ISSN 1330-3651 (Print), ISSN 1848-6339 (Online)
https://doi.org/10.17559/TV-20231219001219
Original scientific paper

Effect of Recycled Aggregates on Physical and Mechanical Performance of Green Concrete Mix

Abdul Hafeez BULLER, Nadiah Md. HUSAIN, Abdul Salam BULLER*, Imran Ali CHANNA, Tariq ALI, Samreen SHABBIR, Irum Naz SODHAR

Abstract: Performance of normally produced concrete is extensively examined both in terms of mechanical and durability point of view using natural aggregates, but due to excessive use of natural resources it is important to use recycled aggregate to reduce not only cost but natural aggregate and environmental pollution. This research study investigates the usage of coarse aggregates from destroyed concrete in new construction and develops strength correction factors for non-standard specimens. Materials used in this study consist of OPC type I, fine aggregate passing from sieve #16 and coarse aggregate of maximum size 25 mm which was obtained from demolished concrete. Performance of recycled aggregate as well as green concrete was examined in terms of compressive, split tensile and flexural strength at 50% replacement of natural aggregate with recycled aggregates. After detailed experimental analysis it is revealed that water absorption capacity increases while decrease in specific gravity was observed compared to conventional coarse aggregates. Recyclable aggregates are used in 50% dosage to prepare green concrete, which has a lower unit weight and density. It was found from test results that recycled aggregates have higher water absorption and lower specific gravity compared to natural coarse aggregates. The unit weight of recycled aggregates concrete (RAC) is 1957 Kg/m³, 11% less than that of concrete with all-natural coarse aggregates (NAC). Tensile strength reductions are more common for RAC cylinders, but the average tensile strength remains within the theoretical range. The study also compares reinforced concrete beams made with natural coarse aggregates and recorded load, deflection, cracks, and cracking patterns at a 5kN load interval until failure.

Keywords: compressive strength; flexural strength; green concrete; natural coarse aggregates; recycled aggregate concrete; tensile strength

1 INTRODUCTION

Over the past few decades, people have moved from rural areas to developed cities, affecting housing and facilities [1]. The construction sector has transitioned from horizontal to vertical development, increasing project costs and environmental problems [2]. Researchers are now interested in proper waste management and on-site waste utilization in landfills [3]. Modern concrete uses recyclable aggregates instead of cement, fine aggregates, and coarse aggregates. Construction and demolishing waste (C&D) is waste generated from demolishing old structures or construction [4]. To minimize C&D waste, key points include dumping it at the source, reusing or refurbishing before reuse, recycling, using waste energy as renewable energy, and dumping it in landfills [5]. Researchers optimize demolition trash use by assessing particles, grading, and assessing aggregate qualities before proportioning them in fresh concrete [6]. Recycling demolition trash for new construction is preferable, replacing NCA with 10% increase and producing recovered coarse aggregates from discarded recycled concrete blocks [5]. Recycling coarse aggregates (RCA) have been used to address environmental issues from demolition waste [1], such as space needed for dumping and construction materials [7, 8]. RCA has similar effects to natural aggregate cylinders (NAC), but high percentage replacements can reduce its performance. Construction wastes with suitable replacement of natural resources can save resources [9], use demolition waste from old structures and prefer 50% replacement of natural aggregate cylinders in ordinary concrete [10] proposed using waste recycled concrete blocks as coarse aggregates in concrete, replacing NCA in 5% to 50% with an increment of 10% [11]. Kumutha & Vijai [12] studied the properties of recycled aggregates in concrete with partial/full replacement of coarse and fine aggregates, observing decreasing patterns in compressive strength [13], flexural strength [14], and tensile strength except modulus of elasticity [15]. Akbari et. al. [16] found that using demolished concrete aggregates in concrete reduced compressive strength, flexural strength, and split tensile strength by 26%. Another perspective was discussed by some authors by showing the behaviour of concrete under crack healing side [17-20], effect of waste materials on construction of rigid payment side [21-23] and more importantly towards fracture behaviour of concrete [19] [24]. Green concrete offers numerous benefits, including reduced carbon dioxide emissions, waste product use, and pollution [11], some work was also reported on creep control and shrinkage testing of recycled aggregate concrete [25-27]. This study aims to provide strength correction coefficients for non-standard specimens, providing a landmark for researchers and industry professionals to ensure the quality of concrete used on site. However, the strength of recycled aggregate-built infrastructure must withstand accidental and natural occurrences for its useful life. International research is focused on understanding the characteristics of concrete built with these aggregates. Recycled aggregates are rarely used in Pakistan, causing waste management and environmental dangers. To reduce these problems and increase project effectiveness, recycled aggregates should be used in fresh concrete. Quality control is conducted through evaluation and testing, with the strength produced varying depending on the size of the field-used mould. Based on above discussion it was observed that many studies have focussed on the investigation of mechanical performance of concrete using recycled aggregate; however few of them have considered the correction factors to investigate the mechanical performance of concrete using recycled aggregate. Therefore, this study investigates the impact of cylindrical mould size on compressive and tensile strength of green concrete made from dismantled construction and demolition waste. It also investigates the coefficient of correction and flexural strength of green concrete with partial recycled coarse aggregates. By adding correction coefficients and calibrating concrete cylinders to standard 150x300 mm strength [26]. The goal is to reduce environmental impact and utilize demolishing waste in new construction.

