Available online at www.CivileJournal.org

Civil Engineering Journal

Vol. 5, No. 7, July, 2019

Effect of 12-hour fire on Flexural Behavior of Recyclable Aggregate Reinforced Concrete Beams

Abdul Hafeez Buller [a]*, Bashir Ahmed Memon [b], Mahboob Oad [c]

[a] *Postgraduate Student, Civil Engineering Department, Quaid-e-Awam University of Engineering Science & Technology Nawabshah, Sindh, Pakistan.*

[b] *Professor, Civil Engineering Department, Quaid-e-Awam University of Engineering Science & Technology Nawabshah, Sindh, Pakistan.*

[c] *Assistant Professor, Civil Engineering Department, Quaid-e-Awam University of Engineering Science & Technology Nawabshah, Sindh, Pakistan.*

Received 13 February 2019; Accepted 15 June 2019

Abstract

Fire being one of the hazards causes external and internal adverse effects on concrete. On the other hand, demolishing waste causes numerous environmental issues due to lack of proper disposal management. Therefore, this research work presents experimental evaluation of effect of 12-hur fire on flexural behavior of reinforced concrete beams made with partial replacement of natural coarse aggregates with coarse aggregates from demolished concrete. The model beams are prepared using both normal and rich mix. Natural coarse aggregates are replaced in 50% dosage. Also, the beams without recyclable aggregates are prepared to check the results of proposed beams. After 28-day curing all the beams are exposed to fire for 12-hour at 1000°C in purpose made oven, followed by testing in universal load testing machine under central point load. During the testing deflection, load, and cracks are monitored. Analysis of flexural behavior and cracking reveals that after 12-hour fire residual strength of the beams is 52%. This shows loss of the strength of reinforced concrete beams thus requires appropriate retrofitting decision before putting again the structure in service after fire. Observation of cracks shows that most of the beams failed in shear with minor flexural cracks. In comparison to the results of control specimen the proposed beams show good fire resistance. The outcome of the research will prove landmark for future scholars and help the industry personals in understanding the behavior of the material in fire.

Keywords: Cube Size; Fire; Flexural Behavior; Recyclable Aggregates; Demolished Waste; Recyclable Aggregate Concrete.

1. Introduction

Green concrete prepared by using alternatives of ingredients of conventional concrete has remained active area of research since couple of decades. Indeed, it is because green concrete is not only environment friendly but also allows preservation of natural deposits of the aggregates. Among several components of demolishing waste, large volumes are of the concrete. This concrete may be used as full or partial replacement of natural coarse aggregates. Several attempts have been made by different scholars around the globe to study the possibilities of using old concrete as coarse aggregates. Memon (2016) presented recent developments on the use of demolished concrete as coarse aggregates in new concrete [1]. Li et al. (2015) also published literature review regarding re-use of demolished concrete as coarse aggregates but they addressed the issue from 2005 to 2014. The authors reviewed possibility of using the old concrete in steel composite sections, reinforced concrete sections and long-term performance of concrete. From the review authors concludes that RC composite members have similar or slightly lower behavior for certain replacements of natural coarse aggregates with recycled coarse aggregates. Hence use of recycled old concrete as aggregates in steel composite

* Corresponding author: ah.buller@quest.edu.pk

http://dx.doi.org/10.28991/cej-2019-03091350

members will be beneficial structural applications [2]. Bhatti and Memon (2014) and Oad and Memon (2014) also made use of old demolished concrete as coarse aggregates in new concrete. In former research the authors studied strength, deflection and cracking behavior of concrete slabs, whereas, the latter article presents compressive strength of concrete cylinder. Both the research articles concluded promising results of the properties of concrete made with recyclable aggregates with negligible degradation of strength particularly with 50% replacement of natural coarse aggregates with old demolished concrete [3, 4].

During service life, the structure has to face several environmental effects, natural hazards or accidental hazards. Fire is one among these hazards which not only affects the appearance of the structures but also degrades several properties of it. The similar effects are definite with concrete made with old demolished concrete as coarse aggregates. Therefore, understanding of the behavior of this new material in and after fire is compulsory particularly with respect to build the confidence to put it again in service after fire. This motivates the research presented in this research paper. Although the effect of fire on green concrete made with full or partial replacement of its ingredients has been addressed by several scholars but the scatter of the results reveals that lot of more work is required in the area.

To check the effect of elevated temperature on normal and high strength concrete, Naus (2006) published review report [5]. Similar attempt has been made by Cree et al. (2013) to check the state-of-art on the mechanical properties of concrete made with partial or full replacement of natural coarse aggregates, particularly compressive strength after fire. Based on the review the authors conclude the paper with statement that still great deal of work is required to improve confidence regarding the behavior of the concrete made with old concrete as aggregates [6].

To study the mechanical properties of green concrete Vieira et al. (2011) used three replacement; 20%, 50% and 100%; of natural coarse aggregates with CA from old concrete. Specimens were then exposed to fire for 1-hour at three different temperatures; 400˚C, 600˚C and 800˚C. From the results of compressive and tensile strengths and modulus of elasticity author found no difference in post fire mechanical properties [7]. In a similar research by Marques et al. (2013), authors observed degradation of mechanical properties after exposing concrete to high temperatures, yet based on the behavior of the concrete authors concluded that careful use of the material in new concrete is possible [8].

