

STRENGTH (COMPRESSIVE) OF CONCRETE MADE BY RECYCLABLE CONCRETE AGGREGATES AFTER SIX HOUR FIRE BY NON-DESTRUCTIVE TESTING

A.H. Buller ^{a,*}, Nadiah Md. Husain ^a, I. Ali ^b, S. Sohu ^c, B.A. Memon ^c, Irum Naz Sodhar ^d

^{a*} Department of Civil Engineering, Kuliyah (Faculty) of Engineering, International Islamic University Malaysia, Jalan Gombak, 50728 Selangor, Malaysia, E-mails: *engrabdulhafeezbuller@gmail.com, drnadiah@iiu.edu.my

^b North American University, Stafford, Texas, United States, E-mail: lali1@na.edu

^c Department of Civil Engineering, Quaid-e-Awam University of Engineering, Science and Technology, Nawabshah, Sindh, Pakistan, E-mail: sohoosamiullah@gmail.com, bashir_m@hotmail.com

^d Department of Information Technology, Shaheed Benazir Bhutto University Shaheed Benazir Abad, Pakistan, E-mail: irumnaz@sbbusba.edu.pk

Received: 08.02.2023 / Accepted: 15.02.2023 / Revised: 02.03.2023 / Available online: 31.05.2023

DOI: [10.2478/jaes-2023-0008](https://doi.org/10.2478/jaes-2023-0008)

KEY WORDS: Old concrete, Coarse aggregates, Fire resistance, Compressive strength, Residual strength, Recyclable aggregates, Non-destructive Testing

ABSTRACT:

Quality of concrete is mainly measured by evaluating its strength. Destructive testing of concrete specimens is used for the purpose. An alternative to it is the non-destructive testing. This research work presents non-destructive testing of concrete cylinders made by using partial replacement of natural coarse aggregates with old concrete as coarse aggregates and exposed to 6-hour fire at 1000°C. Rebound hammer is used in this work to evaluate concrete strength. 240 concrete cylinders are cast using 1:2:4 mix and 0.54 water cement ratio. After 28-days curing half of the cylinders are exposed to fire in purpose made oven. Remaining 50% aggregates are used as control specimen to compare the results. After rebound hammer testing, all the cylinders are tested for compressive strength using universal testing machine. Comparison of the results shows the reliability of non-destructive testing and effectiveness of the rebound hammer technique as the difference between NDT and UTM results is maximum up to 4.7%.

1. INTRODUCTION

All over the world concrete construction is active. This is mainly done to meet the development demand of the region. Growing population particularly in city centres around the globe requires more living space and associated infrastructure. This on other hand becomes difficult due to less availability of space. Therefore, construction industry is forced to build High-rise buildings in place of short height or single-story buildings. New construction not only requires huge quantum of natural aggregates but if it is being done by demolishing old structures, and then generates demolishing waste also. Proper dealing of this waste requires additional funding and space for dumping. One of the options to proper deal this waste is by utilizing it in new construction.

2. LITERATURE REVIEW

Research on use of demolishing concrete as coarse aggregate in new construction is active since more than a decade. The

research on use of old concrete as coarse aggregates in new concrete has been done by several scholars. The researcher reported in his review paper gave detailed note of recent development on use of old concrete as coarse aggregates in new construction (Memon, 2016). Different dosages up to 100% of old concrete has been tried out by studying effect on strength and other properties. Many researcher (Buller et al., 2018), (Nedeljković et al., 2021), (Oad and Memon, 2014) worked on the recycled concrete and the results based on their research finding reports that 50% dosage is the optimum as with this dosage the residual compressive strength at 28 days curing is maximum. In another research work authors used old concrete as coarse aggregate in 50% proportion with natural coarse aggregates to work out the tensile strength (Buller, 2021) (Tanwani and Memon, 2015). For the purpose the authors used cylindrical specimens and based on the finding they concluded that the loss of tensile strength due to use of old concrete as partial replacement of natural coarse aggregates is less than 10%. In another research work, relationship between weight and tensile strength of concrete made by replacing natural coarse aggregates in 50% dosage is developed (Nedeljković et al., 2021), (Memon et al., 2019).

* Corresponding author. Abdul Hafeez Buller, Post-Doctoral fellow, Department of Civil Engineering, Kuliyah (Faculty) of Engineering, International Islamic University Malaysia, Jalan Gombak, 50728 Selangor, Malaysia. Email: engrabdulhafeezbuller@gmail.com

The numerical expression presented in the research work successfully predicts the tensile strength based on the weight of the specimen. Therefore, this research work aims on using the old demolished concrete as coarse aggregate in new concrete. 50% dosage of old concrete is used in preparation of concrete specimen (Buller et al., 2020).

