

24-hour Fire Produced Effect on Reinforced Recycled Aggregates Concrete Beams

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Abstract—In this article, the effect of prolonged fire (24-hour duration) on reinforced concrete beams made with recycled aggregates from demolished concrete was experimentally investigated. Demolished concrete was used recycled coarse aggregates in equal proportion with natural coarse aggregates. Normal and rich mix concrete with water-cement ratio equal to 0.54 were used. As a control specimen, beams with all-natural aggregates were also cast to compare with the results of the proposed beams. All beams were cured for 28 days and exposed to fire at 1000°C in an oven for 24 hours. After the elapse of this fire period, the beams were allowed to air cool, followed by testing till failure in a universal load testing machine. Comparison of the test results shows that rich mix concrete beams more reduction in flexural strength, more increase in maximum load carrying capacity and deflection than normal mix beams. The maximum reduction in flexural strength was 32.41% for beams cast with 50% RCA and rich mix. Although the fire duration used in this study is rare, yet the outcome provides guidelines for taking proper decisions for retrofitting/strengthening of the fire affected structure before putting it back in service.

Keywords—green concrete; fire effect; flexural behavior; demolished waste; recyclable aggregates

I. INTRODUCTION

Green concrete, particularly the concrete produced by using demolished concrete as aggregates has a wide acceptance among researchers and the construction industry, because it is environment friendly, reduces environmental hazards, reduces waste management issues by its on-site consumption in new concrete, and it is less costly. However, its properties and behavior to various effects should be well understood to develop good confidence level on the material, which in turn will lead to assurance of strength and durability during the service life of the structure. Fire is among several hazards, natural or accidental, which a structure may meet. Fire not only affects the appearance by damaging the cladding but due to

thermal stresses and high temperature, affects strength. Fire would affect the green concrete made with demolished concrete as aggregates. Green concrete on the other hand is a relatively new material, thus its behavior should be studied particularly at elevated temperatures for longer duration to set the guidelines for industry and researchers.

Several researchers are actively engaged in evaluating the properties and behavior of green concrete made with demolishing waste [1-3]. Author in [1] reviewed the recent developments regarding the use of demolishing waste in new concrete with respect to challenges, recycling and behavior of green concrete. Authors in [2] reviewed the properties, strength parameters and property numerical equations of green concrete evaluated by several researchers among the available state-of-the-art on the subject. Authors in [3] also reviewed the state-of-the-art, particularly with regard to the waste generated due to heavy floods in BH Serbia. Based on the available research about the material, they concluded that waste can be used to produce conventional and even high-quality concrete subjected to the properties of aggregates from waste. Compressive strength of concrete with demolished concrete as coarse aggregates in different dosages has been studied in [4]. From the experimental results, the authors found that 50% replacement of natural aggregates is the optimum dosage. With this replacement the reduction in strength is minimum. The flexural behavior of reinforced recycled aggregate concrete beams was studied with the use of normal and rich mixes in [5] and [6] respectively. Based on the laboratory findings, the authors observed that the flexural behavior of green concrete beams is in good agreement with the conventional concrete beams. Also, they observed that the deflection in the proposed beams remained within the allowable limits of approximate deflection given by ACI-318.

Towards the evaluation of effect of fire on green concrete, several attempts have been made using different temperatures and fire durations. Green concrete cubes made with demolished