2 EXPERIMENTAL PROGRAM

2.1 Materials and Mix Proportions

The 60-year-old reinforced concrete structure at the government girls' school Nawabshah that created traffic congestion and pollution is examined in this research study. In a lab, the trash was processed to make new concrete. Large concrete blocks that had been demolished were manually reduced in size to 25 mm, with manual hammering being favoured as shown in Fig. 1. Fine aggregates filled the spaces between coarse aggregates after being crushed in natural aggregate quarries in Jamshoro, Sindh. Bolhari hill sand was used as the fine aggregate. In the construction sector, cement is utilised as a binding agent in concrete, with ordinary Portland cement (OPC) being used for specimen preparation. Water is a crucial ingredient in concrete because it initiates the hydration process and the binding action that produces hard rock material. The water used in concrete should be free from impurities, and the pH value of the water used in this work was found to be 7.2, within the acceptable range. Concrete water should be free of impurities, with a pH value of 7.2 within acceptable range. The strength of concrete is evaluated from the running batch to ensure proper strength. Different shapes and sizes are used for shaping and size, while the code requirement requires standard size moulds. Deviations in the size of the mould can affect the resulting strength of the specimen, so it should be corrected before considering quality assurance. Demolished concrete is used as coarse aggregates as a partial replacement for natural coarse aggregates and to check the effect on strength due to variations in cylindrical mould size.

Figure 1 Demolished wastes of structural elements

2.2 Screening of Materials

The process of sorting out unwanted substances from aggregates, such as organic impurities, plastic, glass, and rusted steel, involves separating cracked and un-cracked particles. Cracked particles are weak and can affect the strength of new concrete. The process begins with sorting large blocks of old concrete, which are hammered down to 25 mm size as shown in Fig. 2. Despite careful handling, cracked particles remain, and are manually separated. The percentage of cracked particles may vary between batches and hammering times, but for this research work, it was recorded at 13%.

Figure 2 Concrete Blocks of C&D waste and cracked particles of RCA

2.3 Specimen Casting and Testing

The qualities of the aggregates, such as unit weight, density, water absorption, and specific gravity, are essential for the properties of the concrete mix. Water demand is very important, and the water-cement ratio is changed according to how much water the aggregates can absorb. This research's major study subject, old destroyed concrete, is thought to be more water absorbent due to its age and mortar. Through the use of ASTM C-128 and AASHTO T-85 methods [28], these characteristics are assessed for both natural and recyclable aggregates. Aggregate samples were submerged in cement paste for one minute and dried in the open air to measure specific gravity and water absorption. Concrete cylinders are prepared using a 1:2:4 mix and 0.45 water cement ratio, using ingredients like Pak Land cement, fine aggregates from Bolhari, coarse aggregates from Jamshoro quarries, and potable water. Natural coarse aggregates are replaced with demolished concrete in 50% dosage. The preparation process follows ASTM-C293 and AASHTO standards [23]. Concrete cylinders are available in five sizes: 200 × 400, 150 × 300, 100 × 200, 75 × 150 and 50 × 100 as shown in Fig. 3. The aspect ratio of the moulds is set at 2.

Figure 3 Different size of cylinders before testing

Twelve to sixteen concrete cylinder samples are produced for each size, with 12 standard size samples cast with natural coarse particles. These serve as control specimens for comparison. After 28 days, they are cured, air dried, and tested for compressive and tensile strength using universal load testing machines as shown in Fig. 4.

Figure 4 Selected specimen for compressive strength and spilt tensile strength testing

Beams made of reinforced concrete are cast using the weight batching process, with the precise weight being determined in a laboratory. A concrete mixer first receives the dry components, then the water. Grease/oil is applied to moulds, steel is set, and mortar bats are set beneath the steel cage. A needle vibrator is used to compress the concrete after it has been properly mixed and put into the moulds. The beams' top surface is trowelled to make it level. All beams are tested using central point loading in accordance with ASTM-C293 after air drying as shown in Fig. 5. At regular intervals, deflection, load, and cracks are measured.

