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EFFECTS OF CONDITIONING ENVIRONMENT ON GFRP BARS

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ABSTRACT

Corrosion of steel reinforcement in concrete structures is a critical problem that designers, contractors and owners have to face everywhere. The corrosion resistance of Fiber Reinforced Polymers (FRP) bars makes them attractive for the replacement of steel reinforcement if it can be ensured that their mechanical and physical characteristics remain stable over time under service conditions.

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The durability of Glass FRP (GFRP) materials used in construction is related, among the other things, to the conditions within concrete. Several studies have suggested that the high alkalinity of the cementitious environment and thermal variations act as a catalyst for stress corrosion mechanisms driven by the exchange of alkali metal ions (Na^+ and K^+). At the same time, environmental agents including high relative humidity, freeze-thaw cycles, and high temperatures may produce a reduction of mechanical properties.

This paper compares the effects of two conditioning environments on the physic-mechanical properties of GFRP rods. The aim of the study is to show that the proposed accelerated ageing regimens allow to clearly differentiate between different products.

Two types of GFRP rods investigated in this work were subjected to alkaline solutions at 60 °C for two different exposure times, while other specimens were exposed to environmental ageing in a controlled chamber.

Tensile and short beam tests (SBT), according to provisions from ACI 440 and ASTM D4475, respectively, were used for physic-mechanical characterization, while gravimetric measurements were used to study the absorption behavior.

The correlation between the tensile test results, apparent horizontal shear strength, and gravimetric measurements allowed to determine the changes in mechanical properties due to fibers and resin degradations, as a result of the accelerated aging.

INTRODUCTION

Several experimental studies demonstrated that FRP materials present a wide potential for use in civil infrastructure applications. The corrosion problems of the steel reinforcement and the good mechanical properties of FRP materials opened an opportunity for the use of composites in new constructions and repair. Since the determination of the durability is one of the most important issues to face, previous studies investigated the effects of different external agents on the mechanical behavior of Carbon, Aramid and Glass FRP products for use in civil engineering.

A literature review indicates the following. The effect of moisture absorption on GFRP rods and laminates are related to temperature and they produce a loss in strength and stiffness [1, 2, 3]. UV exposure leads to surface oxidation due different chemical mechanisms related to the resin type [4, 5]. The freezing-thaw cycles without the presence of high moisture do not affect mechanical properties [6].

Cementitious environment conditions were found to be aggressive for the GFRP, due to the high pH level (13.5) of the pore water solutions and presence of alkaline ions. It was seen that the temperature is an accelerating agent for the effects related to high pH and ions attack [7]. The alkaline solutions produce an embrittlement of the matrix and a damage at the fiber-resin interface level due to chemical attack and growth of hydration products, this effects lead to a loss in tensile strength and interlaminar transverse properties [8, 9, 10].

An experimental work is presented herein in order to show a method to study the effects of accelerated ageing of GFRP rods. Durability effects for two GFRP rod types subjected to combined environmental cycles and accelerated alkaline exposure are illustrated.

EXPERIMENTAL PROGRAM

Materials

Two types of GFRP rods were investigated: G1 bars are manufactured with a thermoplastic resin and G2 bars that are made with a polyester matrix, both rod types use E-glass type fibers as reinforcement. The measured diameters (d) of G1 and G2 rods were respectively 12 mm and 6 mm.

Experimental Program

The number of specimens tested in this experimental study under different exposure conditions is reported in table 1.

Accelerated Ageing

The used alkaline solution consisted of 0.16% $Ca(OH)_2$+1% Na(OH)+1.4% K(OH) in weight in distilled water; the measured alkalinity was pH=12.6 that was found to be constant, before and after specimens exposure. The rods were placed in an oven at 60°C in order to accelerate the effects of alkaline conditioning. The following equation can be used to estimate the influence of temperature on the accelerated ageing [7]:

$$N/C = 0.098 \exp(0.0558\ T) \qquad 1$$

Where:
N = age in natural days
T = conditioning temperature in °F
C = days of accelerated exposure at temperature T

It means that 21 and 42 days of exposure (conditions A1 and A2 in table 1) simulated respectively 14 and 28 years in the concrete ambient.

