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Prospects of using Prefabricated Ferrocement Jacket for Semi-Automated Strengthening of RC Column

A. B. M. A. Kaish*
Department of Civil Engineering, Infrastructure University Kuala Lumpur, Kajang-43000, Malaysia,
Lutfun Nahar* & Azizah Jaafar
Institute of Visual Informatics, Universiti Kebangsaan Malaysia, UKM Bangi-43600, Malaysia
Yagoub Ahmed
Department of Civil Engineering, Infrastructure University Kuala Lumpur, Kajang-43000, Malaysia
*Email: amrul.kaish@iukl.edu.my

ABSTRACT: Ferrocement jacketing is an effective strengthening tool for RC column. The installation of ferrocement jacket is very easy; it does not require highly skilled labor to install. However, its' installation is time consuming over the commonly used technique, like fiber reinforced polymer (FRP) jacketing. It also requires 4 weeks curing to achieve strong and dry surface. Therefore, although ferrocement jacketing is a very effective strengthening option for RC column, its' use is not generally recommended for the existing structures. To overcome this limitation, this study presents a unique idea of pre-fabricated ferrocement jacketing system for strengthening of RC column. It is hypothesized that pre-fabricated ferrocement jacketing system will ensure a semi-automated strengthening system where the jacket will be prepared in controlled environment (i. e. in prefabrication factory) with automated technology and then it will be installed in-place using nut-bolted connections. With the help of this semi-automated strengthening system, it will be possible to expedite strengthening activity of existing RC structures. It will also reduce the labor cost as the ferrocement jackets will be prefabricated in factory with the aid of automated construction system. Experimental results also show that the prefabricated ferrocement jacket is effective to strengthen concrete column.

KEYWORDS: Ferrocement Jacket; RC column; Strengthening; Automated construction technology

1 INTRODUCTION

Concrete is the building material that used widely throughout the whole world. However, deterioration in concrete structures is very common due to various factors such as earthquakes and floods and structural factors such as overload, and environmental factors. A variety of methods and materials were used by engineers to increase the strength and ductility of deteriorated or damaged concrete structures.

Ferrocement is thin reinforced mortar system with one or more layers of wire mesh (Kaish et al. 2012; 2013). It can be effectively utilized for strengthening of reinforced concrete (RC) column (Kaish et al. 2015). The most promising advantage of ferrocement is its high in-plane tensile strength and crack resisting properties (ACI 549.1R-93 1993). Its raw materials are abundantly available in developed and developing countries (Kaish et al. 2016). The installation of ferrocement jacket is very easy and it does not require highly skilled labor to install (Kazemi & Morshed 2005). However, there are several problems with the construction of ferrocement jacket. One of the most important issues is its time consuming nature. It requires more time to be casted and also it takes around 4 weeks for curing to achieve strong and dry surface, in this time there are many activities that will be interrupted especially in place of work due to safety reasons. Therefore, we need to re-think about the conventional practice of using ferrocement jacket as strengthening tools. This study proposes pre-fabricated ferrocement jacketing system for strengthening of RC column with the proposition that it will help to ensure automation in strengthening applications of RC column.

2 AUTOMATION IN CONSTRUCTION

Automation is the latest inclusion in construction industry. Being labor intensive, the construction industry requires more numbers of skilled labors. Decreasing quality of work, labor shortages, and safety of labor and working condition of projects sometimes demand for the automation in such projects (Tejankar 2017).

The main activities of construction automation are mainly focused into two large groups; namely, automation in civil infrastructure and automation in buildings (Tejankar 2017). Typical applications of automation in civil infrastructure are the automation in earthwork; automation in road, tunnel and bridge construction, etc. In house building construction, main applications include building skeleton erection and assembly, concrete compaction, interior finishing, etc.

