International Journal of Adhesion & Adhesives 28 (2008) 101–108

International Journal of Adhesion & Adhesives

www.elsevier.com/locate/ijadhadh

Analysis of steel/concrete interfacial shear stress by means of pull out test

L. Bouazaoui, A. Li*

Groupe Mécanique, Matériaux et Structures, UFR Sciences, Université de Reims Champagne Ardenne, Moulin de la Housse, BP 1039, 51687 Reims Cedex, France

Accepted 21 February 2007
Available online 22 July 2007

Abstract

The excellent mechanical performance of epoxy resins has encouraged their wide-spread application in civil engineering. This paper deals with the prediction of the interfacial shear strength between the steel bar surface and concrete surface of steel rods bonded into concrete. The pull out test is used in order to determine the ultimate force and the shear stress of steel–concrete specimens. The relationship between the ultimate force, the diameter and the length embedded into the concrete are investigated by experimental test. After discussing some theoretical models, a theoretical model is also proposed in this work in order to estimate the shear distribution and the critical shear stress at the instance that the first cracks appear and of the ultimate failure of steel/concrete structure. A comparison between the test and the theoretical results is provided.

Keywords: Concrete; Steel; Stress analysis; Pull out

1. Introduction

In reinforced concrete structures, steel/concrete interfacial strength plays an important role. The separation of steel/concrete is one of the principal causes for deterioration or damage of the civil infrastructure. It is well recognized that first cracks appear in a reinforced concrete structure, which then propagate along the steel bar's concrete interface under loading. Also, it is well known that the steel/concrete structure should possess good interfacial shear strength. However, the shear strength depends upon the mechanical properties of the steel and concrete and the surface properties of steel bars and concrete. To improve the steel/concrete interfacial shear strength, an adhesive joint is added between the steel bar surface and the concrete surface. The experimental program involved using pull out tests for purposes of investigating the interfacial adhesion quality and interfacial properties between steel bar and concrete, and the shear stress along the bonded steel rod/concrete interface.

*Corresponding author. Tel.: +33 326 91 3044; fax: +33 326 91 8711.
E-mail address: alex.li@univ-reims.fr (A. Li).

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doi:10.1016/j.ijadhadh.2007.02.006

The single-fibre pull out test is widely used in composite material structures [1–8]. 'Fibres' have included metal rods, carbon filaments, glass fibre and polymer fibres such as Kevlar and ultra-high density polyethylene. In this case, the 'matrix' materials are concrete and epoxy resin.

One of the earliest descriptions of the single-fibre pull out test, which detailed the initial debonding, crack propagation, completion and fibre pull out, was given by Kelly in 1970 [9]. Other literature shows that various analytical and numerical models have been developed for the initiation of crack propagation between fibre and resin, subsequent propagation of this crack, evaluation of the fibre/matrix interfacial shear strength and the load transfer between a single fibre and an infinite matrix [2–5]. These models may be distinguished between two different kinds of analytical approaches: (a) the perfect interface model, which is mainly used for analysis of stress transfer problems in resin matrix composites, and (b) the cohesive interface model, which is frequently applied to analyse cement based matrix composites [10]. The principal difference between these two approaches is that in the first case a 'perfect interface' between fibre/matrix is assumed. There is no slip between fibre and matrix, and displacement and tractions are continuous at the interface. As research progressed, the interpretation of data evolved with the development of models through the shear lag hypothesis as applied by Greszczuk [11] and interfacial fracture energy as applied by Outwater and Murphy [12].

Indeed, the fibre pull out problem has been investigated extensively for the purpose of investigating the interfacial adhesion quality and interfacial properties between fibres and matrix and the elastic stress transfer in the fibre pull out problem [6–8]. However, these studies have not been applied to bonded steel rod–concrete problem.

The present paper tries to analyse mechanical behaviour of steel concrete composite system with an epoxy resin. The specimen configuration consists of a steel rod embedded in concrete matrix or a steel rod bonded with concrete by epoxy resin. This paper also discusses the theoretical analyses of the normal and shear stress distribution in steel/concrete interface along the rod axial axis. The role of epoxy resin layer in improving shear strength is discussed. The experimental programme was carried out in order to determinate the influence of some parameters, such as steel rod diameter, embedded or bonded length and bonded surface on the shear strength and stress distribution along the rod's length direction of steel–concrete structures by using the pull out test.

