

DURABILITY AND SERVICE LIFE PREDICTION OF GFRP FOR CONCRETE REINFORCEMENT

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ABSTRACT

In recent years GFRP (Glass Fibre Reinforced Polymers) has emerged as an alternative to conventional steel reinforcement in steel aggressive applications. However, unlike steel GFRP reinforcement deteriorates due to the alkaline environment represented by concrete. This research project aims at determine the long-term environmental influence of concrete on GFRP reinforcement bars. GFRP specimens have been exposed in concrete at different temperatures and the influence of temperature on the tensile strength deterioration rate has been determined using Arrhenius equation. According to preliminary results 18 months in moisture-saturated concrete at 60°C corresponds to 100 years in the same environmental condition but at outdoor temperature (in the south of Sweden).

1 INTRODUCTION

In the last decade, there has been a considerable increase in the interest of FRP (Fibre Reinforced Polymers) for concrete reinforcement in the construction industry. The most frequently used fibres for FRP reinforcement are carbon (CFRP), aramid (AFRP) and glass (GFRP). The most obvious benefit of FRP is that, unlike steel it is not susceptible to carbonation- or chloride initiated corrosion in concrete. This fact makes the use of FRP reinforcement an interesting option for increasing the service life of concrete structures in severe environments. However, unlike steel FRP reinforcement may deteriorate due to the alkaline environment of concrete.

Both the fibres and the matrix material may degrade in a base and moist environment. In general carbon fibres are considered to have a very good durability in alkaline environments (as well as acid environments), and research has shown (Dejke 1998) that for CFRP normally only small reductions in tensile strength can be found after accelerated exposures. Glass fibres, on the other hand (and consequently GFRP), are known to be susceptible to degradation due to base hydrolysis. The E-glass fibre, which is the most commonly used glass fibre type for GFRP reinforcement, is known to be susceptible to attack by OH-ions when in contact with an base liquid. Hence, an important task for the matrix is to act as a barrier, protecting the glass fibres from harmful agents. However water and possibly alkalis will penetrate through micro cracks or even the un-cracked resin matrix and eventually attack the fibres, the fibre/matrix interface or the matrix itself. Nevertheless, being considerably cheaper than CFRP, GFRP is still an interesting material for concrete reinforcement.

A great deal of research has been addressing durability of FRP in concrete in recent years. The required service life of concrete reinforcement is usually in the order of 50 to 100 years, and as results is desirable within only one or a few years, accelerated ageing is generally used to speed up the degradation. Typically, changes in mechanical properties after exposure in alkaline solutions at an elevated temperature are determined, and considered a measure of the durability. So far most of the durability research conducted in this field have been qualitative, comparing different FRP types to determine which perform better.

For this new material to be generally accepted by the building industry, a good durability must be proven also in quantitative terms. Therefore a big challenge for researchers within this field is to determine the deterioration rate, and thereby the service life of GFRP in concrete. This knowledge is needed to be able to choose proper safety factors, taking account for the deterioration due to environmental influence, for FRP design guidelines.

At Chalmers University of Technology/Department of Building Materials, a research project is now going on, aiming at determine the service life of GFRP reinforcement bars in concrete. The approach for service life prediction used in this project will be discussed and some experimental results obtained so far will be reported.

2 EXPERIMENTS

2.1 Specimens

In this project four types of GFRP reinforcement bars from two manufacturers have been investigated. The bars differ regarding type of glass fibre and polymer matrix according to Table 1.

Table 1 Fibre type and matrix material for the GFRP bars tested.

	Fibre type	Matrix material
Bar A	E-glass	vinyl ester
Bar B	AR-glass	vinyl ester
Bar C	AR-glass	polyester
Bar D	E-glass	vinyl ester

2.2 Exposure conditions

Specimens have been subjected to three environments: alkaline solution, concrete and tap water. The aging was accelerated by using elevated temperatures in the range of 7°C (average outdoors temperature in the south-west of Sweden) to 80°C.

Some specimens are embedded in **concrete** and stored outdoor at 100% relative humidity (RH) to simulate a real concrete structure under highly moist conditions. Other specimens are stored at elevated temperatures, to speed up the degradation process and to be able to determine the level of acceleration for different temperatures. The concrete used were made using Swedish low alkali Portland cement and had a water/cement ratio of 0.5. The bars were extracted from the concrete prior to testing. Certain measures were taken during casting to makes it easy to extract the bars without causing any damage on them during extraction.