concrete as coarse aggregates have been used in [7] to check the effect of 1000°C for 6h. The authors used different dosages of recyclable aggregates. The compressive strength test results of these fire exposed cubes revealed that with 50% replacement the reduction in compressive strength is minimum. The compressive strength of recycled concrete exposed to 500°C temperature for 1h has been investigated in [8]. However, the authors used 75% replacement of natural coarse aggregates and compared the results with conventional concrete made with different water-cement ratios. Based on the test results by ultrasonic and resonance frequency test, the authors observed that the proposed concrete at the above mentioned temperature and duration performs well in comparison with the conventional concrete of low water-cement ratio. The compressive strength of concrete cubes made with 0% to 100% (with increment of 25%) recycled aggregates and heated in electronic oven at 50°C, 100°C, 200°C, 300°C, and 400°C for 8h has also been studied in [11]. The tests' results showed 38% average reduction in strength for all replacements when heated up to 200°C and 45% residual strength when heated from 300°C to 400°C. In a similar study, but with different natural aggregate replacement percentages from 0% to 50% [15], specimens were heated from 200°C to 800°C. From the test results, the authors concluded that the performance of the recycled aggregate concrete was comparable with the one of conventional concrete. Author in [9] used 50% and 100% replacement of natural coarse aggregates with recyclable aggregates to produce green concrete. The specimens were heated to 600°C and 800°C. After heating, the specimens were checked for strength and modulus of elasticity. The authors observed 10% increase in compressive strength of green concrete with 50% RCA and 50% reduction to 100% replacement of natural coarse aggregates. However, they reported no influence of elevated temperature and natural coarse aggregates replacement percentage on the elastic modulus. The authors further reported a strong correlation between the elastic modulus and the square root of compressive strength. Authors in [10][10] checked the mechanical properties of 204 concrete cylinders made with recycled concrete aggregates, river gravel and limestone aggregates. The authors used different dosages of the aggregates and heated the cylinders at 20°C, 250°C, 500°C and 750°C. From the test results of compressive and tensile strength, elastic modulus, damage and cracking, they found the proposed concrete to have good performance. Also, they argued that even at the temperature of 750°C, the proposed concrete did not exhibit any disintegration of the ingredients. In addition to the above, the behavior of fiber reinforced recycled aggregate concrete [12] and geopolymer coated aggregate concrete [13] have been studied. A constitutive theory for recycled aggregate concrete subject to elevated temperatures has been presented in [14]. It may be noted, that a good number of research findings has been published about the properties of recycled aggregate concrete, yet little work is available regarding the effect of high temperatures on recycled aggregate concrete, particularly the effect of longer fire duration (24h). This motivated the work presented in this study. It combines the use of recyclable aggregates from demolished concrete and the effect of a 24h fire on reinforced concrete beams. It is anticipated that the outcome of the work will set suitable guidelines for the

researchers in understanding the behavior of recycled concrete exposed to longer fire durations.

II. MATERIALS AND TESTING

For recycled aggregates, old demolished concrete of an about 50-year old school building was obtained in the shape of large blocks. The large pieces were manually reduced to size approximately equal to 20mm. To ensure well graded aggregates in concrete mix, gradation of both recycled and natural aggregates was done in accordance to ASTM standards. The obtained results are shown in Tables I (recycled aggregates) and II (natural aggregates). Both sets are plotted in Figure 1. Additionally, abrasion test on both types of aggregates was also performed as per the procedure given by ASTM C131-89. The Los Angeles abrasion value for natural aggregates was recorded equal to 18.3% and 26.7% for recycled aggregates. The recycled aggregates exhibited 8.4% more abrasion than natural aggregates. This is mainly due to the old mortar attached with the recycled aggregates. Attempt has been made to separate the mortar powder and pieces, then the abrasion of recycled aggregates was recorded 5.7% more than the one of natural aggregates. The dosage of recycled aggregates used was 50%. The selection of this dosage is based on the conclusions of [4].

TABLE I. GRADATION OF RECALCED COARSE AGGRAGATES

| # | Sieve (mm) | Weight retained (g) | Cumulative | | |
|---|------------|---------------------|--------------|--------------|-------------|
| | | | Wt. Ret. (g) | Retained (%) | Passing (%) |
| 1 | 31.5 | 0.00 | 0.00 | 0.00 | 100.00 |
| 2 | 25 | 95.00 | 95.00 | 4.48 | 95.52 |
| 3 | 19 | 978.00 | 1073.00 | 50.61 | 49.39 |
| 4 | 12.5 | 742.00 | 1815.00 | 85.61 | 14.39 |
| 5 | 9.5 | 262.00 | 2077.00 | 97.97 | 2.03 |
| 6 | 4.75 | 31.00 | 2108.00 | 99.43 | 0.57 |
| 7 | 2.36 | 7.00 | 2115.00 | 99.76 | 0.24 |
| 8 | Pan | 5.00 | 2120.00 | 100.00 | 0.00 |

