Malaysian Journal Of
Civil Engineering

# STRENGTHENING OF FIRE DAMAGED REINFORCED CONCRETE COLUMNS USING FERROCEMENT

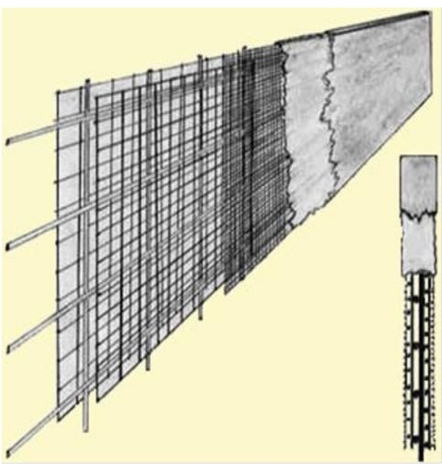
A. K. M. Fayzul Bari*, Al Amin, Riyadul Hashem Riyad, Md. Lutfar Rahman Talukder

Department of Civil Engineering, Faculty of Engineering, European University of Bangladesh, 2/4 Gabtoli, Mirpur, Dhaka-1216, Bangladesh.

**Article history**
Received
*05 September 2021*
Received in revised form
*16 November 2021*
Accepted
*17 November 2021*
*Published online*
*30 November 2021*

*Corresponding author
fayzul.bari20@gmail.com

**Graphical abstract**



**Abstract**

A number of things, like extreme loading and severe environmental exposures, can cause the deterioration of ferroconcrete Reinforced Concrete columns. Ferrocement is currently used as a part of the well-liked method for extending the lifetime of a deteriorated column. The appliance of Ferrocement is restricted to the strengthening of loaded RC columns which have been broken by fire. Depending on the fire's intensity (duration and temperature), the exposure of an RC column to a fireplace may result in a reduction in the strength of the column during both the heating and cooling periods. The utilization of Ferrocement is often effective in restoring the strength of the column, although it'll require careful protection to protect against heating in the future. This research concerns the effectiveness of using Ferrocement confinement to repair RC columns damaged by fire. The effectiveness of confinement is set by comparing the behaviors of retrofitted, controlled, and fire damaged specimens. Locally available materials like steel wire mesh as a neighborhood of Ferrocement confinement have been utilized in this study because of the confining materials. For this purpose, six rectangular short columns with a dimension of 150 mm × 150 mm × 800 mm have been cast and tested. The residual behavior of the columns after being retrofitted is evaluated and compared against that of the control columns. The test results show that the effect of confinement has been evaluated by comparing the results with unconfined and fire damaged specimens. The load capacity of the columns has decreased by about 46 % after the fire damage. Further the capacity is increased by 23% and 49% using Ferro cement confinement with one layer and two layer respectively.

*Keywords*: Ferrocement, retrofitting, wire mesh, confinement, fire.



## 1.0 INTRODUCTION

Reinforced Concrete columns are the main structural apparatuses that significantly contain the building's overall performance and stability. Columns are used as major components in building frames to support compressive loads from roofs and floors and to transmit the vertical forces to the foundations and into the subsoil. During the service life, if the loading conditions change thanks to the purpose of use of the structure, this will result in lowering the performance of the structural elements that were designed earlier. The structures are also vulnerable to deterioration thanks to earthquakes, cyclones, and environmental effects, deficiencies in the materials used, inadequate design and faulty construction. Replacement of the injured structural elements is an extremely challenging and pricey process and also creates risk to the reliability of the opposite connecting members. For these conditions, to repair and reinforce the prevailing structure, external confinement may be a possible solution. The likelihood of using Ferrocement to repair columns that are damaged by fire or heating is low. The intention of this research is to increase our understanding, both practically and theoretically, of the behavior of loaded RC columns during heating and cooling after they need to be strengthened using Ferrocement confinement. The strengthening of ferroconcrete columns through the utilization of an external secondary jacket is predicated on the elemental understanding that the lateral confinement of the concrete core substantially enhances its compressive strength and supreme axial strains [1]. In most developing countries, Ferrocement jacketing (consisting of rich mixed mortar reinforced with steel wire mesh) is usually utilized as an efficient strengthening technique for RC columns due to the supply of its raw materials in these countries [2]. Strengthening the ferroconcrete columns may become essential for a variety of reasons, like subnormal detailing of the steel reinforcement and deterioration of the concrete under severe environmental conditions. Ferrocement possesses some unique properties like waterproofing, fire resistance, low self-weight and sturdy, which makes it a perfect material for wider applications [3]. Reproducible damage is achieved by employing slow cyclic loading. The application of ferrocement retrofit coating to damage columns increases the column's outward stiffness and significantly improves its ultimate load carrying capacity [4, 5].The ratio of axial load, jacketing schemes, and number of wire mesh layers are the parameters considered during this study. From the test results, it's found that the external confinement increases the ductility of the column. FRP jacketed concrete cylinders and FRP tube encased concrete are two examples [6].The load carrying ability and ductility of circular concrete columns confined by Ferrocement include steel bars (FS) where they're proposed to extend the compressive strength alongside the ductility [7]. The comparative analyses of those models show that the compressive strength of FS columns is improved by 30% compared to that of BS columns [8]. Thanks to Ferrocement caging alongside steel bars, specimens showed higher ductility, compressive strength, and energy absorbing capacity than BS or FRP strengthened circular columns [9].