Figure 5 Selected RC beams for flexural strength testing

3 RESULTS AND DISCUSSIONS

3.1 Basic Properties of Recycled Aggregate Concrete

This Research investigates aggregate properties like water absorption and specific gravity for natural and recycled materials. The average values of these properties are presented in Tab. 1, with recycled aggregates having water absorption of 3.90, 120% more than natural coarse aggregates, and a specific gravity of 2.40, 5% less than natural coarse aggregates. Concrete samples were prepared to assess the impact of recycled aggregates on unit weight and density. The unit weight of recycled aggregates concrete (RAC) is 1960 Kg/m³, 11% less than that of concrete with all-natural coarse aggregates (NAC), and the density of RAC is 2360.78 Kg/m³, 5.5% less than NAC. The deviation in these properties is due to the age of concrete and old mortar. Mix design should consider these deviations to ensure better strength and proper workability of the concrete. The ultimate load values for prepared cylinders are recorded and converted into strength by dividing the specimen area.

Table 1 Properties of coarse aggregates

Description	Natural Aggregates	Recycled Aggregates
Unit Weight / Kg / m³	2195	1960
Density / Kg / m³	2495	2360
Specific Gravity	2.56	2.40
Water Absorption / %	1.80	3.90

3.2 Compressive Strength of Recycled Aggregate Concrete

The study compares the compressive strength of six standard-size RAC cylinders using all-natural coarse aggregates. Six to eight cylinders are tested using 50% natural and recycled aggregates in mould sizes, as shown in Tab. 2. The results show that the average compressive strength of natural aggregate concrete cylinders is 31.70 MPa. RAC cylinders of 200 × 400 had a 188% higher compressive strength value, while 150 × 300 and 100 × 200 cylinders experienced a 6.95% reduction. 100 × 200 cylinders had a 4.80% increase in compressive strength compared to natural-aggregate cylinders of standard size. The maximum compressive strength was recorded for the maximum size mould used in the study as shown in Tab. 3. The comparison of parameters is shown in Fig. 6, which shows the maximum compressive strength recorded for the maximum size mould used in the study.

The study compares the compressive strength of six standard-size RAC cylinders using all-natural coarse aggregates. The results show that the average compressive strength of natural aggregate concrete cylinders is 31.70 MPa. RAC cylinders of 200 × 400 had a 188% higher compressive strength value, while 150 × 300 and 100 × 200 cylinders experienced a 6.95% reduction.

Table 2 Maximum Compressive strength of different size (mm) of cylinders

S. No	Cylinder size 200 × 400 (R)	Cylinder size 150 × 300 (R)	Cylinder size 100 × 200 (R)	Cylinder size 75 × 150 (R)	Cylinder size 50 × 100 (R)	Cylinder size 200 × 400 (N)
1	90.89	28.90	30.15	24.78	13.91	30.78
2	91.64	29.28	25.57	22.78	16.70	32.55
3	92.39	31.39	26.73	33.13	13.38	32.93
4	90.89	29.69	31.12	20.86	17.36	32.37
5	87.52	29.28	30.20	18.93	17.10	31.42
6	92.51	28.75	26.82	24.91	15.45	33.49
7	91.64	31.39	27.61	23.78	16.87	32.37
8	92.39	28.90	26.82	28.60	15.15	31.42

Table 3 Average Load and average compressive strength of all cylinders

Cylinder Size	RAC Cylinders					NAC Cylinders
	200 × 400	150 × 300	100 × 200	75 × 150	50 × 100	150 × 300
Load / kN	2856.6	522.00	220.8	109.16	30.88	559.70
Compressive Strength / MPa	91.00	29.50	28.20	24.75	15.75	31.70

100 × 200 cylinders had a 4.80% increase in compressive strength compared to natural-aggregate cylinders of standard size. The maximum compressive strength was recorded for the maximum size mould used in the study as shown in Tab. 3.