In addition to old concrete, Malek et al. (2007) also used plastic and glass in new concrete. The author opted 20% replacement of fine and coarse aggregates. Old concrete is used as replacement of coarse aggregates and plastic and glass are used to replace the fine aggregates. From the experimental evaluation of basic properties of the proposed concrete authors observed that all three proposed materials can be used in new concrete without compromising on the basic properties of the concrete [9]. Buller and Memon (2014) also investigated the effect of fire on compressive strength of concrete cubes. The authors used 50% replacement of natural aggregates and exposed the specimen to fire for from 6 to 9-hour at 1000˚C. Comparison of the results with conventional concrete cubes showed negligible degradation of compressive strength [10]. Dong et al. (2014) also studied the performance of concrete columns with different compressive strengths exposed to fire. From the experimental results and results of simulation by ABAQUS, authors observed that performance of RAC column in fire is better than conventional concrete columns having same compressive strength [11]. Wu and Ji (2018) used u-shaped steel beams filled with demolished concrete lumps and fresh concrete. Demolished concrete lumps are old concrete pieces larger than coarse aggregates size. The authors used these specimens to study various parameters like dosage of demolished concrete lumps, temperature distribution, longitudinal steel ratio, load ratio and thermal insulation. From the obtained results the authors observed very limited effect of fire for demolished concrete lumps in the range of 0% - 33%. They also developed numerical method to predict the proposed parameters for u-shaped beams [12]. Ahmed et al. (2018) studied Shear transfer capacity of reinforced concrete elements exposed to elevated temperatures. The author’s states that shear transfer capacity being function of compressive strength of concrete and yield strength of steel used as reinforcement will get affected if the member is exposed to fire. To check their idea authors used exposed push off specimens to temperature ranging from 250°C and 500°C in an electric furnace. From the test results authors observed reduction in shear transfer capacity, stiffness and crack initiation load with increase in temperature [13].

Sabeur el al. (2019) used thermal analysis and x-ray diffraction techniques to study the thermal stability and microstructural changes in five-year aged cement paste subjected to high temperatures. The authors used cement mortar blocks and air-cooling regimes to study the impact of fire up to 1000˚C in increments of 100˚C for 6-hours. Using 2-year old powdered cement paste authors demonstrated the effectiveness of proposed technique for the purpose [14]. In another experimental study Kigha et al. (2015) evaluated effect of thickness of concrete cover and temperature on the strength of reinforced concrete beams. The authors used different thicknesses of concrete cover to 16 mm diameter bars embedded in concrete and exposed to fire up to 700˚C. After fire bars were taken out of the beams and tested for tensile strength. The comparison of results revealed no significance of thickness of concrete cover on tensile strength in the temperature is less than 700˚C [15]. Sun et al. (2018) used numerical procedure to model reinforced concrete beams exposed to fire. The authors used one dimensional spectral approach to model mechanical response under increasing loads and 2D FEM to model thermal behavior. Both models were integrated to each other. The comparison of results demonstrates validity of proposed approach [16].

Effect of fire on strength of RC structural members using slabs, beams and cubes cast with local aggregates and exposed to fire was studied by Onundi el al. (2019) [17]. The authors exposed the 28-day cured samples to fire for 2-hours followed by cooling using water splashing, CO_2 powder fire extinguisher and air cooling. From the destructive and non-destructive tests of samples author observed that different cooling techniques have different impact on the strength of the members. Comparison of results showed 37.73% to 86.67% (minimum to maximum) loss of strength. Effect of high temperature on physical and mechanical properties of carbonated concrete was studied by Xie et al. (2019) [18]. For the purpose authors used 75 prism specimens divided in to five groups. The samples were exposed to fire from 3 to 6 hours at different temperatures ranging from 300˚C to 700˚C. The authors observed that strength and elastic modulus of naturally cooled specimen was higher than water cured specimens. It was also observed that peak and ultimate strength of proposed material increased after heating but remained lower than uncarbonated cement in same conditions. The authors also coined out a numerical expression for compressive strength of carbonated concrete exposed to high temperatures and validated it by comparing the results with test data.

From the above discussion it is clear that, although several attempts have been made to explore the fire effect on green concrete, yet lot more work is required to establish reasonable confidence level in use of the green concrete. This motivates the experimental investigation of effect of fire on green concrete made with partial replacement of natural coarse aggregates with old demolished concrete. The test results of reinforced concrete beams exposed to fire and tested for flexural behavior are given in relevant sections. It is hoped that the outcome of this work will be very useful in understanding the behavior of reinforced green concrete beams exposed to fire and will lead to proper decision of repair and retrofitting strategies before putting such fire exposed structures in service.

2. Materials and Methods

The old concrete blocks were collected from demolishing waste of a school building about 45 years old. The building was unable to meet the need of large number of admissions. Therefore, it was demolished to construct ground plus two story to meet the space demand. These large blocks were manually hammered to produce coarse aggregates of about 25 mm. After washing and removal of unwanted substance, the aggregates were screened for cracked particles. Despite of all care taken in hammering, the process may produce cracked particles which in turn if used in concrete will result in week product. After screening both natural and old concrete aggregates were sieved in standard manner for well graded material to be used in concrete. Figure 1 shows the grading curve of both natural and recyclable aggregates. It may be observed that both curves have same pattern. Also, the percentage passing from each sieve confirms with the prescribed values of the relevant standards.