Although the process of automation has advanced in other domain, the growth of automation in construction still not reached to that level. The process of automation in construction is slow due to various reasons; such as (Kawade & Satpute 2017):

- Unavailability of the automated fabrication technologies for large scale products,
- Conventional design approaches are not suitable for automation,
- Significantly smaller quantity of final products as compared with other industries,
- Limitations in the materials that could be employed by an automated system, and
- Expensive automated equipment.

However, implementation of automation in construction has several advantages that outweigh its disadvantages. Uniform quality, improved working environment, increased productivity and work efficiency with reduced costs, replacing humans in dangerous environments, are the most important advantages of using automation in construction industry. Automation also helps to reduce waste and factory lead times. Figure 1 shows an automated construction system in Japan.

Figure 1. Automated construction system in Japan.

2.1 *Importance of automation in prefabrication*

Quality concrete production can be obtained by producing it in a controlled environment; i.e., in a prefabrication plant. The prefabrication process involves pouring concrete into molds, and curing it and shipping it to the customer for installation.

The need for industrialized building system (IBS) is increasing every day; and thus the need for prefabricated elements in house building. Therefore, the automatic fabrication and erection on-site of these elements plays a very important role in implementing IBS products. The robot spraying and control crafting system are used for the manufacturing of concrete and composite parts of the building, such as facade panels. The integration of masonry robots for brick and panel manufacturing is performed under the computer integral manufacturing concept (Hanser 1994).

As IBS and prefabrication technology is growing in demand nowadays, it's really important to adopt automated systems in every stage of implementation.

3 AUTOMATED STRENGTHENING SYSTEM

Automated strengthening system was first developed in Japan in the early 90s and later in USA (Cozmanciuc et al. 2009). It was used to strengthen circular RC column or other structures, like Chimneys with fiber reinforced polymer (FRP) (FIB Bulletin 2002). In this system, a robot is used to continuous winding of wet fibers with a slight angle around columns. Currently, three versions of the machine are available for bridge retrofit work depending on the size of the columns being wrapped. The advantages of the technique are the rapid installation of FRP jacket, reduced volume of work on site, and good quality control (Cozmanciuc et al. 2009). However, its main disadvantages are workability to a reduced shape of columns and the requirements of special equipment. The dirty and uneven bonding surface does not provide good bond. Moreover, the adhesive needs a temperature above 10 ℃ to start hardening process. Therefore, the hardening process delays in cold weather. The possibility of brittle failure modes, risk of fire, risk of vandalism and accidental damage makes FRP system unreliable in some cases.

Figure 2 shows an automated strengthening application using FRP to strengthen circular RC columns.

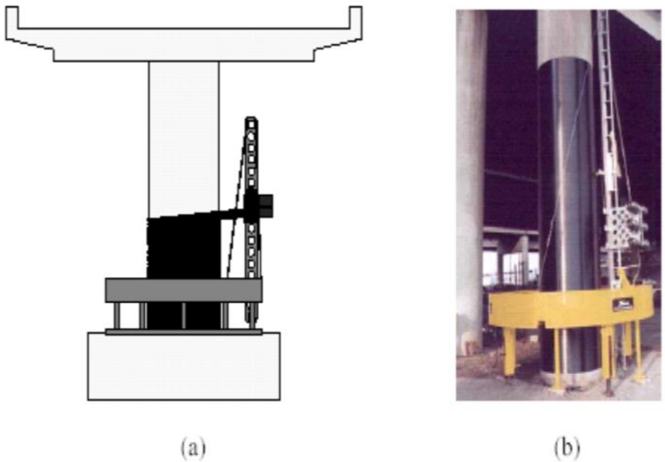

Figure 2. Automated strengthening of RC column (Cozmanciuc et al. 2009; FIB Bulletin 2002), (a) Schematic diagram, (b) Robot-wrapper.