In this research, the suitability and effectiveness of the Ferrocement strengthening system to repair RC columns damaged by heating are investigated. The particular objectives of the present study are as follows:

- ❖ To investigate the performance of normal strength of concrete columns confined by Ferrocement;
- ❖ To supervise experimentally the suitability of Ferrocement for rehabilitating RC columns damaged by fire under axial compression;
- ❖ To evaluate the effect of confinement by comparing the results of confined and unconfined specimens.

## 2.0 METHODOLOGY

### 2.1 Materials and Investigation

The material is shown in Figure 1, and its properties are determined according to the ASTM standard method and summarized in table 1;

a. Coarse Aggregate (stone) b. Fine Aggregate (sand)

c. Reinforcement (steel) d. Wire mesh

**Figure 1**. Research Materials

**Table 1**. Properties of Materials

| Materials | Properties | Unit | Value |
|---|---|---|---|
| Binder (OPC) | Specific gravity | | 3.15 |
| Fine aggregate | Specific gravity (SSD) | | 2.54 |
| | Absorption | % | 3.35 |
| | Unit Weight | Kg/m3 | 1628 |
| | Fineness modulus | | 2.56 |
| Coarse aggregate | Specific gravity (SSD) | | 2.82 |
| | Void | % | 28.90 |
| | Absorption | % | 2.02 |
| | Unit Weight | Kg/m3 | 1619 |
| | Fineness modulus | | 4.52 |
| Reinforcement | Yield Strength | Mpa | 450 |
| | Ultimate Strength | Mpa | 520 |

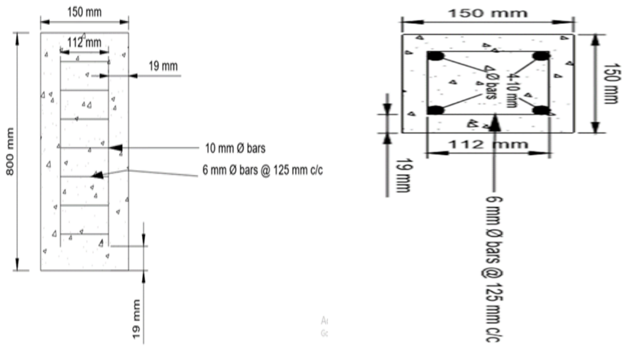
A suitable mix design ratio is used to prepare normal strength concrete according to the ACI standard. The expected compressive strength is 20 mpa after 28 days, but we find 19 Mpa. The ratio of cement to sand to coarse aggregate is 1:1.5:3, and the ratio of cement to water is 0.48.The nominal maximum size of coarse aggregate is 19 mm.

### 2.2 Preparation of Column

The specimens are cast into wooden formwork as beams because of the small size of the column section. Column specimens are demoulded after 24 hours from casting and are presented in Figure 2 and Figure 3.


