Flexural Behavior of Reinforced RAC Beams Exposed to 1000°C Fire for 18 Hours

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Abstract—**In order to meet the socio-economic demands around the globe, construction industry not only consumes concrete at a very fast pace but also yields huge amounts of construction and demolishing waste. The phenomenon gives rise to environmental issues due to production of concrete ingredients and due to dumping of the waste. Therefore, one of the solutions is the production of green concrete utilizing demolished waste. This research work studies the effect of prolonged fire (18 hours) on the flexural behavior of reinforced concrete–recycled aggregate beams. The beams were using 50% replacement of natural coarse aggregates with demolished concrete. The beam samples were cast as both normal and rich mix concrete and were cured for 28 days. After curing, the beams were exposed to fire at 1000°C in a purpose made oven, followed by testing in a universal load testing machine under central point load. The test results show that the proposed beams (cast with rich mix) exhibited about 22% reduction in flexural strength. The failure mode of the beams was observed as shear failure.**

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

I. INTRODUCTION

Fire is one hazard a structure may face during its lifetime. It not only affects a structure's appearance, but also deteriorates its strength. Therefore, a fire damaged structure needs careful examination and proper retrofitting. This requires investigation of the effects of fire, fire duration, temperature gain and behavior of reinforced concrete members during and after fire. On the other hand, to meet the socio-economic development, old or short height structures are demolished to build new, higher, structures, particularly in city centers. The demolishing of the structures generates massive waste, raising, among others, environmental issues. Green concrete, the concrete made with demolishing waste, is one of the solutions. This research work studies the use of demolished concrete as coarse aggregates in new concrete and the effect of prolonged fire (18-hour duration) on it.

Author in [1] highlights the challenges and issues regarding aggregates along with possible solutions. The author also summarized different aspects of recycled aggregates and investigations on concrete made with these aggregates. Similar work is also done in [1, 2] but for composite members. Authors in [4, 13] used different dosages of demolishing waste in making concrete cubes for strength checking after exposing to fire at 1000°C for different durations. They observed that at 50% replacement of the natural coarse aggregates, the compressive strength of the concrete is within acceptable limits. Authors in [5, 6] used 50% replacement of natural coarse aggregates with demolished concrete to check the flexural strength vs strain of reinforced concrete beams. In depth experimental investigations showed comparable performance with specimens made from conventional concrete. Combined use of wollastonite and recycled waste as partial replacement of cement and coarse aggregates is reported in [7]. Additionally, silica was used in 10% by weight to check performance under elevated temperatures (20°C-800°C) among other properties. The results showed that the wallastonite had adverse effects on strength and durability but positive effect on flexural and tensile strength, whereas, the recycled waste as coarse aggregates performed well. Authors in [8] used ilmenite and baryte concretes for the study of the effects of fire on heavy weight concrete used in nuclear structures as shield, and investigated the strength after exposing the samples in fire for 1 to 3 hours at 250°C to 950°C. The results showed that ilmenite concrete was more fire resistant than baryte and normal concrete. Further testing revealed that addition of foam or increased air entrapped percentage led the concrete with better performance than other types as nuclear radiation shield.

Water throwing on burning objects is the most common firefighting method, however other methods may also be used. To this end, authors in [9] studied different cooling methods and their effect on the residual strength of concrete. The authors exposed concrete members to fire from 300°C to 900°C. They used water throwing, immersion in water, covering by plastic and slow cooling (up to 224 days) and tested strength properties. Based on the obtained results they outlined strength changes and related matters related to the subject matter. Ramp slab of a shopping mall damaged due to accidental fire was investigated in [10] from the retrofitting point of view. Various research groups have also studied the effects of fire on the thickness of concrete cover in residential structures [14], the effects of high temperature on physical and

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mechanical properties [15], and reinforced concrete structural material [16]. The discussion above shows the importance of the subject and the variation in results and exploration of the parameters for different condition, which motivated this project on the evaluation of the effects of fire on reinforced concrete beams made with partial replacement of natural coarse aggregates with demolished concrete exposed to prolonged 18-hour fire.

II. Materials and Testing

The demolished concrete used in this research work was obtained from a demolished 50 year old school building in the shape of large blocks (Figure 1). These blocks were manually hammered to obtain aggregates of 25mm in size (Figure 2). The cracked particles were screened and separated carefully (Figure 3). Sieve analysis of both natural and recyclable aggregates was done to have well graded aggregates.