4 FERROCEMENT JACKETING FOR COLUMN STRENGTHENING

The effectiveness of ferrocement as external confining material for concrete specimens has been investigated by many researchers. Kondraivendhan and Pradhan (2009) studied the behavior of ferrocement confined plain cylindrical concrete specimens of different compressive strength. Behavior of plain concrete encased with ferrocement with skeletal steel bars under uniaxial compression was studied by Xiong et al. (2011). Shannag and Mourad developed high strength cementitious matrix for producing the ferrocement laminates for strengthening application (2012). Recently, Kaish et al. (2015) investigated the size effect of the specimens on the behavior of ferrocement confined cylindrical concrete. Ho et al. (2013) investigated the behavior of high-performance ferrocement (HPF) confined circular plain and RC columns under monotonic axial load. Abdullah & Takiguchi (2003) tested shear deficient square RC columns with different ferrocement jacketing schemes to study the effect of different shapes of ferrocement jacket. Kumar et al. (2005) studied the effectiveness of ferrocement jacketing for the seismic retrofitting of the square RC bridge piers.

Therefore, it can be said that ferrocement is already an established material for RC column strengthening. Figure 3 shows conventional way of ferrocement jacketing application.

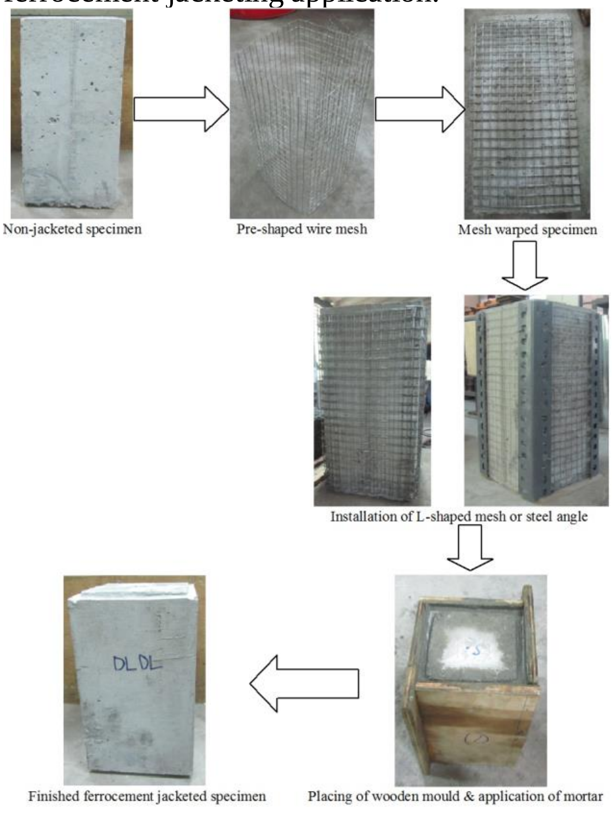

Figure 3. Conventional ferrocement jacketing process.

4.1 *Advantages of ferrocement jacketing*

As a confining material, ferrocement has several advantages over FRP laminates or steel jackets. The following advantages make ferrocement an ideal confining material for confining axially loaded structural members.

- A cost competitive solution for infrastructure rehabilitation in developing countries,
- It requires minimum skilled labor,
- Very high in-plain shear strength capacity,
- No particular measures needed to ensure bond between ferrocement and underlying substrate
- Less sensitive to high temperature,
- Extremely high moment capacity.

However, the application of ferrocement jacketing is time consuming and involves with wet construction process. This strengthening technique is therefore not well accepted by the construction industries although it's a low cost and effective technique. Thus, there is a need for making this technique more attractive to the industries.

5 PREFABRICATED FERROCEMENT JACKETING

Prefabrication technique, with the aid of automated or semi-automated process of ferrocement jacketing application, could be an effective way to improve this technique from its' present state. It will not only make the technique attractive but also ensure better quality of jacketing system.