a). Mixing procedure b). Slump test

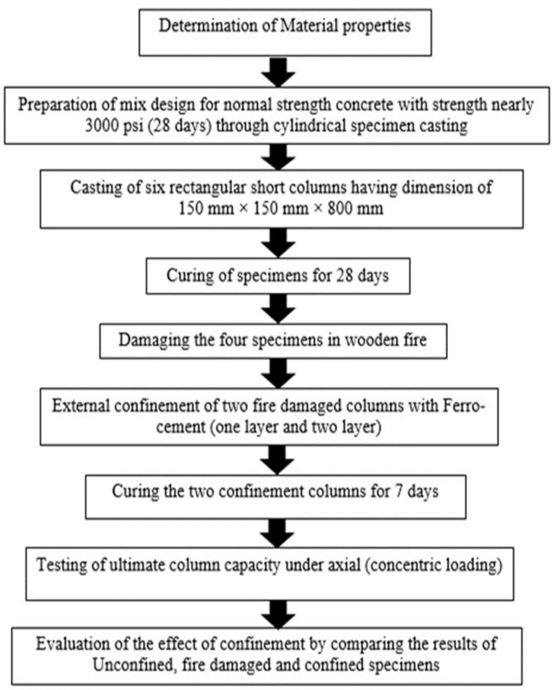
**Figure 2**. Preparation of Concrete




a. Longitudinal b. Cross-section

**Figure 3.** Proposed Sectional view

Total procedures are performed by a flow diagram, which is shown in the flowchart;

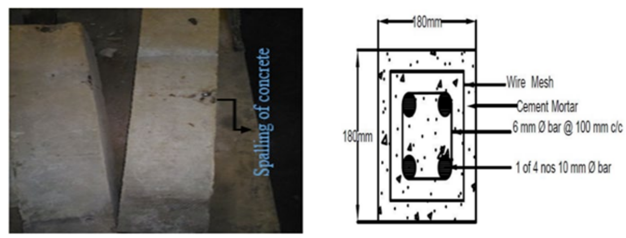



For heating the columns, a chamber is made using bricks, CI sheets, and steel reinforcements. The temperature is measured by a thermocouple and a digital meter. Figure 4. The highest temperature was 805 0c and the temperature varied at a range of 700-800 $^{0}$c for two hours and then cooled to room temperature. When the columns are cooled down, there are some cracks and spalling of concrete seen on the columns.

a. Casting b. Burning

**Figure 4.** Column casting and damaging

After fire damage, two samples are confined with a Ferrocement layer (one layer and two layers) are displayed in figure 5. A single layer square shaped steel wire mesh having a wire spacing of 10 mm and a thickness of 0.6 mm is used. A rich mortar ratio of cement/sand of 1:2 and a w/c ratio of 0.4 is selected. The sand is used, and the sample passing through the No.16 sieve is 80%. The confinement thickness is 15 mm on all sides, and the overlapping between the wire mesh layers is 75 mm, making the confined specimen dimension 180 mm × 180 mm × 800 mm. Hand plastering is used during the period of the confinement process. Mortar is pressed through the pores of wire mesh as presented in Figure 6. Plastering is properly done to ensure an even and smooth surface. The Ferro cement confined samples are further cured for 7 days, but the test is performed in 28 days.




a. After Burnt b). Cross section using Mesh

**Figure 5**. Burnt and strengthening beam

a. Retrofitted column b. Test by Testing Machine

**Figure 6.** Retrofitting and testing column

## 3.0 RESULTS AND DISCUSSION

The ultimate load-carrying capacities of normal strength columns after fire damaged and confined columns are determined from the testing under the universal testing machine. Lateral deformations at the mid-height of the specimens and vertical deformations from an adjusted scale are also recorded with an incremental load of 5 (kN). A load vs lateral deflection diagram for all types of specimens has been established through averaging the four dial gauge readings. The effect of confinement has been evaluated by comparing the results with unconfined and fire damaged specimens. The load capacity of the columns has decreased by about 46% after the fire damage. Further, the capacity is increased by 23% and 49% using Ferro cement confinement with one layer and two layers, respectively are displayed in Figure 7.

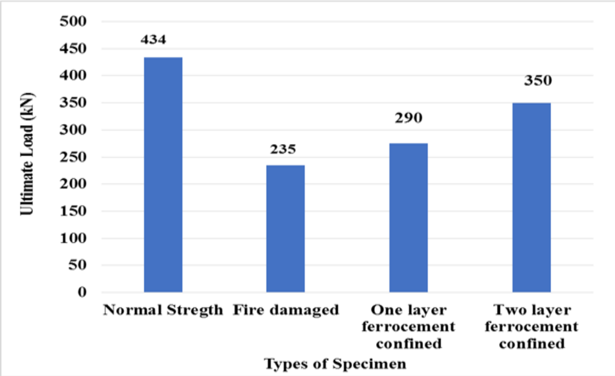


Figure 7: Comparison of Ultimate load capacities

The lateral (mid-height) deflections for the corresponding loads are observed from the dial gauge readings. The readings are averaged for the individual specimen categories and tabulated. Suitable graphs showing the comparison of deflection criteria among different confined, fire damaged, and unconfined specimens have also been plotted.

