Journal of Building Pathology and Rehabilitation (2022) 7:95
https://doi.org/10.1007/s41024-022-00227-5

RESEARCH ARTICLE

Residual load carrying capacity of un-stressed RC columns under fire

Bhargavi Eranki[1] · Potharaju Malasani[1]

Received: 1 June 2022 / Revised: 28 July 2022 / Accepted: 29 July 2022

Abstract
The present research work is carried out to investigate the effect of cover, temperature, and fire duration on the residual load carrying capacity of unstressed Reinforced Concrete (RC) columns exposed to fire. Experiments were conducted at increased temperatures of 300,500, and 800 °C on 150 × 150 mm RC columns with an L/D ratio of 4, concrete covers of 20,30, and 40 mm, and fire durations of F30 (0.5 h), F60 (1.0 h), F90 (1.5 h), and F120 (2.0 h). Additionally, the residual compressive strength of plain concrete (same batch mix of columns) was evaluated after being exposed to similar fire durations. At all temperatures and fire durations, the percentage residual load carrying capacity of 30 and 40 mm cover columns is almost identical. The residual load carrying capacity decreased with the increase in the temperature. Maximum loss occurred at 800 °C, the loss being 28.10%, 36.15%, 44.69% and 55.34% at 0.5, 1.0, 1.5 and 2.0 h respectively in columns with 40 mm cover. The results of compressive strength of concrete are in good agreement with the column results.

Keywords Residual load carrying capacity · Residual compressive strength · Fire duration · RC column

1 Introduction

Along with other natural disasters, fire is regarded as one of the most destructive sources of structure destruction. If fire breaks out in a structure, the temperature rises and the structural materials fail due to differential thermal expansion coefficients. Reinforced concrete is a widely utilised structural material throughout the world. The principal components of RC structures and bridges, such as slabs, beams and columns, may crack and lose bearing capability if they are exposed to an accidental fire. Component member failure can lead to partial or complete collapse of structures; hence RC columns are crucial components in many structures. The various parameters such as cross-section area, fire duration, temperature, cover thickness, diameter of main reinforcement, concrete grade, percentage of main reinforcement, applied load during fire etc**.,** affect the load carrying capacity of RC columns when subjected to fire [1]. If a structure is damaged by fire, its residual compressive strength can be used to determine whether it should be retrofitted or demolished and rebuilt. Many experimental studies in stressful conditions, such as the application of compressive load during heating and cooling, have been done to determine the compressive strength of post-fire concrete. A very few studies are available in unstressed condition. The unstressed residual strength test has been argued to be more prudent in evaluating the post-fire or residual characteristics of concrete [2–5]. Yaqub M [6] reported that the residual compressive strength of unstressed concrete on the seventh day after cooling to ambient temperature following exposure to 200 °C, 300 °C, 450 °C, 500 °C, and 550 °C was found to be 80%, 76%, 60%, 47%, and 30% of the original value, respectively. Zahid MZA [7] conducted experiments on square and circular RC columns with dimensions of 150 × 150 × 500 mm and 155 mm diameter, respectively, exposed to 600°C for 2 h to investigate the residual load carrying capacity in the unstressed state. According to the study, circular and square columns' strength was reduced by 49% and 51%, respectively. A concrete cube's compressive strength has dropped to approximately 53% of its original value. M. Shariq [8] investigated experimentally, residual load bearing capacity of 100 × 450 mm concrete reinforced cylinders under unstressed condition at increased ranging temperatures from 200 to 800 °C, with 200 °C intervals, for a 3 h holding period. When compared to the bearing load

✉ Bhargavi Eranki
vbhargavi1974@gmail.com

Potharaju Malasani
pmalasan@gitam.edu

[1] Department of Civil Engineering, GITAM, Deemed to be University, Visakhapatnam, Andhra Pradesh, India

capacity at ambient temperature, the reported percentage loss in residual load carrying capacity after heating at 200, 400, 600, and 800 °C is 24.5percent, 38.8percent, 63.3percent, and 83.7percent, respectively.

