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NON-DESTRUCTIVE TESTING OF RC BEAMS MADE WITH PARTIAL REPLACEMENT OF COARSE AGGREGATES FROM DEMOLISHED CONCRETE EXPOSED TO FIRE

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ABSTRACT

Population growth particularly in city centers around the globe have forced the construction industry to build high rise structures in place of old and short height buildings. This on other hand led waste disposal crisis. An approach to reduce these crises is to reuse the demolishing waste in new construction. Therefore, this research work used 50% replacement of natural coarse aggregates with coarse aggregates from demolished concrete. Generally, quality of concrete is estimated by measuring its strength. Laboratory testing of strength is time consuming therefore, non-destructive test methods provide good alternative to destructive testing. In this research work rebound hammer tests are used to estimate the compressive strength of reinforced concrete beams made by 50% replacement of coarse aggregates with coarse aggregates from old demolished concrete. 48 RC beams are cast using normal and rich mix concrete. 12 beams are cast using all-natural aggregates to compare the results of proposed beams. After curing of 28-days in standard manner rebound hammer is used to measure the compressive strength of the beams, followed by exposing the beams to fire for 6- and 12-hours at 1000°C in purpose made oven. The comparison of results with control specimen shows that proposed beams has good fire resistance and can be used initially in areas of low load.

KEYWORDS: Alternative Aggregates, Demolished Concrete, Fire, Non-Destructive Testing.

1. INTRODUCTION

Vertical expansion of structures is need of the present era due to increasing demand for accommodation and associated facilities particularly in city centers around the globe. This indeed is due to the increasing population and less available space around the city centers. High rise construction requires demolishing of the old or short height structures. This on other hand gives rise to demolishing waste and its dumping issues. One way of dealing this problem is by reusing it in the new construction. Filling of floors in and outside the structure has accomplished successfully by utilizing this waste. Several attempts are also made at research level, lab scale and in practical field for reusing the demolishing waste. Coarse aggregate is the major component of new concrete; therefore reuse of old concrete as coarse aggregates in new concrete is the active area of research. This not only solves the dumping of waste issue to some extent but also saves the natural coarse aggregates which on other hand is being consumed at rapid rate.

Memon[1] in his review paper presented recent developments on the use of demolished concrete as coarse aggregates in new concrete. Although the state-of-art is available on the subject matter, but still more research is required to develop good confidence level for using old concrete as coarse aggregate in new concrete both in design procedures and construction industry.

In two separate studies Tanwani and Memon[2-3] used 50% replacement of natural coarse aggregates with coarse aggregates from old concrete to develop numerical relationship between weight and compressive strength and tensile strength respectively. The authors validated their proposed equations by comparing the results with test results on the cylinder specimen used for the purpose.

During service life of the structure it has to face several climate changes and natural hazards. Fire is one among them. It not only damages the appearance of the structure but also impact on its performance. Therefore, it is important to understand the post fire behavior of the reinforced concrete structures for rehabilitation and reusing it with confidence. Normally strength measurement is the key component for determining the quality of reinforced concrete components. Core cutting and testing of existing structures is not only difficult particularly after fire, but also time consuming. Therefore, non-destructive testing provides an alternate solution. The availability of non-destructive test equipment and ease of its use have increased its use in the industry.

Proverbio[5] in his research article studied reliability of non-destructive test methods. The author used UPV and rebound hammer to check properties of concrete. Based on the results he concluded that for better calibration of the methods a good knowledge property is necessary. He further proposed use of combined methods of non-destructive testing for better results.

Kairu and Wilson[6] used laboratory calibrated rebound hammer and profometer to check the concrete strength of commercial and residential buildings in Nairobi. The authors used profometer to check the position of the reinforcement and rebound hammer to estimate the concrete strength. After comparison of the results the authors concluded the validity of non-destructive methods.

Patamand and Danupon[7] used rebound test hammer and x-ray diffraction to estimate residual strength of fire affected concrete structures. The authors used reinforced concrete beams heated up to 800°C. The authors observed no change in rebound value up to 420°C due to surface hardness verified from x-ray diffraction and electron scanning microscopy. Comparison of results with those of core testing revealed significant decrease in compressive strength.

Colombo and Felicetti[8] proposed new technique based on ultrasonic pulse velocity and drilling resistance to estimate fire damage caused to reinforced concrete structures. They applied the technique on two full scale reinforced concrete structures surviving from real fire to plot fire damage profile. The authors compared their results with laboratory testing to validate their proposed technique. The authors also discussed pros and corns of the proposed technique.