As a second conditioning regimen, specimens were subjected to four combined environmental cycles. A single exposure regimen consisted of 50 freeze-thaw cycles 150 temperature and 120 high relative humidity cycles, as illustrated in figure 1. UV radiation was applied with the high temperature cycles. The UV lamps positioned in the chamber exposed the specimens to an irradiance of 6.80×10^{-2} W/ cm^2 in a spectral band of 300-800 nm and of 6.10×10^{-3} W/ cm^2 in a spectral band of 300-400 nm. The minimum temperature reached in the freeze-thaw cycles was -18°C, while the maximum temperature in the high temperature cycles was 49°C and the maximum relative humidity was 90% as plotted for a single cycle shown in figure 1. The specimens were exposed totally to 200 freeze-thaw cycles, 480 humidity cycles and 600 high temperature cycles totally. The conditions reproduced in laboratory could correspond to a period of eight years in a region such as continental Europe or central U.S.

Physic-Mechanical Tests

For the preparation of the tensile specimens, steel pipes filled with expansive cement were used for anchoring the FRP rods as illustrated in figure 2. The gage length of G1 tensile specimens was 152 cm, while the test length (L) was 62 cm; the gage length of G2 tensile specimens was 122 cm, while the test length was 46 cm. In both cases an L/d ratio larger than 40/1 was guaranteed as recommended in previous studies. Drilled PVC caps were used to align and center the rods inside the pipes. (See figure 2).

An electronic extensometer with 51 mm gage length and 0.025 mm accuracy was mounted on the center of the specimen test section to measure rod displacement. Strain gauges were also bonded to measure the strain, load, displacement and strain values were collected by a data acquisition system, which consisted of a Data General Conditioner Rack and a Labview 6.0 acquisition software. The sampling rate was set to 1-Hz, and the loading rate was 22-kN per minute.

The dimensions of the specimens used for the Short Beam Test, according to ASTM D4475 were chosen in order to avoid flexural effects that could alter the desired mode of failure. The shear span for G1 and G2 specimens were 26 and 19 mm respectively.

In the SBT the rate of the loading crosshead was 1.3 mm/min according to ASTM D4475. The data were recorded automatically by a SATEC TCS 1200 acquisition system.

All the SBT specimens were weighted to observe the absorption behavior related to the immersion in alkaline solution, using a 10 mg accuracy balance.

Results and Discussion

All tensile test specimens showed fiber rupture in the test length region, as shown in figure 3. This confirmed that the alignment of the rods and the adopted grip system worked successfully. The results in terms of ultimate strength and elastic modulus collected after tensile tests are shown in table 2. All the showed numbers represent average values minus/plus the coefficient of variation; the values of standard deviation were very low: for instance, for control specimens G1 and G2 the standard deviation values were 34 and 21 MPa respectively. The values recorded with strain gauges and with the extensometer were found to be in good accordance.

It can be observed, as reported in figure 4 that G1 rods showed an excellent durability, residual properties were the same before and after accelerated ageing. Due to alkali attack, a significant loss of properties in terms of tensile strength was observed for G2 specimens,. The environmental exposure did not affect either rod types, only few oxidations of the superficial region of the rods were observed.

The weight measurements were taken from SBT specimens immersed in alkali solution. All the coupons were dried at 20 °C before weighting, in order to record only the absorption behavior.

The results of gravimetric measurements are shown in figures 5 and 6. The increase of weight, expressed in %, (see figure 5) represent the solution content present in the rods after exposure.

The diagram in figure 6 shows a first region of fickian diffusive behavior, (the first 160 hours of exposure); then a rapid increase in diffusivity was observed until a constant saturation value of solution content was reached after about 480 hours of immersion. The solution absorbed by G1 rods showed to be smaller than G2 rods, as it is shown in figure 5. It is evident that the polyester resin of G2 rods did not provide a good protection against solution diffusion. It was also observed that the penetration of alkali ions in G2 produced micro cracks in the resin that were visible in the dried specimens. The presence of microcracks increased the void contents to be filled by a further penetration of alkali. The thermoplastic resin of G1 did not showed cracks or other visible damages.

The variations of interlaminar properties investigated with short beam test are shown in figure 7.

It can be observed both the tested rods showed a progressive decrease in interlaminar properties, and G2 specimens lost their strength after 42 days exposure. Both rod types showed a more brittle behavior caused by the alkali penetration, this was observed also during tensile tests, in which a premature delamination accompanied the tensile failure of the fibers. The environmental agents did not affect the properties of the resin in both rod types.

CONCLUSIONS

This study showed how the resin properties affect the structural performance of GFRP rods used for concrete reinforcement. The following remarks can be drawn after the experimental investigations:

- If the alkali environment damages the GFRP rod causing embrittlement and micro-cracks of resin, longitudinal and transverse mechanical properties show a significant decrease.
- Under the same exposure conditions, a different resin may provide excellent protection to the fibers, preventing the alkali penetration that causes the chemical attack of the fibers.
- Mechanical properties are related to absorption behavior of the resin.
- Combined environmental agents did not affect the mechanical properties of the tested rods.