2 Experimental study

2.1 Casting

In this experimental work, 36 square RC columns with a dimension of 150 × 150 × 600mm and a longitudinal reinforcement of 2% were cast to determine the residual load carrying capacity after a fire. As a control column set, a single set of three columns was used. 36 cubes 150 × 150 × 150 mm in size were cast to determine the residual compressive strength of concrete after a fire. The columns were strengthened longitudinally with 4#12 mm diameter HYSD (Fe500) and transversely with 8 mm dia@150mmc/c mild steel (Fe250). Figure 1 illustrates the columnar placement of reinforcement. The columns were horizontally cast with the aid of wooden moulds.

Three columns and three cubes were cast simultaneously from a single batch of concrete and cured under water for 28 days to test the concrete's strength. The concrete mix consists of river sand, 10 mm and 20 mm crushed stone aggregate, and 53-grade Ordinary Portland Cement (OPC). The mix proportion was designed to obtain a characteristic compressive strength of 25 MPa after 28 days. The concrete mix contained 300 kg m^{-3} cement, 150 kg m^{-3} water, 752 kg m^{-3} sand and 1236 kg m^{-3} crushed stone aggregate (Fig. 2).

2.2 Heating

In this study, RC columns were heated at different temperatures of 300 °C, 500 °C, and 800 °C for 0.5, 1.0, 1.5, and