Yaqub[9] in his research paper presented case study of fire affected 16 story RC building in Pakistan. The authors used rebound hammer, ultrasonic pulse velocity testing and core testing the estimate the strength of unaffected and fire affected portions of the building. Core walls, beams and slabs of both affected and unaffected regions were selected for testing. Testing of cores from selected regions showed residual strength of 77.3%, 48.1% and 72.7% in fire affected core walls, beams and slabs respectively. In comparison to it ultrasonic pulse velocity gave 82%, 43% and 57% results whereas the same when tested with rebound hammer gave 79%, 96% and 81% strength of selected regions. Based on the comparison of the results the author concluded that the non-destructive testing gives good estimate of the strength in fire affected reinforced concrete structures.

Yilmaz and Sendir[10] conducted research to develop empirical relationship between rebound number, unconfined compressive strength and modulus of elasticity in gypsum. The authors used gypsum samples from various locations of Sivas (Turkey). Regression analysis was performed on the test results to obtain the empirical equation to calculate unconfined compressive strength. The authors used empirical equations from the literature to validate their proposed equation. Based on the comparison of results the authors concluded that their proposed equation may comfortably be used to estimate unconfined compressive strength of gypsum. In another study by Vasconcelos et al[11] the authors proposed use of ultrasonic pulse velocity and rebound hammer to check the mechanical properties of granite.

In a research conducted by Basu and Aydin[12] for normalizing the rebound hammer results in non-horizontal direction, the authors argues that the curves provided by the manufacturer of the equipment is normally limited to few directions. Whereas, field testing may require different directions. Therefore, the authors proposed a theoretical procedure of normalizing the rebound hammer results in non-horizontal directions and validated their procedure with wide range of rock materials.

This motivates the experimental work presented in this research article. It combines the use of old demolished concrete as coarse aggregates in 50% proportion as replacement of natural coarse aggregates with non-destructive testing of reinforced concrete beams exposed to fire for 6- and 12-hours. The 50% replacement is opted based on the findings of Oad and Memon [4]. The authors in their research work conclude that 50% is the optimum dosage of old demolished concrete as coarse aggregate at which minimum loss of strength of new concrete is observed. Total of 48 reinforced concrete beams of length 900 mm are prepared. Details of beams are given in relevant section. 12 beams are cast with 0% RCA and treated as control specimen to compare the results of proposed reinforced concrete beams. Comparison of the results verifies that the proposed reinforced concrete beams has good fire resistance.

2. Material Description and Model Testing

To prepare the proposed beams demolished old concrete is collected in the shape of large blocks. The old concrete was of a reinforced concrete slab of a building approximately 55-years-old. These blocks are then hammered to smaller pieces of size approximate equal to 25mm. Old concrete aggregates and natural coarse aggregates are then sieved separately through 25mm sieve. Other ingredients of concrete to prepare the beams are ordinary Portland cement and hill sand. To make the beams reinforced 2#4 bars are used both in tension and compression zones as longitudinal steel. To keep it in position and meet the shear requirements #3 bars are used as stirrups at 150 mm c/c distance all along the length of beam. The size of beam is 900mm x 150mm x 150mm and is kept same for all beams.

The ingredients of concrete are then batched using weight method of batching. Two mix ratios 1:2:4 and 1:1.5:3 are adopted with fixed water cement ratio of 0.56. Detail of the beams is given in Table 1. 24 beams each for normal and rich mix are prepared. In each mix half of the beams are prepared using 50% coarse aggregates from old concrete and remaining half are cast with all-natural coarse aggregates. These beams are treated as control specimen and are used to compare the results of proposed beams. All the beams are cured for 28-days using standard water curing. Last column of Table 1 shows fire duration to which the beams are exposed. 0+6-hour duration means beams are tested before exposing to fire, then the beams are exposed to fire for 6-hour duration.