TABLE II. GRADATION OF NATURAL COARSE AGGREGATES

| # | Sieve (mm) | Weight retained (g) | Cumulative | | |
|---|------------|---------------------|--------------|--------------|-------------|
| | | | Wt. Ret. (g) | Retained (%) | Passing (%) |
| 1 | 31.50 | 0.00 | 0.00 | 0.00 | 100.00 |
| 2 | 25.00 | 55.00 | 55.00 | 2.49 | 97.51 |
| 3 | 19.00 | 945.00 | 1000.00 | 45.25 | 54.75 |
| 4 | 12.50 | 680.00 | 1680.00 | 76.02 | 23.98 |
| 5 | 9.50 | 487.00 | 2167.00 | 98.05 | 1.95 |
| 6 | 4.75 | 37.00 | 2204.00 | 99.73 | 0.27 |
| 7 | 2.36 | 0.00 | 2204.00 | 99.73 | 0.27 |
| 8 | Pan | 6.00 | 2210.00 | 100.00 | 0.00 |

To reinforce the beams, 4#4 steel bars were used with two bars in tension and compression zones. To ensure the shear capacity of the beams, #3 ties at 150mm center-to-center were used throughout the length of the beam (Figure 2). The size of all beams was kept the same. A total of 24 beams were cast for the purpose. The details of the beams with respect to curing age, concrete mix and dosage of recycled aggregates are given in Table III. After casting the reinforced concrete beams in standard fashion and water curing for 28 days, all the beams were exposed to fire for 24h in an oven made for the purpose. The source of fire was wood and it took almost 1.5h to reach 1000°C, and then the temperature was maintained. During the

process of heating the temperature was regularly monitored using a digital thermometer (Figure 3). After the elapse of 24h the source of fire was cutoff and the beams were left in the oven for a day to avoid sudden attack of atmospheric moisture. Then, the beams were tested until failure under central point load (Figure 4) as per the recommendations of ASTM C293 [17].

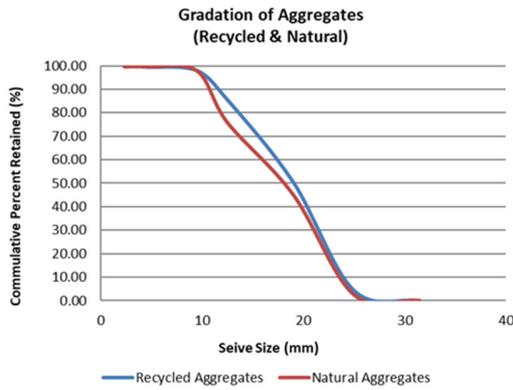


Fig. 1. Gradation of RA and NA

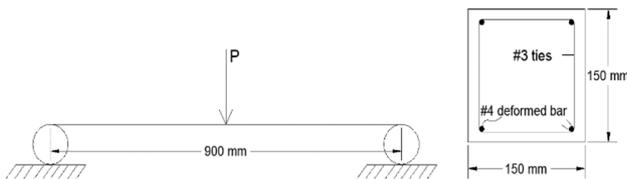


Fig. 2. Model dimensions



Fig. 3. Temperature monitoring



Fig. 4. Beam mounted on the UTM

TABLE III. SPECIMEN DETAILS

| Mix | RCA % | No of Beams | w/c ratio | Curing (days) |
|---------|-------|-------------|-----------|---------------|
| 1:2:4 | 50 | 6 | 0.54 | 28 |
| | 0 | 6 | 0.54 | 28 |
| 1:1.5:3 | 50 | 6 | 0.54 | 28 |
| | 0 | 6 | 0.54 | 28 |

During the load testing, deflection and cracking were monitored. At failure crack, the pattern was recorded and the flexural strength of the beams was computed using a numerical formula given by the above mentioned ASTM standard.

