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Use of a single lap shear test to characterize composite-to-concrete or composite-to-steel bonded interfaces

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ABSTRACT

Adhesively bonded composite reinforcements are increasingly being used for civil engineering structures. For an adequate use of such a technique, a better knowledge is needed regarding the stress transfer mechanisms involved in polymer joints. This article introduces a single lap shear test for the characterization of the composite-to-concrete or composite-to-steel bonded assemblies. In the first part, an extensive description of the test set-up is given and various methods are proposed to analyse the experimental results. According to Chen's classification (2005) [1], the test under consideration is a near-end supported single-shear test. A first series of tests is reported, that investigates the differences between reinforcement processes based on either pultruded laminates or impregnated carbon fabrics (wet lay-up method), both used for the strengthening of civil infrastructures. The following part discusses the influence of the distance between the extremity of the concrete specimen and the free edge of the adhesive layer. Finally, differences between bonding on concrete and bonding on steel substrates are investigated in a last part.

These experimental investigations have allowed us to build-up a considerable body of experience on such usual composite reinforcements, and a large database on this experimental setup and its interpretation.

1. Introduction

Adhesive bonding is increasingly used in the field of civil engineering. It was first used for repair works, where reinforcing materials such as steel were adhesively bonded to the structure. Nowadays, a considerable amount of research has improved our knowledge about this technique, allowing its use for new structures [2–5]. Bonding has several advantages such as the reduction of stress concentration and weight, but adequate design procedures are needed if this technique is to be applied more widely.

The difficulties encountered with regard to bonding mainly arise from the number of mechanisms involved in the adhesion process. Bonding is the outcome of mechanical anchorage, physical bonding (electrostatic for example), and chemical bonding [6]. Relative contributions of these mechanisms to the bond strength depend mainly on the surface preparation and the materials involved. Thus it is widely accepted that during destructive testing cohesive failure is preferable to adhesive failure, which is difficult to predict [7]. Cohesive failure occurs in one of the materials, either the adherend or the polymer joint, in contrast to adhesive failure which occurs at the interface between the polymer joint and one of the adherends. When cohesive failures occur, a failure criterion can be expressed that depends on the properties of the material. For this, the mechanical characterization of the materials involved is required as well as a predictive tool to determine the stress profiles in the joint.

Besides, it must be highlighted that there exist heterogeneities in the stress distribution when using adhesive bonding. It has been indeed shown in many studies that the stress was transferred along a characteristic anchorage length or transfer length linked to the materials and the geometry [4]. This characteristic anchorage length represents the lap length which would be sufficient to transfer most of the ultimate capacity of the adhesively bonded joint and requires a precise stress profile study to be determined.

This study deals with structural reinforcement using composite materials which can be adhesively bonded to concrete or steel elements. It focuses particularly on the characterization of the behaviour of composite-to-concrete or composite-to-steel joints in shear because this is a key parameter which affects the way the reinforcement behaves and which may constitute the weak link in reinforced structures [8]. There are several different kinds of shear tests, which have been usefully classified by Chen [1]. According to this classification, the test described here is a near-end supported

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single-shear test. In addition, several ways of analyzing the results have been described in studies or design guides [9,10].

The aim of this article is not to compare the various possible test setups, nor to compare the possible analyses but rather to present the test setup we used for the single lap shear test and some interesting results from several series of tests. The first part will thus describe the setup and the way the results will be expressed in the rest of the paper. The first series of tests that is presented involves several commercial reinforcement processes which we tested and compared in order to study classical parameters linked to geometry and mechanical reinforcement characteristics. Both the ultimate capacity and the anchorage length have been investigated, and the main results are reported here. Then, a careful investigation of how the position of the joint edge affects the test results has been carried out. This parameter has a major impact on the test results and the chosen configuration must therefore be stated when experimental investigations are described. The last part of the paper describes an experimental comparison between composite-to-concrete and composite-to-steel bonded joints. The failure mode and the capacity of the joint are, of course, considerably modified. The same test setup has been used in numerous studies and provided a good understanding of the behaviour of adhesively bonded joints [11–14]. It is currently being used in a number of studies to optimize mechanical anchorage and study new configurations

2. Description of the shear test

The setup we used was originally developed to characterize adhesively bonded steel-to-concrete joints with regard to the use of the steel bonding technique to reinforce concrete structures [15]. It has since been adapted in order to characterize adhesively bonded composite-to-concrete joints as steel plates were tending to be replaced by composite elements because of their lower specific weight. The first part of this section provides a detailed description of the test set-up (Fig. 1). The instrumentation will then be described. The section that follows will list the types of results which may be obtained from this test and describe the analysis approaches that have been chosen for the experimental investigations presented afterwards.