After curing all the beams are first tested using rebound hammer. On each beam three readings are taken and averaged. The obtained results of compressive strength along with rebound number are given in Tables 2 to 7. Thereafter, beams B1 – B24 are exposed to fire for 6-hour and beams B25 – B48 are exposed to fire for 12-hour duration at 1000°C in purpose made oven. After elapse of required time in fire beams are taken out of oven and left in open space so that the temperature comes down to ambient level. Then these beams are tested using rebound hammer. Table 2 gives strength details of reinforced concrete beams of both normal and rich mix concrete with 0% RCA before fire. Similarly, Table 3 presents the same results for reinforced concrete beams made with 50% RCA before fire. The strength results of beams made with 0% RCA and exposed to 6-hour fire duration are given in Table 4. Similarly, Table 5 gives the strength results of beams made with 50% RCA and exposed to fire for 6-hours. Table 6 and Table 7 presents the strength results of both groups of beams (0% RCA and 50% RCA) exposed to fire for 12-hours.

Table 1: Details of reinforced concrete beams.

#	Beams	Ratio	% RCA	Fire Duration (Hours)
1	B1 - B6	1:2:4	0	0 + 6
2	B7 - B12	1:1.5:3	0	0 + 6
3	B13 - B18	1:2:4	50	0 + 6
4	B19 - B24	1:1.5:3	50	0 + 6
5	B25 - B30	1:2:4	0	0+12
6	B31 - B36	1:1.5:3	0	0+12
7	B37 - B42	1:2:4	50	0+12
8	B43 - B48	1:1.5:3	50	0+12

Table 2: Strength of RC beams made with 0% RCA before fire.

#	Beam	R	Strength (MPa)		Beam	R	Strength (MPa)
		Ratio=1:2:4				Ratio=1:1.5:3	
1	B1	32.0	19.7		B7	37.0	24.8
2	B2	33.5	21.5		B8	35.5	23.0
3	B3	33.0	20.9		B9	35.0	22.4
4	B4	34.5	21.9		B10	35.5	23.0
5	B5	33.0	20.9		B11	37.5	25.4
6	B6	34.5	21.9		B12	37.0	24.8
Average:		**33.4**	**21.1**			**36.3**	**23.9**

Table 3: Strength of RC beams made with 50% RCA before fire.

#	Beam	R	Strength (MPa)		Beam	R	Strength (MPa)
		Ratio=1:2:4				Ratio=1:1.5:3	
1	B13	29.0	16.3		B19	31.5	18.6
2	B14	30.5	18.0		B20	32.0	23.0
3	B15	30.5	18.0		B21	31.0	20.4
4	B16	31.0	18.6		B22	30.0	17.4
5	B17	30.5	18.0		B23	30.5	18.0
6	B18	30.5	17.4		B24	30.5	18.0
Average:		30.3	17.7			30.9	19.2

Table 4: Strength of RC beams made with 0% RCA and 6-hours in fire.

#	Beam	R	Strength (MPa)		Beam	R	Strength (MPa)
		Ratio=1:2:4				Ratio=1:1.5:3	
1	B1	30.0	17.4		B7	32.5	20.3
2	B2	29.5	16.9		B8	33.0	20.9
3	B3	28.5	15.7		B9	32.5	20.3
4	B4	30.0	17.4		B10	31.5	19.2
5	B5	29.0	16.3		B11	30.5	18.0
6	B6	29.5	16.9		B12	31.5	19.2
Average:		29.4	16.8			31.9	19.6

Table 5: Strength of RC beams made with 50% RCA and 6-hours in fire.

#	Beam	R	Strength (MPa)		Beam	R	Strength (MPa)
		Ratio=1:2:4				Ratio=1:1.5:3	
1	B13	28.5	15.7		B19	29.5	16.9
2	B14	29.5	16.9		B20	29.0	16.3
3	B15	29.0	16.3		B21	29.0	16.3
4	B16	27.5	14.6		B22	30.0	17.4
5	B17	29.0	16.3		B23	29.5	16.9
6	B18	28.0	15.1		B24	29.5	16.9
Average:		28.6	15.8			29.4	16.8

Table 6: Strength of RC beams made with 0% RCA and 12-hours in fire.

#	Beam	R	Strength (MPa)		Beam	R	Strength (MPa)
		Ratio=1:2:4				Ratio=1:1.5:3	
1	B25	29.0	16.3		B31	28.5	15.7
2	B26	29.0	16.3		B32	28.5	15.7
3	B27	29.5	16.9		B33	29.5	16.9
4	B28	28.5	15.7		B34	28.5	15.7
5	B29	28.0	15.1		B35	28.0	15.1
6	B30	29.5	16.9		B36	29.5	16.9
Average:		28.9	16.2			28.8	16.0

Table 7: Strength of RC beams made with 50% RCA and 12-hours in fire.