Fig. 1. Demolished concrete

Fig. 2. Hammering process

Fig. 3. Cracked particles

As old mortar is attached with the demolished concrete and requires more water in the concrete mix to ensure workability, water absorption test of recyclable and natural coarse aggregates was done in standard fashion. The water absorption of natural coarse aggregates was obtained equal to 1.80% and that of recyclable aggregates was equal to 3.92%. Accordingly, the water demand in concrete mix was adjusted. Twenty four reinforced concrete beams were prepared using 1:2:4 (normal mix) and 1:1.5:3 (rich mix). In each concrete mix 50% beams were cast with all-natural coarse aggregates and 50% with equal proportion of the natural and recyclable aggregates following the conclusions of [3, 12]. To reinforce the beams, 2#4 deformed steel bars were used both in tension and compression zones along with #3 bars as shear reinforcement at 150mm center to center along the beam length. The size of all beams was taken equal to 900mm×150mm×150mm. The prepared beams (Figure 4) were cured for 28 days by fully immersing in water, and were air-dried for 24 hours. All the beams were then exposed to fire for 18 hours in a purpose made oven (Figure 5) at 1000°C. Burnable wood was used as the source of fire. It was observed that 1 hour was required to reach the temperature of 1000°C, which was then maintained for the required duration of time. After the elapse of fire duration, the fire source was cut off and beams were left in the oven for 24 hours to avoid sudden attack of atmospheric moisture.

Fig. 4. Beam samples

Fig. 5. Oven

Fig. 6. Beam testing

Finally, all the beams were tested in a universal testing machine under central point load in accordance with [11] (Figure 6) until failure. During the testing load, deflection and cracking were monitored at regular intervals. The flexural capacity of the beams was then computed using the numerical expression given in [11]. The obtained results for the beams cast with all-natural coarse aggregates (G1) and 50% recyclable aggregates (G2), with normal mix are given in Tables I and II respectively. Similarly, Table III lists the test results of reinforced concrete beams cast with rich mix and all-natural coarse aggregates (G3) while the results of reinforced concrete beams cast with rich mix and equal proportion of natural and recyclable aggregates (G4) are given in Table IV. All beams were exposed to fire for 18 hours.

TABLE I. TEST RESULTS-GROUP G1

S. No	Beam No	Load (N)	Deflection (mm)	Flexural Strength	
				N/mm²	Psi
1	19	45279	8.40	18.11	2626.18
2	20	41360	8.05	16.54	2398.88
3	21	45836	8.30	18.33	2658.49
4	22	45570	7.90	18.23	2643.06
5	23	45365	8.10	18.15	2631.17
6	24	45697	8.30	18.28	2650.43
Average		44851.17	8.18	17.94	2601.37

TABLE II. TEST RESULTS-GROUP G2

S. No	Beam No	Load (N)	Deflection (mm)	Flexural Strength	
				N/mm²	Psi
1	49	36650	9.05	14.66	2125.70
2	50	37235	9.15	14.89	2159.63
3	51	36870	9.2	14.75	2138.46
4	52	36272	9.0	14.5	2103.8
5	53	36560	9.15	14.62	2120.48
6	54	36980	9.0	14.792	2144.84
Average		36761.17	9.13	14.70	2132.15

TABLE III. TEST RESULTS-GROUP G3

S. No	Beam No	Load (N)	Deflection (mm)	Flexural Strength	
				N/mm²	Psi
1	109	45145	9.50	18.06	2618.41
2	110	42120	9.05	16.85	2442.96
3	111	42730	9.10	17.09	2478.34
4	112	45216	9.65	18.09	2622.53
5	113	43976	9.45	17.59	2550.61
6	114	45225	9.55	18.09	2623.05
Average		44068.67	9.38	17.63	2555.98

TABLE IV. TEST RESULTS-GROUP G4

S. No	Beam No	Load (N)	Deflection (mm)	Flexural Strength	
				N/mm²	Psi
1	79	35125	10.10	14.05	2037.25
2	80	35070	10.25	14.03	2034.06
3	81	35235	10.35	14.09	2043.63
4	82	33840	10.20	13.54	1962.72
5	83	32480	10.25	12.99	1883.84
6	84	35350	10.45	14.14	2050.30
Average		34516.67	10.27	13.81	2001.97

III. Results and Discussion

The load and deflection recorded are graphically shown in Figures 7-10 for groups G1-G4 respectively. It may be observed that the load-displacement pattern of the beams within and across the group is similar except peak values.