III. RESULTS AND DISCUSSION

The maximum load attained by the reinforced concrete beams is plotted in Figure 5. Average peak load, average deflection, and average flexural strength exhibited by the six beams of the group are given in Table IV. From this Table it may be observed that reinforced concrete beams cast with all-natural aggregates and normal mix showed less maximum load than the beams of the other groups. Considering the maximum load of these beams as control value, the RC beams cast with normal mix and 50% RCA exhibited 23.57% reduction. In contrast to normal mix, rich mix beams cast with all-natural aggregates showed 5.67% reduction in average peak load, while 32.41% reduction in average peak load was recorded for the beams cast with rich mix and 50% recycled aggregates. After fire exposure for 24h, beams showed reduced maximum load. The rich mix beams of both natural and recycled aggregates exhibited reduction in load in comparison to normal mix beams. Even the rich mix concrete beams cast with recycled aggregates showed 3.34kN less maximum load when compared to normal mix beams with the same percentage of recycled aggregates. Therefore, more attention should be given to fire exposed (particularly prolonged fire) structural members cast in rich mix.

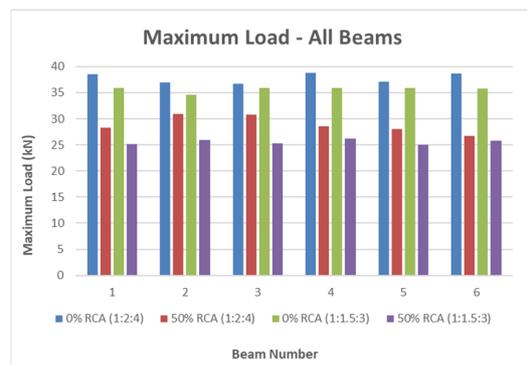


Fig. 5. Maximum load

Figure 6 shows the graphical comparison of the maximum deflection observed by all beams in each group. In this Figure, the increasing trend of deflection may be observed. The maximum deflection is observed in beams cast with 50% RCA and rich mix and is equal to 12.2mm. The value in comparison to ACI-318 maximum allowable deflection is about 2.5 times larger. Observation of average values of the deflection shows that normal mix RC beams cast with all-natural aggregates due to exposure to fire showed 9.66mm deflection. This is double

than the ACI-318 allowable values. Considering it as base value, RC beams cast with 50% RCA and normal mix exhibited 9.92% more deflection. 8.02% and 20.10% increase in deflection was also recorded for rich mix beams cast with 0% and 50% RCA. The load-deflection pattern for normal and rich mix beams are shown in Figures 7 and 8 respectively. It may be observed that the trend of load-deflection is the same for all beams except the peak values of the parameters.