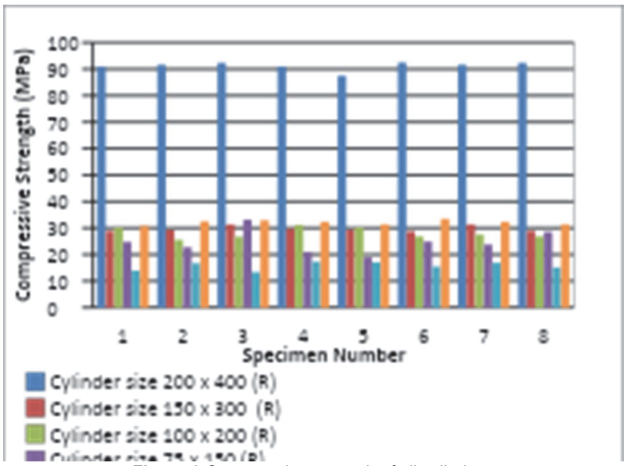

Figure 6 Compressive strength of all cylinders

3.3 Compressive Strength Correction Coefficient

The standard size cylinder is 150 × 300, and its strength is considered the base value. To map other values, the strength correction coefficients are computed and listed in Tab. 4 to Tab. 5. The strength of the cylinder is divided with the coefficients to map it in line with the compressive strength of the standard size cylinder. The same correction coefficients are evaluated for natural aggregate concrete cylinders of standard size, and the coefficients can be used to divide the strength of RAC cylinder in hand to correlate it with the compressive strength of the standard size cylinder of conventional concrete. The correction coefficients are plotted as bar charts in Fig. 7 and Fig. 8 for visualization purposes.

Table 4 Correction coefficients with respect to standard size RAC cylinders

Size of cylinder / mm	200 × 400	150 × 300	100 × 200	75 × 150	50 × 100
Correction coefficient	3.085	1.000	0.955	0.838	0.534

Table 5 Correction coefficients with respect to standard size NAC cylinders

Size of cylinder / mm	200 × 400	150 × 300	100 × 200	75 × 150	50 × 100
Correction coefficient	2.871	0.931	0.889	0.78	0.497

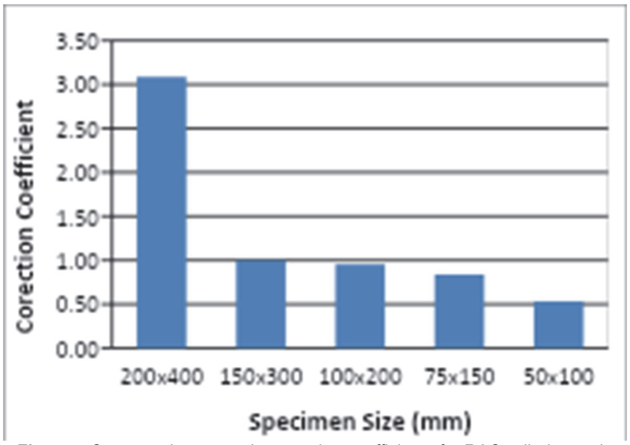

Figure 7 Compressive strength correction coefficients for RAC cylinders only

3.4 Tensile Strength of Recycled Aggregate Concrete

The study compares the results of natural aggregate concrete cylinders (RAC) and RAC cylinders using all-natural coarse aggregates. Six cylinders of standard size were cast, cured for 28 days, and tested for tensile strength. The results show that natural aggregate concrete cylinders have an average tensile strength of 4.8 MPa, which is 15.14% of the compressive strength of the cylinders.

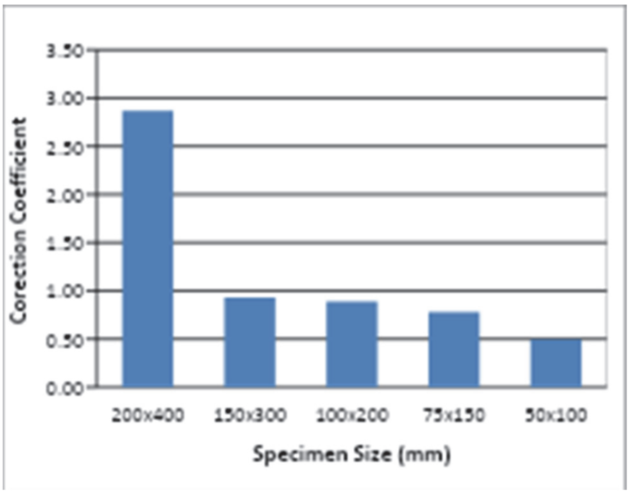

Figure 8 Compressive strength correction coefficients for RAC versus NAC cylinders

RAC cylinders of size 200 × 400 sustained 70.83% tensile strength, while 150 × 300 and 100 × 200 cylinders experienced 8.33% and 27.71% reductions, respectively. The 75 × 150 and 50 × 100 cylinders experienced 29.78% and 33.96% reductions, respectively as shown in Tab. 6. Most cylinders experienced more reduction in tensile strength compared to compressive strength reduction. However, the average tensile strength of most cylinders remained within the theoretical range. The 200 × 400 and 50 × 100 cylinders experienced 3.70% and 20% reductions in compression to compressive strength, respectively as shown in Tab. 7. As the size of the cylinder mould increases, tensile strength decreases, while decreasing the size of the mould gives rise to even greater strength. The tensile strength of all cylinders, including those cast with all-natural coarse aggregates, is plotted in Fig. 9, showing that the maximum tensile strength is recorded for standard size cylinders made with all-natural coarse aggregates.