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REFERENCES

[1] Tannous F.E., and Saddatmanesh H., “Durability of AR Glass Fiber Reinforced Plastic Bars”, Journal of Composites for Construction, Vol. 3 No. 1, (1999), pp.12-19.

[2] Karbhari V.M., Zhao L., Murphy K., and Kabalnova L., “Environmental Durability of Glass Fiber reinforced Composites – Short Term Effects”, Proc. 1st Conference on Durability of FRP Composites for Construction (CDCC'98), Sherbrooke (Canada), August 5-7th 1998, pp.513-524.

[3] Fried N., “Degradation of Composite Materials: The Effect of Water on Glass Reinforced Plastics”, Proc. 5th Symposium on Naval Structural Mechanics, Philadelphia, USA, 1967, pp. 813-837.

[4] Chin J.W., Aouadi K., and Nguyen T., “Effects of Environmental Exposure on Fiber-Reinforced Plastic (FRP) Materials Used in Construction”, Journal of Composites and Technology Research, Vol. 19, No. 4, (1997), pp.205-213.

[5] Kato Y., Mishimura T., and Uomoto T., “The Effect of Ultraviolet Rays to FRP Rods”, Proc. 1st Conference on Durability of FRP Composites for Construction (CDCC'98), Sherbrooke (Canada), August 5-7th 1998, pp.487-497.

[6] Homam S. M., and Sheikh S. A., “Durability of Fiber Reinforced Polymers Used in Concrete Structures”, Proc. 3rd International Conference on Advanced Materials in Bridges and Structures, Ottawa, Canada, August 15-18th 2000, pp.751-758

[7] Vijay P.V., and Gangarao H.V.S., "Accelerated and Natural Weathering of Glass Fiber Reinforced Plastic Bars", Proc. FRPRCS-4, November 1-4th, 1999, Baltimore, USA, pp. 605-614.

[8] Zhang S., and Karbhari V.M., "Effects of Alkaline Environment on the Durability of E-Glass Fiber Composites for Use in Civil Infrastructure" 14th Technical Conference, September 27-29th 1999, Dayton, USA.

[9] Nanni A., Bakis C.E., and Mathew J.A., "Acceleration of FRP bond Degradation", Proc. 1st Conference on Durability of FRP Composites for Construction (CDCC'98), Sherbrooke (Canada), August 5-7th 1998, pp.45-56.

[10] Bascom, W.D., in E.P. Plueddemann Ed., "The Surface Chemistry of Moisture-Induced Composite Failure", Interfaces in Polymer Matrix Composites, Academic Press, New York, 1974, pp. 79-108.

TABLES AND FIGURES

Table 1: Experimental program (number of specimens)

Specimen	Alkaline exposure			Control	Environmental cycles
	A1*	A2**	A2***		
G1 tensile	3	3	-	5	4
G2 tensile	3	3	-	5	4
G1 SBT	6	6	6	6	6
G2 SBT	6	6	6	6	6

* A1 = 21 days @ 60°C in alkaline solution
**A2 = 42 days @ 60°C in alkaline solution
***A3 = 42 days @ 22°C in alkaline solution

Table 2: Tensile test results

Rod	Control		A1*		A2**		Env. Cycles	
	σ_u (MPa)	E (GPa)	σ_u (MPa)	E (GPa)	σ_u (MPa)	E (GPa)	σ_u (MPa)	E (GPa)
G1	924±3%	43±3%	924±2%	40±5%	928±2%	41±6%	908±5%	40±3%
G2	362±12%	30±23%	252±11%	31±13%	215±19%	30±13%	338±16%	27±7%

σ_u = ultimate strength ± coefficient of variation
E = elastic modulus ± coefficient of variation
* A1 = 21 days @ 60°C in alkaline solution
**A2 = 42 days @ 60°C in alkaline solution