Among several natural hazards which a concrete structure has to face during the service life, fire is one. Fire not only destroys the appearance of the structure but also reduces its strength considerably. Therefore, checking fire affected structures for residual strength is very important for taking proper decisions of retrofitting. Additionally, if the concrete is made by full or partial replacement of coarse aggregates with old concrete, effect of fire needs to be evaluated and understood. No matter it is new concrete or fire affected structure strength evaluation is one of the key parameters to ensure the quality of concrete (Soomro et al., 2023). Laboratory testing of the concrete specimen from running batch of concrete in case of new construction is the standard procedure for ensuring the quality of concrete. Whereas, in case of old structures or fire affected structures core cutting and testing following the standard procedures is done to check the quality of concrete. An alternative to core cutting and testing is the strength evaluation by non-destructive testing. Among several available methods of non-destructive testing, use of rebound hammer is not only easier and economical but is also reliable. To this end various scholars have used non-destructive techniques to evaluate concrete properties. Authors (Memon et al., 2018) (Alharthy, 2021) used Ultrasonic Pulse Velocity (UPV) method to estimate quality of reinforced concrete beams made with old concrete as coarse aggregates. The authors used 50% dosage of old concrete to cast 96 reinforced concrete beams of 1:2:4 and 1:1.5:3 ratios. Curing of the beams was done for 7- and 28-days. Based on the findings the authors concluded the concrete quality as good. Ultrasonic Pulse Velocity method has also been used (Kirchhof et al, 2015). The authors used this technique to predict numerical expression for predicting the residual strength of concrete exposed to high temperatures. For the purpose the authors used 0.25, 0.3 and 0.5 water cement ratio to cast cylindrical specimen. The specimens were then heated to temperatures from 200°C to 600°C in electric furnace. The specimens were tested using UPV technique. Based on the UPV and compressive strength results the authors developed numerical expression and verified its validity. Based on the finding the authors concluded UPV method as trustworthy technique for estimating concrete strength. Not only for concrete exposed to high temperatures but UPV technique has also been successfully used for studying concrete properties with fly ash and old concrete as aggregates with and without admixtures (Abed, 2021), (Colombo, 2007).

The author (Buller et al, 2018) used rebound hammer testing to estimate the residual strength of reinforced concrete beams made by partial replacement of natural coarse aggregates with old concrete. The authors used 50% replacement for casting 12 reinforced concrete beams. After 28-days curing beams were exposed to fire for 6 and 12 hours at 1000°C. The authors from comparison of results of proposed beams with control specimen observed that the proposed beams have good fire resistance and can be used initially in low load areas. Another author (Kumavat, 2021) used non-destructive testing i.e. seismic refraction method and ground penetrating radar investigation to study the fired Mont-Blanc tunnel walls. The authors used these methods by arguing that rebound hammer, UPV techniques or

core testing give results at a point only. Whereas, methods used in this research work give extensive view of the entire depth. Based on the observations the authors concluded that the proposed methods are more effective and give details of damage over entire depth of the sample being observed. The methods use UPV and rebound hammer techniques collectively. From the obtained results of testing damaged concrete, the authors concluded that if the duration of fire exposure or chemical attack is known then the proposed method gives better idea of residual strength of concrete. The author (Kurad et al, 2018) studied the odds and evens of three non-destructive testing techniques by conducting tests on a precast RC building surviving from fire and a tunnel exposed to repeated hydrocarbon pool fire tests. The authors used UPV, concrete colorimetry and real-time drilling resistance. The authors also discussed in situ viability of each method. From the obtained results the authors concluded that the proposed techniques give better insight of the concrete strength after fire (Buller et al., 2021).

Above discussion motivates the research presented in this article. This research work presents the strength evaluation of concrete made by using old demolished concrete as coarse aggregates and exposed to 6-hour fire by rebound hammer testing. Total of 240 cylinders of standard size are prepared and cured for 28-days. After curing cylinders are exposed to fire at 1000°C for 6-hours (Buller et al., 2018). Non-destructive testing by using rebound hammer is performed before and after exposing the cylinders to fire (Kurda et al., 2018) (Buller et al., 2021). Finally, all the cylinders are tested using universal testing machine for compressive strength. The results are presented and discussed in relevant section. It is observed that non-destructive test results are in good agreement with those obtained from universal testing machine.

3. MATERIAL AND TESTING

For casting concrete cylinders old concrete in shape of large pieces is collected from beams and slab of a demolished reinforced concrete structure. These large pieces and then hammered down to maximum size equal to 25 mm followed by manual sorting of aggregates for cracked particles and debris. Sieve analysis of these aggregates is done in standard fashion. Gradation of natural coarse aggregates of same size is also done. Table 1 and 2 shows details of the sieve analysis of old concrete and natural coarse aggregates. Comparison of both is shown in figure 1.

