Composite Structures 100 (2013) 548–553

Contents lists available at SciVerse ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Evaluation of shear stress and slip relationship of composite lap joints

Sabrina Fawzia *

School of Civil Engineering and Built Environment, Science and Engineering Faculty, Queensland University of Technology, Brisbane 4000, Australia

ARTICLE INFO

Article history:
Available online 16 January 2013

Keywords:
Single strap joint
Double strap joint
Bond
Steel and adhesive

ABSTRACT

Advanced composite materials offer remarkable potential in the strengthening of Civil Engineering structures. This research is targeted to provide in depth knowledge and understanding of bond characteristics of advanced and corrosion resistant material carbon fibre reinforced polymer (CFRP) that has a unique design tailor-ability and cost effective nature. The objective of this research is to investigate and compare the bonding mechanism between CFRP strengthened single and double strap steel joints. Investigations have been made in regards to failure mode, ultimate load and effective bond length for CFRP strengthened double and single strap joints. A series of tensile tests were conducted with different bond lengths for both type of joints. The bond behaviour of these specimens was further investigated by using nonlinear finite element analysis. Finally a bilinear relationship of shear stress-slip has been proposed by using the Finite element model for single and double strap joints.

1. Introduction

Steel, being one of the primary construction materials for decades, is used in construction of wide range of structures across the world, for instance; truss, primary vertical elements, vast parking shades, bracing members, etc. Applications of steel also include large warehouses, shopping malls, churches, community halls, amusement rides and bridges. Construction industry mostly rely on the conventional construction products when it comes to retrofitting, rectification, strengthening or repair. The conventional method of repairing or strengthening steel structures is to cut out and replace plating or to attach external steel plates. These conventional methods are less effective and increase maintenance costs [1]. Thus there is a need of more efficient and reliable retrofitting and restoration method.

Carbon fibre reinforced polymer (CFRP) has been used in the military and aerospace applications for more than two decades [2]. More recently there has been an increasing trend to use these materials to retrofit aging structures. CFRP sheet has high strength to weight ratio, resistance to corrosion and environmental degradation. It is very flexible to form all kinds of shapes, and easy to handle during construction [3,4]. The material has been used to strengthen concrete structures for a decade [5], however has recently been adapted to strengthen steel structures. Zhao [6] explained recent research on CFRP strengthened metallic structures. Fawzia [7] has undertaken research on CFRP strengthened double strap joint configuration with Araldite 420 adhesive to identify the bond characteristics of strengthened structures. Araldite 420 is a two component adhesive of high tensile strength. Fawzia [7] has experimentally investigated the strength of this adhesive and found it to be 32 MPa.

Limited research has been conducted on single strap joint configurations. Campilho et al. [8] have conducted an experimental and numerical study concerning the tensile behaviour of CFRP laminate single strap repairs. However, there appears to be a lack of research in single strap joints with CFRP sheet application under tensile loading. In this study, two series of tests were conducted with double strap and single strap specimens of different bond lengths using the same adhesive, Mbrace saturant. Mbrace saturant is a two-part adhesive with tensile strength of 24.8 MPa [7]. It was necessary to prepare double strap joint in conjunction with single strap joint for direct comparison. Fawzia [7] has conducted double strap joint experiment using Araldite 420 adhesive with different specimen size. Therefore those results cannot be directly compared with present results. Testing was conducted in the Instron machine at QUT (Queensland University of Technology) laboratory. As mentioned earlier, the main objectives of this study is to investigate and compare bond characteristics of double and single strap joint in regards to failure mode, effective bond length and ultimate load. The bond behaviour of the specimens is further investigated by using nonlinear finite element analysis. Finite element model is used to determine shear stress and slip relationship of double and single strap joints.

* Tel.: +61 7 3138 1012; fax: +61 7 3138 1170.
E-mail address: sabrina.fawzia@qut.edu.au

0263-8223/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.compstruct.2012.12.027

Nomenclature

E_a	tensile modulus of adhesive	t_a	thickness of the adhesive layer
E_f	tensile modulus of carbon fibre	t_f	thickness of carbon fibre layers
$E_{e,CFRP}$	equivalent longitudinal modulus of CFRP	τ_f	adhesive maximum shear stress (MPa)
l_1	shorter bond length	δ_1	initial slip (mm)
l_2	longer bond length	δ_f	maximum slip (mm)

2. Material properties and specimen preparations

2.1. Material property

2.1.1. CFRP material

For the experimental program in this study, unidirectional Mbrace fibre CF130 was chosen as the test CFRP. Fawzia [7] has conducted coupon tests on Mbrace fibre in accordance with ASTM:D 3039 [9] and found that the modulus of elasticity and tensile strength of the CFRP were 230 GPa and 2675 MPa respectively.

2.1.2. Adhesive material

The adhesive chosen for the experimental program is a two part adhesive called Mbrace saturant. Fawzia [7] has conducted coupon tests of Mbrace saturant in accordance with ASTM:D 638-01 [10] and found that the modulus of elasticity and tensile strength of the adhesive were 2028 MPa and 24.8 MPa respectively.

2.1.3. Steel plate

The steel plate used in the testing was 25 mm wide and 10 mm thick. The steel yield strength and ultimate tensile strength are 320 MPa and 440 MPa respectively.

2.2. Specimen preparation

The first step of specimen preparation is to measure the thickness of steel plates. Grinding was then commenced on one side of the steel plate for single strap specimens and on both sides of the steel plate for double strap specimens. Fig. 1 shows the different grinded length of the steel. The thickness of the steel along the bond length was measured again after grinding. Thicknesses were taken in three different locations and then averaged. The steel plates were then cut to the size of the specimen (i.e. the combined length of the two plates that each specimen would be assembled from). After specimens were grinded and cut in right sizes, bonding of the CFRP could commence. The two plates were first bonded together at the shorter end of the plate. Prior to the application of this adhesive the ends were cleaned with acetone to remove rust and other contaminants. The specimens were then left to cure overnight. A layer of adhesive was then applied to the specimen and a sheet of carbon fibre was laid. The specimen was then pressed with a ribbed roller to ensure there is no void in the adhesive layer. This process was repeated until three layers of CFRP sheet had been applied. The same procedure was followed in the other side of steel plate for double strap joint. The thickness of the full specimen along the bond length was measured after the application of CFRP. Single strap and double strap specimens prepared for the experiments are shown in Fig. 2. Fig. 2 is representing different bond length specimens. A schematic of the single and double strap specimens are shown in Fig. 3. In this figure l_1 represents shorter bond length and l_2 represents longer bond length. One side of the bond length was kept longer to make sure that failure happened on shorter bond length. In some cases transverse wrapping was also used to provide extra strength to the longer bond length side.

3. Experiments

3.1. Test setup

Each specimen was loaded in Instron machine as shown in Fig. 4 and the specimens were tested under tensile load at ambient temperature and humidity. A displacement control regime was used at a constant displacement rate of 2 mm/min. The failure load was recorded for each specimen. Ten single strap and eleven double strap specimens were tested.

3.2. Test results

3.2.1. Failure mode

The test results showed that all of the specimens exhibited steel adhesive interface debonding (Fig. 5). There was a clean break in all cases, with no adhesive remaining on the steel. Details of these types of failure mode can be found in Zhao and Zhang [11].

Fig. 1. Grinded surface of the steel.

Fig. 2. Test specimens. (a) Double strap joint. (b) Single strap joint.