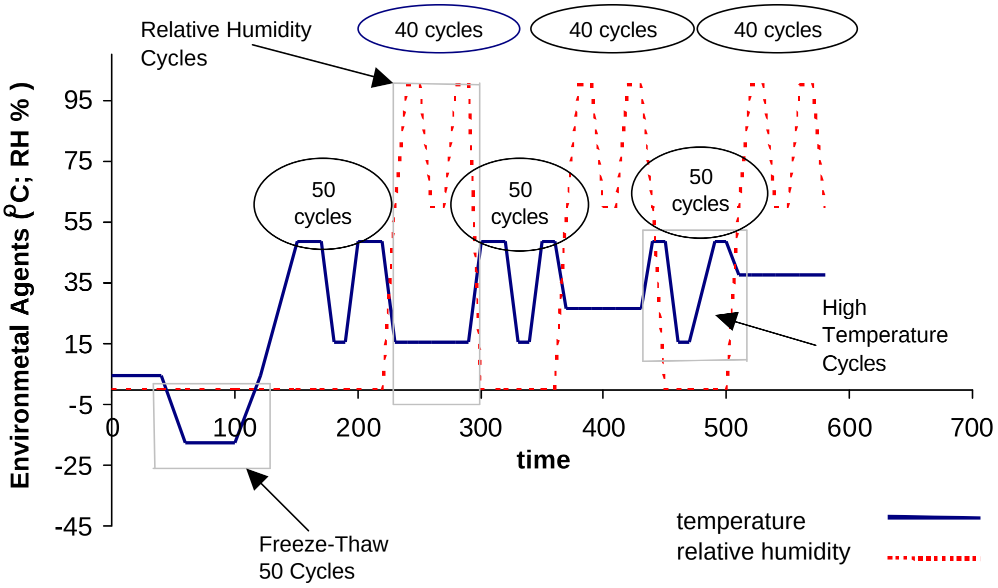


Figure 1: Environmental conditioning

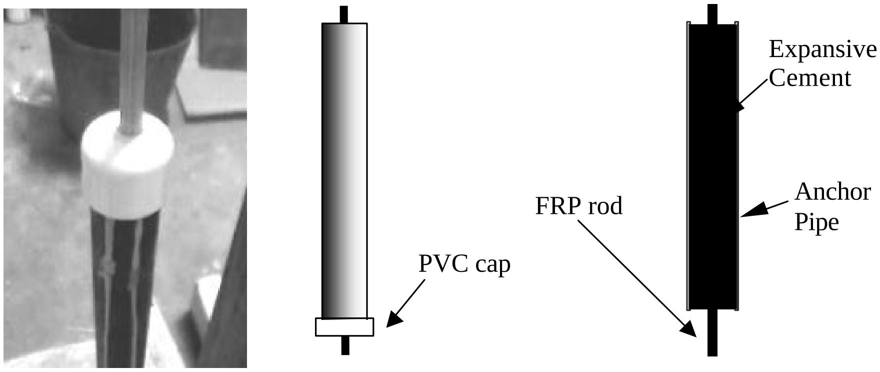


Figure 2: Anchorage system used for tensile test

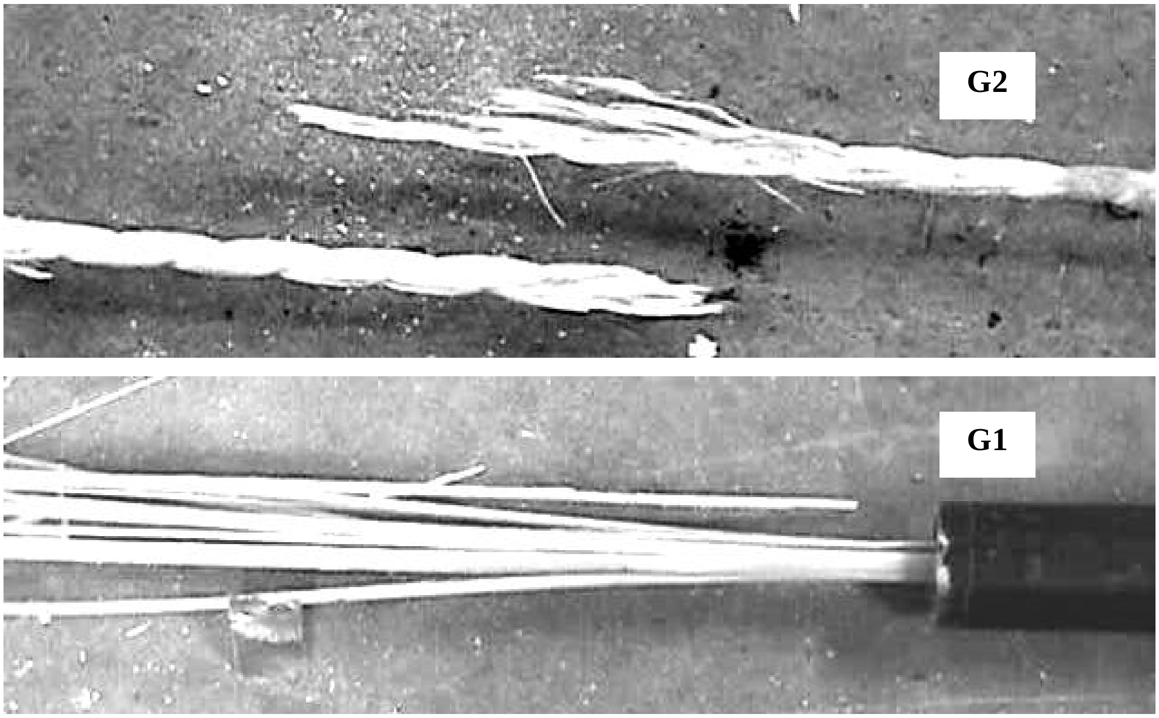


Figure 3: Fiber rupture after tensile test

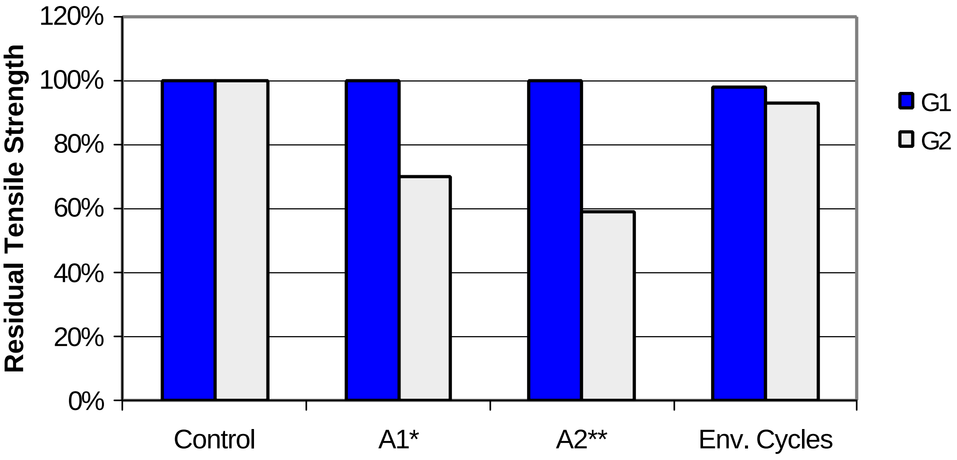