A common way to evaluate the durability of FRP reinforcement for concrete among researchers is to immerse bars in **alkaline solution**, and then test the mechanical properties. However, it has been shown that a pure alkaline liquid represents a more aggressive environment than that of concrete. This exposure condition was used in order to evaluate if immersion of GFRP bars in alkaline solution can be used as a valid method to accelerate the ageing of GFRP bars, and if so, to determine the influence on the deterioration rate. Apart from water the solution consists of sodium hydroxide (NaOH), potassium hydroxide (KOH), and calcium hydroxide (Ca(OH)₂) giving a pH value of 13.7, in a composition simulating the concrete described above.

Tap Water was chosen as a reference environment to be able to determine how large part of the total deterioration that can be attributed to the alkalis and water respectively.

2.3 Test methods

The mechanical properties of the specimens have been tested after different exposure durations in the range of 1 day to roughly 1 year. The mechanical properties measured were tensile strength and Inter Laminar Shear Strength (ILSS), obtained in a short bar bending test. Tensile strength is primarily controlled by the fibre strength while the matrix mainly influences ILSS and the fibre/matrix interface strength. ILSS is considered to be strongly related to the bond strength of FRP reinforcement in concrete.

2.4 Preliminary results and discussion

Deterioration in tensile strength and ILSS has been found for all GFRP types and for all exposure conditions considered. However the magnitude of deterioration was found to vary considerably between the GFRP types tested.

A summary of the tensile strength and ILSS results for bars A-D after being embedded in concrete at 60°C for approximately 1 year is shown in Figure 1.

One conclusion that can be drawn from the results is that different mechanical properties may deteriorate at different rate. As a consequence, to study only one mechanical property may not be enough to determine which one of two bar types is the more durable. For instance, testing only tensile strength would not reveal the poor ILSS performance of Bar C and consequently give the impression that Bar C is more durable than Bar D. However, testing also ILSS would lead to the conclusion that Bar D has the better overall durability.

It is evident from Figure 1 that the E-glass/vinyl ester systems (Bar A and Bar D) have considerably better environmental resistance regarding ILSS compared to the other systems investigated. Bar C almost completely lost it's ILSS after the exposure. The poor performance of glass/polyester composites after exposure in alkaline environments has been reported by several researchers (Comyn 1985) and was expected. For all bars, including those with AR-glass (AR for alkali resistant), significant losses in tensile strength were measured. It appears from Figure 1 that the E-glass/vinyl ester systems have the best overall durability.

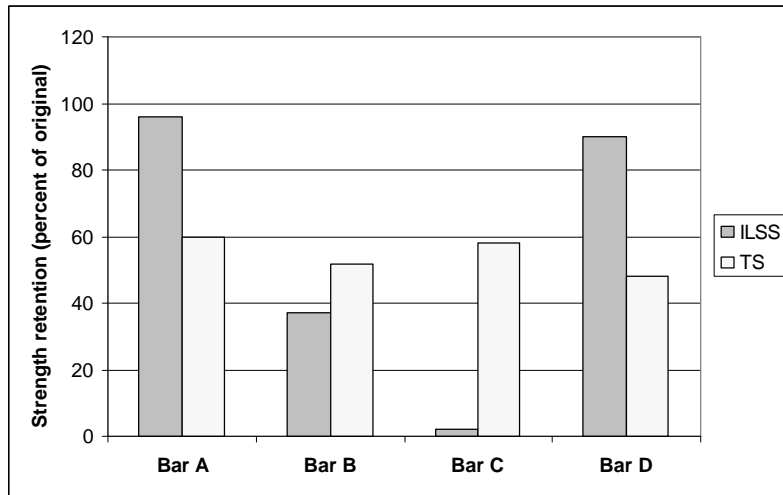


Figure 1 *Inter Laminar Shear Strength and tensile strength for GFRP bars after being embedded in concrete at 60°C for approximately 1 year (10 months for Bar D in tensile strength).*

Figure 2 gives an indication of the severity of different exposure environments and temperature levels. In the figure, the course of tensile strength deterioration for Bar A is shown. As can be seen, alkali solution appears to be a slightly more aggressive environment than concrete at 100% RH. Note also that pure tap water can cause considerable weakening of the material. In Figure 3, the deterioration in ILSS is shown for the same material and under the same exposure conditions as those in Figure 2.