S. No.	Sieve		Weight Retained (gm)	Cumulative Weight Retained (gm)	Cumulative %	
	mm	inch			Retained	Passing
1	31.5	1.25	0	0	0	100
2	25	1.0	103	103	4.57	95.43
3	19	0.75	1050	1153	51.18	48.82
4	12.5	0.5	748	1901	84.38	15.62
5	9.5	0.375	269	2170	96.32	3.68
6	4.75	#4	60	2230	98.98	1.02
7	2.36	#8	13	2243	99.56	0.44

Table 1. Sieve analysis of recycled old concrete aggregates (RCA)

S. No.	Sieve		Weight Retained (gm)	Cumulative Weight Retained (gm)	Cumulative %	
	mm	inch			Retained	Passing
1	31.5	1.25	0	0	0	100
2	25	1	55	55	2.38	97.62
3	19	0.75	1105	1160	50.22	49.78
4	12.5	0.5	640	1800	77.92	22.08
5	9.5	0.375	460	2260	97.84	2.16
6	4.75	#4	45	2305	99.78	0.22
7	2.36	#8	0	2305	99.78	0.22

Table 2. Sieve analysis of natural coarse aggregates (NCA)

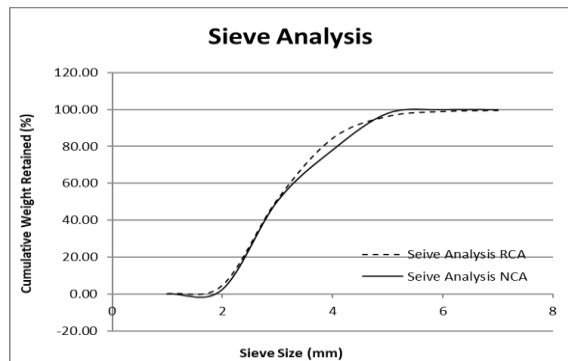


Figure 1. Sieve analysis of RCA and NCA

Total of 240 cylinders of size 150 mm x 300 mm are prepared using 1:2:4 mix and 0.54 water cement ratio. Half of the cylinders are prepared using both natural aggregates and old concrete as aggregates in 50% proportion (Batch – A). Remaining half of the cylinders are prepared using all-natural coarse aggregates to compare the results (Batch – B). The cylinders after casting in standard fashion are cured for 28-days. After elapse of the curing time all the cylinders are tested using rebound hammer. Three readings of the rebound hammer are taken on each cylinder followed by calculation of average of the readings. Table 3 gives the details of rebound hammer readings and corresponding cylindrical compressive strength for cylinders before exposed to fire. Table 4 gives similar details of the cylinders of batch – B.

S. No.	R (Average)	Strength (MPa)	S. No.	R (Average)	Strength (MPa)
1	33	20.12	31	34	21.28
2	34	21.28	32	33	20.12
3	37	24.79	33	33	20.12
4	34	21.28	34	34	21.28
5	33	20.12	35	34	21.28
6	34	21.28	36	33	20.12
7	33	20.12	37	33	20.12
8	34	21.28	38	33	20.12
9	36	23.64	39	34	21.28
10	35	22.43	40	34	21.28
11	35	22.43	41	34	21.28
12	34	21.28	42	34	21.28
13	35	22.43	43	37	24.79
14	35	22.43	44	36	23.64
15	34	21.28	45	36	23.64
16	34	21.28	46	35	22.43
17	34	21.28	47	34	21.28
18	35	22.43	48	35	22.43
19	36	23.64	49	35	22.43
20	34	21.28	50	35	22.43
21	34	21.28	51	35	22.43
22	35	22.43	52	35	22.43

23	35	22.43	53	34	21.28
24	35	22.43	54	36	23.64
25	34	21.28	55	34	21.28
26	34	21.28	56	34	21.28
27	35	22.43	57	34	21.28
28	34	21.28	58	34	21.28
29	35	22.43	59	35	22.43
30	35	22.43	60	35	22.43

Table 3. NDT of Batch – A

S. No.	R (Average)	Strength (MPa)	S. No.	R (Average)	Strength (MPa)
1	36	25.05	31	37	26.19
2	38	27.34	32	38	27.34
3	36	25.05	33	38	27.34
4	36	25.05	34	38	27.34
5	36	25.05	35	37	26.19
6	36	25.05	36	38	27.34
7	37	26.19	37	37	26.19
8	37	26.19	38	36	25.05
9	35	23.9	39	36	25.05
10	35	23.9	40	36	25.05
11	37	26.19	41	35	23.9
12	36	25.05	42	36	25.05
13	36	25.05	43	36	25.05
14	36	25.05	44	37	26.19
15	37	26.19	45	36	25.05
16	36	25.05	46	37	26.19
17	35	23.9	47	37	26.19
18	36	25.05	48	37	26.19
19	36	25.05	49	37	26.19
20	37	26.19	50	37	26.19
21	37	26.19	51	36	25.05
22	37	26.19	52	37	26.19
23	36	25.05	53	37	26.19
24	36	25.05	54	36	25.05
25	37	26.19	55	37	26.19
26	36	25.05	56	36	25.05
27	37	26.19	57	38	27.34
28	37	26.19	58	38	27.34
29	37	26.19	59	38	27.34
30	37	26.19	60	38	27.34

Table 4. NDT of Batch – B

120 cylinders (60 with 50% coarse aggregates from old concrete and 60 made using all-natural coarse aggregates) are then exposed to fire in purpose made oven for six hours at 1000°C. The cylinders are then allowed to cool in oven. After taking out the cylinders from oven non-destructive testing is performed in similar way as was done before exposing the cylinders to fire. Table 5 shows the non-destructive test results of the cylinder made with 50% natural and 50% old concrete aggregates after 6-hour fire (Batch – C). Whereas, table 6 gives same details for cylinders made with all-natural aggregates after 6-hour fire (Batch – D). Finally, all the cylinders are tested using universal testing machine for compressive strength.

