Available online at www.sciencedirect.com
ScienceDirect
Cement & Concrete Composites 28 (2006) 857–868
Cement & Concrete Composites
www.elsevier.com/locate/cemconcomp

Durability issues of FRP rebars in reinforced concrete members

Francesca Ceroni [a,*], Edoardo Cosenza [b], Manfredi Gaetano [b], Marisa Pecce [a]

[a] Department of Engineering, University of Sannio, P.zza Roma 21, 82100 Benevento, Italy
[b] Department of Structural Analysis and Design, University of Naples Federico II, via Claudio 21, 80125, Italy

Available online 30 August 2006

Abstract

The use of fibre reinforced polymers (FRPs) as rebars in reinforced concrete (RC) elements is a viable means to prevent corrosion effects that reduce the service life of members employing steel reinforcement. However, durability of FRP rebars is not straightforward as it is related to material properties as well as bar–concrete interaction. A state of the art of durability of FRP rebars is presented herein in order to highlight issues related to the material properties and interaction mechanisms which influence the service life of RC elements. The design approach implemented in international codes is discussed and the reduction factors taking into account the durability performances are summarized.

Keywords: Durability; FRP bars; Environment effect; Long-term behaviour; Thermal effects

1. Introduction

The increasing use of fibre reinforced polymers (FRPs) as rebars in reinforced concrete (RC) structures has been supported by the "durability" of this novel material. However, the high durability of FRPs has been defined only with regard to that of steel rebars. The latter are detrimentally affected by corrosion phenomena governing the effective life of structures and their maintenance costs. Unfortunately durability of FRP rebars is a not straightforward subject; it tends to be more complex than corrosion of steel reinforcement, because degradation of the material could depend both on resin and fibres and on their interface bond behaviour. Furthermore, the types of rebars available on the market are various and the commercial products are continuously changed. Different fibres are characterized by different behaviour under high temperature, environmental effects and long-term phenomena. In addition concrete could be an unfavourable environment due to alkali and moisture absorption.

The durability of FRP materials has not been yet assessed thoroughly and hence reliable design rules for RC structures are still lacking. Nevertheless, it has been observed [69,60,33,7,37] that the durability of concrete members reinforced with FRP rebars depends on the effect of concrete environment for the composite material and cracking and concrete–bar bond. The latter is of paramount importance and depends on the rebar surface adopted by the manufacturer to improve bond (e.g. sanded, ribbed, etc.). It has also been noted [42] that crack openings are generally higher than in RC members with steel rebars, being the Young's modulus of FRPs lower than in mild steel, thus reducing the protection due to concrete.

Recently, many studies have been carried out on durability of FRP bars [6,25,26,32,36,38,53,69]; however, there are still many aspects to be investigated to provide reliable design rules to be implemented in codes of practice.

The durability may be defined as the capacity of a material or a structure corresponding to the initial performance and is kept constant during time. In structural engineering durability is thus the property related the effective life of the construction. Materials and structures can be characterized in several manners. Variations of mechanical

* Corresponding author. Tel.: +39 824 30 55 75; fax: +39 824 32 52 46.
E-mail address: ceroni@unisannio.it (F. Ceroni).

0958-9465/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cemconcomp.2006.07.004

properties as Young's modulus, tensile strength, interlaminar shear and bond strength are the most suitable indicators of FRP deterioration. Considering the interaction with concrete, durability is also the ability to prevent cracking, chemical degradation, delamination, wearing, and similar effects of ageing with time, under the conditions of sustained loads and/or design environmental conditions.

In this paper a state of the art of durability of FRP rebars is dealt with. The adopted framework can be divided in three parts: effects of external and concrete environment, long-term effects, influence of concrete–FRP mechanisms.

Experimental results relative to the effects of temperature, chemical agents and moisture are presented to compare different types of fibres and resins. Long-term phenomena are also discussed and the role of fibres type and the consequences on RC elements are presented. Finally, direct influence of interaction mechanisms between concrete and rebar, especially due to bond, are outlined.

References to specific provisions available in the technical literature and/or codes are introduced, as appropriate, for each of the features influencing the durability.

2. Durability of FRP material

Experimental tests to investigate durability have long durations and require accelerated methods to activate the environmental effects. Thus the accuracy of the results in terms of real time performances has to be determined. There is no full agreement about the test procedures; the topic is further complicated by the variability in FRP products and their use in concrete members.

It is essential in structural applications to identify standard test procedures that could be confidently recommended for materials.

FRP bars include two different phases, a resin matrix and unidirectional fibres. As a result, the properties of both components and resin/fibres interface have to be investigated with special emphasis on the influence of environmental and mechanical parameters. All the above components play a role in defining the characteristics of the composite material and can be susceptible to attack by various aggressive environments, so that the adequate performance of all three elements has to be fully warranted throughout the design life of the structure.

Matrix protects fibres and transfers uniformly stresses between them, therefore the type of resin and the quality of its realization are fundamental. The effectiveness of the resin depends on its continuity of surface and absence of defects. For example, cuts at the ends of composite expose directly fibres to external environment giving undesirable effects in a durability viewpoint. In such regions environmental effects can produce damage of the fibre/matrix bond, because of the exposure of the fibres along their length, matrix and the resin/fibre interface of internal parts to direct attacks from the environment.

The characteristics of resins that could reduce durability of FRP materials, independently from resin and fibres type are:

- Resin wet out (how well the fibres are covered by resin);
- Absence of cracks (either surface or through thickness);
- Absence of voids (generally smaller and well distributed is preferable);
- Degree of cure of resin (if the production process was not well controlled the resin may be insufficiently cross-linked to provide the designed protection).
  Other qualities of resins are significant for durability, but can be controlled by selecting the type of resin:
- Resistance to alkali and chloride attack;
- Toughness to resist microcracking;
- Impermeability to environment penetration to the interior;
- Easy manufacturing to minimise quality variations;
- High compatibility with fibres to ensure a strong fibre/matrix bond.

Fibres provide stiffness and strength to composite material, i.e. the performance of structural systems depends on their main mechanical properties and durability behaviour. The durability of glass, aramid and carbon fibres, that are the most common types used in civil engineering applications, are different and have to be underlined for all the effects assessed hereafter. In general glass fibres, that are largely used also because are the cheapest ones, are less durable when used as rebars in concrete, due to high chemical sensibility to alkali environment. However, these observations should lead to a review of the existing design process to consider that improving of performances can arise by optimizing the manufacturing techniques and coupling with various resins.

Durability of a composite material is related not only to the properties of its constitutive materials (fibres and matrix), but also to the integrity of the interface between these two components. Bond of FRP reinforcement relies upon the transfer of shear and transverse forces at the interface between bar and concrete, and between individual fibres within the bar. These resin-dominated mechanisms are in contrast to the fibre-dominated mechanisms that control properties such as longitudinal strength and stiffness of FRP bars. Environments that degrade the polymer resin or fibre/resin interface are thus also likely to degrade the bond strength of an FRP bar.

Usually a strong fibre/matrix interface is needed and inadequate selection of fibre or matrix types or incorrect processing can lead to a weak interface to environmental attacks. A deterioration of this interface reduces the capacity of load transfer between fibres with a consequent weakness of the composite material [26]. The use of a coupling agent on the fibre surface improves the strength of the interface, and protects the fibres against environmental attack or reaction with moisture or alkalis. However, the chemical bond between the coupling agent and the surface