2. Materials

Three materials, steel bar, concrete and epoxy resin, are used in this work. The steel bar used was a type S275. Three diameters 12, 16 and 20 mm of steel bar were selected with five different embedded lengths (100, 150, 200, 250 and 300 mm). The yield strength and Young's modulus of the steel bar obtained by test was $f_y = 340$ MPa and $E_s = 198{,}000$ MPa, respectively. The initial state of the surface was smooth. The surface of the steel bar was then treated by mechanical sandblasting.

The concrete specimen was a cylinder, which had a diameter of 160 mm and a length of 320 mm. The concrete had an average compressive strength at 28 days of 40 MPa. The measured tensile strength was 3.3 MPa and the elastic modulus E_c was 37,800 MPa. The steel bar was embedded in the centre of the concrete cylinder. The relationship between strain and stress is presented in Fig. 1. In the elastic region, the relationship for concrete can be described by the following formula [13]:

$$f_c = f'_c\left[\frac{2\varepsilon_c}{\varepsilon_0} - \left(\frac{\varepsilon_c}{\varepsilon_0}\right)^2\right], \tag{1}$$

where f_c is the compressive stress, f'_c is the average compressive strength of concrete at 28 days. ε_c is the concrete strain and ε_0 is the strain corresponding to the ultimate compressive strength which is determined by the following formula:

$$\varepsilon_0 = \frac{2f'_c}{E_c}, \tag{2}$$

with E_c being the elastic modulus of concrete.

When the concrete reaches its ultimate compressive strength, the strain ε_0 depends only on the compressive strength f'_c and the strain value is equal to 0.003. The tensile stress of concrete f_t is calculated as $f_t = 0.6(1 + 0.1f_c)$.

The selected adhesive is an epoxy resin with two components. The measured elastic tensile modulus of epoxy adhesive is $E_a =$ 3600 MPa and its tensile strength is $\sigma_a = 22$ MPa.

The geometry of the pull out test is shown in Fig. 2. The diameter and the height of concrete were 160 and 320 mm,

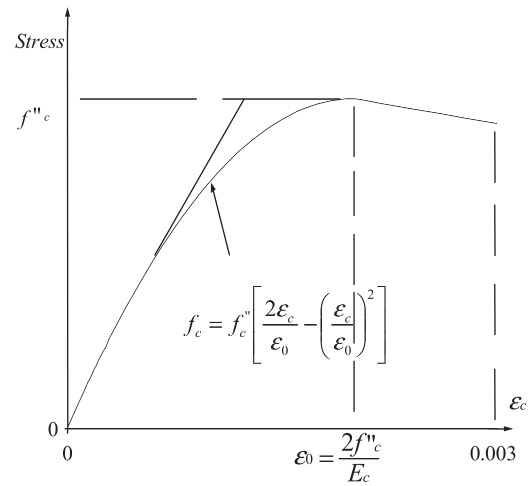

Fig. 1. Uniaxial stress–strain relationship of concrete in compression.

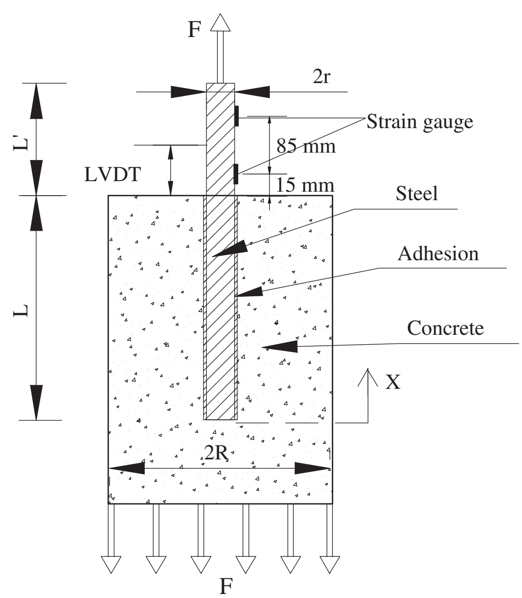

Fig. 2. Geometry of pull out model.