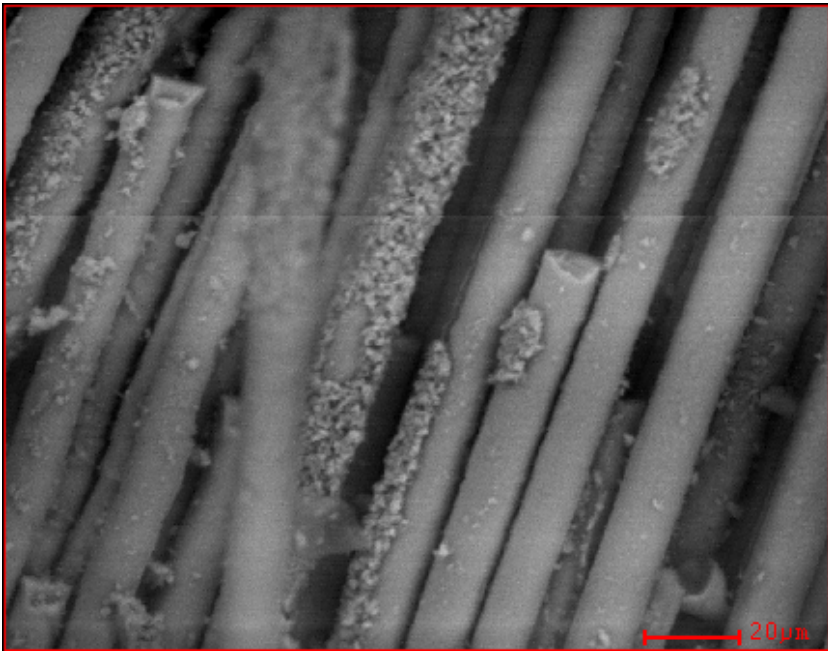
90-7,1% BS



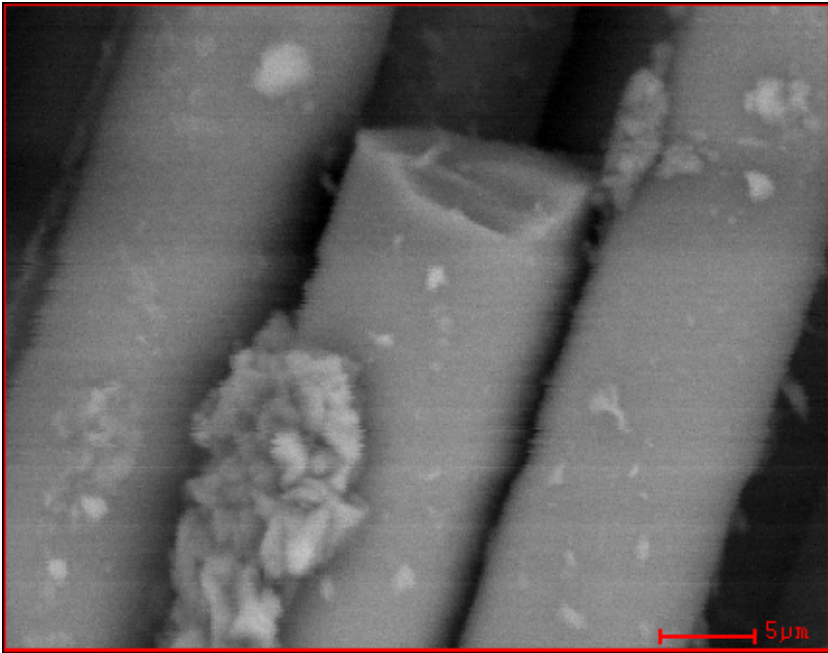
90-7,1% SE



90-7,1% SE



90-7,1% BS



90-7,1% BS



90-7,1%

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 to 7% polymer solids to the weight of cement of Forton polymer, and reinforced with alkali resistant glass fiber, results in a composite that maintains a stable LOP, and a high MOR in a natural weathering environment.
- The composite containing Forton polymer also maintains a high, and stable, 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 Alkali Resistant glass fibers.