In this work 50% replacement of natural coarse aggregates with old demolished concrete is used. The selection of 50% replacement is based on the conclusion on Oad and Memon (2014) [4]. These aggregates along with hill sand, ordinary Portland cement and potable water were used in casting of 48 reinforced concrete beams. The beams are cast using two concrete mix ratios; normal mix (1:2:4) and rich mix (1:1.5:3) The water cement ratio for both concrete mixes is kept same equal to 0.5. To reinforce the beams deformed steel is used. 2#4 bars are used in each tension and compression zones. Shear reinforcement in the form of stirrups (#3 bars) were used at 150 mm center to center along full length of the beams. The size of all beams is kept equal to 900 mm x 150 mm x 150 mm. The details of all beams cast in batches are given in Table 1.

After casting all beams are cured for 28-day by fully immersing in water. After curing all the beams except control specimens are exposed to fire for 12-hour at 1000°C in purpose made oven. Wood was used as source of fire. The temperature was monitored by digital thermometer and maintained accordingly. After elapse of fire exposure time, source of fire was cut-off and beams were left in oven to cool down. It is opted to avoid the sudden moisture attack on fire exposed concrete beams, which deteriorates the surfaces of beam badly.

Table 1. Details of the beams

Batch	No. of Beams	RCA Dosage (%)	Fire Duration (Hour)	Concrete Mix
B1	6	0	0	1:2:4
B2	6	50	0	1:2:4
B3	6	0	12	1:2:4
B4	6	50	12	1:2:4
B5	6	0	0	1:1.5:3
B6	6	50	0	1:1.5:3
B7	6	0	12	1:1.5:3
B8	6	50	12	1:1.5:3

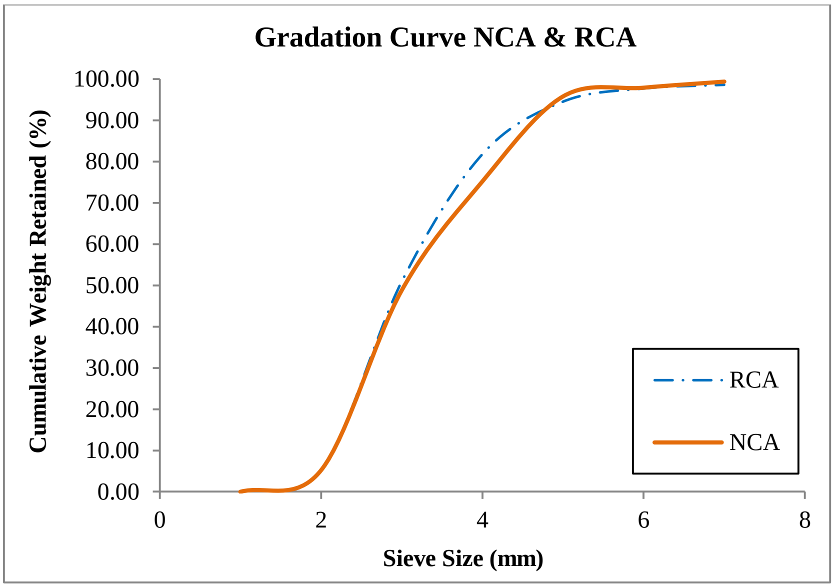


Figure 1. Sieve analysis of both NCA and RCA

All the beams are then tested in universal load testing machine in turn with central point load in accordance with the procedure specified by ASTM [19]. The load was applied gradually at the rate of 0.5 kN/s. During testing load, deflection and crack pattern are monitored at regular intervals. The deflection is monitored using dial gauges. The electronic display of the machine was utilized to monitor and record the load. Visual inspection and photographs of the beams was made to record the cracks. At failure, maximum load sustained, maximum deflection and cracking pattern is recorded.

3. Results and Discussion

The load and deflection monitored at increment of about 5kN for all eight batches of reinforced concrete beams are plotted in Figures 2 to 5. In each figure subplot (a) shows load vs. deflection of beams made with all-natural aggregates and subplot (b) shows the same for reinforced concrete beams with the 50% replacement of natural aggregates with recyclable aggregates. It may be noted from the figures that all the beams observed reduction in maximum attained load. Also, increase in deflection due to induction of recyclable aggregates is observed. Further, reduction in load and increase in deflection due to exposure to fire is also recorded. However, it may be noted form the figures that except few minor jerks both maximum load and maximum deflection remained within the 15% range. It may also be observed from the figure that trend of load vs. deflection is similar for all beams. This shows similarly of performance of both groups of the beams, hence the good performance of the recyclable aggregates in new concrete.

It is noted that RC beams of batch B2 observed 4.01% less load than control specimens (B1) and the maximum load reduced by 38.51% when these beams (B4) are exposed to fire for 12-hour, whereas, batch B3 beams (cast with all-natural aggregates) observed 29.06% reduction in maximum load due to 12-hour fire. Analogous to normal mix beams rich mix beams also observed reduction in maximum load due to use of recyclable aggregates and fire exposure. With respect to control specimens of rich mix beams (B5), the beams made with recyclable aggregates (B6) observed 2.96% reduction in load. When these beams (B8) were exposed to fire, reduction in load is recorded equal to 48%. The reduction in load of the same beams (B8) in comparison to control specimens of normal mix (B1) observed 42.38%. It may be inferred from above discussion that the maximum reduction observed by normal mix beams due to both recyclable aggregates and exposure to fire is equal to 48%. Whereas, the same for rich mix beams is equal to 42.38%. Rich mix beams are supposed to be stronger than normal mix beams, therefore percentage reduction in maximum attained loads is less compared to normal mix beams. Impact of fire on normal mix reinforced concrete beams is more as it contains more quantity of aggregates than rich mix beams.