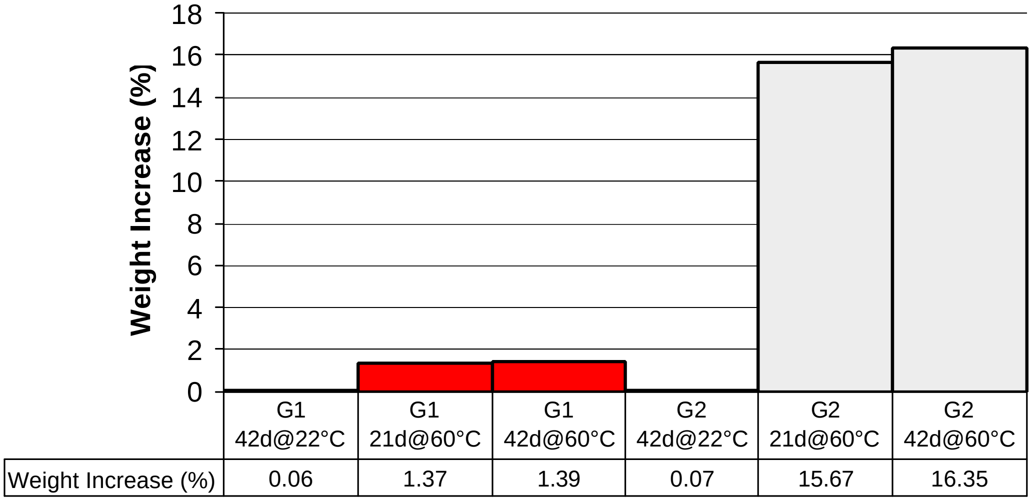


Figure 4: Residual tensile strength

* A1 = 21 days @ 60°C in alkaline solution
**A2 = 42 days @ 60°C in alkaline solution



	G1 42d@22°C	G1 21d@60°C	G1 42d@60°C	G2 42d@22°C	G2 21d@60°C	G2 42d@60°C
Weight Increase (%)	0.06	1.37	1.39	0.07	15.67	16.35

