

# Effect of Six Hour Fire on Flexural Strength of RC Beams made with 50% Coarse Aggregates from old concrete: Part 1: Normal mix

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## Abstract

Shifting of people from villages/small cities to big cities poses a serious issue of accommodation and other associated infrastructure. For the solution of said issue, demolition of old structures to construct new high-rise buildings is opted. The demolishing waste is an additional problem for the project, particularly due to unavailability of the dumping space in many areas. A method of addressing the issue is by using it in new concrete. This research study presents an experimental investigation to check the effect of a 6-hour fire at 1000°C on the bending resistance of reinforced concrete beams prepared by replacing 50% conventional coarse aggregate with coarse aggregate from demolished concrete. 24 RC beams of 0.9m × 0.15m × 0.15m size are cast using 1:2:4 mix and 0.54 water cement ratio. To reinforce the beams 2#4 bars in each tension and compression zones are used. Out of 24 beams, 12 are cast with all-natural coarse aggregates to compare the results. After 28-days standard curing, all beams are exposed to fire for 6 hours in purpose made oven. The beams are then left at room temperature for 24-hours followed by testing of all the beams in universal load testing machine with central point loading. Load and deflection are monitored at regular intervals. Comparison of the results with control specimen shows that the proposed beams observed 13.43% reduction in flexural strength which is quite smaller. The beams failed in shear which complies with the failure mode of normal concrete beams. Thus, the proposed material has good fire resistance when used in reinforced concrete beams.

**Keywords**—Deflection, Fire, Flexural Stress, Demolishing Waste, Old Concrete, Recycled Coarse Aggregates

## 1 Introduction

CONCENTRATION of population in city centers have created problem of accommodation space and space for associated facilities around the world. To meet the demand construction industry has opted replacement of ancient and short-height structures by new high-rise ones. The process alleviated the space problem to a large extent, but it also created a great amount of demolition trash. Lack of dumping space and expenditure involved in transportation of this waste to far distances for dumping led the researchers for reusing it in the new construction. Since the past few decades, researchers have been studying the reuse of demolition trash in new building. Several waste

components have been utilised in new construction. Coarse aggregate is one of the major constituent of concrete which consumes large space in body of concrete. Therefore, reuse of old concrete as coarse aggregates as full or partial replacement of natural coarse aggregates has also been studied by several scholars [1-3]. But the literature reveals that there is still need of more research on the topic to build confidence about the new product.

During its service life, the structure is exposed to a variety of natural dangers, which not only impairs the building's performance and load sustainability, but also needs particular maintenance and repair actions before it can be reused. One of these dangers is fire. It not only degrades the beauty, but it also reduces the strength. This prompts the investigation of the effect of fire on suggested concrete beams described in this article.

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Beam is one of the important structural members and flexural strength is the key property for determination of serviceability of the member. Memon and Bhatti [4] conducted research to evaluate flexural behaviour of RC Beams built using coarse aggregates from old concrete replacing 50% of the conventional coarse particles. The authors used different dosages of old concrete in reinforced concrete beams to study the flexural behaviour. Based on the experimental evaluations and comparison of the results with control specimen, the authors concluded that 50% is the optimum dosage at which least reduction in flexural strength is observed. The authors concluded their research with remarks that the old concrete can effectively be used in new concrete particularly beams in low load areas.

Amnon [5] in a research work used laboratory waste of 28 MPa concrete cured at age of 1, 3 and 28 days as recycled aggregates. The author studied properties of aggregates and concrete made from it with nearly 100% replacement of natural coarse aggregates. Based on the results, the author concluded that aggregate properties were inferior to natural aggregates. There was no effect of curing age of old concrete. 1- and 3-day cured concrete aggregates showed better performance than 28-day cured concrete aggregates.

In another study to evaluate mechanical properties of concrete made by using crushed mosaic as coarse aggregates in M20 concrete, Malliga[6] found that mosaic has almost similar properties like natural aggregates. Comparison of the results showed that 40% replacement of natural aggregates with crushed mosaic gives maximum compressive and tensile strength. The author concluded that crushed mosaic can be utilized as a partial replacement for natural coarse aggregates in new construction based on the findings.