Flexural strength is computed using numerical expression given by ASTM [19] for point load at center. Average of all six beams in the batch is evaluated for all batches. The average load, maximum deflection and average flexural strength of all batches of the beams are listed in Table 2.Computed flexural strength for normal and rich mix reinforced concrete beams is also plotted in Figure 6 (all batches of normal mix beams) and Figure 7 (all batches of rich mix beams). It is important to note that the percentage reduction of flexural strength is same as that of maximum attained load for all beams. It may also be noted that flexural strength of recycled aggregate reinforced concrete beams cast in rich mix observed 5.72% less reduction than the same beams cast with normal mix. Therefore, flexural capacity and flexural behavior of rich mix concrete beams is observed better than normal mix in fire of 12-hour duration.

Table 2. Average Load, flexural strength and Maximum deflection

Batch	Average Load (kN)	Maximum Deflection (mm)	Average Flexural Strength (MPa)
B1	71.54	4.69	28.62
B2	68.67	5.04	27.47
B3	50.75	6.71	20.3
B4	43.99	7.05	17.6
B5	79.26	4.7	31.7
B6	76.92	5.3	30.8
B7	48.45	7.9	19.4
B8	41.22	8.4	16.5

During testing of the reinforced beams cracks are monitored carefully. It is noted that due to exposure to fire several hairline cracks appears on the surfaces of the beams. Therefore, initiation of cracks during testing process is very difficult to monitor. It is possible that new crack, other than already present cracks may initiate, but checking and monitor it is extremely difficult. Therefore, it was not possible to record first crack load. Most of time it is observed that already present cracks on the surfaces of beams propagates due to increase in load. Cracking at failure are recorded and analyzed. Crack pattern at failure for selected beams is shown in Figure 8. At failure almost all the beams observed shear cracks and arching action. Few beams also observed flexural cracks along with shear cracks. Therefore, shear failure in beams is recorded. This confirms with theoretical basis of good performance of the beams.

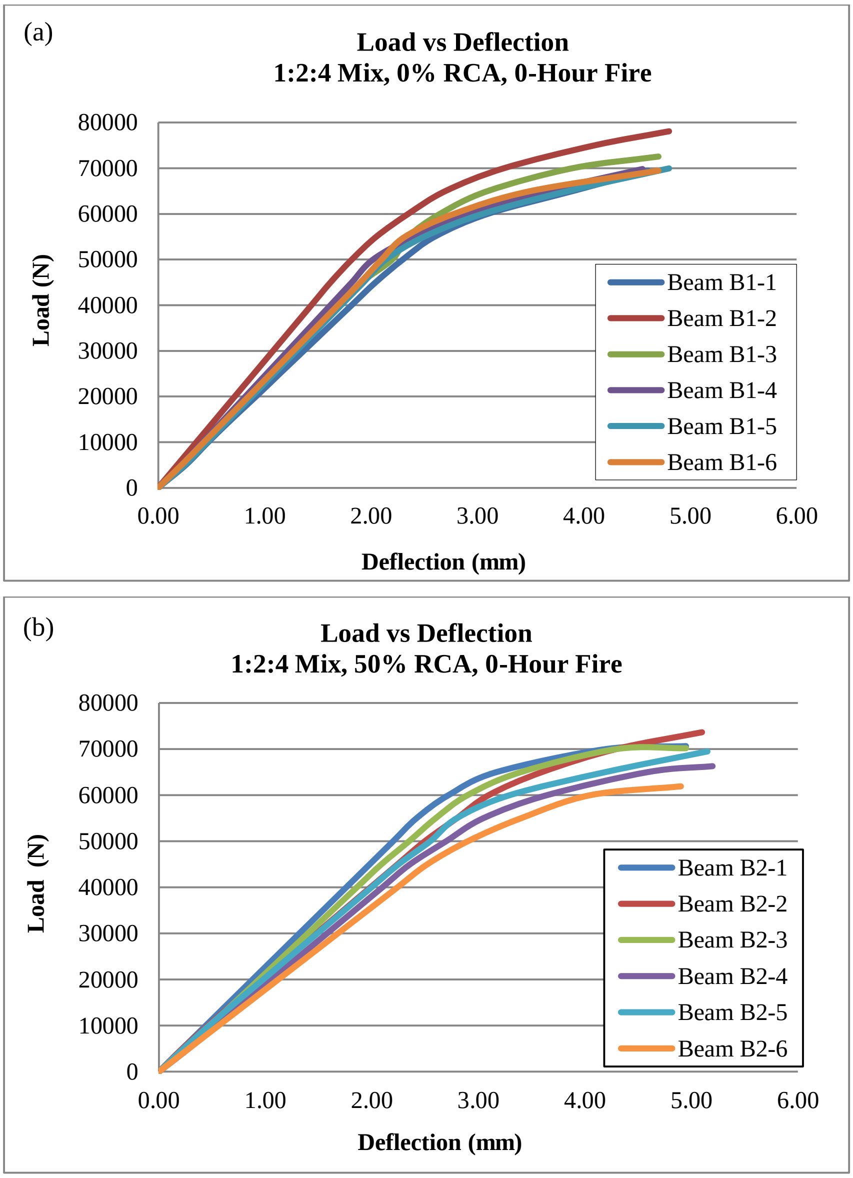


Figure 2. Load vs. deflection – 1:2:4 mix, 0-hr fire. (a) 100% NA; (b) 50% NA and 50% RCA