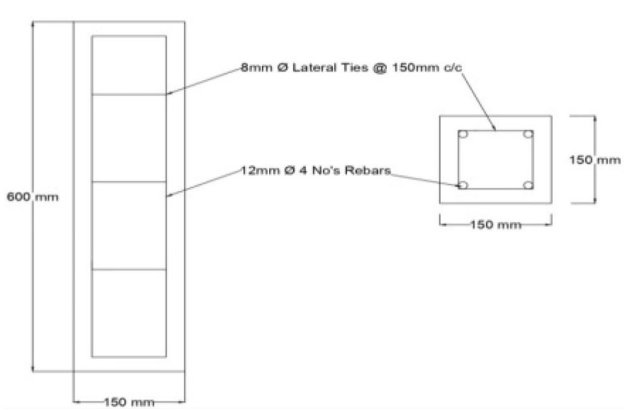

Fig. 1 Reinforcement placement in column

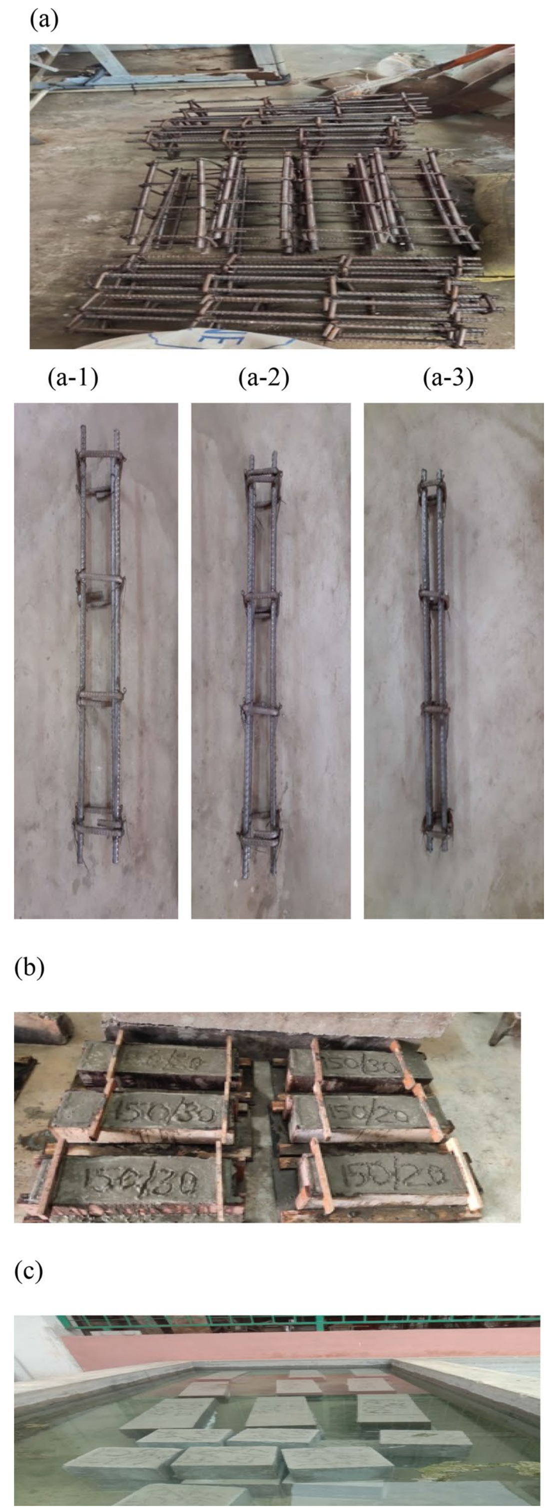

Fig. 2 **a** Reinforcement cages, **a-1** 20 mm cover cage, **a-2** 30 mm cover cage, **a-3** 40 mm cover cage **b** casting in wooden moulds **c** curing under water

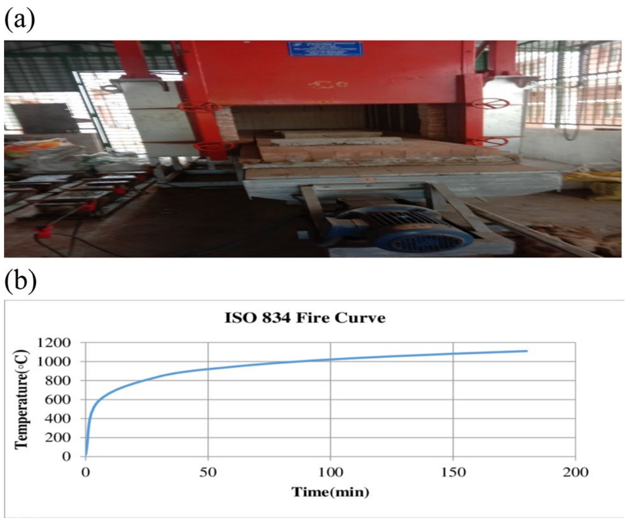

Fig. 3 **a** Bhogie Hearth Furnace **b** time-temperature curve

2.0 h in a Bhogie Hearth Furnace. The heating chamber measures 750 × 600 × 2000mm. The furnace operates at a temperature range of 25–1200 °C. The heating profile of the furnace complies with the ISO 834 fire rating standard. Three columns and three cubes are heated simultaneously to a specified temperature for a predetermined duration without applying load (Fig. 3).

2.3 Testing

The load bearing capacity of the unheated and heated columns was determined using axial concentric loading in a 1000 kN UTM. The initial crack load, ultimate load, and breaking load were all recorded during the testing. To determine the compressive strength of concrete, pre- and post-heated cubes were loaded under a compressive testing machine (Fig. 4).

3 Results and discussions

3.1 Residual compressive strength

To determine the residual compressive strength of concrete cubes heated to 300 °C, 500 °C, and 800 °C in an unstressed state, they were compressed in a compression testing machine. The percentage residual compressive strength of post-heated cubes is illustrated in Fig. 5 as a function of temperature over a range of fire durations. At a specific temperature, the percentage residual compressive strength is represented as the ratio of the percentage compressive strength of post-heated concrete cubes at that temperature to the compressive strength of unheated concrete cubes.