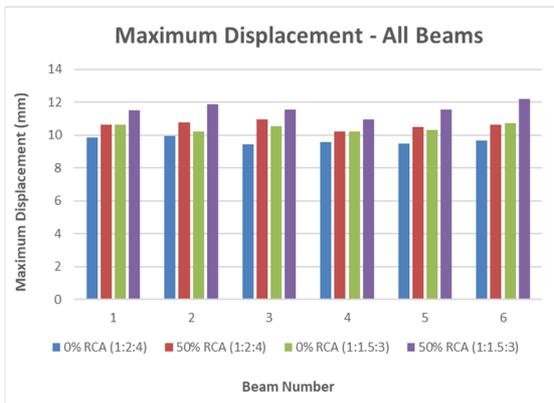


Fig. 6. Maximum deflection

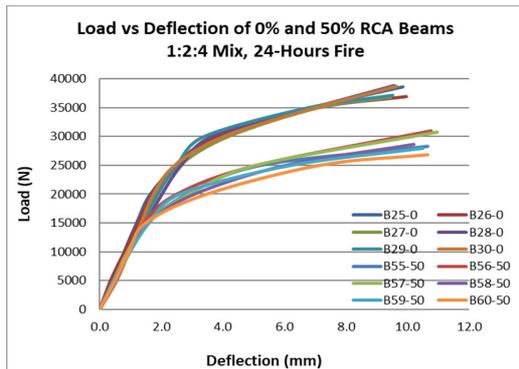


Fig. 7. Load vs deflection of normal mix beams

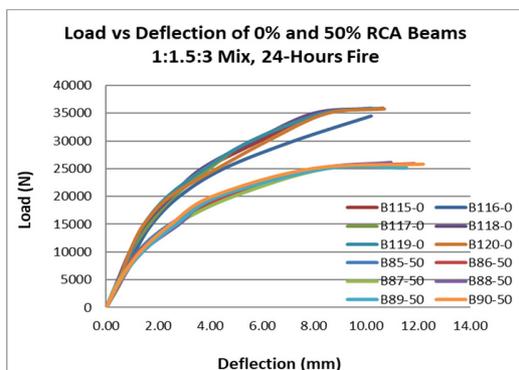


Fig. 8. Load vs deflection of rich mix beams

TABLE IV. PARAMETER AVERAGE VALUES

| Mix | RCA (%) | Load | Def | FS |
|---------|---------|-------|-------|-------|
| 1:2:4 | 0 | 37.80 | 9.66 | 15.12 |
| 1:2:4 | 50 | 28.89 | 10.62 | 11.56 |
| 1:1.5:3 | 0 | 35.66 | 10.43 | 12.89 |
| 1:1.5:3 | 50 | 25.55 | 11.60 | 10.22 |

The average values of the computed flexural strength are given in Table IV. Considering 0% RCA, normal mix reinforced concrete beams as control specimen, the average flexural strength attained by rich mix concrete beams of 0% and 50% dosage of RCA is shown in Figure 9. Like the reduction in peak load, the reduction in flexural strength is recorded with maximum reduction equal to 32.41% in rich mix beams with 50% dosage. It is 20.73% smaller than its counterpart with all-natural aggregates.

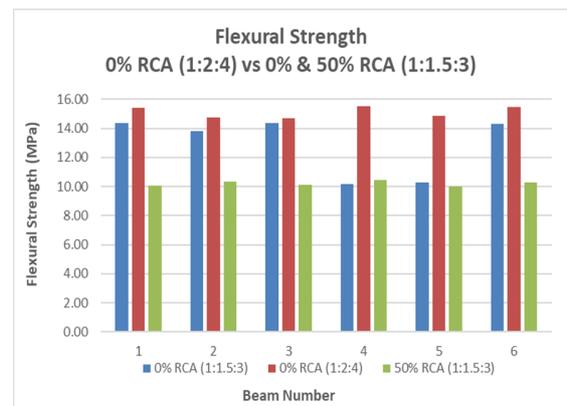


Fig. 9. Average flexural strength (rich mix vs normal mix)

Due to the long fire exposure and cooling process, several hair line cracks appeared on the surface of the beams which made difficult the monitoring of the first crack during testing. Therefore, the crack pattern after failure was recorded. The observations show shear cracks in most of the specimens with few beams showing both flexural and shears cracks. Shear cracks were dominant in all beams. Therefore, the failure mode of the beams is considered as shear failure.

IV. CONCLUSION

Based on the experimental observations of the reinforced concrete beams exposed to 24-hour fire at 1000°C, the following observations are made.

- Normal mix reinforced concrete beams exhibited more residual strength than rich mix reinforced concrete beams.
- Due to fire exposure, beams exhibited reduction in maximum load carrying capacity.
- Addition of recycled aggregates added more reduction of maximum load carrying capacity.
- Increasing trend of deflection is recorded in all beams.
- Load-deflection behavior of all beams is similar, except peak values.

- Maximum of 32.41% reduction in flexural strength of rich mix reinforced concrete beams cast with 50% dosage of recyclable aggregates is recorded in comparison to beams cast with all-natural aggregates and normal mix.
- Shear failure in all beams was observed.

Although 24-hour fire is a rare occasion, yet the proposed beams showed minimum of about 68% residual strength. Therefore, the performance of the beams is comparable with conventional concrete's. Hence, the outcome of this research provides experimental information and sets guidelines regarding the effect of prolonged fire on green concrete made with demolished concrete as coarse aggregates.

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