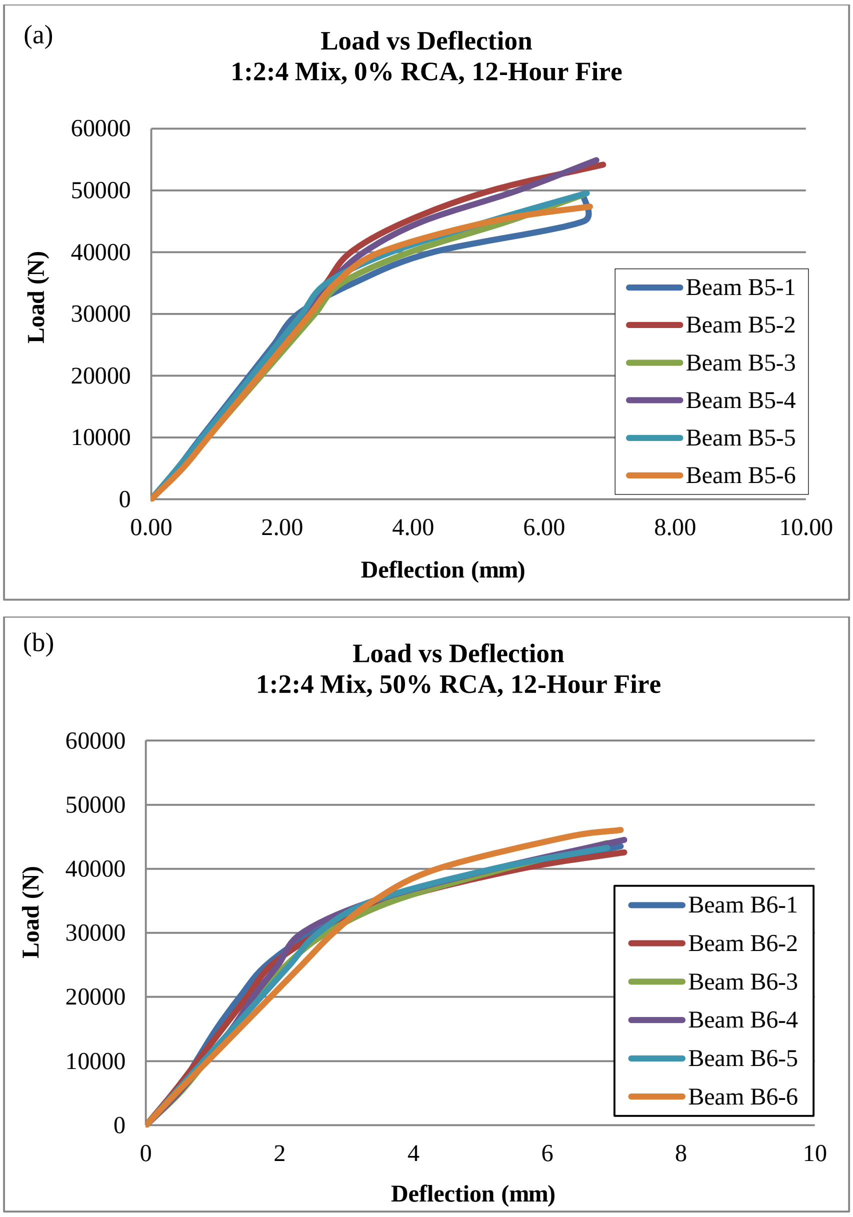
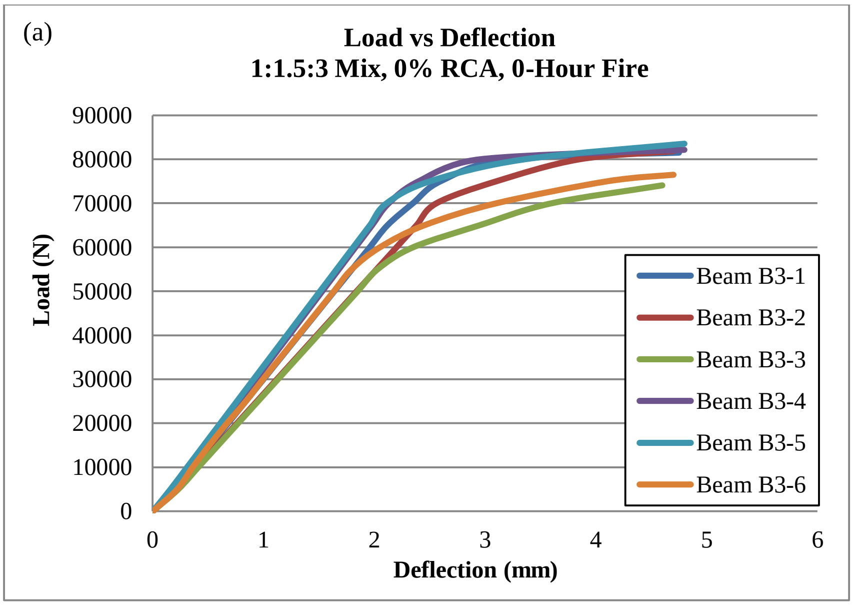


Figure 3. Load vs. deflection – 1:2:4 mix, 12-hr fire. (a) 100% NA; (b) 50% NA and 50% RCA