5.1 *Designing prefabricated ferrocement jacket*

Before fabricating the ferrocement jacket, we need to design it very carefully. As the prefabricated jacket will be installed in an existing RC column, we cannot fabricate it as hollow cylinder (for circular column) or hollow square/rectangular (for square/rectangular column) jacket. In case of circular column, the jacket should be consisted of two half circles with appropriate connection mechanism. On the other hand, in case of square/rectangular column, the jacket must be consisted of two half squares/rectangles. These half squares/rectangles also need special attention in designing them, as it could be either "L" shaped or "C" shaped as shown in Figure 4. For square/rectangular jacket, corners are more susceptible to cracking (Kaish et al. 2012; 2016). Therefore, all the corners need carefully designed as suggested by Kaish et al. (2012; 2016).

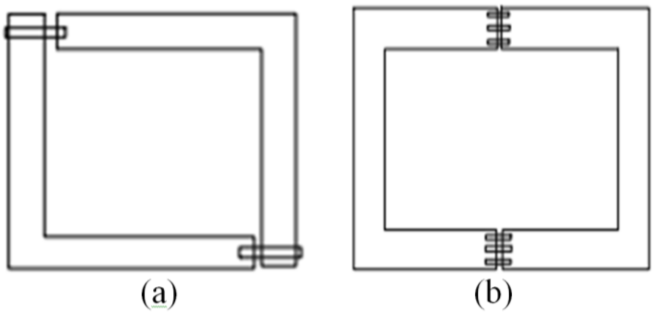

Figure 4. Design of prefabricated ferrocement jacket for square/rectangular column, (a) "L" shaped jacket; (b) "C" shaped jacket.

As the corners are vulnerable to cracking, "L" shaped half squares/rectangles should be avoided in order to avoid joints at the corner. Figure 5 illustrates a schematic diagram of RC column confined with "C" shaped prefabricated ferrocement jacket.

5.2 *Designing joints*

In prefabricated construction, joints are always very important and thus needs to be designed as strong as possible. It can be designed in several ways, such as followings:

- Using bolted connection (as shown in Figure 4),
- Using sliding dovetail joint (as shown in Figure 6).

A sliding dovetail joint consists of a long groove with angled sides to serve as the tail for the sliding dovetail joint,

-Using a small piece of metal attached with one side with a hole, in which a bolt can be screwed into,

- Using a lap joint with bolted connections.

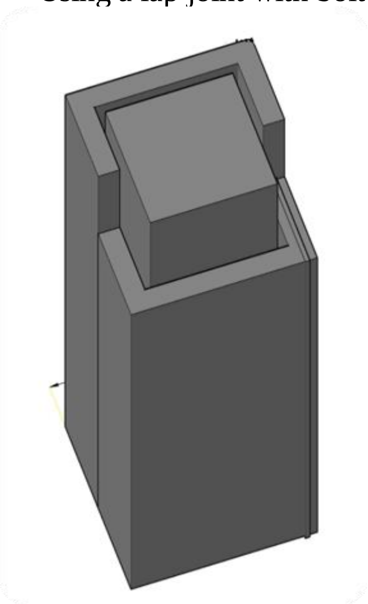

Figure 5. Column confined with "C" shaped prefabricated ferrocement jacket.