Figure 1

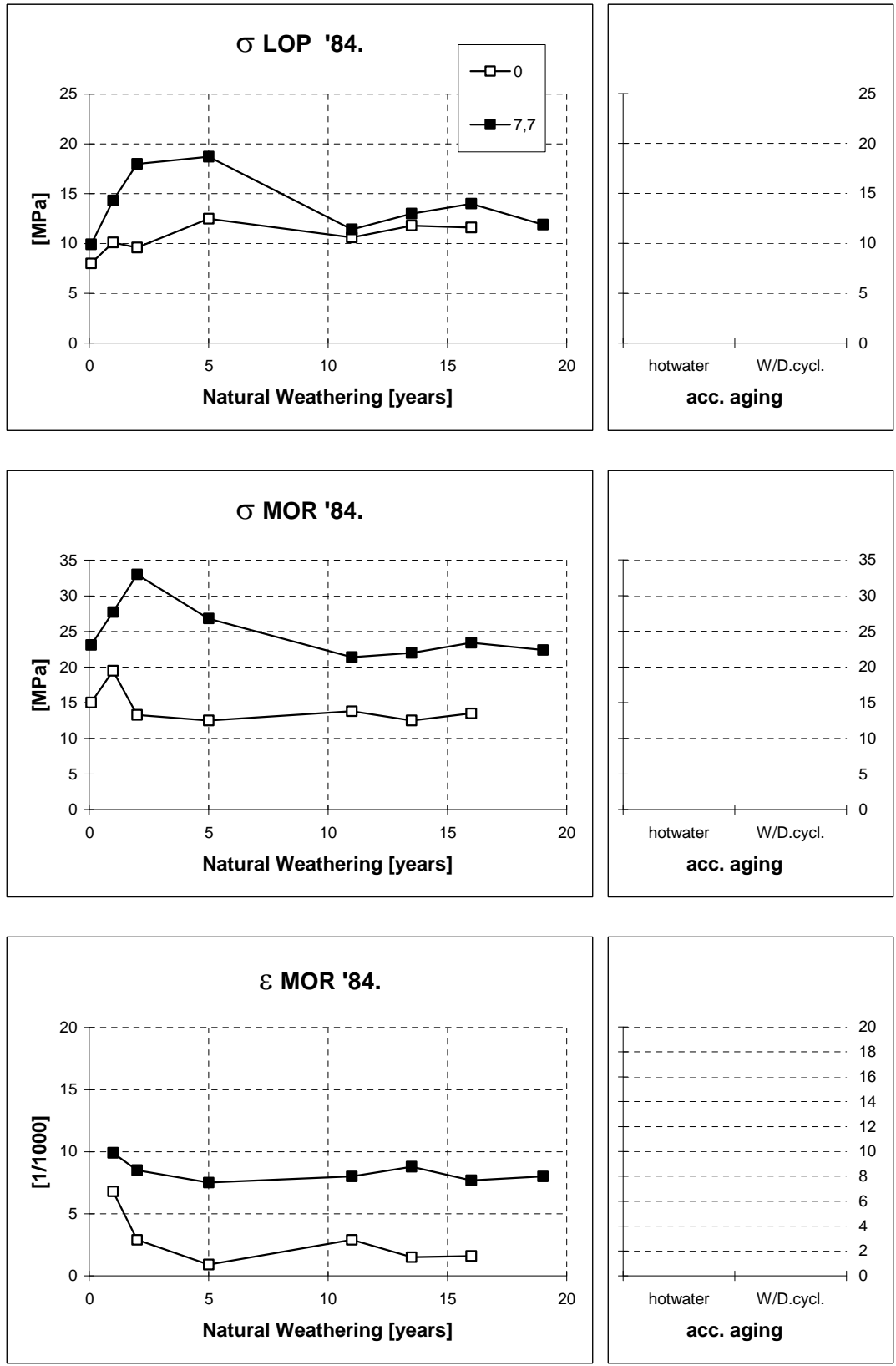


Figure 2

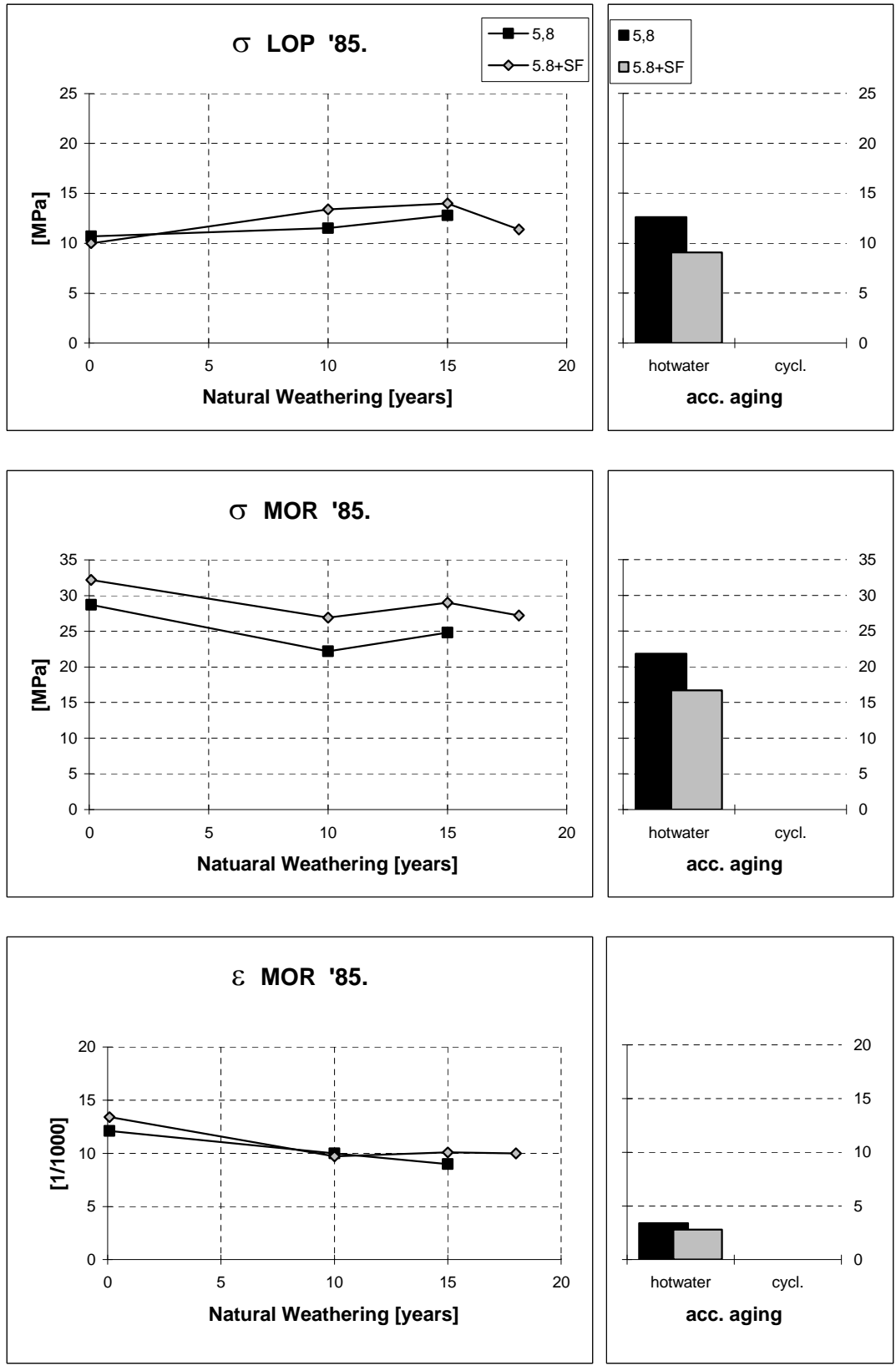


Figure 3