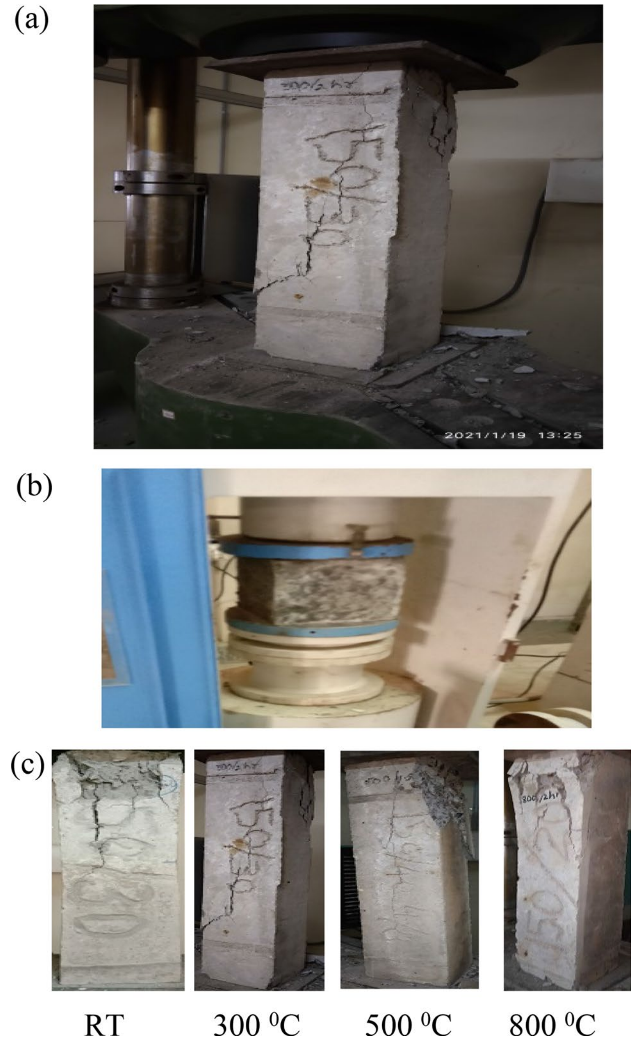

Fig. 4 **a** column test set up **b** cube test set up **c** tested columns at room temperature-RT, 300 °C, 500 °C, 800 °C

As illustrated in Fig. 5, the % residual compressive strength decreased slightly around 300 °C. At 500 °C and

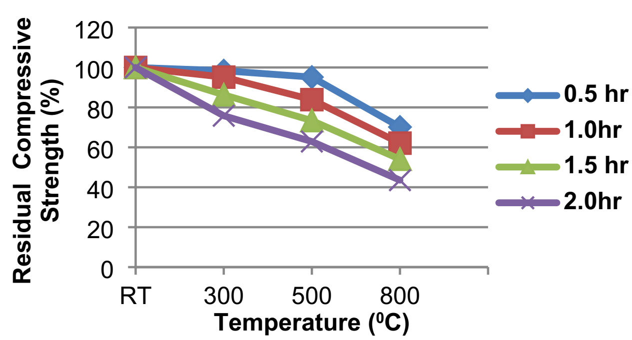

Fig. 5 Percentage residual compressive strength variation with temperature

higher, it decreased significantly. This is because calcium silicate begins to breakdown into quick lime and silica at temperatures exceeding 450 °C. The percentage residual compressive strength falls as the temperature and exposure time rise. This is consistent with [M.Yaqub's] findings. At 0.5 h exposure, the percentage residual compressive strengths were 98.38, 95.16, and 70.16 at 300 °C, 500 °C, and 800 °C, respectively; at 2 h exposure, they were 75.80, 62.90, and 43.54 at 300 °C, 500 °C, and 800 °C, respectively.

3.2 Temperature VS percentage residual load carrying capacity

The RC columns heated to 300 °C, 500 °C and 800 °C in unstressed condition, were tested in hot state in UTM to assess the Residual Load Carrying Capacity. At a certain temperature, the percentage residual load carrying capacity is represented as the ratio of the percentage load carrying capacity of post-heated RC columns at that temperature to the load carrying capacity of un-heated RC columns. The Figs. 6, 7, and 8 illustrate the variation in the % residual load carrying capacity of columns as a function of temperature for varied fire durations and concrete covers of 20, 30, and 40 mm.

It was observed from the Figs. 6, 7 and 8 that the percentage residual load carrying capacity of columns decreases with the rise in temperature irrespective of duration. This is an agreement with the findings of [M. Shariq]. The maximum percentage residual load carrying capacity of columns after heating to 300 °C, 500 °C, and 800 °C was reported to be 70, 60, and 40, respectively. The reduction in load carrying capacity with temperature may be attributed to the bond failure.