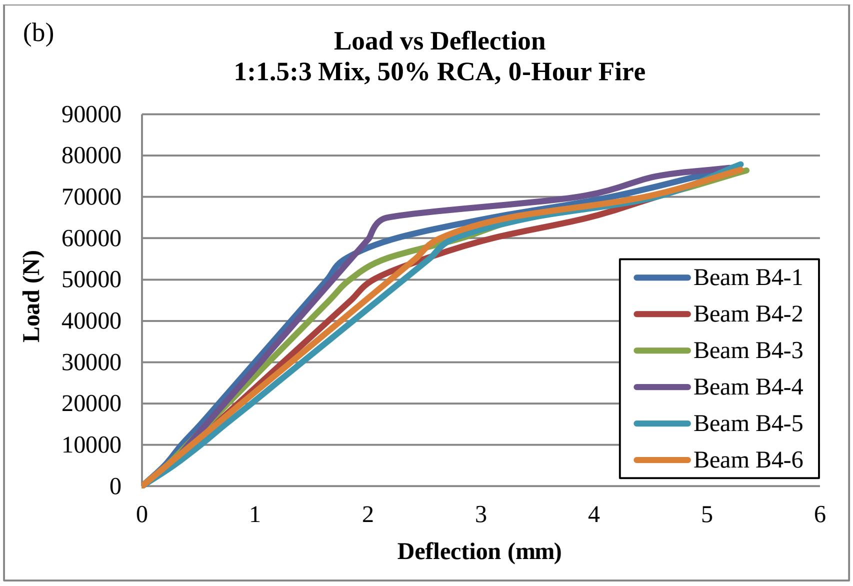
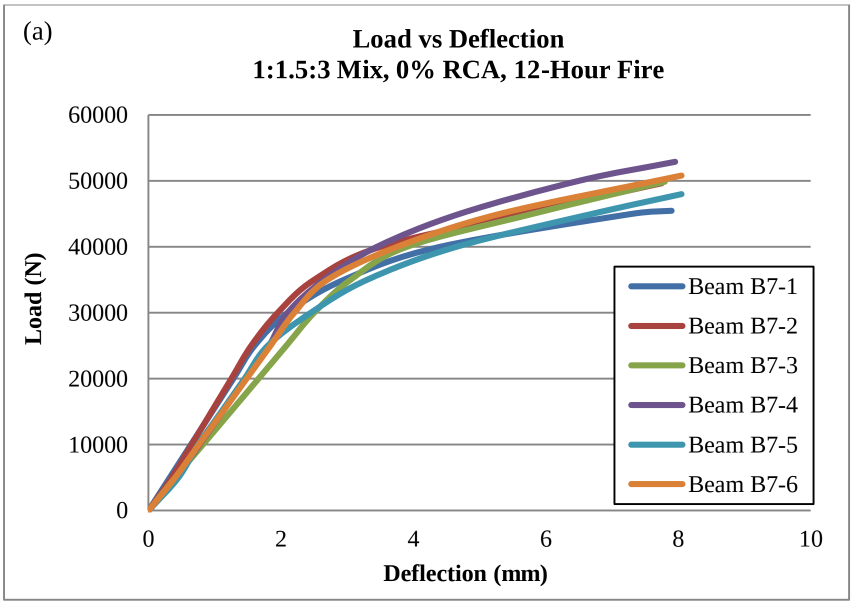


Figure 4. Load vs. deflection – 1:1.5:3 mix, 0-hr fire. (a) 100% NA; (b) 50% NA and 50% RCA



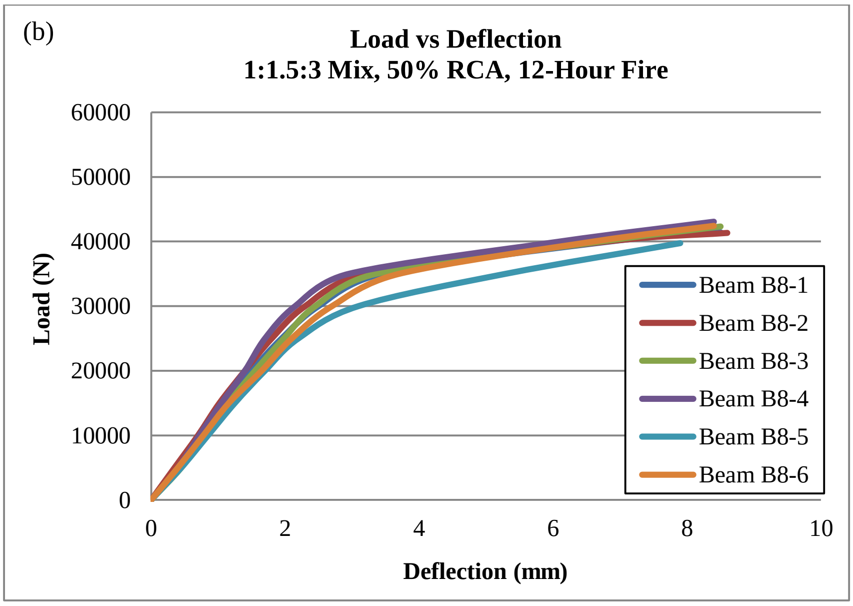


Figure 5. Load vs. deflection – 1:1.5:3 mix, 12-hr fire. (a) 100% NA; (b) 50% NA and 50% RCA