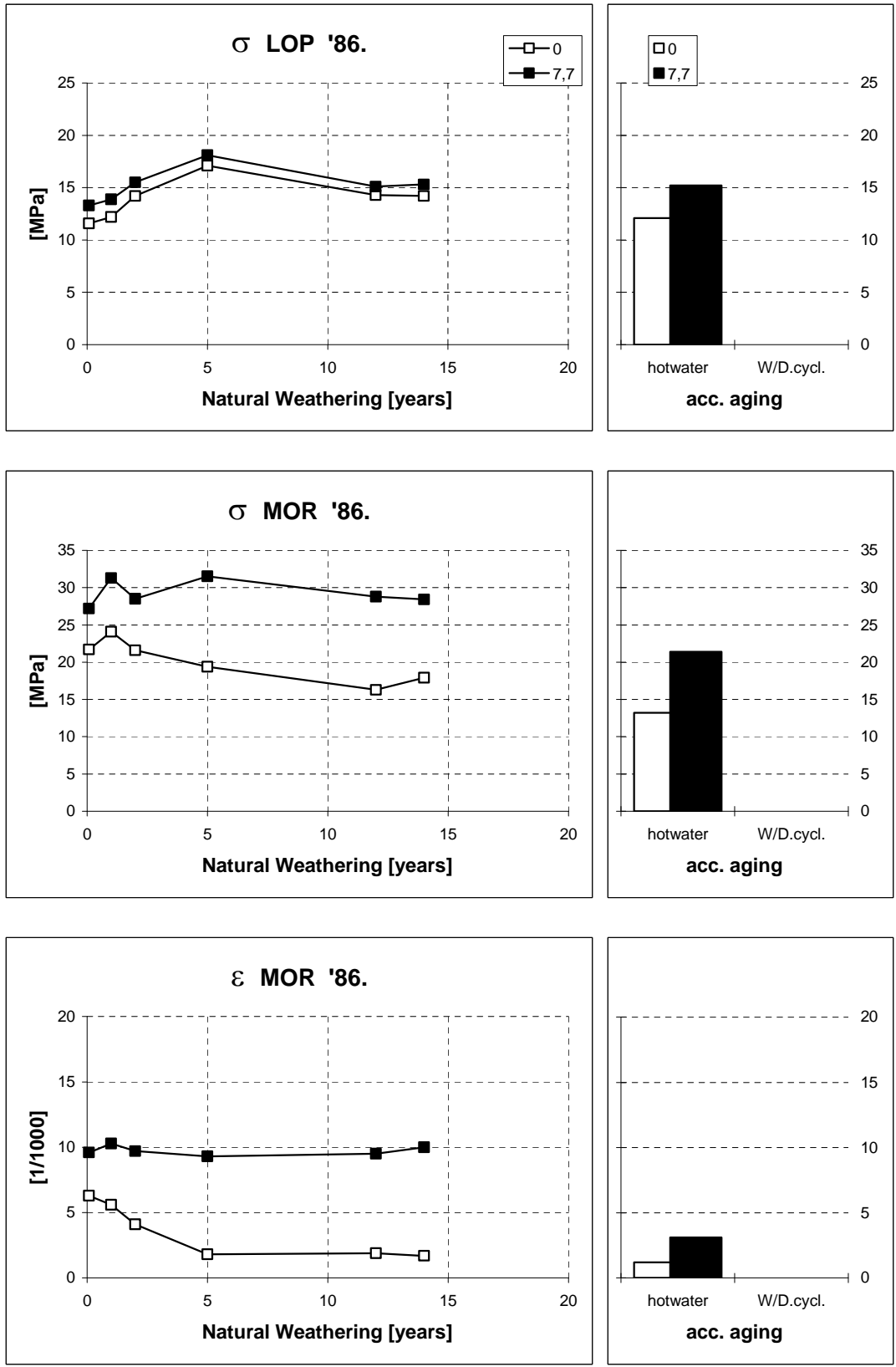


Figure 4

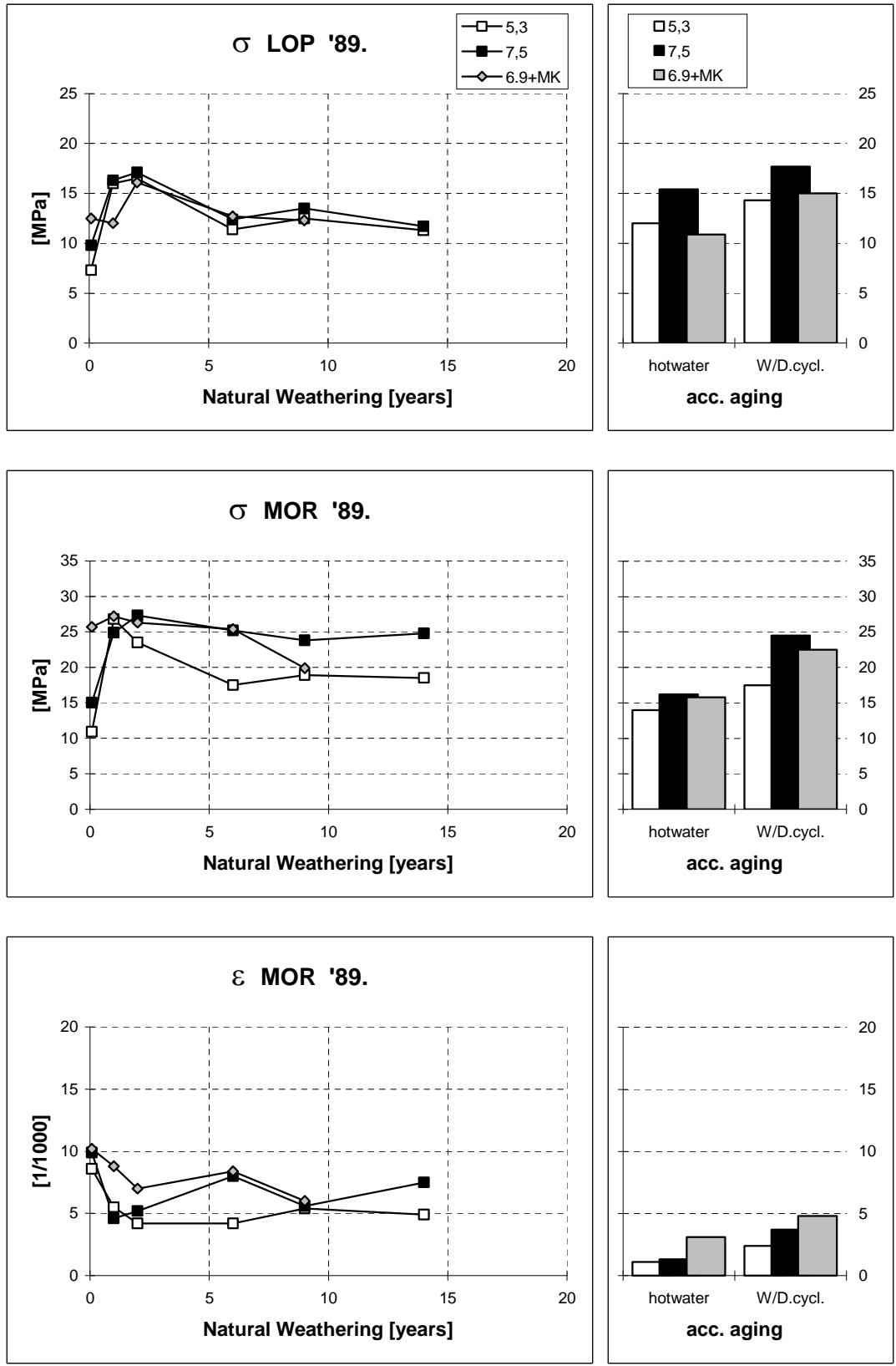


Figure 5