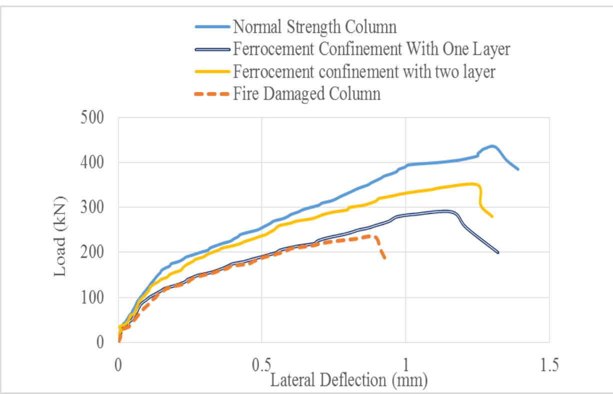


**Figure 8:** Comparison of load vs Lateral deflections for different specimens

Initially, the deflection in the two layered Ferrocement confined specimen was less than the unconfined specimen, and after the initiation of cracks in the Ferrocement layers, the deflection gradually increased in the mid-height zone. Compared to the two layered confined specimens, the one layered Ferro cement confined specimens produce more cracks at mid-height and produce more deflection. All the cases showed slow crack initiation and spread with respect to the same amounts of load over the unconfined and fire damaged samples are represented in figure 8.

The vertical deflection for the corresponding loads is observed by a digital scale attached to the universal testing machine. Proper graphs showing the comparison of deflection criteria among different confined, fire damaged, and unconfined specimens have also been plotted;

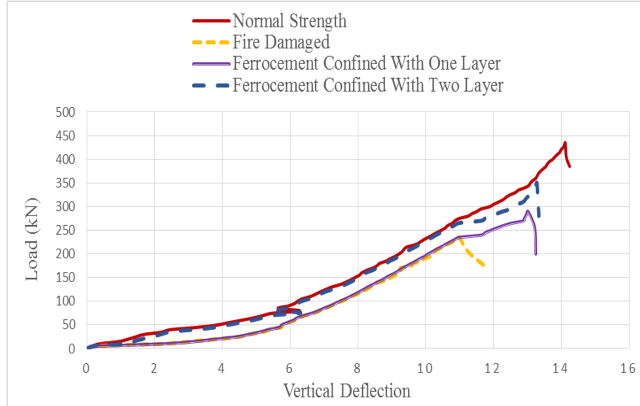


**Figure 9**: Comparison of load vs vertical deflections for different specimens

In Figure 9, the control specimen exhibits more deflection than other specimens and also resists more load compared to the other specimens. For a damaged specimen, it is shown that the vertical deflection increased early and continued until the failure of the specimen. The confined specimen shows better behavior than the fire damaged specimen.

Failure criteria and crack formation behaviors are shown in figure 10 of all the specimens are observed under the increasing load. The crack pattern for normal strength (unconfined), fire damaged, and Ferrocement confined columns is investigated in this section.