S. No.	R (Average)	Strength (MPa)	S. No.	R (Average)	Strength (MPa)
1	27	14.61	31	32	19.73
2	27	14.61	32	32	19.73
3	32	19.73	33	32	19.73
4	27	14.61	34	32	19.73
5	30	18	35	29	16.86
6	32	19.73	36	28	15.76
7	27	14.61	37	32	19.73
8	30	18.00	38	32	19.73
9	31	19.15	39	32	19.73
10	31	19.15	40	27	14.61
11	32	19.73	41	29	16.86
12	31	19.15	42	29	16.86

13	32	19.73	43	29	16.86
14	32	19.73	44	27	14.61
15	32	19.73	45	29	16.86
16	32	19.73	46	32	19.73
17	32	19.73	47	29	16.86
18	30	18.00	48	32	19.73
19	30	18.00	49	27	14.61
20	29	16.86	50	28	15.76
21	32	19.73	51	32	19.73
22	29	16.86	52	29	16.86
23	30	18.00	53	28	15.76
24	30	18.00	54	29	16.86
25	30	18.00	55	32	19.73
26	31	19.15	56	29	15.76
27	31	19.15	57	31	19.15
28	31	19.15	58	29	16.86
29	30	18.00	59	31	19.15
30	31	19.15	60	32	19.73

Table 5. NDT of Batch – C

S. No.	R (Average)	Strength (MPa)	S. No.	R (Average)	Strength (MPa)
1	36	23.64	31	36	23.64
2	35	22.43	32	36	23.64
3	31	19.15	33	36	23.64
4	36	23.64	34	36	23.64
5	32	19.73	35	36	23.64
6	34	21.28	36	36	23.64
7	27	14.61	37	29	16.86
8	34	21.28	38	36	23.64
9	32	19.73	39	32	19.73
10	32	19.73	40	37	26.19
11	32	19.73	41	28	15.76
12	34	21.28	42	29	16.86
13	32	19.73	43	36	23.64
14	36	23.64	44	28	15.76
15	36	23.64	45	36	23.64
16	36	23.64	46	36	23.64
17	28	15.76	47	29	16.86
18	36	23.64	48	36	23.64
19	29	16.86	49	32	19.73
20	30	18.00	50	27	14.61
21	29	16.86	51	32	19.73
22	36	23.64	52	36	23.64
23	37	26.19	53	28	15.76
24	32	19.73	54	28	15.76
25	32	19.73	55	36	23.64
26	28	15.76	56	29	16.86
27	36	23.64	57	36	23.64
28	37	26.19	58	36	23.64
29	30	18.00	59	32	19.73
30	30	18.00	60	36	23.64

Table 6. NDT of Batch – D

Table 7 shows the compressive strength results of cylinders of made with partial replacement of coarse aggregates with coarse aggregates from demolished concrete before exposing to fire (Batch – A). Table 8 give details of compressive strength of cylinders made with all-natural coarse aggregates before exposing to fire (Batch – B). Similarly, Table 9 and Table 10 shows the results of the cylinders after exposing to fire for 6-hours (Batch – C and Batch – D).

S.No.	Load (KN)	Strength (MPa)	S.No.	Load (KN)	Strength (MPa)
1	435.8	24.67	31	411.8	23.31
2	481.3	32.89	32	507.43	28.73
3	378.9	21.45	33	422.5	23.92
4	395.7	22.4	34	409.3	23.17
5	445.7	25.23	35	404.1	22.88

6	378.97	21.46	36	406.4	23.01
7	401.6	22.74	37	405.2	22.94
8	398.7	22.57	38	410.3	23.23
9	482.3	27.31	39	411.1	23.28
10	412.7	23.37	40	431.7	24.44
11	386.5	21.88	41	432	24.46
12	387.5	21.94	42	411.2	23.28
13	402.2	22.77	43	426.4	24.14
14	401.7	22.74	44	428.4	24.25
15	503.6	28.51	45	426.5	24.15
16	399.7	22.63	46	410.2	23.22
17	398.6	22.57	47	391.5	22.17
18	426.8	24.16	48	390.5	22.11
19	425.7	24.1	49	396.7	22.46
20	426.9	24.17	50	395.8	22.41
21	426.7	24.16	51	399.2	22.6
22	430.2	24.36	52	432.2	24.47
23	429.3	24.31	53	430.7	24.38
24	428.9	24.28	54	431.8	24.45
25	421.4	23.86	55	436.4	24.71
26	422.3	23.91	56	414.7	23.48
27	422.6	23.93	57	429.5	24.32
28	527.5	29.87	58	440.5	24.94
29	403.4	22.84	59	397.6	22.51
30	410.8	23.26	60	422.3	23.91