Table 6 Maximum tensile strength of different size (mm) of cylinders

S. No	Cylinder size 200 × 400 (R)	Cylinder size 150 × 300 (R)	Cylinder size 100 × 200 (R)	Cylinder size 75 × 150 (R)	Cylinder size 50 × 100 (R)	Cylinder size 200 × 400 (N)
1	3.41	4.68	3.87	3.76	3.25	4.75
2	3.44	4.75	3.44	3.11	3.13	4.68
3	3.46	4.01	3.00	3.14	3.18	4.99
4	3.41	4.66	3.72	3.40	3.23	4.89
5	3.28	4.46	3.26	3.24	3.36	4.74
6	3.47	4.01	3.58	3.20	3.12	4.55
7	3.41	4.68	3.87	3.52	2.95	4.75
8	3.44	4.75	3.00	3.60	3.18	4.68

Table 7 Average Load and average tensile strength of all cylinders

Cylinder Size / mm	RAC Cylinders					NAC Cylinders
	200 × 400	150 × 300	100 × 200	75 × 150	50 × 100	150 × 300
Load	428.50	313.00	109.00	59.50	24.90	336.70
Tensile Strength	3.43	4.50	3.46	3.36	3.18	4.75

3.5 Tensile Strength Correction Coefficient

The standard size of cylinder is 150 × 300 and its strength is considered the base value. To map other values, the tensile strength of the standard size cylinder is used. Strength correction coefficients are computed and listed in Tab. 8. The strength of the cylinder in hand is divided with the coefficients to map it in line with the tensile strength of the standard size cylinder. In a second attempt, the tensile strength of natural aggregate concrete cylinders of standard size is taken as the base strength and the correction coefficients are evaluated as shown in Tab. 9. The coefficients can be used to divide the strength of RAC cylinder in hand to correlate the tensile strength with the standard size cylinder of conventional concrete. For visualization, the correction coefficients of Tab. 8 are plotted as bar chart in Fig. 10 and the coefficients from Tab. 9 are graphically represented in Fig. 11.

Table 8 Correction coefficients with respect to standard size RAC cylinders

Size of cylinder / mm	200 × 400	150 × 300	100 × 200	75 × 150	50 × 100
Correction coefficient	0.773	1.000	0.789	0.766	0.720

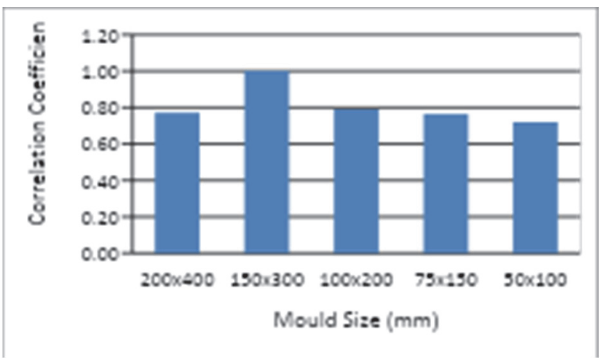

Figure 10 Tensile strength correction coefficients for RAC cylinders only

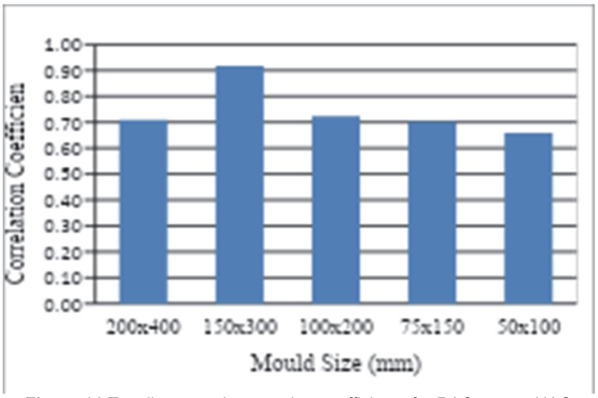

Figure 11 Tensile strength correction coefficients for RAC versus NAC cylinders

Table 8 Correction coefficients with respect to standard size NAC cylinders

Size of cylinder / mm	200 × 400	150 × 300	100 × 200	75 × 150	50 × 100
Correction coefficient	0.708	0.917	0.723	0.702	0.660