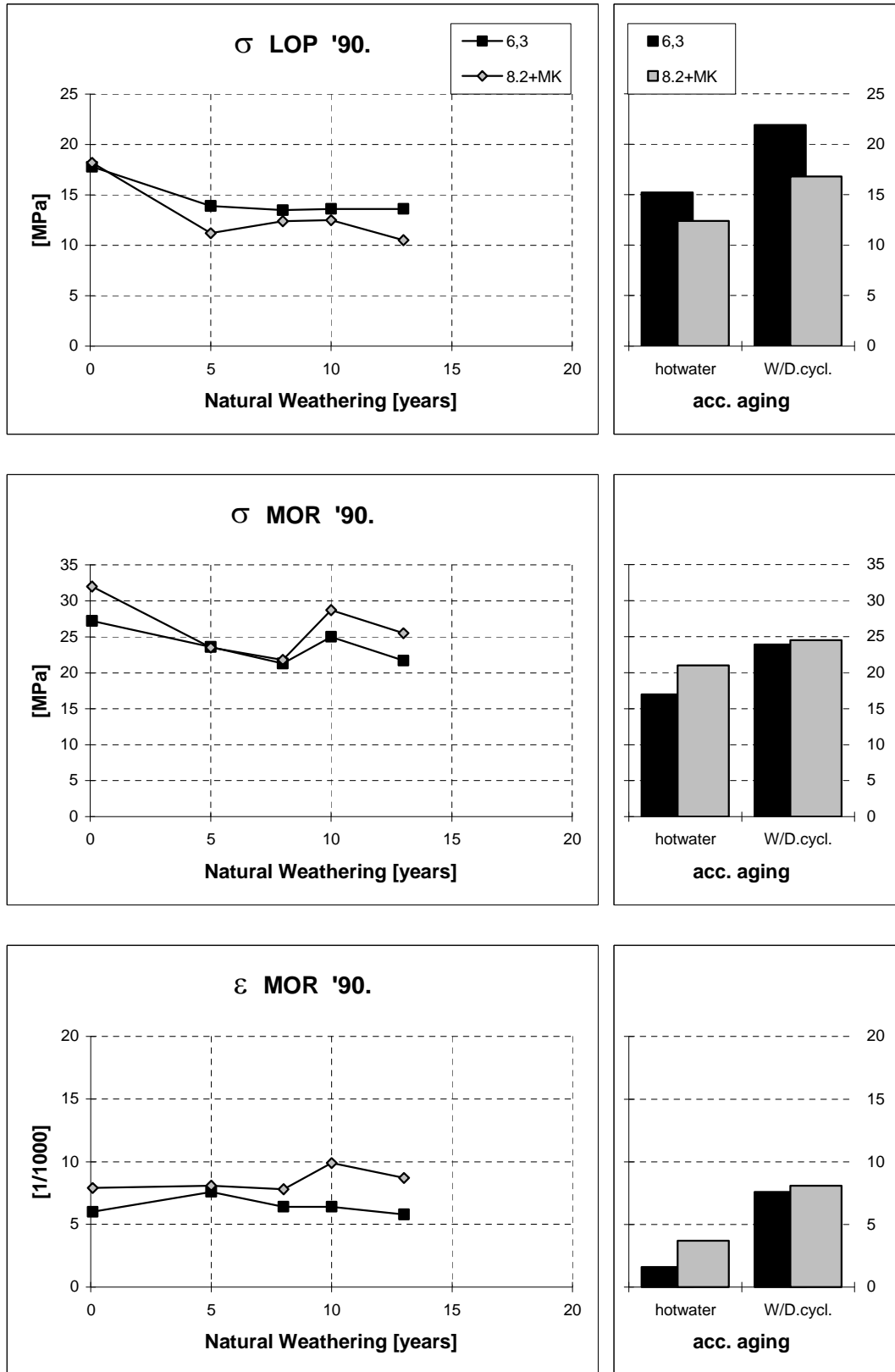


Figure 6

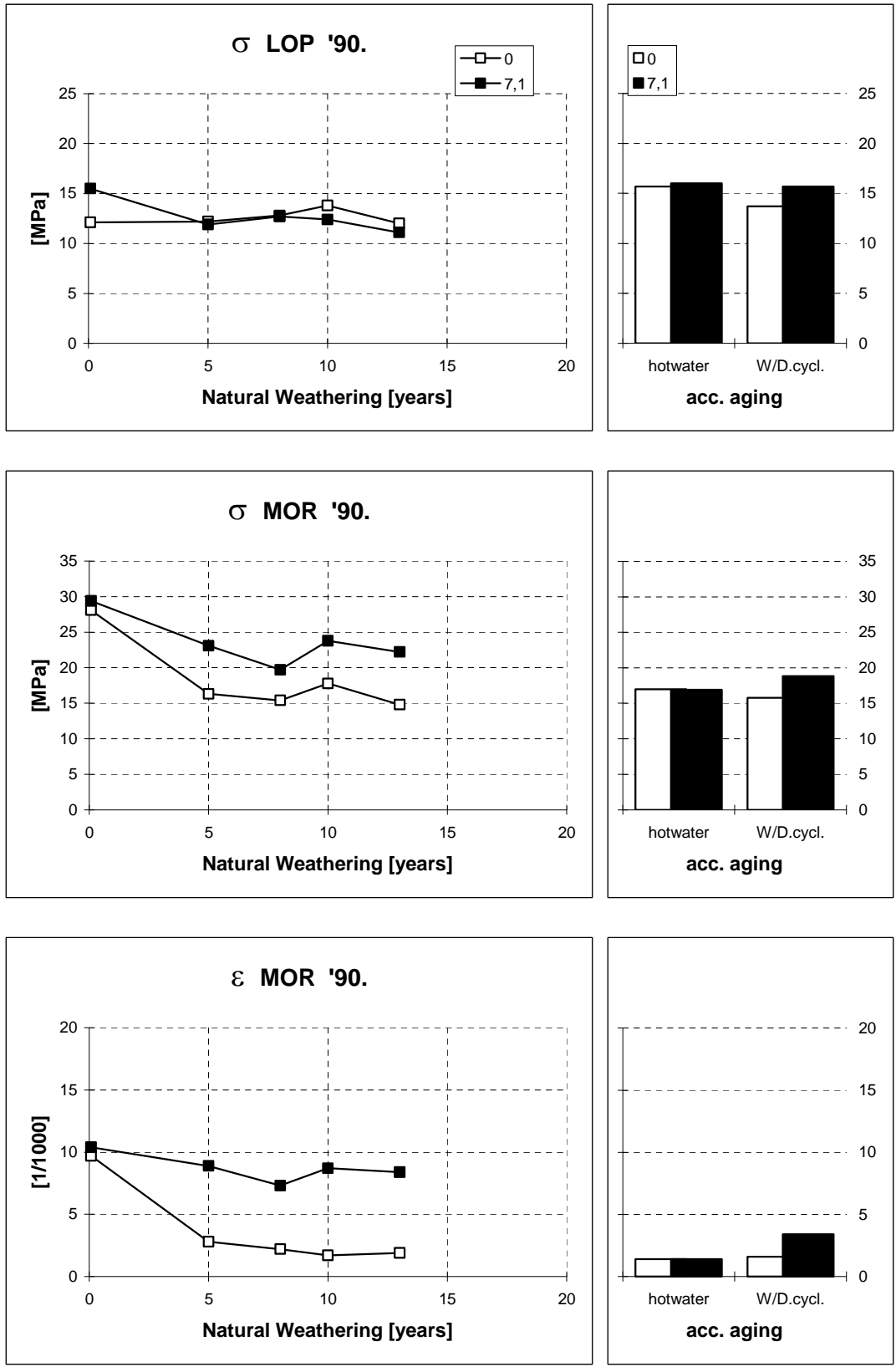


Figure 7

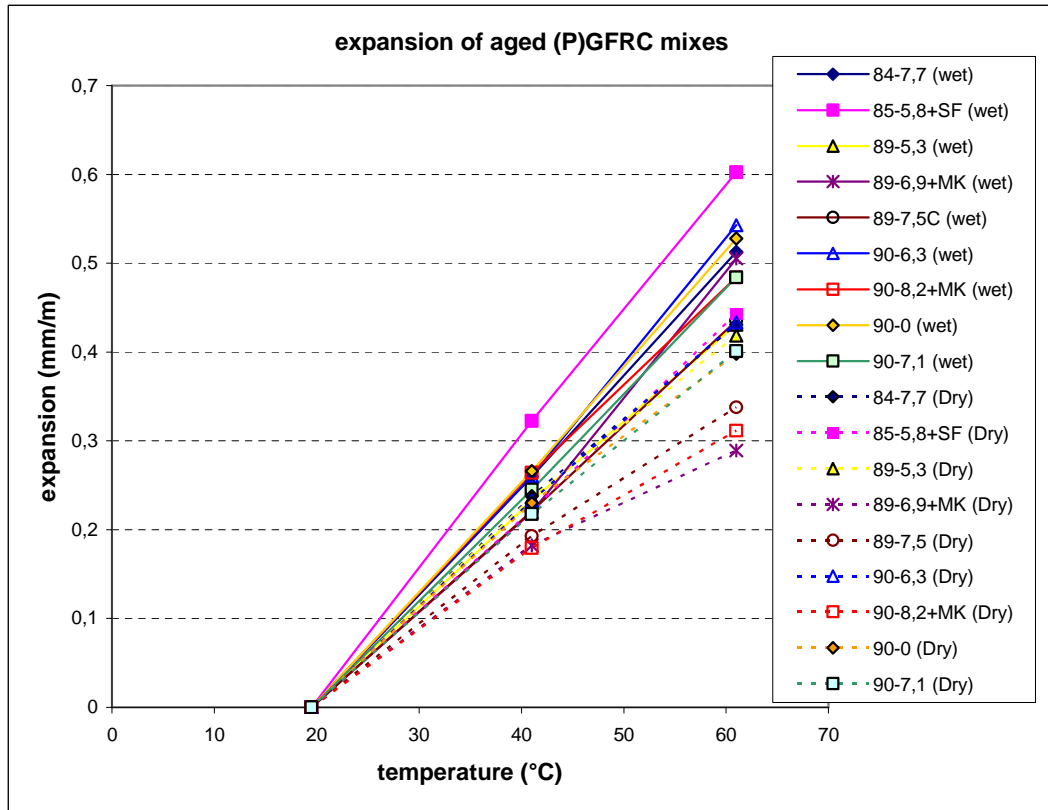