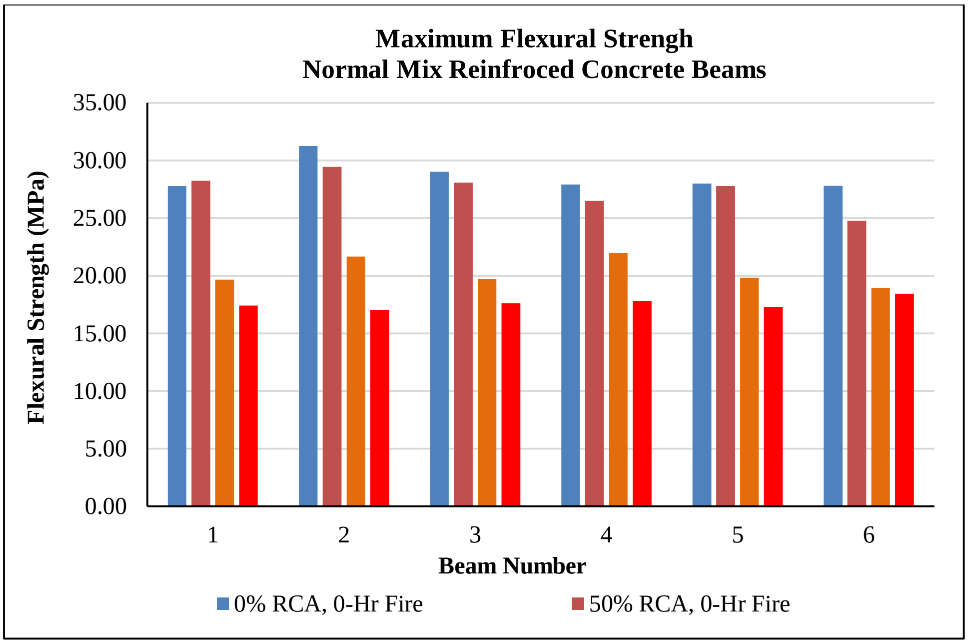


Figure 6. Maximum flexural strength (normal mix)

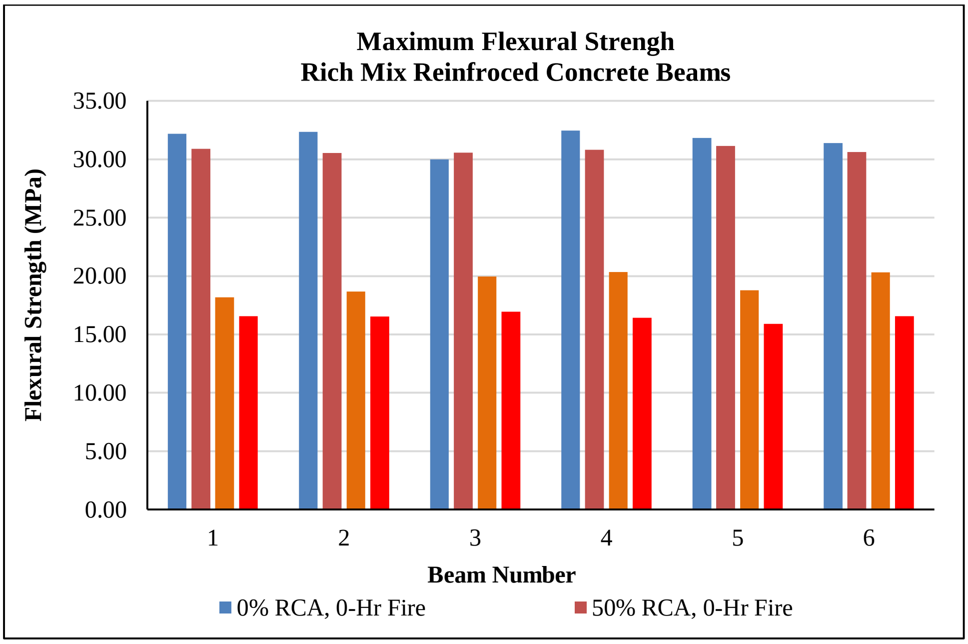


Figure 7. Maximum flexural strength (rich mix)

Figure 8. Crack pattern in RC beams

4. Conclusion

This research work was aimed to evaluate the effect of 12-hour fire exposure at 1000°C on the reinforced concrete beams made by using 50% replacement of natural coarse aggregates with recyclable concrete aggregates from demolished concrete. Old demolished concrete was collected from demolishing of a local school building. Large blocks of demolished concrete were reduced to required size followed by cleaning and sieving. The model beams were cast using both 1:2:4 and 1:1.5:3 mix and cured for 28-days. The beams were then exposed to fire in oven for 12-hours at above mentioned temperature. After 24-hours of elapse of fire duration, the beams were tested under central point load till failure. The comparison of obtained results shows similar trend of load vs deflection of proposed beams in comparison to control specimen. Increase in deflection and reduction in peak load is recorded in all beams. The maximum loss of flexural strength is recorded equal to 48% in normal mix reinforced concrete beams. Whereas, the performance of rich mix reinforced concrete beams is observed better than normal mix beams.

Analysis of cracks reveals that dominant failure pattern in all beams remained shear failure with shear cracks. However, in some beams shear cracks were augmented with flexural cracks also. The load-deflection pattern and failure mode of proposed beams shows better performance of proposed material in reinforced concrete beams. However, as residual strength of the beams is only 52% therefore, it requires proper decision of retrofitting before putting the structure in service again.

5. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] Memon, Bashir Ahmed. "Recent development on use of demolished concrete as coarse aggregates." International Journal of Emerging Technology and Innovative Engineering 2, no. 1 (2016): 1-11. doi: 10.13140/RG.2.2.34109.92648.

[2] Li, Wengui, Jianzhuang Xiao, Caijun Shi, and Chi Sun Poon. "Structural Behaviour of Composite Members with Recycled Aggregate Concrete — an Overview." Advances in Structural Engineering 18, no. 6 (June 2015): 919–938. doi:10.1260/1369-4332.18.6.919.

[3] Bhatti, Asif Ali, and Bashir Ahmed Memon. "Strength, Deflection and Cracking Behavior of Concrete Slab Using Demolished Concrete as Coarse Aggregates." (2014): 492-506. doi: 10.13140/RG.2.2.15654.98882.

[4] Oad, M., and B. A. Memon. "Compressive Strength of Concrete Cylinders using Coarse Aggregates from Old Concrete." In 1st National Conference on Civil Engineering (NCCE 2013-14)-(Modern Trends and Advancements). April 28th – 29th, 2014. doi:10.13140/RG.2.2.20772.73602.

[5] Naus, Dan J. "The Effect of Elevated Temperature on Concrete Materials and Structures - a Literature Review", US Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Washington, (March 1, 2006). doi:10.2172/974590.

[6] Cree, D., M. Green, and A. Noumowé. "Residual Strength of Concrete Containing Recycled Materials after Exposure to Fire: A Review." Construction and Building Materials 45 (August 2013): 208–223. doi:10.1016/j.conbuildmat.2013.04.005.

[7] Vieira, J.P.B., J.R. Correia, and J. de Brito. "Post-Fire Residual Mechanical Properties of Concrete Made with Recycled Concrete Coarse Aggregates." Cement and Concrete Research 41, no. 5 (May 2011): 533–541. doi:10.1016/j.cemconres.2011.02.002.

[8] Marques, A.M., J.R. Correia, and J. de Brito. "Post-Fire Residual Mechanical Properties of Concrete Made with Recycled Rubber Aggregate." Fire Safety Journal 58 (May 2013): 49–57. doi:10.1016/j.firesaf.2013.02.002.

[9] Batayneh, Malek, Iqbal Marie, and Ibrahim Asi. "Use of Selected Waste Materials in Concrete Mixes." Waste Management 27, no. 12 (January 2007): 1870–1876. doi:10.1016/j.wasman.2006.07.026.

[10] Buller, A.H., and Memon, B.A., "Effect of Fire on Strength of Concrete Cubes with RCA as Coarse Aggregates", 1st National Conference on Civil Engineering (NCCE 2013-14) - (Modern Trends and Advancements), April 28th – 29th, 2014. doi:10.13140/RG.2.2.10404.94086.

[11] Dong, Hongying, Wanlin Cao, Jianhui Bian, and Jianwei Zhang. "The Fire Resistance Performance of Recycled Aggregate Concrete Columns with Different Concrete Compressive Strengths." Materials 7, no. 12 (December 8, 2014): 7843–7860. doi:10.3390/ma7127843.

[12] Wu, Bo, and Mingming Ji. "Fire Behavior of U-Shaped Steel Beams Filled with Demolished Concrete Lumps and Fresh Concrete." Applied Sciences 8, no. 8 (August 13, 2018): 1361. doi:10.3390/app8081361.

[13] Ahmad, Subhan, Pradeep Bhargava, and Ajay Chourasia. "Shear Transfer Capacity of Reinforced Concrete Exposed to Fire." IOP Conference Series: Earth and Environmental Science 140 (April 2018): 012146. doi:10.1088/1755-1315/140/1/012146.

[14] Sabeur, Hassen, Mickaël Saillio, and Julien Vincent. "Thermal Stability and Microstructural Changes in 5 Years Aged Cement Paste Subjected to High Temperature Plateaus up to 1000 °C as Studied by Thermal Analysis and X-Ray Diffraction." Heat and Mass Transfer (March 1, 2019). doi:10.1007/s00231-019-02599-w.

[15] Kigha, F, JA Sadeeq, and OS Abejide. "Effects of Temperature Levels and Concrete Cover Thickness on Residual Strength Characteristics of Fire Exposed Reinforced Concrete Beams." Nigerian Journal of Technology 34, no. 3 (June 27, 2015): 429-437. doi:10.4314/njt.v34i3.1.

[16] Sun, Rui, Bo Xie, Ricardo Perera, and Yongjun Pan. "Modeling of Reinforced Concrete Beams Exposed to Fire by Using a Spectral Approach." Advances in Materials Science and Engineering 2018 (July 18, 2018): 1–12. doi:10.1155/2018/6936371.

[17] Onundi, Lateef O., M. Ben Oumarou, and Abba M. Alkali. "Effects of Fire on the Strength of Reinforced Concrete Structural Members." American Journal of Civil Engineering and Architecture 7, no. 1 (2019): 1-12.

[18] Xie, Qifang, Lipeng Zhang, Shenghua Yin, Baozhuang Zhang, and Yaopeng Wu. "Effects of High Temperatures on the Physical and Mechanical Properties of Carbonated Ordinary Concrete." Advances in Materials Science and Engineering 2019 (February 17, 2019): 1–10. doi:10.1155/2019/5753232.

[19] ASTM C 293-02, "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Central Point-Loading", ASTM, International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, United States. doi:10.1520/c0293-02.