Table 7. Compressive strength of cylinders of Batch – A by UTM

S.No.	Load (KN)	Strength (MPa)	S.No.	Load (KN)	Strength (MPa)
1	502.1	28.43	31	505.8	28.64
2	515.4	29.18	32	510.1	28.88
3	510.7	28.91	33	510.8	28.92
4	495.8	28.07	34	510.4	28.9
5	470.7	26.65	35	511.2	28.94
6	488.9	27.68	36	501.3	28.38
7	481.2	27.24	37	509.7	28.86
8	492.6	27.89	38	508.1	28.77
9	490.4	27.77	39	499.8	28.3
10	490.4	27.77	40	489.3	27.7
11	499.6	28.29	41	505.8	28.64
12	502.3	28.44	42	514.3	29.12
13	504.2	28.55	43	501.2	28.38
14	505.2	28.6	44	506.7	28.69
15	504.8	28.58	45	498.8	28.24
16	513.7	29.08	46	501.2	28.38
17	510.2	28.89	47	501.8	28.41
18	511.6	28.97	48	505.6	28.63
19	509.7	28.86	49	507.4	28.73
20	504.3	28.55	50	507.2	28.72
21	508.9	28.81	51	507.8	28.75
22	510.1	28.88	52	509.8	28.86
23	511.2	28.94	53	501.2	28.38
24	492.5	27.88	54	505.8	28.64
25	499.3	28.27	55	503.3	28.5
26	498.7	28.23	56	499.2	28.26
27	503.5	28.51	57	489.3	27.7
28	510.4	28.9	58	488.9	27.68
29	598.9	33.91	59	530.2	30.02
30	502.3	28.44	60	547.3	30.99

Table 8. Compressive strength of cylinders of Batch – B by UTM

S.No.	Load (KN)	Strength (MPa)	S.No.	Load (KN)	Strength (MPa)
1	385.1	21.8	31	356.5	20.18
2	349.8	19.8	32	355.2	20.11
3	358.9	20.32	33	344.5	19.5
4	345.7	19.57	34	364.8	20.65
5	385.7	21.83	35	361.9	20.49
6	399.8	22.64	36	325.9	18.45

7	352.3	19.95	37	335.4	18.99
8	390.5	22.11	38	388.9	22.02
9	392.5	22.22	39	387.6	21.94
10	388.9	22.02	40	387.2	21.92
11	387.3	21.93	41	388.2	21.98
12	388.2	21.98	42	387.9	21.96
13	390.2	22.09	43	390.6	22.11
14	360.6	20.42	44	391.3	22.15
15	365.8	20.71	45	349.8	19.8
16	370.2	20.96	46	359.5	20.35
17	362.7	20.54	47	361.5	20.47
18	397.6	22.51	48	372.2	21.07
19	366.4	20.74	49	354.2	20.05
20	366.7	20.76	50	398.8	22.58
21	366.8	20.77	51	349.1	19.77
22	376.3	21.31	52	369.5	20.92
23	355.5	20.13	53	379.6	21.49
24	393.2	22.26	54	348.5	19.73
25	392.4	22.22	55	349.8	19.8
26	399.8	22.64	56	352.7	19.97
27	385.2	21.81	57	363.3	20.57
28	372.5	21.09	58	361.3	20.46
29	351.6	19.91	59	342.5	19.39
30	347.2	19.66	60	351.5	19.9

Table 9. Compressive strength of cylinders of Batch – C by UTM

S.No.	Load (KN)	Strength (MPa)	S.No.	Load (KN)	Strength (MPa)
1	446.4	25.27	31	436.5	24.71
2	439.7	24.9	32	438.6	24.83
3	410.1	23.22	33	436.8	24.73
4	425.6	24.09	34	435.2	24.64
5	407.5	23.07	35	435.2	24.64
6	395.9	22.41	36	435.6	24.66
7	430.2	24.36	37	435.8	24.67
8	406.2	23	38	422.9	23.94
9	431.6	24.44	39	425.1	24.07
10	433.5	24.54	40	440.5	24.94
11	402.3	22.78	41	441.6	25
12	408.6	23.13	42	442.3	25.04
13	423.8	23.99	43	440.8	24.96
14	410.2	23.22	44	440.1	24.92
15	435.6	24.66	45	440.5	24.94
16	413.9	23.43	46	442.1	25.03
17	420.1	23.78	47	401.6	22.74
18	411.3	23.29	48	405.2	22.94
19	412.2	23.34	49	405.9	22.98
20	440.2	24.92	50	401.5	22.73
21	441.5	25	51	422.8	23.94
22	441.6	25	52	401.3	22.72
23	441.5	25	53	402.5	22.79
24	409.2	23.17	54	406.8	23.03
25	413.3	23.4	55	409.4	23.18
26	440.6	24.95	56	416.2	23.56
27	432.3	24.48	57	411.5	23.3
28	442.8	25.07	58	440.6	24.95
29	445.9	25.25	59	407.6	23.08
30	440.1	24.92	60	408.5	23.13

Table 10. Compressive strength of cylinders of Batch – D by UTM

4. RESULTS AND DISCUSSIONS

From table 3 to table 6 graphs of rebound hammer number vs compressive strength are plotted in figures 2 to 5. Figure 2 shows trend of rebound number and compressive strength of cylinders made with 50% natural and 50% old concrete aggregate before exposing them to fire. Figure 3 shows same relationship for cylinders made with all-natural aggregates. Similarly figure 4 and figure 5 presents rebound number vs

compressive strength of the cylinders exposed to fire for 6-hour duration at 1000°C.