figure 8

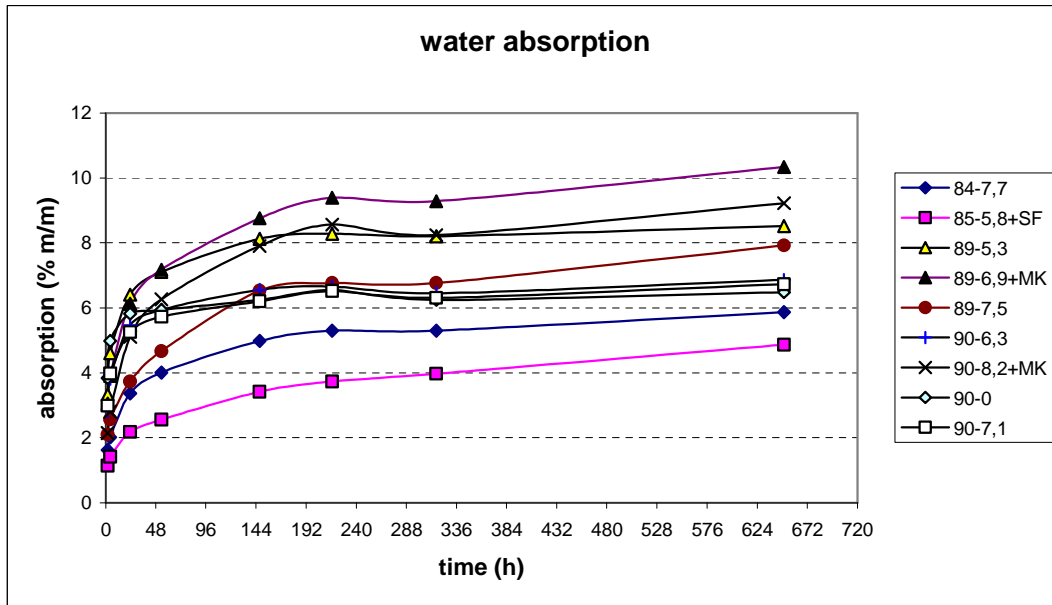
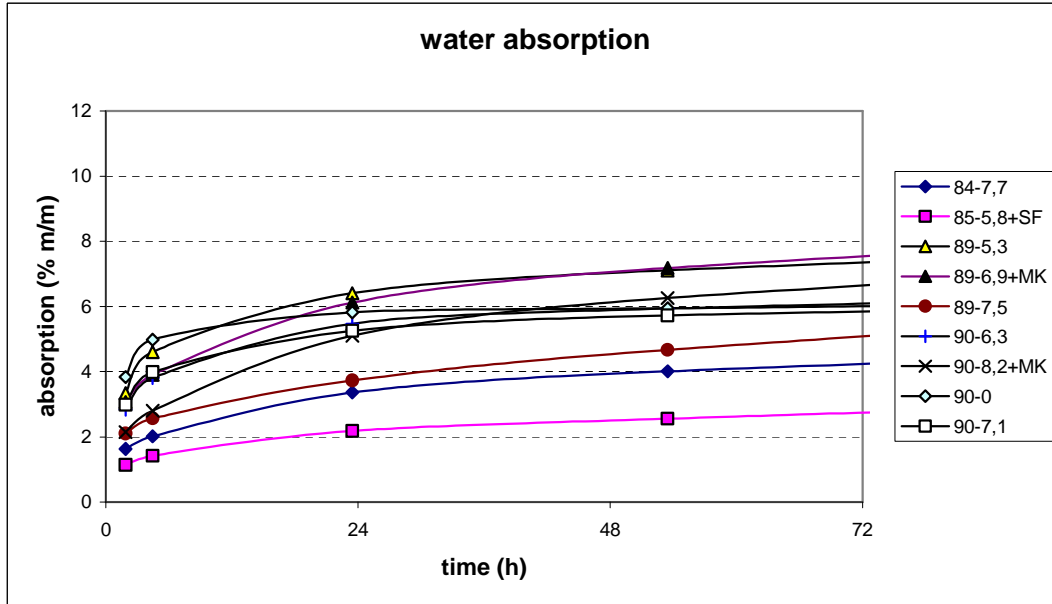


