CHAPTER 10

DURABILITY

10.1 General

This chapter provides a brief overview of the durability of FRP-based strengthening systems with regard to a number of factors, namely:

- Temperature effects
- Moisture
- Ultraviolet light exposure
- Alkalinity and acidity
- Galvanic corrosion
- Creep, stress rupture, stress corrosion
- Fatigue
- Impact

10.2 Temperature effects

As reported already in Chapter 2, high temperatures, in the order of 60-80 °C, cause a dramatic degradation of properties in resins (matrix material in FRPs, adhesive at the FRP-substrate interface). Much higher temperatures, such as those developed during fire, result in complete resin decomposition; hence FRPs during fire cannot carry any stresses. The decomposition of glass, carbon and aramid fibers starts at about 1000 ^{o}C, 650 ^{o}C and 200 ^{o}C, respectively. Experimental results have shown that CFRP jackets suffer substantial strength reduction at temperatures exceeding approximately 260 ^{o}C. Hence, an FRP strengthening system without special fire protection measures should be considered as ineffective during (and after) fire. Fire protection may be provided using either standard mortar plastering (with a minimum thickness of at least 40 mm, according to the JSCE 2001 guidelines), special mortars or gypsum-based boards.

10.3 Moisture

FRP materials are, in general, highly resistant to moisture. Occasionally, extremely prolonged exposure to water (either fresh or salt) may cause problems with some fiber/resin combinations. The resin matrix absorbs water, which causes a slight reduction in strength and the glass transition temperature. However, most structural adhesives (high quality epoxy resins) are extremely resistant to moisture (Blaschko et al. 1998). As far as the fibers are concerned, the high susceptibility of aramid to moisture deserves special attention; carbon fibers are practically unaffected, whereas glass fibers have an intermediate behavior.

At this point it is worth pointing out that full jacketing with FRP provides a moisture/vapor/air barrier which increases the longevity of members by protecting them from harsh conditions (e.g. chlorides, chemicals). On the hand, in case of poor concrete conditions, the encapsulation is at risk if the member is exposed to extreme climate cycling and/or excessive moisture. Applications of FRP to a structural member that is at risk of water pooling should not involve fully encapsulating the concrete. Good internal and surface concrete conditions, proper surface preparation, adequate concrete substrate exposure and proper application of an adequate FRP system may substantially reduce this risk.

10.4 UV light exposure

UV light affects the chemical bonds in polymers and causes surface discoloration and surface microcracking. Such degradation may affect only the matrix near the surface exposed to UV, as well as some types of fibers, such as aramid (Ahmad and Plecnik 1989); carbon and glass fibers are practically unaffected by UV. Anti-UV protection may be provided by surface coatings or special acrylic or polyurethane – based paints.

10.5 Alcalinity and acidity

The performance of the FRP strengthening over time in an alkaline or acidic environment will depend on both matrix and the reinforcing fiber. Carbon fibers are resistant to alkali and acid environment, glass fibers can degrade and aramid displays an intermediate behavior. However, a properly applied resin matrix will isolate and protect the fibers and postpone the deterioration. Nevertheless RC structures located in high alkalinity combined with high moisture or relative humidity environments should be strengthened using carbon fibers.

10.6 Galvanic corrosion

The contact of carbon fibers with steel may lead to galvanic corrosion, a problem which is not of concern in the case of glass or aramid fibers.

10.7 Creep, stress rupture, stress corrosion

In general, *creep* strains in composite materials loaded parallel to the fibers are very low. CFRP does not creep, the creep of GFRP is negligible, but that of AFRP cannot be neglected. Hence, the creep behavior of CFRP - or GFRP - plated RC members is governed primarily by the compressive creep of concrete (e.g. Plevris and Triantafillou 1994). As AFRP creeps itself, long-term deformations increase considerably in the case of AFRP-strengthened elements. However, it should be born in mind that in (the very common) case when FRP strengthening systems are designed for additional loads (beyond the permanent ones), creep is not of concern.

Another important issue regarding time-effects is the poor behavior of GFRP under sustained loading. Glass fibers exhibit premature tensile rupture under sustained stress, a phenomenon called *stress rupture*. Hence the tensile strength of GFRP drops to very low values (as low as 20%) when the material carries permanent tension.

Stress corrosion occurs when the atmosphere or ambient environment is of a corrosive nature but not sufficiently so that corrosion would occur without the addition of stress. This phenomenon is time, stress level, environment, matrix and fiber related. Failure is deemed to be premature since the FRP fails at a stress level below its ultimate. Carbon fiber are relatively unaffected by stress corrosion at stress levels up to 80% of ultimate. Glass and aramid fibers are susceptible to stress corrosion. The quality of the resin has a significant effect on time to failure and the sustainable stress levels. In general, the following order of fibers and resins gives increasing vulnerability either to stress rupture or to stress corrosion: carbon-epoxy, aramid-vinylester, glass-polyester. We may also state that, in general, given the stress rupture of GFRP and the relatively poor creep behaviour of AFRP, it is recommended that when the externally bonded reinforcement is to carry considerable sustained load, composites with carbon fibres should be the designer’s first choice.

10.8 Fatigue

In general, the fatigue behavior of unidirectional fiber composites is excellent, especially when carbon fibers are used, in which case the fatigue strength of FRP is even higher than that of the steel rebars (e.g. Kaiser 1989, Deuring 1993, Barnes and Mays 1999).

10.9 Impact

The strength of composites under impact loading is highest when aramid fibers are used (hence the use of these materials in bridge columns that may suffer impact loading due to vehicle collision) and lowest in the case of carbon fibers. Glass gives intermediate results.