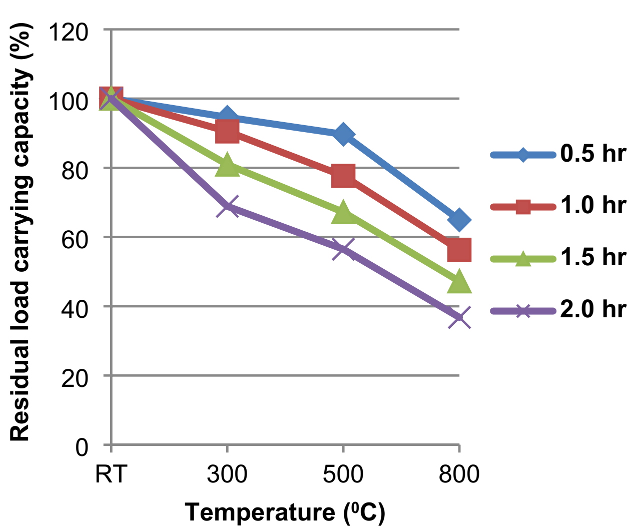

Fig. 6 percentage residual load carrying capacity variation with temperature for 20 mm cover

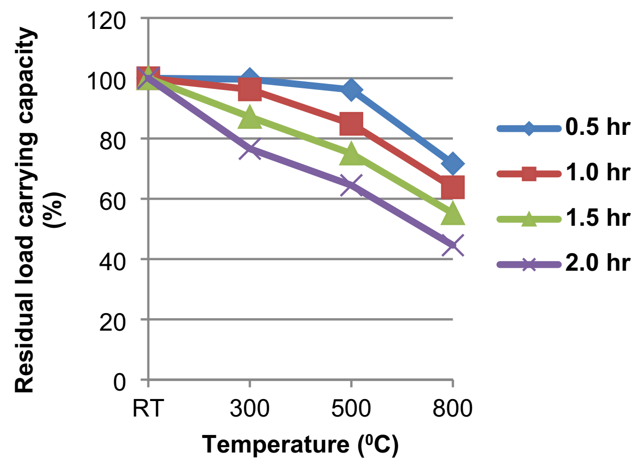

Fig. 7 percentage residual load carrying capacity variation with temperature for 30 mm cover

3.3 Concrete cover VS percentage residual load carrying capacity

It was observed from the Figs. 6, 7 and 8 that the percentage residual load carrying capacity of columns increases with the increase in concrete cover. Higher is the cover higher is the load carrying capacity. The load carrying capacity is less affected in the initial hours of fire exposure compared to later hours. This may be attributed to the less propagation of heat in the initial hours. The least percentage residual load carrying capacity was found to be 36.79, 44.59, and 44.65, respectively at 20, 30 and 40 mm covers heated to 800 °C for 2 h. It was observed that though residual load carrying capacity increases with cover, at 30 and 40 mm covers,

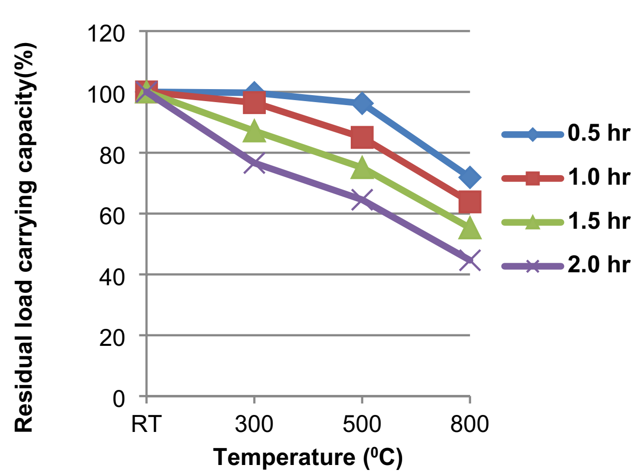

Fig. 8 percentage residual load carrying capacity variation with temperature for 40 mm cover

the increase is marginal. Hence it can be concluded that the 30 mm cover is optimal.