figure 9

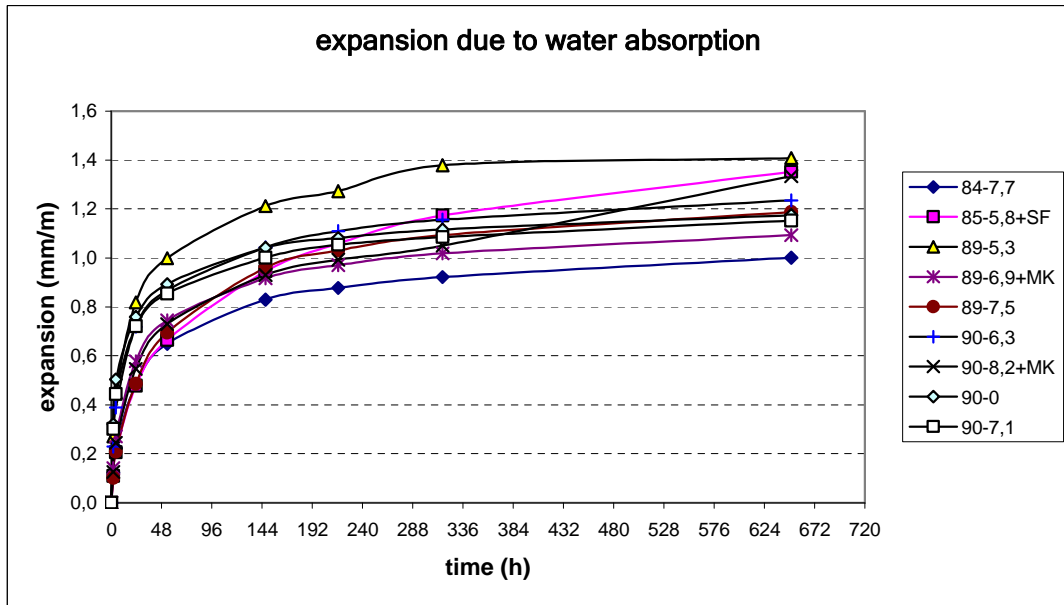
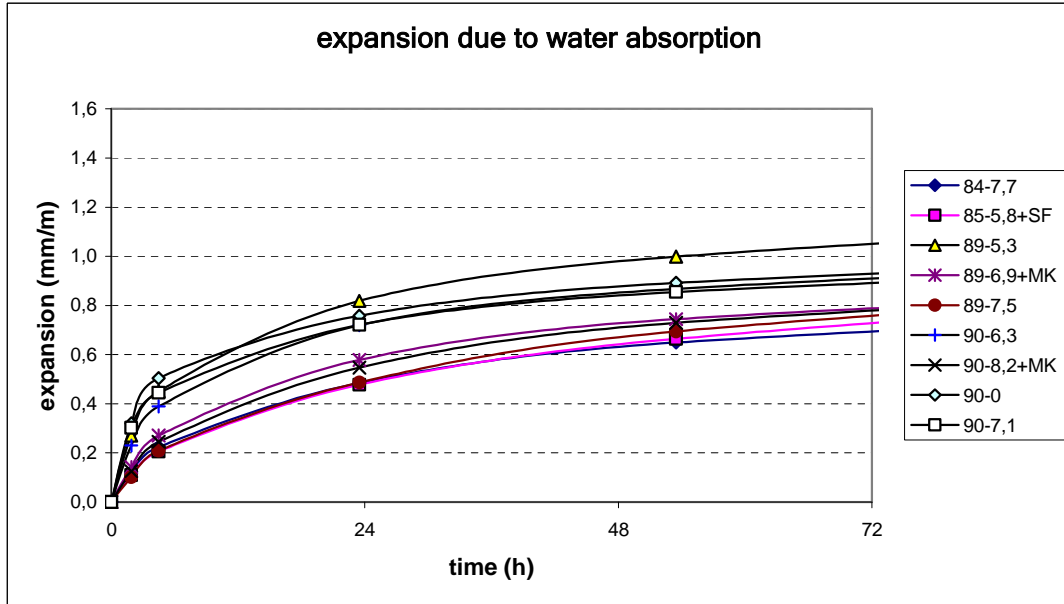