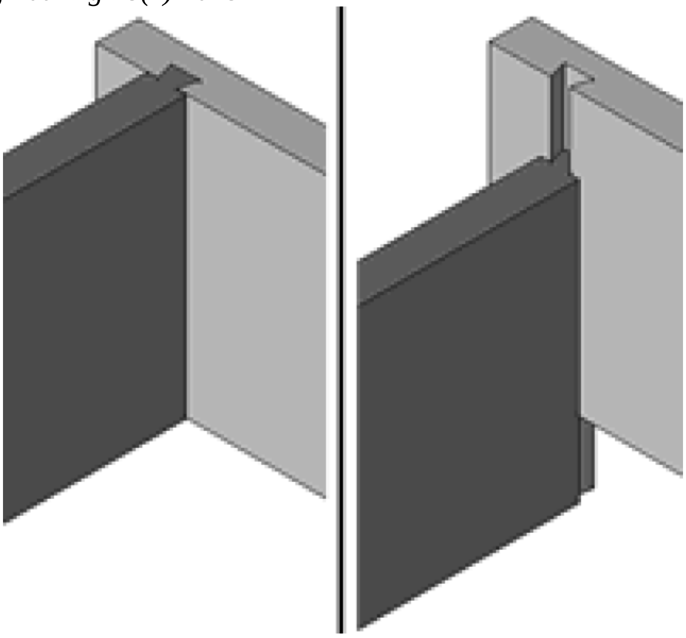

Figure 6. A sliding dovetail joint.

5.3 *Advantages of pre-fabricated ferrocement jacket*

Prefabricated ferrocement jacket has some special advantages over conventional ferrocement jacket for strengthening of RC column. These advantages will make it more attractive to the engineering community. The advantages of prefabricated ferrocement jacket are as follows:

- It will speed up the installation process and thus will reduce the work interferences in existing building,
- As prefabricated ferrocement jacket will be casted in controlled environment, it will ensure the quality of construction.
- Automated construction of prefabricated ferrocement jacket will reduce the labor intensiveness of ferrocement construction.

6 PRELIMINARY EXPERIMENTAL INVESTIGATIONS

A preliminary experimental investigation was carried out to understand the behavior of prefabricated ferrocement jacketing for strengthening of square concrete stub. Six concrete stubs of 300 mm height and 150 mm × 150 mm cross-section were fabricated with 20 MPa concrete. Four of those stubs were jacketed with prefabricated ferrocement jacket. The jackets were shaped into types, 1) L-shape, and 2) C-shape. All the jackets and square concrete stubs were prefabricated and cured for 28 day. After that the prefabricated jackets were used to strengthen the concrete stab. Cement grout was used as a binder between the jacket and concrete stub. Figure 7 shows the schematic diagram of jacketed specimens.

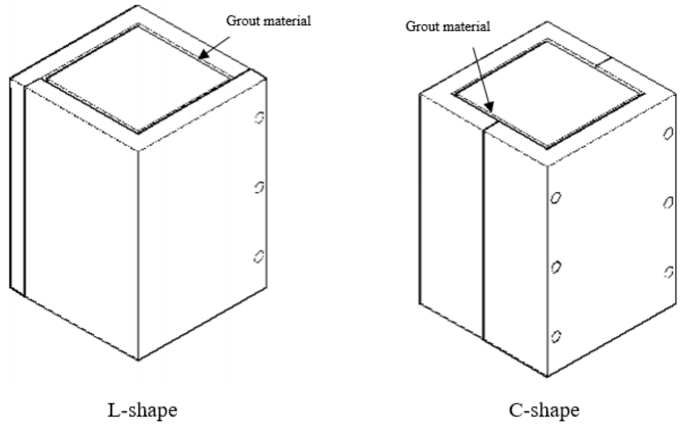

Figure 7. Prefabricated ferrocement jacketed specimens.

6.1 *Test setup*

The test was carried out using a universal testing machine of 2000 kN capacity. Vertical and horizontal deflections were measured through a set of 6 linear variable transducers. Figure 8 shows the experimental setup.