3.6 Flexural Strength of Recycled Aggregate Concrete Beams

Tab. 10 displays the results of reinforced concrete beams made with all-natural coarse aggregates. These beams are treated as control specimens to compare the results of proposed beams. During testing, load, deflection, cracks, and cracking patterns are carefully marked at a load interval of 5 kN until failure. The beam failed at a load of 69.431 kN with 4.6 mm deflection. The load is converted to flexural strength and recorded as 27.77 MPa. Tab. 10 shows the maximum load carrying capacity, deflection, and flexural strength for beams. The load versus deflection pattern of all six beams is almost similar, with a maximum variation of 6.25% in deflection results. The maximum flexural strength in this group is 31.23 MPa. This table also presents the results of beams casted with 50% replacement of natural coarse aggregates with coarse aggregates from demolished concrete and tested at a load interval of 5 kN. Beams failed at a load of 70.65 kN, deflecting to 4.95 mm. Maximum load, deflection, and flexural strength of beams are given in Tab. 10. The load vs deflection pattern is almost similar for all beams, with minor variation in maximum load and 4.81% maximum variation in deflection. Results of maximum load and maximum deflection are plotted in Fig. 12 and Fig. 13. Flexural strength for this group of beams is plotted in Fig. 14, showing a 5.73% reduction in flexural strength compared to beams cast with all-natural coarse aggregates.

Table 10 Flexural strength testing results of RC beams

S.No	0% RCA Replacement			50% RCA Replacement		
	load / N	Def: / mm	N/mm^2	load / N	Def: / mm	N/mm^2
1	73431	4.60	29.3724	68637	4.95	27.4548
2	74087	4.80	29.6348	67808	5.10	27.1232
3	73515	4.70	29.406	68973	4.95	27.5892
4	73805	4.55	29.522	67250	5.20	26.9
5	73945	4.80	29.578	68431	5.15	27.3724
6	73460	4.70	29.384	67912	4.90	27.1648

Table 11 Average values of RC beams

S.No	Description	Unit	0% RCA Replacement	50% RCA Replacement
1	load / N	N	73707.17	68168.50
2	Deflection / mm	mm	4.69	5.04

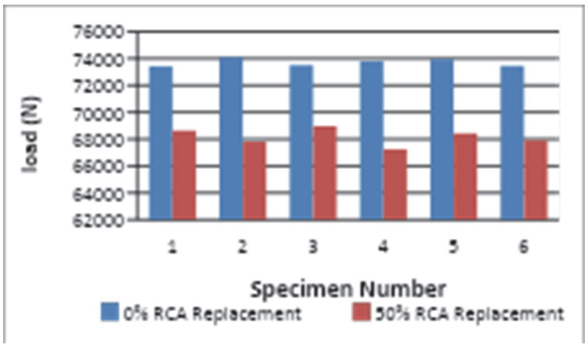

Figure 12 Beams carrying maximum load (N)

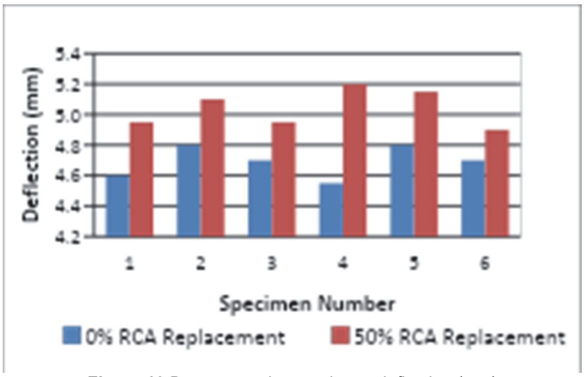

Figure 13 Beams carrying maximum deflection (mm)

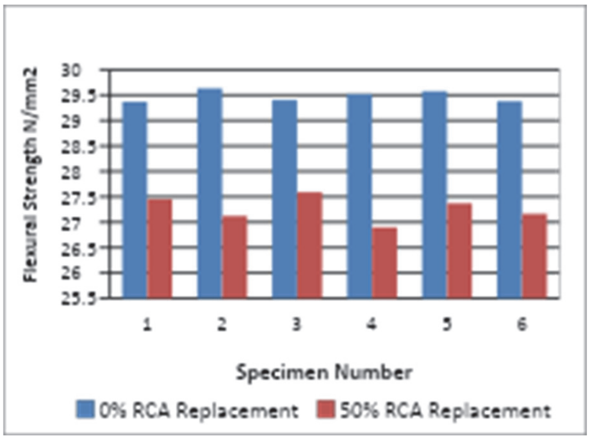

Figure 14 Beams carrying maximum flexural strength

4 CONCLUSIONS

The study explores the use of old, demolished, or recycled concrete as coarse aggregate in green concrete, focusing on its impact on basic and mechanical properties. The demolished concrete was reduced to 25 mm using manual hamming, revealing increased water absorption and decreased specific gravity compared to conventional coarse aggregates. Green concrete, prepared with 50% recycled aggregates, has a lower unit weight and density. The study found that recycled aggregates have higher water absorption and specific gravity, with a unit weight of 1957 Kg/m³, 11% less than natural coarse aggregates. The compressive strength of six standard-size RAC cylinders using all-natural coarse aggregates is 31.7 MPa, compared to the average of 31.7 MPa for natural aggregate concrete cylinders. Tensile strength reductions are more common for RAC cylinders, but the average remains within theoretical range. The study recommends using more cylindrical specimens, different dosages of recyclable aggregates, different curing ages, larger cylinder sizes, and admixtures to improve recycled concrete properties.