Figure 10

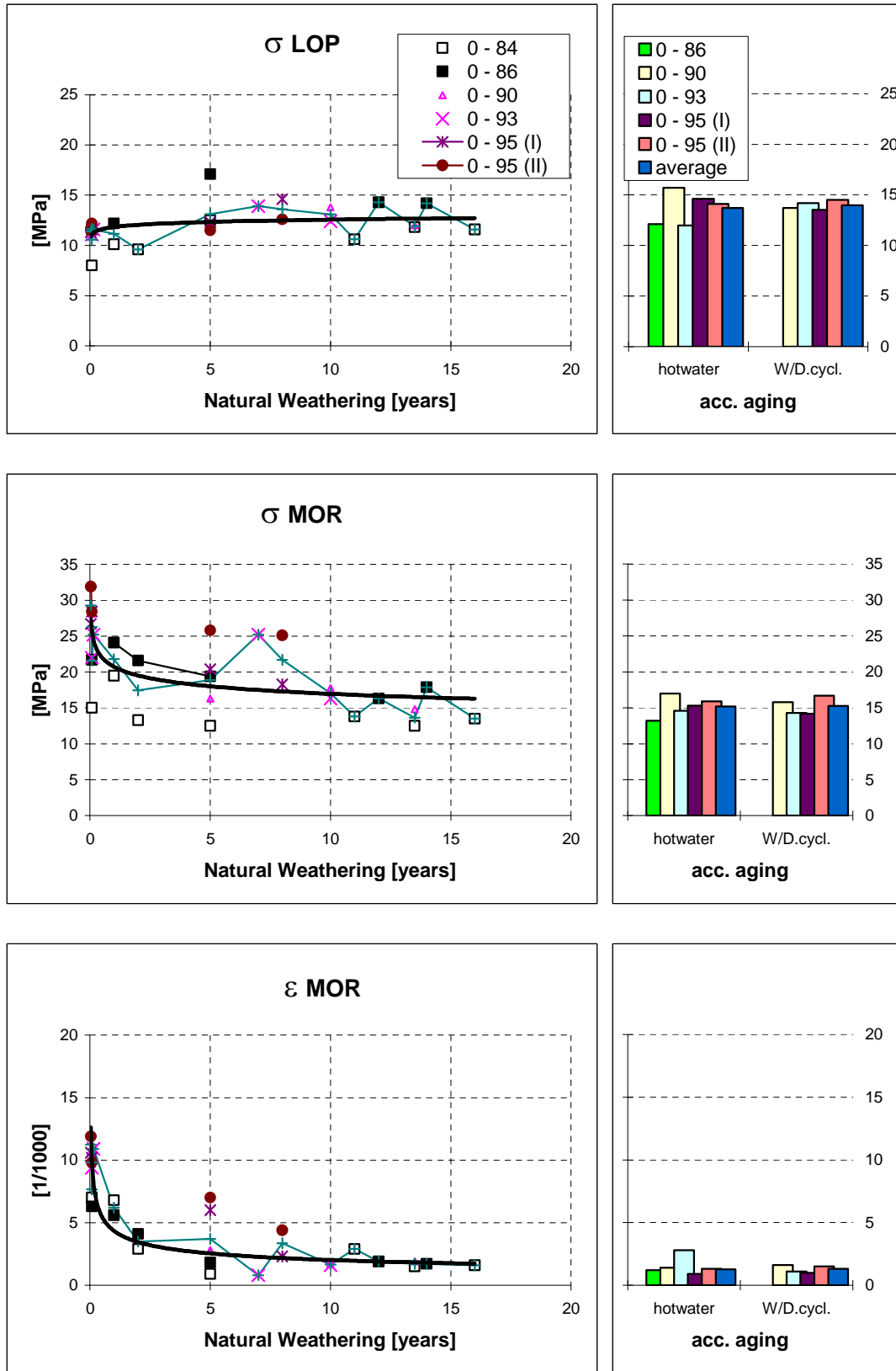


Figure 11

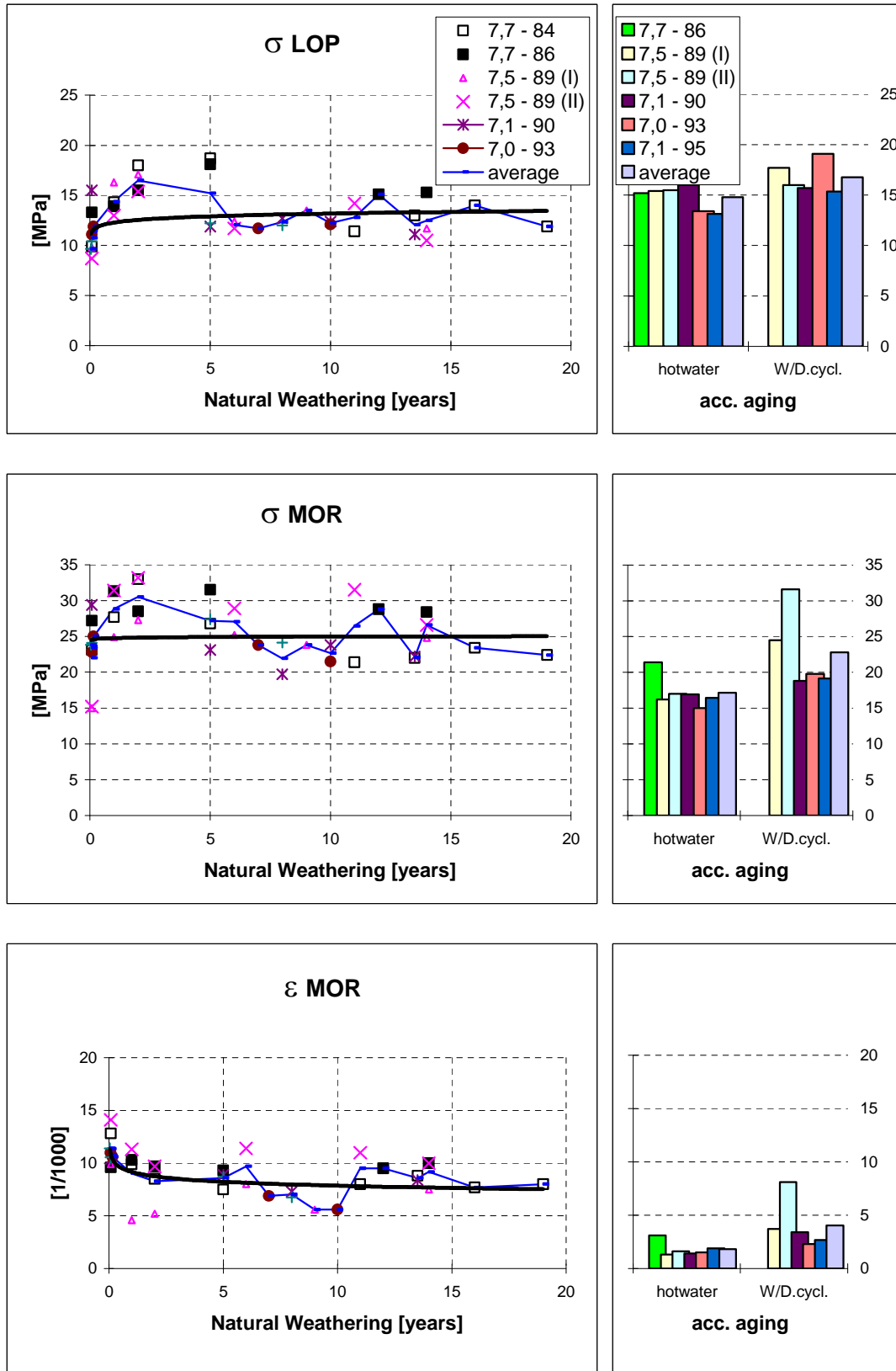


Figure 12

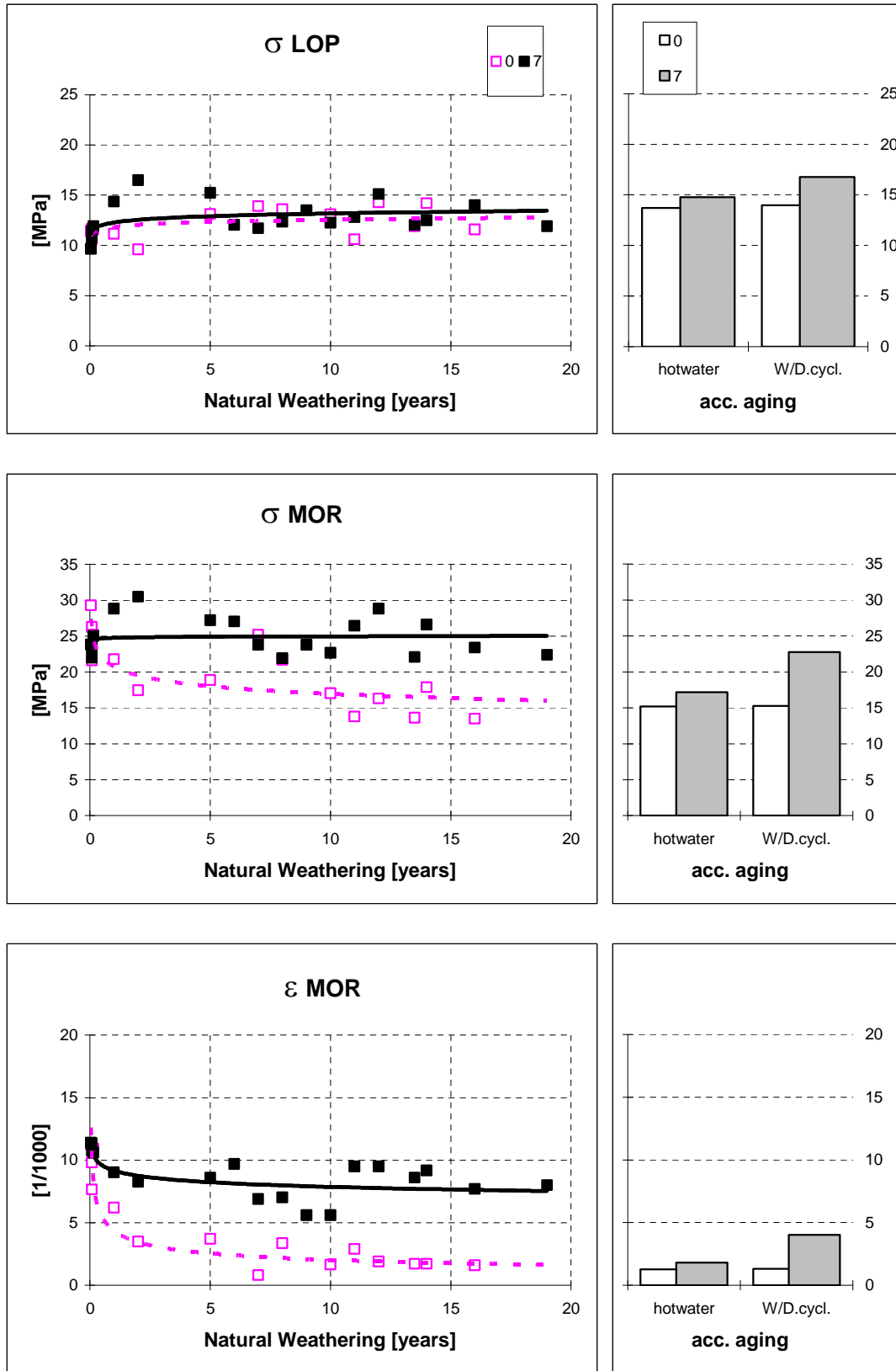