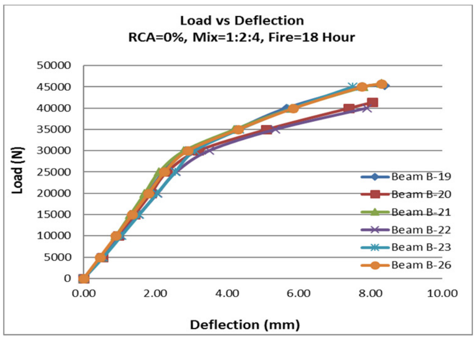

Fig. 7. Load vs displacement – G1 beams

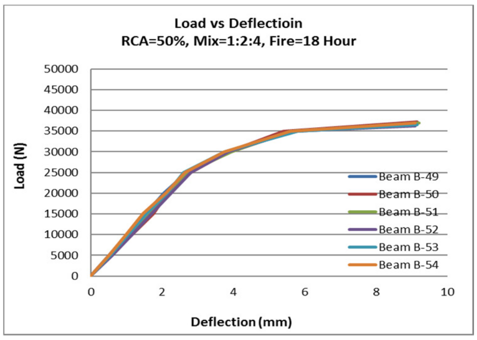

Fig. 8. Load vs displacement – G2 beams

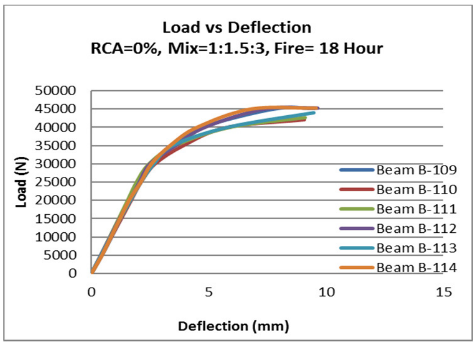

Fig. 9. Load vs displacement – G3 beams

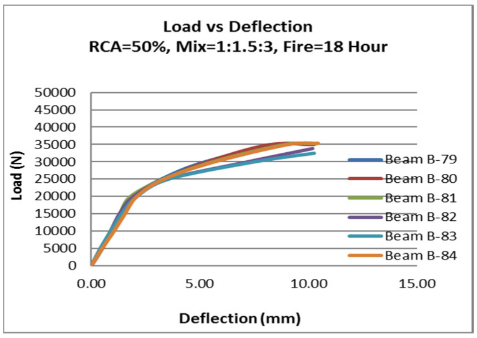

Fig. 10. Load vs displacement – G4 beams

The comparison of maximum load attained is shown in Figure 11. The same relationship between G3 and G4 beams is shown in Figure 12. It may be observed from these graphs that due to induction of recyclable aggregates, normal mix beams exhibit 19.06% reduction in maximum load, whereas, the same for rich mix concrete beams is equal to 21.82% with respect to its counterpart. It may be noted that the rich mix concrete beams exhibited more reduction in maximum load capacity (14.4%) than normal mix beams due to fire exposure. This is mainly attributed to the larger cement content in these beams. Fire loss of moisture from the body of concrete weakens the bond leading to reduction of load carrying capacity. Therefore, more care should be taken while considering rich mix concrete with recycled aggregates and fire exposure.

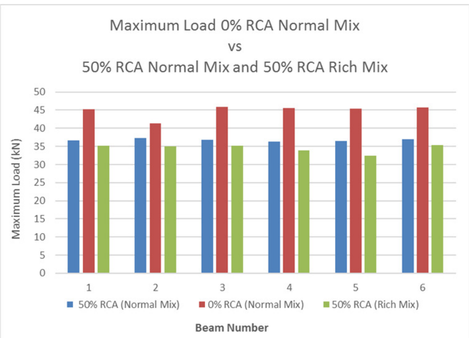

Fig. 11. Maximum load – G2, G1, G4 beams

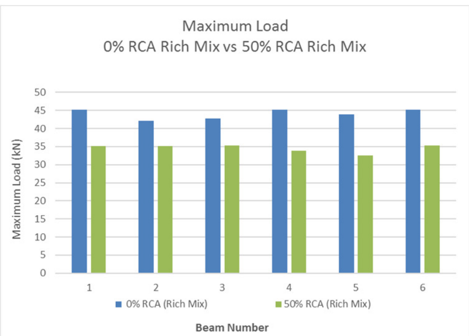

Fig. 12. Maximum load – G3 and G4 beams

All the beams containing recycled aggregates showed reduction in flexural strength with the same percentage decrease as peak load. The results of the deflection showed increase for both normal and rich mix concrete beams. Normal mix beams with recycled aggregates exhibited 17.61% increase in comparison to their counterpart cast with all-natural aggregates. Whereas, mix concrete beams with recycled aggregates recorded equal increase to 9.48%. In comparison to ACI-318 specified approximate allowable deflection values, the deflection at failure in normal mix beams tripled and in rich mix beams doubled. Therefore, rich mix concrete beams showed better performance regarding deflection in comparison to normal mix reinforced concrete beams. Cracks and cracking pattern at failure were also observed during testing. Due to fire exposure, several surface cracks were presented even before the start of the test, therefore it was difficult to monitor the first crack due to loading. Crack pattern after failure was observed as diagonal cracks from center towards supports or near to supports, with arching action in some of the specimens. Therefore, the failure mode of the beams was identified as shear failure (Figure 13).

Fig. 13. Cracking in beams

IV. Conclusion

The presented experimental study aimed to evaluate the effects of 18-hour fire on reinforced concrete beams cast with 50% dosage of both natural and recycled aggregates. Normal and rich mix concrete were used in reinforced concrete beams. Control specimens with all-natural aggregates were cast to compare the results. After exposure to fire, all beams were tested for peak load, deflection and cracking. The obtained flexural strength of the proposed beams was 19.06% and 21.82% reduced for normal and rich mix beams respectively. At failure, increase in deflection up to three times than approximate allowable deflection by ACI-318 and shear failure were observed. Although 18 hours of fire is a prolonged duration, the loss of flexural strength or peak load is about 22%. This reduction is due to the combined effects of recycled aggregates and exposure to fire, therefore may be considered a reasonably low value. However, proper retrofitting decision should be taken before putting the structure back in service.

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