2.1. The test setup

In the case of a near-end supported single-shear test, only one joint is tested for each specimen. The adhesive joint is loaded in shear by applying tension at the free end of the bonded plate. The hydraulic jack, which applies the load, is supported by the side

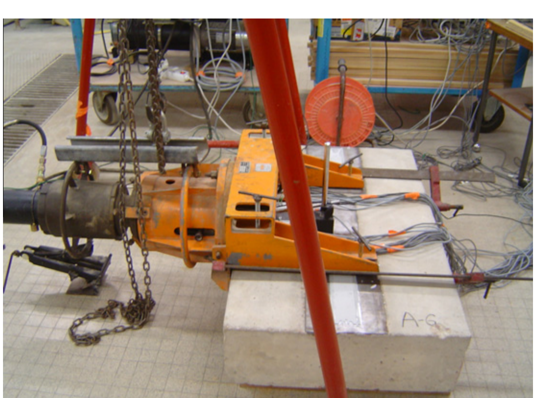

Fig. 1. The experimental setup.

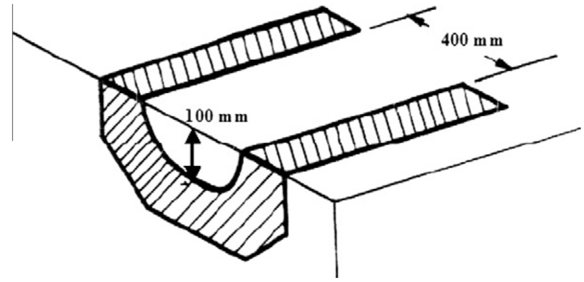

Fig. 2. The support area.

of the concrete plate and the upper face of the concrete block to which the composite is bonded. The maximum value of the load which can be applied is 100 kN, and, due to the size of the grips, the load can be applied to composite systems with a maximum width of 100 mm and a maximum thickness of 8 mm (Fig. 2).

The test set-up is shown in more detail in Fig. 3. A hydraulic jack transmits the stress to the composite via a steel cable that is fixed to the conical grips. A steel support that is connected to the jack is in contact with the slab's vertical surface. This support also has two arms that are in contact with the horizontal surface of the slab to which the composite has been bonded. In order not to interfere with the test, the two arms are 400 mm apart, leaving a distance of more than 150 mm between each arm and the composite. The loading axis can be easily aligned with the composite using adjustment screws.

The test procedure was similar in all cases and consisted of the following stages:

– The vertical position of the jack was adjusted so that the grips were aligned with the composite when no load was applied. This reduced the peeling stress applied to the end of the joint.
– The grips were then pushed into place to clamp the free end of the composite. A low level of tension was then applied to ensure good closure.
– The test was then started using constant a force or a constant grip displacement rate.

2.2. Instrumentation

The applied force and the displacement of the grips were recorded during the test at a frequency of 25 Hz using a displacement sensor placed against the side of the upper grip (Fig. 4). The applied force was measured by a load cell located inside the jack. Additional Data on displacements and strain in the composite were also available. More particularly, the strain on the upper face of the composite was used to determine the shear transfer profile along the joint. Indeed, contrary to what is commonly thought, a bonded joint subjected to shear does not exhibit constant shear transfer along the bonded length. There is a concentration phenomenon caused by the elastic behaviour of the adherends and which was first explained in [16]. This concentration effect is linked to the existence of a characteristic anchorage length which is an extremely important design criterion in the case of adhesive bonding. The main purpose of strain measurements is for determining this characteristic length which depends on the geometry of the joint and the properties of the adherends.

In the following investigations, strain measurements were made in two different ways. The first is referred to as the "usual measurement", and the second as the "more precise measurement". Five 20 mm-long gauges were used for the "usual measurements", and 23 gauges for the "more precise measurements" (the first ten were 1 mm-long, the following ten 2 mm-long, and the