Figure 5: Weight increase due to alkaline solution absorption

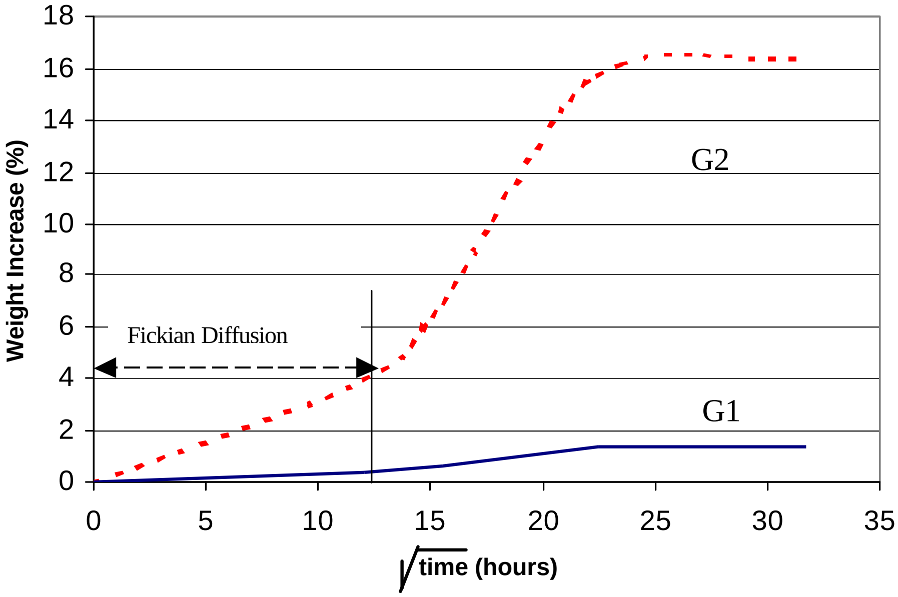
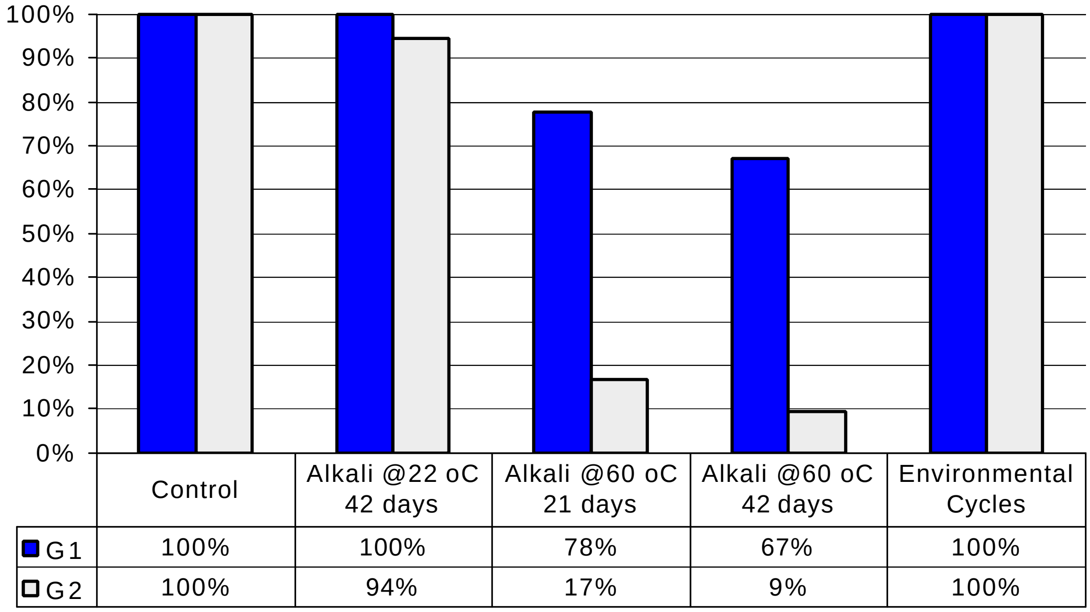


Figure 6: Diffusive behavior of alkaline solution



	Control	Alkali @22 oC 42 days	Alkali @60 oC 21 days	Alkali @60 oC 42 days	Environmental Cycles
■ G1	100%	100%	78%	67%	100%
☐ G2	100%	94%	17%	9%	100%

Figure 7: Residual interlaminar shear stress

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