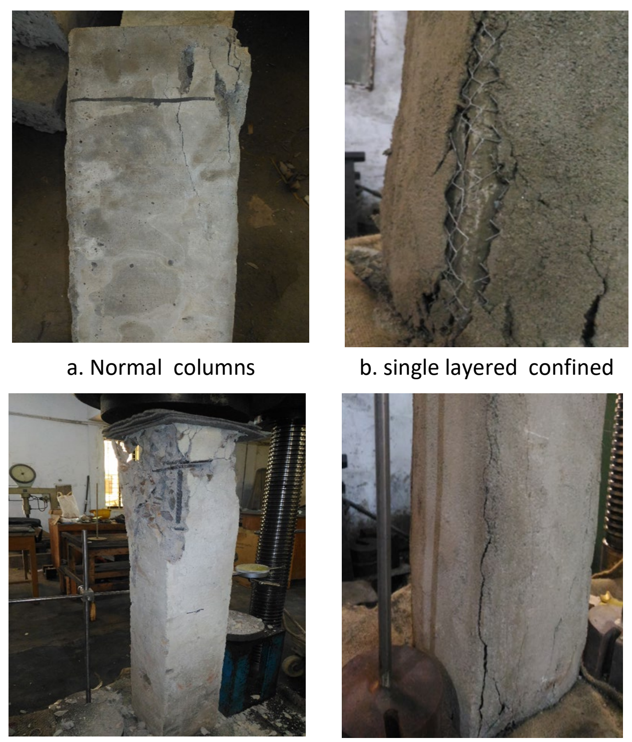

a. Normal columns b. single layered confined
c. Fire damaged columns d. Double layered confined

**Figure 10.** Cracking and failure pattern in columns

## 4.0 CONCLUSIONS

The behavior of loaded RC columns subjected to heating and cooling, and the repair of such damaged columns by wrapping with Ferro cement, the level of heating exposure considerably reduced the residual concrete compressive strength by about 46 %. The strength of RC columns increases directly in proportion to the number of Ferrocement layers. All the wrapped columns exhibit an enhancement in both strength and ductility. One-layered confined columns with strengthened edges increase load capacity by approximately 23% over fire-damaged specimens.For two layered Ferro cement confined columns, the load carrying capacity increases by about 49% over the fire damaged specimens. The Ferro cement confinement with two layers shows greater improvement than the confinement technique with one layer, both in load carrying capacity and slow crack formation.

Based on the findings of this research, it is considered that further research should be undertaken to fully characterize the complex behavior of Ferrocement materials and Ferrocement strengthened concrete structural members under elevated temperatures. Strengthening of fire-damaged RC columns is done using ferrocement under eccentric load. Strengthening of fire-damaged FRP can be used to reinforce concrete columns beneath under sustained load. However, the vertical steel bars could be replaced with FRP bars (sometimes done to prevent corrosion) and the effect of heating and cooling on the reinforced member considered.

## Acknowledgements

The author wants to express thankfulness to Almighty ALLAH at first that the research is completed. The author would like to express his greatest gratitude to his beloved parents and sister for their unconditional love, caring and passions. The author is also grateful to all the laboratory technicians, Department of Civil Engineering, KUET for their co-operation to this research.

## References

[1] Benzaid, R., Chikh, N. E. & Mesbah, H. 2008. Behaviour of square concrete column confined with GFRP composite WARP. *Journal of Civil Engineering and Management,* 14: 115-120.

[2] Kondraivendhan, B. and Pradhan B. 2009, "Effect of Ferrocement confinement on behavior of concrete*", Journal of Construction and Building Materials*; 23(3): 1218–22.

[3] Amin, A., Pial, M. A., Ahmad, M. & Ahamed, M. J. 2021. Comparison in Strengthening Of Rcc Concrete Column Using Ferrocement and Polypropylene Fiber Rope. *Eurasian Journal of Science Engineering and Technology*, 2 (1): 18-24.

[4] Xiong, GJ. Wu, XY, Li, FF., and Yan, Z., 2011, "Load carrying capacity and ductility of circular concrete columns confined by Ferrocement including steel bars", *Journal of Construction and Building Materials.* 25: 2263–68.

[5] Volety, I. V. 2006. "Modeling of Fiber Reinforced Polymer confined concrete cylinders". LSU Master's Theses. 3658.

[6] Kaish, A.B.M.A., Alam, M.R., Jamil, M., Zain, M.F.M. and Wahed, M.A. (2012), "Improved Ferrocement jacketing for re-strengthening of square RC short column", *Journal of Construction and Building Materials*; 36: 228–237.

[7] Amin, A., Tamal, S., Bari, A. K. M. F., Mazumder, M. & Hasan, M. A. (2022). Strengthening of fire damaged reinforced beams by using ferrocement. *Turkish Journal of Engineering*, 6(3): 206-210.

[8] Kaish, A. B. M. A., Jamil, M., Raman, S. N., & Zain, M. F. M. 2015. Axial behavior of Ferrocement confined cylindrical concrete specimens with different sizes. *Construction and Building Materials*, 78: 50-59.

[9] Amran, Y. M., Alyousef, R., Rashid, R. S., Alabduljabbar, H., & Hung, C. C. 2018. Properties and applications of FRP in strengthening RC structures: A review. In *Structures*. 16: 208-238. Elsevier.