#	Beam	R	Strength (MPa)		Beam	R	Strength (MPa)
		Ratio=1:2:4				Ratio=1:1.5:3	
1	B37	26.0	12.8		B43	27.5	14.6
2	B38	27.5	14.6		B44	27.5	14.6
3	B39	28.5	15.7		B45	28.0	15.1
4	B40	28.0	15.1		B46	26.5	13.4
5	B41	27.5	14.6		B47	26.0	12.8
6	B42	28.5	15.7		B48	27.5	14.6
Average:		27.7	14.8			27.2	14.2

3. RESULT DISCUSSION

Table 8 gives average values of rebound number and compressive strength of all groups of reinforced concrete beams. From this Table it may be observed that the control specimen of RC beams of 1:2:4 mix made with all-natural coarse aggregates attained average strength of 21.1 MPa. These beams when exposed to 6-hour fire observed 20.38% reduction in comparison to strength observed before fire. The same beams observed 23.21% reduction in strength in comparison to strength values before 12-hour fire. Figure 1 shows the trend and comparison of reinforced concrete beams made with 0% RCA before and after fire.

Normal mix (1:2:4) beams made with 50% RCA as replacement of natural coarse aggregates observed average strength of 17.7 MPa before fire. When these beams are exposed to fire for 6- and 12-hours observed 10.7% and 16.38% reduction respectively. It is further observed that reinforced concrete beams made with recycled old concrete as coarse aggregates showed better residual strength than reinforced concrete beams made with all-natural coarse aggregates. Figure 2 shows trend and comparison of proposed beams of normal mix before and after fire.

The details of strength results of reinforced concrete beams made with all-natural coarse aggregates and rich mix (1:1.5:3) are detailed in table 2. Average strength of 23.9 MPa is observed for these beams. It is 13.3% higher than the strength of normal mix beams of same group. After exposure to 6-hour fire these beams observed 17.99% reduction in strength and 33.3% reduction in strength when exposed to 12-hour duration in fire. Figure 3 shows comparison of strength vs rebound number of these beams before and after fire.

From Table 3 it may be observed that the rich mix reinforced concrete beams made with 50% RCA gave average compressive strength equal to 19.2 MPa which is 80.33% of the same mix beams made with all-natural aggregates. The beams showed reduction in strength equal to 17.99% and 40.58% when exposed to fire for 6- and 12-hours respectively.

The analysis of the results further shows that with 50% replacement of natural coarse aggregates with coarse aggregates from demolished old concrete, observed 16.1% and 19.66% reduction in strength for normal and rich mixes. The minimum loss of strength recorded is for normal mix reinforced concrete beams exposed to 6-hour fire at 1000°C and is equal to 10.7% where as the 12-hour fire damaged the proposed concrete beams more and the strength loss recorded is equal to 40.58% with residual strength of concrete equal to 59.42%. Whereas, the normal mix reinforced concrete beams observed less loss of strength as compared to rich mix. This might be due to longer fire duration and weaker aggregates in those particular beams. Therefore, this aspect requires more detailed study to conclude better. However, the overall performance of the proposed beams remained better in fire even for 12-hour duration at 1000°C. Therefore, the proposed material has promising effect to be used in new concrete with good fire resistance.

Table 8: Average strength and rebound number for all beams.

#	Beams	% RCA	Ratio	Fire Duration (Hours)	Average R	Average Strength (MPa)
1	B1 - B6	0	1:2:4	0	33.4	21.1
2	B7 - B12	0	1:1.5:3	0	36.3	23.9
3	B13 - B18	50	1:2:4	0	30.3	17.7
4	B19 - B24	50	1:1.5:3	0	30.9	19.2
5	B1 - B6	0	1:2:4	6	29.4	16.8
6	B7 - B12	0	1:1.5:3	6	31.9	19.6
7	B13 - B18	50	1:2:4	6	28.6	15.8
8	B19 - B24	50	1:1.5:3	6	29.4	16.8
9	B25 - B30	0	1:2:4	12	28.9	16.2
10	B31 - B36	0	1:1.5:3	12	28.8	16.0
11	B37 - B42	50	1:2:4	12	27.7	14.8
12	B43 - B48	50	1:1.5:3	12	27.2	14.2

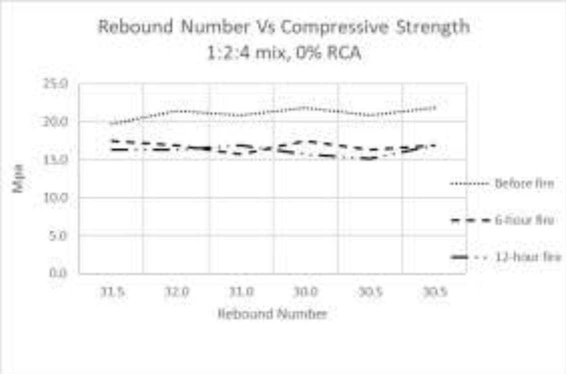

Figure 1: 1:2:4 mix RC Beams with 0% RCA.

