Engineering Structures 56 (2013) 555–566

Contents lists available at SciVerse ScienceDirect

Engineering Structures

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

External jacket of FRP wire for confining concrete and its advantages

Eunsoo Choi [a,1], Jong-Su Jeon [b,*], Baik-Soon Cho [c], Kyoungsoo Park [d]

[a] Department of Civil Engineering, Hongik University, Seoul 121-791, Republic of Korea
[b] School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332, USA
[c] Department of Civil Engineering, CTRC, Inje University, Kimhae 621-749, Republic of Korea
[d] School of Civil and Environmental Engineering, Yonsei University, Seoul 120-749, Republic of Korea

ARTICLE INFO

Article history:
Received 22 October 2012
Revised 10 May 2013
Accepted 12 May 2013
Available online 28 June 2013

Keywords:
FRP wires
Concrete confinement
Seismic retrofit
Stiffness ratio
Confinement ratio

ABSTRACT

This study investigates the effectiveness of FRP wire to confine concrete. For this purpose, axial compressive tests are conducted with three parameters, peak strength of concrete, confining amount of FRP wire, and epoxy application. The behavior of the FRP-wire confined concrete is examined in the axial and circumferential directions as well as in terms of volumetric strain. Each behavior is discussed according to the stiffness ratio of the confining FRP wire to concrete. Moreover, the confinement effectiveness of the FRP wire is estimated using the actual rupture strain of the FRP wire as well as the ultimate tensile strain. Both cases show slightly larger effectiveness than that of FRP sheet confined concrete. The external jacket of the FRP wire increases the peak strength satisfactory and restrains volumetric expansion when the stiffness ratio of the jacket is sufficiently large. The failure of the FRP wire confined concrete occurs at the mid-height of the cylinder. Furthermore, this study investigates the behavior of partially confined concrete exhibiting smaller peak strength compared to the corresponding fully confined specimen, as it appears to have a smaller stiffness ratio.

1. Introduction

External jackets using steel plates initially showed good performance in terms of increasing the displacement ductility and flexural strength of lap-spliced reinforced concrete (RC) columns [1,2]. However, the installation method of the steel jacket was somewhat inconvenient due to the requirement of grouting to fill up the gap between steel and concrete. Moreover, the grouting increased the cross-sectional area at the jacketed region and the dynamic characteristics of the jacketed structure were disturbed relative to the as-built structure. Jackets using fiber reinforced polymer (FRP) sheets or tubes subsequently came to the forefront as an alternative to the steel jacket on the basis of several relative benefits. The strong points of the FRP jacket are that it does not increase the cross-sectional area and a multiple layered jacket is available. However, an adhesive should be used to bond the FRP sheet to the concrete surface or another FRP sheet. This process is usually conducted manually, and tight attachment is not guaranteed. Perfect attachment of the FRP sheet on the concrete is one of the critical factors to induce immediate causing the confining pressure of the FRP sheet against the bulge of concrete.

Harries and Carey [3] conducted experimental tests to examine the effect of the gap between the concrete and the jacket on the behavior of confined concrete. They carried out compressive tests of concrete cylinders with a gap between the concrete and the jacket and compared them to the results with those obtained for a case without a gap. In the test, the gap was built by wrapping typical plastic wrap used in the kitchen. The effect of the gap was that the peak strength as a function of lateral strain appeared early. The measured lateral strain on the jacket did not represent the bulge of the concrete inside, given that the jacket did not dilate immediately according to the bulge inside the concrete due to the gap.

Several prestressing techniques have been introduced to overcome this problem. However, the prestressing methods are not easily applied to RC columns, as they require a special and/or large device to stretch FRP sheets. Xiao and Ma [4] suggested an external pressing method to attach a prefabricated FRP jacket on a RC column using several belts. However, they still used an adhesive on the concrete surface to bond the prefabricated FRP jacket as well as lateral band-strips to apply lateral pressure on the FRP jacket. This method was more efficient to obtain perfect attachment of the FRP sheet than the previous manual attachment methods since they apply external pressure on the FRP jackets.

Choi et al. [2,5] suggested a new steel jacketing method for RC columns, where external pressure is used to attach the steel jacket to concrete instead of grouting. The effectiveness of the jacketing

* Corresponding author. Tel.: +1 404 895 5241; fax: +1 404 894 1641.
E-mail addresses: eunsoochoi@hongik.ac.kr (E. Choi), jongsu.jeon@gatech.edu (J.-S. Jeon), civcho@inje.ac.kr (B.-S. Cho), k-park@yonsei.ac.kr (K. Park).
[1] Tel.: +82 2 320 3060; fax: +82 2 332 1244.

0141-0296/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.engstruct.2013.05.019

method was proved through the experimental tests of concrete cylinders and RC columns. The method is similar to Xiao and Ma's method and the perfect attachment is critical to obtain satisfactory performance. Harries and Kharel [6] and Harries and Carey [3] noted the presence of a gap between the concrete and the confining jacket due to the slackness in the confinement and explained the effect of the gap. They also indicated that the behavior of woven fabric was similar to that of the gap. As presented in the aforementioned studies, overcoming the problem of the gap or the slackness of the jackets of steel plate or FRP fabrics is challenging. This study sheds light on the advantages of wire-type jackets for confining concrete structures without a gap or slackness.