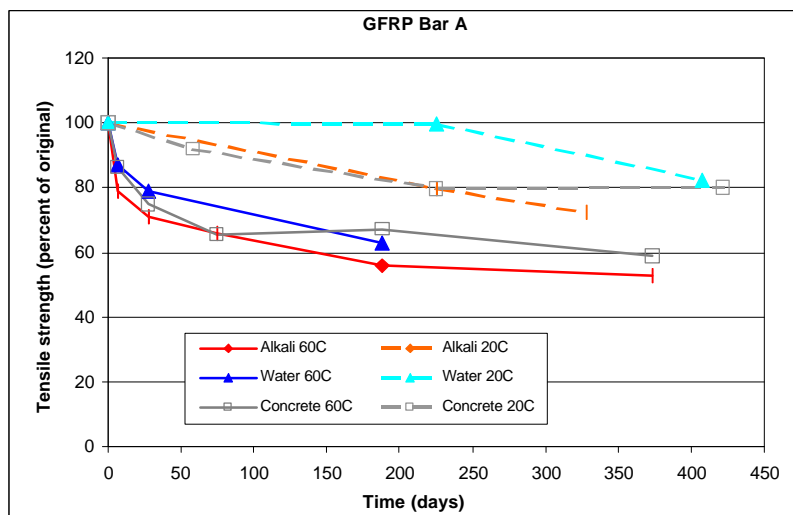


Figure 2 *Tensile strength retention for Bar A exposed to alkali solution, concrete and water at 20°C and 60°C. Each data point in the diagram represents the average of one to three tests.*

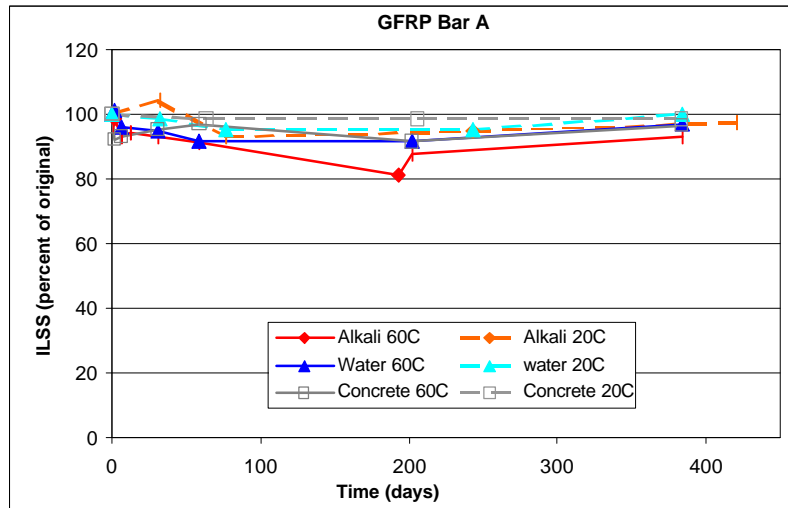


Figure 3 *Inter Lamellar Shear Strength retention for Bar A exposed to alkali solution, concrete and water at 20°C and 60°C. Each data point in the diagram represents the average of two to six tests.*

3 SERVICE LIFE PREDICTION OF GFRP FROM ACCELERATED TESTS

To obtain durability results within reasonable times accelerated aging is generally used. Often specimens are immersed in simulated concrete pore solution at an elevated temperature in such tests. In this way an acceleration of any degradation is obtained partly as a result of the elevated temperature but also as a consequence of the “boundary condition”, that is, a pure liquid instead of a solution in a solid porous material where alkali movements are to some extent restricted. The problem is how to correlate the time under accelerated exposure to that in a real application.

3.1 Approaches found in the literature

One approach suggested (Porter et al 1998, Vijay et al 1999) is to use time shift factors established for aging of GRC (glass fibre reinforced concrete) at elevated temperatures, on GFRP immersed in alkaline solutions or embedded in concrete. The benefit of using that approach is that reliable aging data for GRC is available for relatively long exposure times (at least 10 years). However, it is not obvious that the time-temperature relationship that applies for the degradation of GRC is valid also for GFRP. For instance movements of alkali is more restricted in thermosetting plastics than in concrete and furthermore, the time dependence of degradation mechanisms taking place in the fibre/polymer interface is not included in the “time-shift factor” that apply for GRC.