5 REFERENCES

[1] Makul, N., Fediuk, R., Amran, M., Zeyad, A. M., Murali, G., Vatin, N., Klyuev, S., Ozbakkaloglu, T., & Vasilev, Y. (2021). Use of Recycled Concrete Aggregates in Production of Green Cement-Based Concrete Composites: A Review: *Crystals, 11*, 232. https://doi.org/10.3390/cryst11030232

[2] Qasrawi, H. & Marie, I. (2013). Towards Better Understanding of Concrete Containing Recycled Concrete Aggregate. *Adv. Mater. Sci. Eng.*, 1-8. https://doi.org/10.1155/2013/636034

[3] Xiao, Z., Ling, T.-C., Poon, C.-S., Kou, S.-C., Wang, Q., & Huang, R. (2013). Properties of partition wall blocks prepared with high percentages of recycled clay brick after exposure to elevated temperatures. *Constr. Build. Mater., 49*, 56-61. https://doi.org/10.1016/j.conbuildmat.2013.08.004

[4] Buller, A. S., Abro, F. ul R., Lee, K.-M., & Jang, S. Y. (2019). Mechanical Recovery of Cracked Fiber-Reinforced Mortar Incorporating Crystalline Admixture, Expansive Agent, and Geomaterial. *Adv. Mater. Sci. Eng.*, 1-14. https://doi.org/10.1155/2019/3420349

[5] El-Haggar, S. M. (2007). Sustainability of construction and demolition waste management. *Sustain. Ind. Des. Waste Manag. Cradle-to-Cradle Sustain. Dev.*, 261-292. https://doi.org/10.1016/B978-012373623-9/50010-1

[6] Kaarthik, M. & Maruthachalam, D. (2021). A sustainable approach of characteristic strength of concrete using recycled fine aggregate. *Mater. Today Proc., 45*, 6377-6380. https://doi.org/10.1016/j.matpr.2020.11.058

[7] Alani, A., Lesovik, R., Lesovik, V., Fediuk, R., Klyuev, S., Amran, M., Ali, M., de Azevedo, A., & Vatin, N. (2022). Demolition Waste Potential for Completely Cement-Free Binders. *Materials (Basel), 15*, 6018. https://doi.org/10.3390/ma15176018

[8] Malešev, M., Radonjanin, V., & Marinković, S. (2010). Recycled Concrete as Aggregate for Structural Concrete Production. *Sustainability, 2*, 1204-1225. https://doi.org/10.3390/su2051204

[9] 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. *Civ. Eng. J., 5*, 1181-1188. https://doi.org/10.28991/cej-2019-03091322

[10] Soomro, F. A., Memon, B. A., Oad, M., Buller, A. H., & Tunio, Z. A. (2019). Shrinkage of Concrete Panels Made with Recyclable Concrete Aggregates. *Eng. Technol. Appl. Sci. Res., 9*, 4027-4029. https://doi.org/10.48084/etasr.2595

[11] Błaszczyński, T., & Król, M. (2015). Usage of Green Concrete Technology in Civil Engineering. *Procedia Eng., 122*, 296-301. https://doi.org/10.1016/j.proeng.2015.10.039

[12] Kumutha, R. & Vijai, K. (2010). Strength of concrete incorporating aggregates recycled from demolition waste. *ARPN J. Eng. Appl. Sci., 5*, 64-71.

[13] Buller, A. H., Husain, N. M., Ali, I., Sohu, S., Memon, B. A., & Sodhar, I. N. (2023). Strength (Compressive) of Concrete Made by Recyclable Concrete Aggregates after Six Hour Fire by Nondestructive Testing. *J. Appl. Eng. Sci., 13*, 57-64. https://doi.org/10.2478/jaes-2023-0008

[14] Buller, A. H., Husain, N. M., Oad, M., Memon, B. A., & Sodhar, I. N. (2022). Investigating the Deflection and Strain of Reinforced Green Concrete Beams Made With Partial