Kumutha et. al. [7] in their research work evaluated the possibility of reusing old concrete and old bricks as partial or full replacement of coarse aggregates and fine aggregates respectively. The authors used both materials from 0% to 100% with increment of 20% and studied density, modulus of elasticity, compressive, tensile and flexural strengths of concrete. During the analysis of results, the authors observed that strength properties of new concrete observed reduction with increase in dosage of aggregates. Based on the results the authors concluded that 100% natural coarse aggregates may be replaced with old concrete and 60% replacement of fine aggregates may be made with old crushed bricks. In another attempt Akbari et. al. [8] used increment of 15% with three different water cement ratios. Based on the results, the authors observed 25%, 26% and 23% reduction in compressive, flexural and tensile strength of concrete.

Fire is a dangerous natural phenomenon; it creates heat and can change the internal and external properties of any strong object. Because of fire, all concrete properties are affected, leaving the negative effect on the appearance and performance of the concrete elements [9]. Various researchers have reported in the literature that temperatures as high as 95°C have little effect on resistance and other concrete properties. Beyond this threshold, cement paste contracts because of dehydration and aggregates expand because of temperature rise [10-14].

Castillo [15] worked on the effect of high temperature (100°C to 800°C) on high strength concrete properties. From the results, the author observed 20% reduction in compression strength at 100°C to 300°C and 30% reduction in compressive strength at 400°C to 800°C. Nearly similar observations were made by Mamillapalli [16].

Hisbani [9] used 36 reinforced concrete beams in a research program. Beams were cured for 28 days. After curing, half the beams were coated with 3/4-inch-thick plaster and then hardened for 7 days. After curing, all beams were exposed to fire, then tested in UTM. Based on the findings, the author observed decrease in compressive strength of reinforced concrete beams due to the fire effect.

Li et. al. [17] reported that the fire affects the structural elements and damages especially the RC beams. In this study, four different temperature durations were considered to check the effect of the fire on the steel. For every fire interval, six samples were used. After being heated to the required temperature, all samples were cooled in water at room temperature, then tested for tensile strength. Based on the results, the author concluded that the reduced tensile strength is evident at 900°C.

Memon and Buller [21] reviewed the use of demolishing waste as recycled aggregates in new concrete with particular reference to its exposure to fire. In separate studies Buller et. al. used recycled aggregates in new concrete to study the relationship between cubical and cylindrical strength [19], effect of specimen size [20], effect of curing methods [22], strength evaluation by non-destructive testing [24]. The authors in another research work studied the effect of fire on concrete cubes made with 50% replacement of NA with CA from old concrete [18]. They used 180 concrete cubes of standard size cured at 7, 14 and 28 days. The specimens were exposed to fire at 1000°C for 3, 6 and 12 hours. The obtained results were compared with results of cubes made from all-natural coarse aggregates. From the comparison of the results, the authors observed 25% reduction in compressive strength for

28-day cured cubes exposed to fire for 12 hours.

Ivanka et. al. [25] in their research work used diabase, steel slag, crushed bricks, and crushed tiles as replacement of coarse aggregates in concrete prisms cured for 28-days. The authors exposed the prisms to fire and studied compressive and flexural strength. From the comparison of results with normal concrete prisms, the authors observed that steel slag and crushed bricks proved to be the good replacement of natural coarse aggregates not only from strength performance point of view but also in terms of better waste management.

Tang et. al. [26] used recycled rubber in recycled aggregate concrete to check its thermo-mechanical properties at elevated temperature. Using three different temperature levels and durations authors observed that presence of rubber reduces the spalling of the concrete. In another research study, Fran-cisco et. al. [27] used 25%, 50% and 100% replacement of conventional aggregates with recycled aggregate to study the effect of high temperature (350°C and 850°C) on resulting concrete. The authors unlike the reporting in literature observed an increase in the strength of the concrete. Dong et. al. [28] used different compressive strength (C20, C30 and C40) concrete columns to check their fire resistance. Experimental and Analytical (ABAQUS) results showed the authors that smaller cross-section columns perform better against fire. Khan et. al. [28] also studied the effect of elevated temperature on recycled aggregate concrete. The authors used 0, 30%, 50%, 70% and 100% dosage of recycled aggregate to prepare the samples. The samples were exposed to fire from 250°C to 900°C. From the results, the authors observed more or less similar behaviour of recycled aggregate concrete as of conventional concrete, but more deterioration. Based on the results, the authors also developed residual strength factor to estimate the residual strength of both NAC and RAC after exposure to fire. Sham-sulddin [30] in his research program to study the fire effect on RAC, used 10%, 20%, 30% and 40% recycled aggregates to prepare the samples. The samples were then exposed to fire at 32°C, 250°C and 500°C for 6 hours. The author observed noticeable changes in both physical and mechanical properties of the concrete beyond 250°C.