Another approach were used by Katsuki and Uomoto (1997). They utilized Fick's law to simulate the deterioration of GFRP rods quantitatively. GFRP bars were immersed in alkaline solution and the sodium (Na) penetration depth in the GFRP material could be determined after different exposure durations using an EPMA (Electron Probe Microscope Analyser). By assuming that the strength in the GFRP material was totally lost in parts reached by the Sodium front, the deterioration in tensile strength could be calculated from the ingress depth. Accordingly, the deterioration could be predicted by knowledge of the diffusivity of Na in the composite. A similar approach was used by Saadatmanesh and Tannous (1997) to predict the reduction in tensile strength of various FRP tendons. This approach presupposes that the ingress of alkali ions in the GFRP material can be measured. However, it is doubtful if modern, high quality GFRP materials actually allow ingress of alkali ions in measurable quantities (Chin et al, 1997; Jones, 1998; Caddock et al, 1987). Furthermore, a bar that loses all tensile strength in a layer penetrated by alkali ions probably also loses its bond strength. Hence, for the assumptions made in that method, deterioration in bond strength is likely to control the service life rather than the tensile strength.

3.2 Suggested approach

In this project an aim is to quantify the time shift factor describing the relationship between accelerated and non-accelerated exposure, by using only data from tests on GFRP. If the shape of the curve describing the change in some mechanical property with time, is similar for different exposure temperatures then an Arrhenius type relationship can be expected. In that case the "time shift factor" can be obtained from the distance between two such curves, established for different temperatures, in a diagram having logarithmic time scale.

Preliminary time shift factors have been established for Bar A. In Figure 4 the strength reductions after exposure in concrete and alkaline solution at 20°C and 60°C are shown. In the diagram (with a logarithmic time scale) the shape of the strength retention curves have been approximated by straight parallel lines. Comparing the displacement of the curves with respect to temperature gives a time shift factor of approximately 21. That is, one year exposure in moisture-saturated concrete at 60°C should give the same reduction in tensile strength as 21 years in moisture saturated concrete at 20°C. However this value of the time shift factor is only valid for tensile strength and under the above assumptions and environmental conditions.

This approach can be used to determine the relative time-shift factor between any two exposure temperatures, under the assumption that Arrhenius time-temperature relationship is valid for the whole temperature range considered. For example, under the above assumption, 18 months in concrete at 60°C correspond to 100 years at outdoor conditions in the south-west of Sweden (where the mean annual temperature is 7°C). The calculation procedure is shown in Equation 1.

$$TSF = e^{\frac{B}{T_1+273.15} - \frac{B}{T_2+273.15}} \quad (1)$$

Where: TSF is the Time Shift Factor
 B is a constant determined using the time-shift shown in Figure 4
 T_1, T_2 are the temperatures (in °C) between which the TSF is calculated

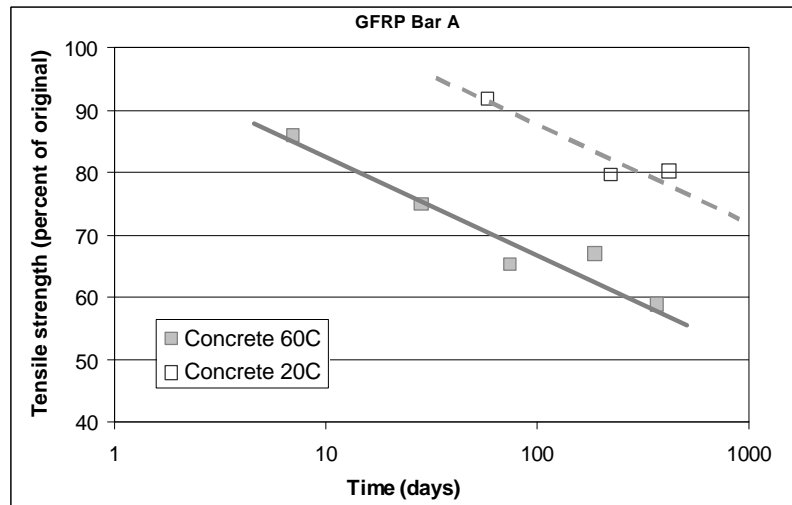


Figure 4 Strength retention versus time for Bar A after being embedded in concrete at 20°C and 60°C. The shapes of the strength retention curves have been approximated by straight lines.