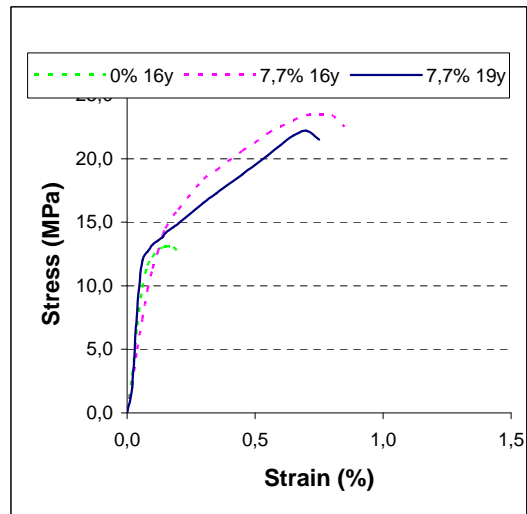
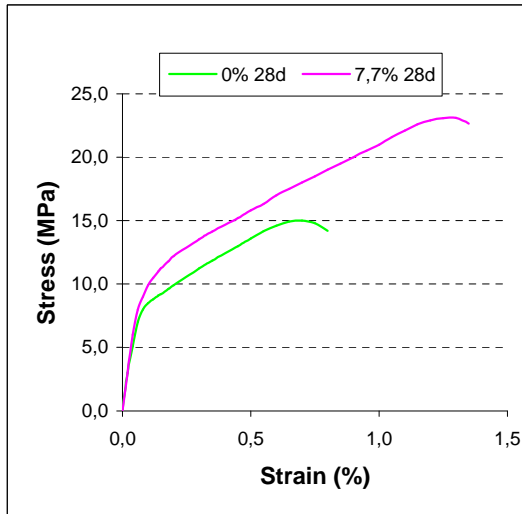
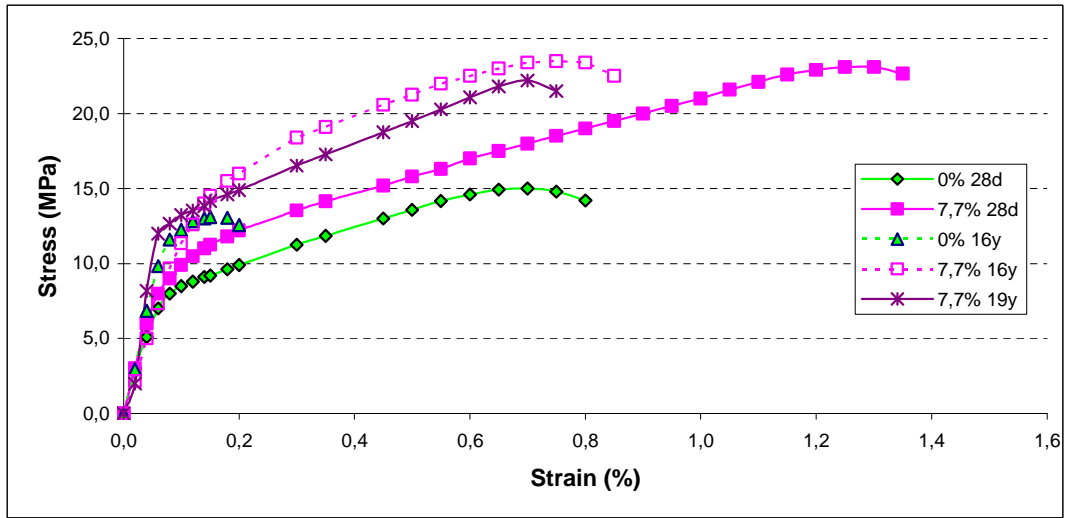


Figure 14



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