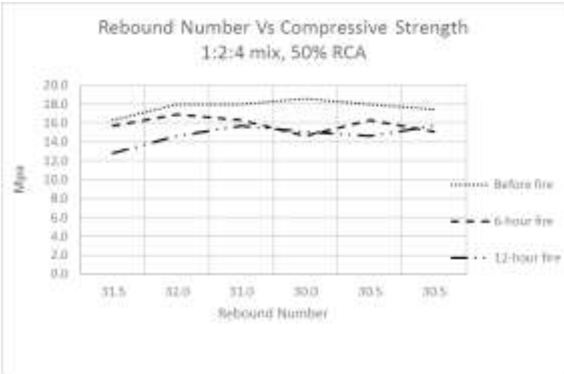

Figure 2: 1:2:4 mix RC Beams with 50% RCA.

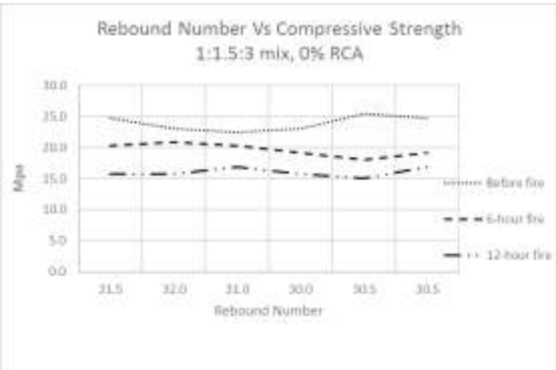

Figure 3: 1:1.5:3 mix RC Beams with 0% RCA.

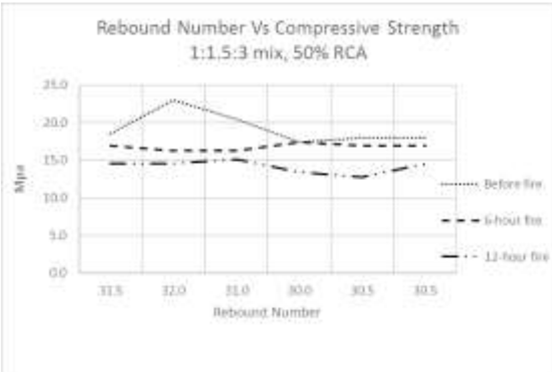

Figure 4: 1:1.5:3 mix RC Beams with 50% RCA.

4. CONCLUSION

This research paper presents compressive strength evaluation of reinforced concrete beams made with 50% replacement of natural coarse aggregates with aggregates from old concrete by rebound hammer. 48 reinforced concrete beams are prepared using 1:2:4 and 1:1.5:3 concrete mixes. 12 beams are cast using all-natural coarse aggregates with 6 beams in each normal and rich mix concrete to compare the results. After water curing of 28-days compressive strength using rebound hammer is evaluated. Three readings on each beam are taken and averaged. Then beams are exposed to fire at 1000°C for 6- and 12-hour in purpose made oven. After elapse of required time beams are taken out of oven and left in open space to let the temperature comes down to ambient level. Then the rebound hammer is used again to measure compressive strength. The obtained results are compared with the results of control specimen. The comparison shows that residual strength of normal mix reinforced concrete beams after 6- and 12-hour fire is equal to 83.9% and 70.1 % respectively. Whereas, residual strength of rich mix reinforced concrete beams is equal to 70.29% and 59.41% for 6- and 12-hours fire. Although rich mix beams show more strength loss for 12-hour fire which might be because of weaker coarse aggregates, the proposed beams show good fire resistance. Therefore, based on this experimental work it is concluded that the reinforced concrete beams made with 50% replacement of natural coarse aggregates with aggregates from demolished old concrete has good fire resistance and confidently be used in new construction initially in low load areas.

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