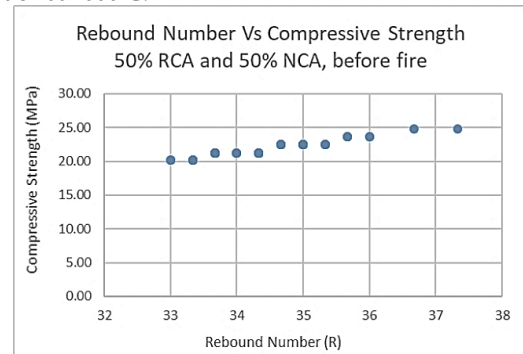


Figure 2. R vs σ for batch – A

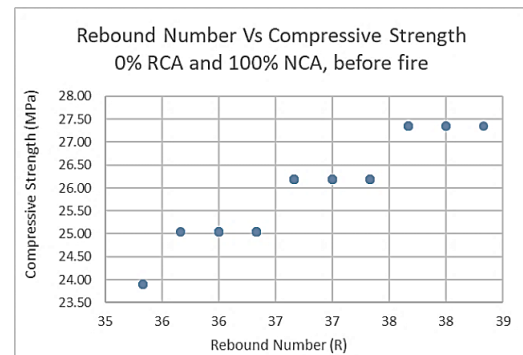


Figure 3. R vs σ for batch – B

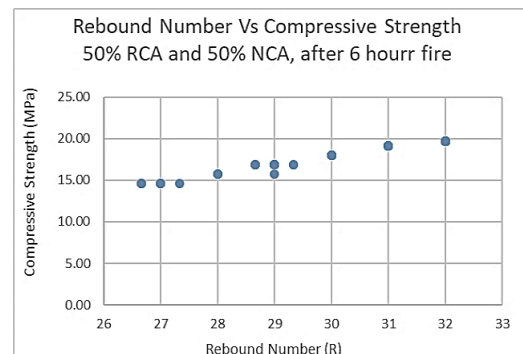


Figure 4. R vs σ for batch – C

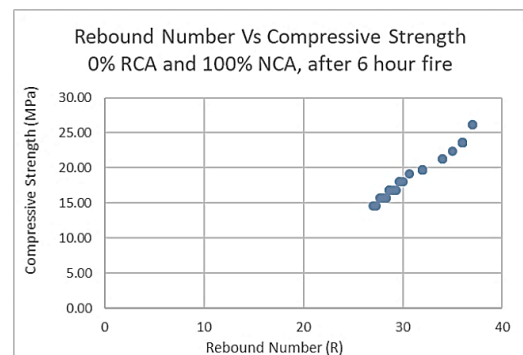


Figure 5. R vs σ for batch – D

From these graphs it is observed that maximum and minimum deviation with respect to average compressive strength is 6% and 5.6% respectively for the cylinders before exposed to fire. Whereas the same is recorded as 19% and 18% respectively.

After discarding the specimen with deviation more than 15% average values are listed in table 11.

Batch	Reference	RCA (%)	Fire (Hour)	R			Average Strength (MPa)	
				min	max	Avg.	NDT	UTM
B1	Cylinders with RCA	50	0	33	37	35	22.04	23.8
B2	Cylinders with NCA	0	0	35	38	37	25.62	28.5
B3	Cylinders with RCA	50	6	27	32	30	17.77	20.99
B4	Cylinders with NCA	0	6	27	36	33	20.28	23.77

Table 11. Average values of rebound hammer and Compressive strength of all cylinders

From this table it is observed that difference between the compressive strength obtained from rebound hammer test and universal testing machine is in the range of 7.4% and 15.31% which is reasonably good and matches with the theoretical difference in results of non-destructive and destructive testing.

The comparison of compressive strength obtained by non-destructive testing of 50% RCA cylinders before and after fire with respect to 0% RCA cylinders before fire is shown in figure 6(a). It is observed from this figure that 50% RCA cylinders are 15.4% less in strength in comparison to 0% RCA cylinders before fire. After exposure to fire for 6-hours, 50% RCA cylinders observed 30.07% reduction in compressive strength in comparison to 0% RCA cylinders without exposing them to fire. From figure 6(b), compressive strength of 20.79 MPa is recorded by non-destructive testing for 0% RCA cylinders exposed to fire for 6-hour. In comparison to it, 50% RCA cylinders before exposing to fire were 4.8% higher in strength but when exposed to fire for 6-hour observed 13.3% reduction in strength. Altogether the reduction in compressive strength of 50% RCA cylinders after exposure of 6-hour fire in comparison to 100% NCA cylinders without exposing to fire is recorded as 28.1%.