3.4 Fire duration VS percentage residual load carrying capacity

Figures 6, 7, and 8 illustrate that the percentage residual load carrying capacity reduces as the fire duration increases. The effect of fire duration during the initial hours has a smaller effect on the percentage residual load carrying capacity. After heating to 300 °C for 0.5, 1.0, 1.5, and 2.0 h, the maximum reported loss of residual load carrying capacity was 0.3%, 3.5%, 12.8% and 23.3%, respectively. It was reported that after heating to 500 °C for 0.5 h, 1.0 h, 1.5 h, and 2.0 h, the percentage residual load carrying capacity reduced by nearly 4%, 15%, 25%, and 35%, respectively. These findings are consistent with those of [9]. At 800 °C, the greatest loss of percentage residual load carrying capacities were found to be 28.10%, 36.15%, 44.69%, and 55.34%, respectively, when the exposure period of fire increased by 0.5 h, 1.0 h, 1.5 h, and 2.0 h.

4 Conclusions

Temperature, fire duration and concrete cover have significant influence on Residual load carrying capacity of columns exposed to fire.

The residual compressive strength of concrete reduces as the temperature and duration of the fire increases.

The percentage residual load carrying capacity of columns decreases with the rise in temperature. Columns exposed to 800 °C temperature lost their strength by more than 50% of their original strength.

Residual load bearing capacity of fire exposed column increases with the increase of concrete cover. The maximum loss of strength is found to be more at 800 °C that is 63.21%, 55.41%, and 55.34% corresponding to 20, 30 and 40 mm concrete covers.

Though the residual load carrying capacity increases with cover, the increase is marginal at 30 and 40 mm covers. Hence it can be concluded that the 30 mm cover is optimal.

The effect of fire duration is predominant at later hours compare to initial hours of fire duration. The maximum loss of strength is found to be more at 800 °C that is 28.10%, 36.15%, 44.69% and 55.34% corresponding to 0.5 h, 1.0 h, 1.5 h and 2.0 h.

Funding The authors did not receive support from any organization for the submitted work. No funding was received to assist with the preparation of this manuscript. No funding was received for conducting this study. No funds, grants, or other support was received. The authors have no relevant financial or non-financial interests to disclose. The authors have no competing interests to declare that are relevant to the content of this article. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. The authors have no financial or proprietary interests in any material discussed in this article.

Declarations

Conflict of interest The authors have not disclosed any competing interests.

Ethical approval This is an observational study. This study was reviewed and deemed exempt by our GITAM institutional Review Board.

Consent to participate and/or consent to publish Obtaining consent of anyone is not required for this study.

References

1. Bikhiet M, El-Shafey NF, El-Hashimy HM (2014) Behavior of reinforced concrete short columns exposed to fire. Alex Eng J 53:643–653. https://doi.org/10.1016/j.aej.2014.03.011
2. Abrams MS (1977) Compressive strength of concrete at temperatures to 1600F fire. PCA Res Dev Bull. https://doi.org/10.14359/17331
3. Phan LT (1996) Fire performance of high strength concrete. A report of the state of the art. National Institute of Standards and Technology, Gaithersburg
4. Purkiss AJ (2007) Fire safety engineering design of structures, 2nd ed
5. Hertz KD (2005) Concrete strength for fire safety design. Mag Concr Res 57(8):445–453. https://doi.org/10.1680/macr.2005.57.8.445
6. Yaqub M, Bailey CG (2016) Non-destructive evaluation of residual compressive strength of post-heated reinforced concrete columns. Constr Build Mater 120:482–493. https://doi.org/10.1016/j.conbuildmat.2016.05.022
7. Mohd Zahid MZA, Abu Bakar BH, Muhamad Nazri F (2006) Behaviour of post heated reinforced concrete columns. IOP Conf Ser. https://doi.org/10.1088/17551315/244/1/012006
8. Shariq M, Masood A, Umar A, Masroor Alam M, Haiyan A (2020) Residual load carrying capacity of reinforced concrete cylinders after heating at elevated temperature. SN Appl Sci 2:1671. https://doi.org/10.1007/s42452-02003483-7
9. Balaji A, Muhamed Luquman K, Nagarajan P, Madhavan Pillai TM (2016) Studies on the behavior of reinforced concrete short column subjected to fire. Alex Eng J 55:475–486. https://doi.org/10.1016/j.aej.2015.12.02