2. FRP wire jacket and specimens

2.1. FRP wire jacket

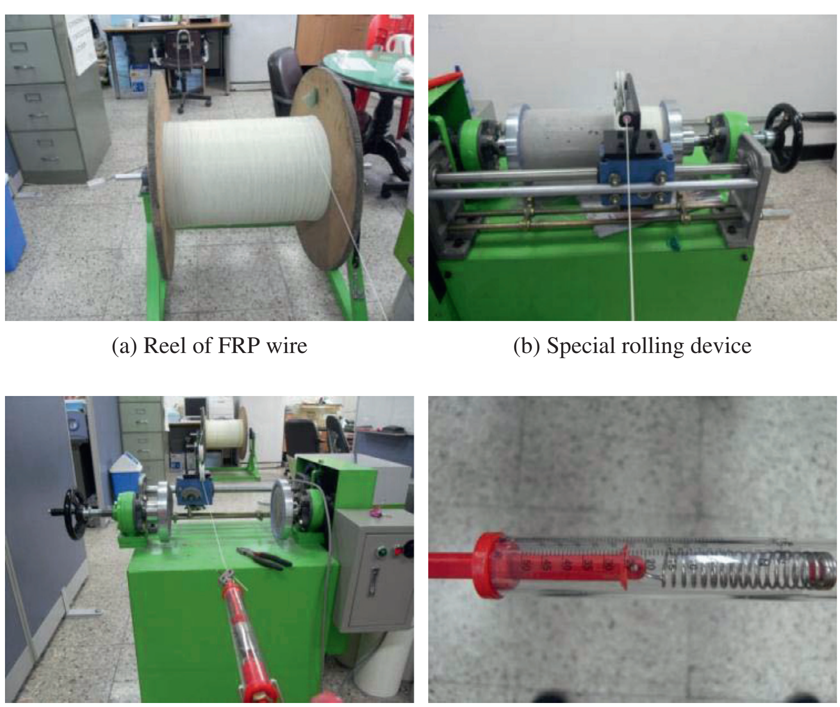
Glass-fiber reinforced polymer (GFRP) wire of 1.0 mm diameter was used in this study. The area of the wire was 0.785 mm^2 and the tensile strength and ultimate strain of the wire were 1230.6 MPa and 2.94×10^{-2}, respectively. Therefore, the estimated Young's modulus in tension was 41.84 GPa. Firstly, the wire was wound around a large reel, as shown in Fig. 1a, and the reel was equipped with a device to provide friction resistance at its side when rolling. The wire was stretched over a concrete cylinder on a special device manufactured for this study, as shown in Fig. 1b. The device held a concrete cylinder and wrapped the wire around the cylinder with a specific pitch. Note that no adhesive was applied on the concrete surface. During the winding, the wire was stretched with a constant tension because of the frictional resistance of the reel. Tensile force of 25 N was measured using a spring balance, as shown in Fig. 1c and d. Therefore, the stress and strain in the wire due to the tensile force were 31.83 MPa and 7.73×10^{-4}, respectively. The stress was too small to develop an active confining effect on the concrete but sufficient to tightly wind the wire on the concrete surface without any gap. After several windings of the wire, super glue was applied on the wire to prevent release of the wire during the rolling. After finishing the winding, super glue was also applied on the wire at the other side. The glue provided holding action for the wire and prevented release of the wire. Fig. 2 shows the process of confining the concrete cylinder by the FRP wire jacket. Several previous studies of shape memory alloy (SMA) wire jackets were conducted [7–10] and have used anchoring nails to hold SMA wire. The FRP wire jacket, however, can be fixed by applying glue at both ends and does not make any scar on the concrete surface. A 10 mm section of the cylinder at both ends was not wrapped by the FRP wire in order to avoid interaction of the FRP wire jacket during a compressive test. The proposed jacketing method can wrap a concrete cylinder with multiple layers; the second layer of the jacket can be built following the same procedure as used for the first layer. Fig. 3 shows the cases of single-, double-, and triple-layered FRP wire jackets and an epoxy applied specimen.

2.2. Specimens and test set-up

This study used concrete cylinders with a diameter of 150 mm and height of 300 mm to obtain the compressive behavior of confined concrete. Two variables were considered, peak strength of concrete and amount of confining FRP wire; three design strengths of concrete and three amounts of FRP wire were also considered. The design strengths were 25, 35, and 45 MPa, respectively, and the amounts of FRP wire were one, two, and three layers. The volumetric ratio for the FRP wire jacket can be calculated using the following equation:

$$\rho_v = \frac{4A_j}{sD} \quad (1)$$

where A_j = cross-sectional area of the jacket, D = diameter of cylinder, and s = spacing between wires. The calculated volumetric ratios for each amount of FRP wires were 2.09%, 4.19%, and 6.28%, respectively. To obtain an equivalent thickness of FRP sheet jackets which



(a) Reel of FRP wire

(b) Special rolling device

(c) Measuring tensile force of the wire

(d) 25 N tensile force

Fig. 1. FRP wire and tensile force.