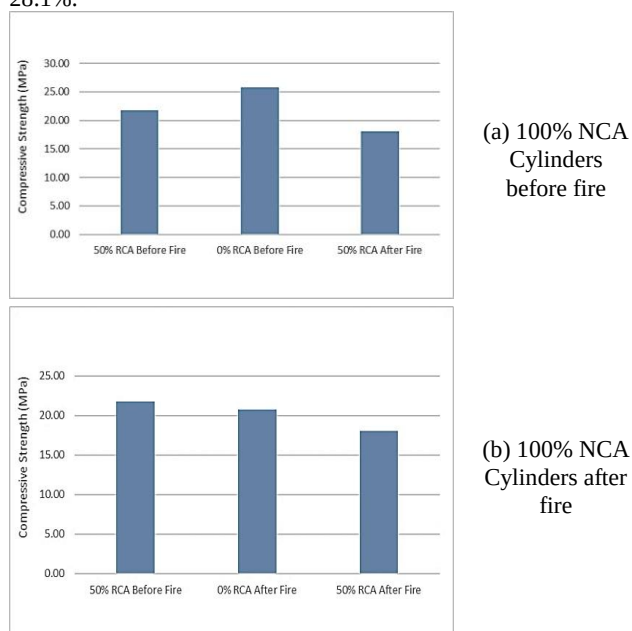


Figure 6. Compressive Strength of 50% RCA Cylinders vs 100% NCA by Rebound Hammer Testing

The compressive strength results obtained from universal load testing machine are listed in table 11 and shown in figure 7.

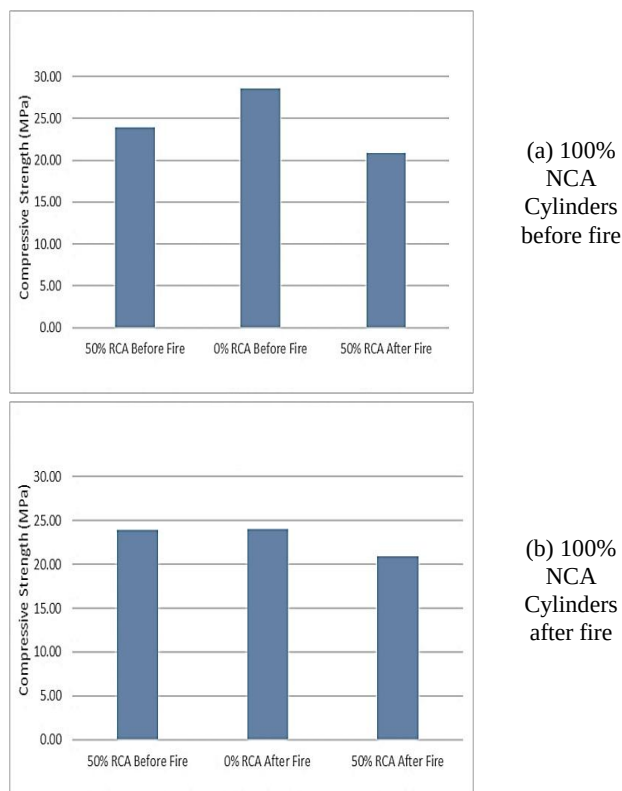


Figure 7 - Compressive Strength of 50% RCA Cylinders vs 100% NCA by UTM

Sub plot (a) and sub plot (b) of this figure gives comparison of strength result obtained from UTM as explained for figure (6). It is observed that 50% RCA cylinders before exposed to fire observed 16.4% reduction in strength as compared to 100% NCA cylinders. Whereas 26.9% reduction in strength of these cylinders is observed when exposed to 6-hour fire.

Using universal load testing machine compressive strength of 100% NCA cylinders exposed to fire for 6-hours is recorded equal to 24.05 MPa.

In comparison to it 50% RCA cylinders before exposing to fire observed 0.01% less strength and same when exposed to 6-hour fire observed 13.01% less strength.

Altogether strength reduction in 50% RCA cylinders exposed to fire for 6-hours in comparison to 100% NCA cylinders not exposed to fire is recorded by UTM equal to 26.9%.

Looking at these values it is observed that difference in both sets of results (non-destructive and destructive) is maximum up to 4.7%, which is in the range of tolerable limit of 5%.

From table 11 it is also observed that the difference between NDT and UTM results for 50% RCA cylinders before exposed to fire is 8.88%, whereas 9.95% difference in both sets of results for 100% NCA cylinders before exposed to fire is recorded.

After exposing to 6-hour fire, the difference between two sets of results for 50% RCA cylinders is 13.86% and for 100% NCA cylinders 13.55%.

From the above discussion it is evident that non-destructive testing using rebound hammer reliably predict the compressive strength for concrete cylinders made by 50% replacement of natural aggregates with aggregates from old concrete and exposed to 6-hour fire at 1000°C. However, 15% margin should be kept in mind while estimating the strength.