These kinds of predictions are important, as the maximum tensile strength utilizable in design with FRP is that of the material at the end of the service life. The experimental results discussed in this article mainly apply for tensile strength retention of GFRP bars exposed to moisture-saturated concrete and without any stress acting on them. In the majority of real applications the RH of the concrete is not 100% but considerably less (in Sweden the RH of outdoor concrete is generally around 80%). Hence, under outdoor conditions the degradation is likely to take place at a lower rate than that for moisture saturated concrete in the lab. However, in a real application reinforcement is usually subjected to tensile load to some degree, which probably will make any degradation to take place at a higher rate (for example by open up micro cracks that allow ingress of water and harmful agents into the composite). It is therefore important to determine the strength retentions and time shift factors for all the conditions (regarding environment and stress) faced by GFRP when used as concrete reinforcement. However, a reasonable assumption should be that the time shift factor suggested in this article applies fairly well with that for GFRP reinforced

concrete in an outdoor application with moderate stress acting on the reinforcement.

A drawback with all service life predictions is that in reasonable time, it is not possible to compare the whole strength-versus-time curve, obtained under non-accelerated exposure, with that obtained under accelerated conditions. It is therefore essential to follow up the long-term deterioration under non-accelerated conditions to be able to calibrate the acceleration factors determined at an earlier stage.

The influence on degradation rate of stress on GFRP reinforcement and different moisture levels of the concrete in which the GFRP reinforcement is embedded will be the subject for future research at Chalmers University of Technology.

4 CONCLUSIONS

In this article an approach aiming at quantifying the deterioration of GFRP in concrete has been presented. Furthermore, preliminary results have been reported and discussed. From the results obtained within the research project so far, the following conclusions can be drawn:

- ✓ Different mechanical properties may deteriorate at different rate for GFRP reinforcement. Therefore, a satisfactory performance of one mechanical property after environmental aging cannot be considered a guaranty for an overall good durability.
- ✓ Of the GFRP types tested, it appears as if the E-glass/vinyl ester systems have the best overall durability in alkaline environments.
- ✓ Alkali solution seems to represent a more aggressive environment than that of moisture saturated concrete (both having the same pH value).
- ✓ Time-temperature relationships can be determined from strength retention curves obtained for GFRP exposed to concrete at different temperatures. According to preliminary results, 18 months in concrete at 60°C corresponds to 100 years under outdoor conditions (in the south-west of Sweden).

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6 REFERENCES

Caddock B. D., Evans K. E. and Hull D., "The diffusion of hydrochloric acid in polyester thermosetting resins", *Journal of Materials Science* 22, 1987, pp. 3368-3372.

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

Comyn J., "Polymer permeability", Chapman and hull, Printed in Great Britain by Ipswich Book Co, Ipswich, Suffolk, 1985, (reprinted 1994).

Dejke V., "Durability of fibre reinforced polymers (FRP) as reinforcements in concrete structures - An update of knowledge and an overview of current research activities", Report P-98:18, Chalmers University of Technology, Department of Building Materials, 1998.

Jones F. R., "Designing composites for durability in aqueous and corrosive environments", *Designing Cost Effective composites*, Editor Banks W., 1998, pp. 65-81.

Katsuki F. and Uomoto T., "Evaluation of alkali resistance of GFRP Rods", *Concrete Library of JSCE No. 29*, June 1997.

Porter M L, Barnes B A, "Accelerated Durability of FRP Reinforcement For Concrete Structures", *Proceedings from the First International Conference on Durability of Fibre Reinforced Polymer (FRP) Composites for Construction*, Sherbrooke, August, 1998, pp. 191-201.

Saadatmanesh H, Tannous F, "Durability of FRP Rebars and Tendons", *Non-Metallic (FRP) Reinforcement for Concrete Structures: Proceedings of the Third International Symposium*, Vol 2, Sapporo, Oct. 1997, pp. 147-154.

Vijay P. V., and GangaRao V. S., "Accelerated and Natural Weathering of Glass Fiber Reinforced Plastic Bars", *Proceedings from Fourth international Symposium, Fiber Reinforced Polymer Reinforcement for Reinforced concrete Structures*, ACI Ed. Dolan C. W., Rizkalla S. H. and Nanni A., Baltimore 1999, pp. 605-614.