In another experimental study of fire resistance of reinforced ceramsite concrete beams, Yuan and Wang [31] used ceramsite as partial replacement of coarse aggregates to cast concrete beams. They studied both compressive and flexural strength before and after fire. In addition, they also performed finite element analysis for bending of the beams. Based on the results, the

authors observed a reduction in both compressive and flexural strength of beams when compared to the test results of normal concrete beams.

Recycled aggregate from demolition concrete is also used in virgin concrete to study various properties and concrete shrinkage [35]. However, the spread of results is clear, indicating that more research is needed in this area. Therefore, in this study, laboratory evaluation and analysis of the bending strength of reinforced concrete girders will be carried out by replacing 50% of the natural aggregate after the fire with coarse aggregate of old concrete. Twenty-four reinforced concrete girders are poured to achieve this goal. The proposed material is poured into half of the beams and natural aggregate is used in the other half to confirm the results. The beam is exposed to fire for 6 hours and then subjected to bending strength testing on a universal load tester. A comparison of the results shows that the proposed beam bending strength observed a 6.53% decrease after a 6-hour fire. This demonstrates the suitability of the proposed material as a new concrete coarse aggregate for a fire that lasts for 6 hours.

## 2 Material & Testing

The concrete mix used in this research work has been designed for 21 MPa (3000 psi) by following ACI mix design method as shown in Table 1. Both the aggregates were used in 50% proportion. The selection of 50% for coarse aggregates from old concrete was done based on the recommendations of Oad and Memon[3] and many other researchers. Natural and old concrete aggregates were then mixed with hill sand and conventional Portland cement in a 1: 2: 4 ratio and a water binder ratio of 0.54. The proportion of water cement was determined in consideration of the water absorption rate (5.42%) of the recycled aggregate.

To reinforce the beam, two # 4 deformation bars were placed in both the tension zone and the compression zone, and according to the ACI specifications used, # 3 as a stirrup with a center-to-center 150 mm spacing along the entire length of the beam. I placed a transformation bar. The details are shown in Figure 1. Twelve reinforced concrete beams (B31 to B42) of 0.9m × 0.15m × 0.15m in size were cast by placing concrete in layers. For compaction, rodding was used. Another twelve reinforced concrete beams (B1 to B12) of same size and material but without coarse aggregates from old concrete were also cast. These specimens are termed as control specimen and are used to check the result of proposed beams.

The old demolition concrete used in this experimental work was collected from the demolition of a

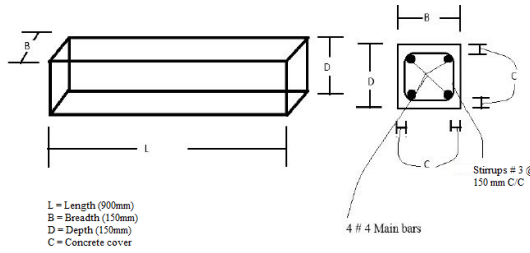


Fig. 1: Reinforced Concrete Beam



Fig. 2: Purpose made oven

reinforced concrete building near the city of Nawabshire about 75 years ago. Old concrete was collected in the form of large blocks. Then manually hammer these blocks to a size of approximately 25 mm (Figure 3). Next, the aggregate obtained from the hammer process was examined for cracked particles to avoid use in new concrete. Next, both natural and old concrete aggregates were screened as standard with a maximum screen size of 25 mm.

All the beams were cured for 28-days by fully immersing in water. After curing, all the beams were ex-posed to fire at 1000°C in purposed made oven for 6-hours as shown Figure 2. Then the beams were left at room temperature for 24-hours to cool (figure 5), followed by testing of the beams in universal testing machine with central point loading (Figure 6) in accordance with ASTM C-293[37].

Load and central point deflection in all beams ware monitored at regular intervals. The maximum value of these parameters along with flexural strength obtained by using ASTM C-293[37] formulation is given in Table 2 for reinforced concrete beams made with 50% RCA. Table 3 gives the same details for control specimen.