5. CONCLUSIONS

This research paper presents experimental work to evaluate compressive strength of concrete cylinders due to combined effect of 50% replacement of natural coarse aggregates with old concrete as coarse aggregates and exposure to 6-hour fire at 1000°C by rebound hammer.

The combined effect not only leads to partial solution of dumping of demolishing waste but also addresses one of the natural hazards and its impact on concrete strength. Proposed technique is used on 240 concrete cylinders made by using 1:2:4 mix and 0.54 water cement ratio.

After evaluation of strength before and after fire by rebound hammer technique, all the cylinders are testing using universal testing machine.

The obtained results and their analysis show that maximum difference between results of NDT and UTM is 4.7%.

This shows the effectiveness and reliability of rebound hammer test for evaluation of concrete strength even after exposure to fire for 6-hours at 1000°C.

References

- Abed, M.A., 2021. Indirect Evaluation of the compressive strength of recycled aggregate concrete at long ages and after exposure to freezing or elevated temperatures. *Russian Journal of Non-destructive Testing*, 57(3), pp.195-202.
- Bhat, J.A., 2021. Effect of strength of parent concrete on the mechanical properties of recycled aggregate concrete. *Materials Today: Proceedings*, 42, pp.1462-1469.
- Buller, A.H. and Memon, B.A., 2018. Non-Destructive Testing Of Rc Beams Made With Partial Replacement Of Coarse Aggregates From Demolished Concrete Exposed To Fire. *World Journal of Engineering, Research and Technology*, 4(2).
- Buller, A.H., Memon, B.A., Buller, A.S. and Sodhar, I.N., 2021. Modeling Fire Effect of Reinforced Recycled Aggregate Concrete Beams by Regression Analysis. *International Journal of Emerging Technology and Innovative Engineering*, 12(1).
- Buller, A.H., Memon, B.A., Sodhar, I.N., Oad, M. and Buller, A.S., 2020. Reuse Of Construction and Demolished Waste as Aggregates in Concrete: A Review. *Journal of Computer Engineering In Research Trends*, 7(8), pp.41-48.
- Buller, A.H., Memon, B.A., Sodhar, I.N., Oad, M., & Sohu, S. (2021). Effect of 6 Hour Fire on Flexural Strength of RC Beams made with 50% Coarse Aggregates from old concrete: Part 1: Normal mix. *Quaid-E-Awam University Research Journal of Engineering, Science & Technology*, Nawabshah., 19(2), 22-29.
- Buller, A.H., Oad, M. and Memon, B.A., 2018. Relationship between Cubical and Cylindrical Compressive Strength of Recycled Aggregate Concrete. *International Journal of Innovative Research in Engineering & Multidisciplinary Physical Sciences*, 6(5), pp.133-138.
- Colombo, M. and Felicetti, R., 2007. New NDT techniques for the assessment of fire-damaged concrete structures. *Fire Safety Journal*, 42(6-7), pp.461-472.
- Kirchhof, L.D., Lorenzi, A. and Silva Filho, L.C.P., 2015. Assessment of concrete residual strength at high temperatures using ultrasonic pulse velocity. *The e-Journal of Nondestructive Testing*, 20(7), pp.1-9.
- Kumavat, H.R., Chandak, N.R. and Patil, I.T., 2021. Factors influencing the performance of rebound hammer used for non-destructive testing of concrete members: A review. *Case Studies in Construction Materials*, 14, p.e00491.
- Kurda, R., de Brito, J. and Silvestre, J.D., 2018. Indirect evaluation of the compressive strength of recycled aggregate concrete with high fly ash ratios. *Magazine of Concrete Research*, 70(4), pp.204-216.
- Memon, B.A., 2016. Recent development on use of demolished concrete as coarse aggregates. *International Journal of Emerging Technology and Innovative Engineering*, 2(1), pp.1-11.
- Memon, B.A., Oad, M., Buller, A.H. and Memon, N.A., 2018. Quality of RC beams made with old concrete as partial replacement of Coarse aggregates by UPV method. *International Journal of Emerging Technology and Innovative Engineering*, 4(7).
- Memon, B.A., Oad, M., Buller, A.H., Shar, S.A., Buller, A.S., & Abro, F.R. (2019). Effect of Mould Size on Compressive Strength of Green Concrete Cubes. *Civil Engineering Journal*, 5(5), 1181-1188.
- Nedeljković, M., Visser, J., Šavija, B., Valcke, S. and Schlangen, E., 2021. Use of fine recycled concrete aggregates in concrete: A critical review. *Journal of Building Engineering*, 38, p.102196.
- Oad, M. and Memon, B.A., 2014. 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)*.
- Soomro, M., Tam, V.W., Shigeishi, M., Kencanawati, N.N., Namihi, T., & Kalinowska, K. (2023). Quality improvement of recycled aggregate. In *Recycled Concrete* (pp. 161-194). Woodhead Publishing.

Tanwani, S. and Memon, B.A., 2015. Tensile Strength of Concrete Cylinders Made By Partial Replacement Of Natural Coarse Aggregates With Coarse Aggregates From Old Concrete. International Journal of Emerging Technology and Innovative Engineering, 1(4), pp.1-10.