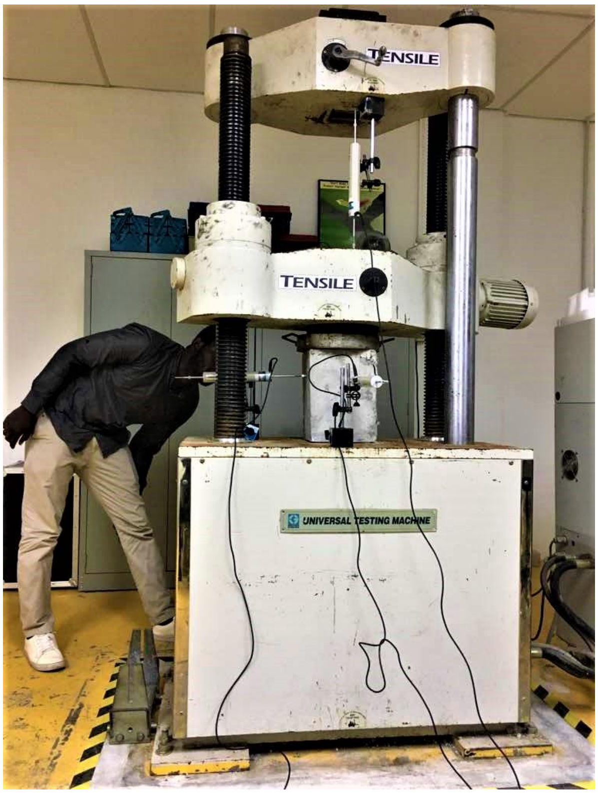

Figure 8. Experimental setup.

6.2 *Test results*

The test results were recorded through a data acquisition system (data logger) in terms of ultimate axial load and axial deflection. Results are presented in Table 1. It can be shown from Table 1 that the prefabricated ferrocement jacket is very effective in increasing the load carrying capacity of concrete stub. Among both types of jacket, C-shape enhances more in terms of load carrying and deflection capabilities.

Table 1. Experimental results.

Specimens type	Ultimate stress (MPa)	% increase in ultimate stress	Ultimate strain
Non Jacketed	20.2	-	0.0052
Confined with L-shape jacket	28.3	40	0.0069
Confined with C-shape jacket	34	68.3	0.0072

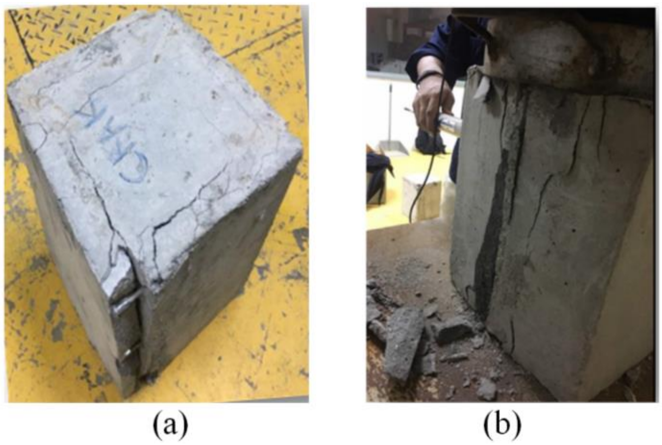

Figure 9. Failure patterns of specimens confined with (a) L-shape jacket, (b) C-shape jacket.

Figure 9 shows typical crack pattern of jacketed specimens. Both of the jackets were seen to be failing at the joint. Significant amount of cracks are also appeared away from the joints as well in both types of jackets. No cracks were appeared in the corner of C-Shape jacket. On the other hand, little bit cracks were appeared in the corner of L-Shape jackets. Therefore, it can be said that the C-Shape jacket is more effective than L-Shape ferrocement jacket (Kaish et al. 2012; 2013; 2016).

7 CONCLUSIONS

The available strengthening materials and methods are costly as well as time and labor intensive in nature. In order to solve these problems, this article proposes a new semi-automated technique to strengthen RC column. All of these problems can be solved by implementing prefabricated ferrocement jacketing for RC column strengthening. Moreover, automated fabrication of ferrocement jacket in controlled environment will ensure quality in construction. Furthermore, the installation time of ferrocement jacket will be greatly reduced as curing is not required for prefabricated ferrocement jacket. Therefore, it is expected that the proposed system will be highly welcomed by the scientific community. However, before implementing the proposed system, a proper design of prefabricated ferrocement jacket with effective connection mechanism is highly required. Full scale test is also required for the proposed system.

8 ACKNOWLEDGEMENT

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