### 3 Results & Discussion

It is observed that the lowest value of flexural strength is recorded as 22.946 N/mm<sup>2</sup> for beam number B41 as shown in Table 2. This value is approximately 8% less when compared with maximum value of flexural strength recorded in all 12 beams (B40). Flexural strength of all other beams remained less than 8% in

Materials and their Source		
Cement:	OPC Pak Land	
Coarse Aggregate:	Crushed Stone	
Fine Aggregate:	Hill Sand	
<b>Required Strength: 20 MPa</b>		
Design Strength:	0	MPa
Modified free W/C Ratio:	0.54	
Slump:	25 – 75	mm
Max Aggregate Size:	25	mm
Fineness Modulus:	2.41	
Sp. Gravity of CA:	2.37	
Sp. Gravity of FA:	2.27	
Sp. Gravity of Cement:	3.15	
Water Absorption of Coarse Aggregates:	1.8	
Unit Weight of Fine Aggregates:	1805	kg/m <sup>3</sup>
Unit Weight of Coarse Aggregates:	1620	kg/m <sup>3</sup>
Concrete Density:	2443	Kg/m <sup>3</sup>
Quantities		
By Weight (per meter cube)		
Water	213	Kg
Cement	395	Kg
Coarse Aggregates	1580	Kg
Fine Aggregates	790	Kg
Air	2	%
<b>Ratio 1:2:4</b>		
Cement	1	
Fine Aggregates	2	
Coarse Aggregates	4	

TABLE 1: Concrete mix design (normal mix)

No.	Beam No.	Load (N)	Deflection (mm)	Flexural Strength (N/mm <sup>2</sup> )
1	B31	60120	10.76	24.048
2	B32	58790	12.73	23.516
3	B33	59630	12.65	23.852
4	B34	61980	10.92	24.792
5	B35	59910	10.87	23.964
6	B36	60120	11.55	24.048
7	B37	59570	11.5	23.828
8	B38	59591	12.7	23.836
9	B39	57642	11.3	23.057
10	B40	62383	9.6	24.953
11	B41	57364	11.6	22.946
12	B42	60984	10.35	24.394
Average:			10.89	27.65
Standard Deviation:			1.03	1.26

TABLE 2: Load, deflection and flexural strength for beams B31-B42



Fig. 3: Old concrete blocks and aggregates



Fig. 6: Testing of beam UTM



Fig. 4: 0% RAC beams after 6-hour fire

comparison to maximum value of flexural strength in this group. Similarly, Table 3 shows that maximum value of flexural strength is 29.48 N/mm<sup>2</sup> (B9) and the minimum value of flexural strength recorded is 26.07 N/mm<sup>2</sup>. Therefore, deviation of flexural strength within beams of this group remained in the range of 0-11.5%.

The load-deflection behaviour of beams cast with 50% coarse aggregates from old concrete is shown in Figure 7. Similarly Figure 8 shows the load-deflection



Fig. 5: 50% RAC Beam after 6-hour fire

No.	Beam No.	Load (N)	Deflection (mm)	Flexural Strength (N/mm <sup>2</sup> )
1	B1	65180	10.45	26.07
2	B2	65320	11.42	26.13
3	B3	72600	12.7	29.04
4	B4	70840	10.91	28.34
5	B5	68230	9.19	27.29
6	B6	69760	10.31	27.9
7	B7	65254	10.2	26.1
8	B8	65254	11.4	26.1
9	B9	73700	12.7	29.48
10	B10	71010	10.8	28.4
11	B11	70786	10.53	28.31
12	B12	71516	10.1	28.61
Average:			11.38	23.94
Standard Deviation:			0.97	0.6

TABLE 3: Load, deflection and flexural strength for beams B31-B42

behaviour of all 12 beams cast with all-natural coarse aggregates. From the graphs, it is clearly observed that the pattern of load-deflection is almost identical for both groups of beams after exposed to fire. Average values of load deflection and flexural strength are given in Table 4. This table also gives the percentage loss of flexural strength of proposed beams in comparison to beams made with 0% RCA. It is noted from this table that flexural strength of proposed beams observed 13.43% loss in comparison to control specimen. It is also noted that proposed beams observed 4.5% more deflection than control specimen. However, average deflection of both groups of beams remained within the allowable limits. Figure 9 shows graphical comparison of flexural strength of all beams.

Figure 10 and 11 show the cracking pattern and failure of 50% and 0% RCA beams respectively. It may be observed from these figures that the cracks started from centre towards supports in diagonal fashion. This shows that the failure mode of the beams is shear

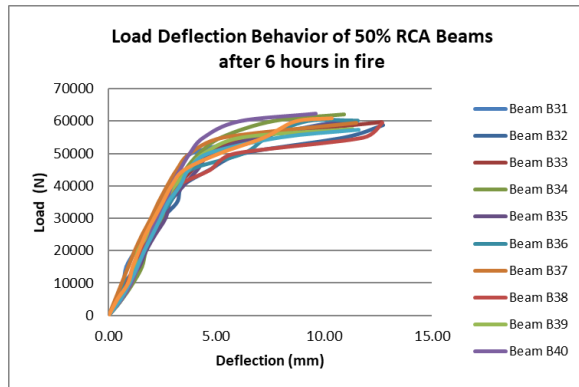


Fig. 7: Load-deflection behaviour of RC beams B31 to B42.



Fig. 10: Cracking in 50% RCA beam

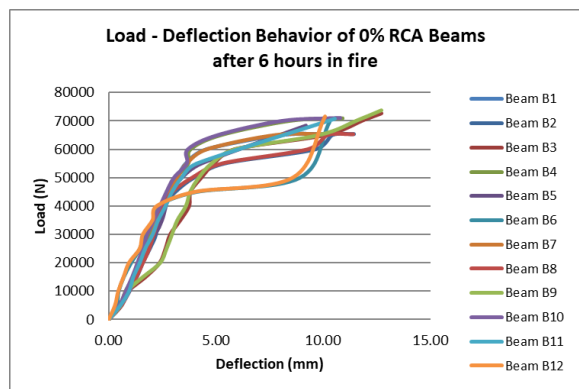


Fig. 8: Load-deflection behaviour of RC beams B1 to B12.



Fig. 11: Cracking in 0% RCA beam

failure which complies with the failure mode of normal concrete. However, it is further observed that wider cracks in 50% RCA beams are observed near failure in comparison to 0% RCA beams. It is most probably due to the old aggregates.

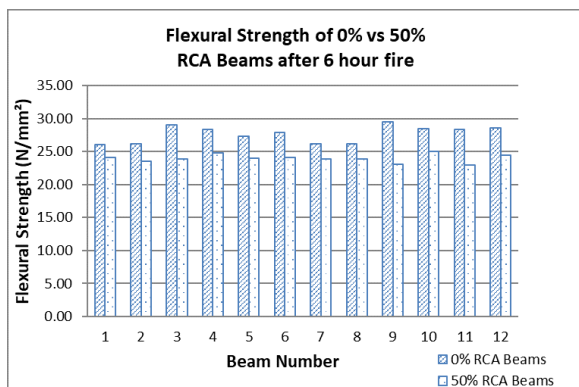


Fig. 9: Flexural strength of beams with 0% vs beams with 50%.

#### 4 Conclusion

This research article presented effect of 6-hour fire on RC beams made with 50% replacement of conventional coarse aggregates with coarse aggregates from demolished concrete and exposed to fire at 1000°C. The analysis of test results reveals that proposed specimens gave 86.57% residual strength compared to the specimens not exposed to fire. The average deflection in the beams remained well within allowable limit of relevant ACI standards. The failure in the beams is rectified as shear failure which also confirms the requirement of the failure of beams. The cracking pattern and failure mode of beams made with recycled coarse aggregates were same as as the beams made with normal concrete. Therefore, it is concluded that the proposed material has good fire resistance for 1000°C temperature and 6-hour duration.

#### 5 Research Significance

It is observed since last few decades that people migrated from villages, towns and small cities to developed cities. This migration of people in large quantum caused problem of accommodation and associated facilities in those developed cities. Providing

#	% RCA	Load (N)	Deflection (mm)	Flexural Strength		
				(N/mm <sup>2</sup> )	% Retained	% Loss
1	0	69120.83	10.89	27.65	-	-
2	50	59840.33	11.38	23.94	86.57	13.43

accommodation to these migrants in led to many problems. On the other hand, unavailability of space for new construction particularly in developed cities of globe forced the construction industry to shift from horizontal development to vertical development by demolishing the old structures. This technique has solved the problem to great extent but posed the problem of effective management of huge quantum of the construction and demolition (C&D) waste generated as a result of demolishing of old structures.

On the other hand, fire is one among many hazards to which structure has to be exposed during service life. The exposure of the concrete to fire may change appearance and several properties. The concrete should be strong enough to resist much of these effects so that it may be re-used without or with retrofiting. In light of above this research work presents the effect of fire on the strength of reinforced recycled aggregates concrete beams.

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