Replacement of RCA under Sustained Loading. *Eng. Technol. Appl. Sci. Res., 12*, 9203-9207. https://doi.org/10.48084/etasr.5170
[15] Liu, Q., Xiao, J., & Sun, Z. (2011). Experimental study on the failure mechanism of recycled concrete. *Cem. Concr. Res., 41*, 1050-1057. https://doi.org/10.1016/j.cemconres.2011.06.007
[16] Akbari, Y. V, Arora, N. K. & Vakil, M. D., (2011). Effect on recycled aggregate on concrete properties. *Int. J. Earth Sci. Eng., 4*, 924-928.
[17] Buller, A. S., Abro, F.-R., Ali, T., Jakhrani, S. H., Buller, A. H., & Ul-Abdin, Z. (2021). Stimulated autogenous-healing capacity of fiber-reinforced mortar incorporating healing agents for recovery against fracture and mechanical properties. *Mater. Sci., 39*, 33-48. https://doi.org/10.2478/msp-2021-0009
[18] Abro, F. ul R., Buller, A. S., Ali, T., Ul-Abdin, Z., Ahmed, Z., Memon, N. A., & Lashari, A. R. (2021). Autogenous Healing of Cracked Mortar Using Modified Steady-State Migration Test against Chloride Penetration. *Sustainability, 13*, 9519. https://doi.org/10.3390/su13179519
[19] Buller, A. S., Abro, F.-R., Ali, M., Ali, T., & Bheel, N. (2024). Effect of silica fume on fracture analysis, durability performance and embodied carbon of fiber-reinforced self-healed concrete. *Theor. Appl. Fract. Mech., 130*, 104333. https://doi.org/10.1016/j.tafmec.2024.104333
[20] Buller, A. S., Buller, A. M., Ali, T., Tunio, Z. A., Shabbir, S., & Malik, M. A. (2021). Experimental Characterization of Bacterial Concrete Against Mechanical and Durability Performance. *Eng. Technol. Appl. Sci. Res., 11*, 6703-6707. https://doi.org/10.48084/etasr.3983
[21] Lashari, A. R., Ali, Y., Buller, A. S., & Memon, N. A. (2023). Effects of partial replacement of fine aggregates with crumb rubber on skid resistance and mechanical properties of cement concrete pavements. *Int. J. Pavement Eng., 24*, 2077940. https://doi.org/10.1080/10298436.2022.2077940
[22] Ali, Y., Irfan, M., Buller, A. S., Khan, H. A., & Gul, H. M. F. (2019). A binary logistic model for predicting the tertiary stage of permanent deformation of conventional asphalt concrete mixtures. *Constr. Build. Mater., 227*. https://doi.org/10.1016/j.conbuildmat.2019.07.334
[23] Ali, Y., Hussain, F., Irfan, M., & Buller, A. S. (2021). An eXtreme Gradient Boosting model for predicting dynamic modulus of asphalt concrete mixtures. *Constr. Build. Mater., 295*, 123642. https://doi.org/10.1016/j.conbuildmat.2021.123642
[24] Abro, F. ul R., Buller, A. S., Lee, K.-M., & Jang, S. Y. (2019). Using the Steady-State Chloride Migration Test to Evaluate the Self-Healing Capacity of Cracked Mortars Containing Crystalline, Expansive, and Swelling Admixtures. *Materials (Basel), 12*, 1865. https://doi.org/10.3390/ma12111865
[25] Kekanović, M., Krstić, K., & Petrov, R. (2021). Problematika Ispitivanja Tečenja I Skupljanja Kod Očvrslog Betona. *Zb. Rad. Građevinskog Fak., 37*, 385-394. https://doi.org/10.14415/konferencijaGFS2021.37
[26] Kekanović, M., Đurić, N., & Pištalo, S. (2020). NATURAL Crushed Rock As Aggregate For Ultra High Strength Cement Concretes. *Arch. Tech. Sci., 1*. https://doi.org/10.7251/afts.2019.1121033K
[27] Association, N. R. M. C. (2003). CIP 35-testing compressive strength of concrete. *Concr. Pract. What, Why How*.
[28] Astm, A. (2015). *C127-15 standard test method for relative density (specific gravity) and absorption of coarse aggregate*. Am. Soc. Test. Mater. West Conshohocken, PA, USA.

Contact information:

Abdul Hafeez BULLER, Post-Doctoral Fellow
Kulliyyah (Faculty) of Engineering,
International Islamic University Malaysia,
Civil Engineering Department, Malaysia
E-mail: engrabdulhafeezbuller@gmail.com

Nadiah Md. HUSAIN, Assistant Professor
Kulliyyah (Faculty) of Engineering,
International Islamic University Malaysia,
Civil Engineering Department, Malaysia
E-mail: drnadiah@iium.edu.my

Abdul Salam BULLER, Associate Professor
(Corresponding author)
NED University of Engineering and Technology, Karachi,
Civil Engineering Department (TIEST), Pakistan
E-mail: engr.salam@neduet.edu.pk

Imran Ali CHANNA, Lecturer
Quaid-e-Awam University of Engineering, Science and Technology,
Civil Engineering Department, Pakistan
E-mail: channaimran99@gmail.com

Tariq ALI, Assistant Professor
The Islamia University of Bahawalpur, Bahawalpur,
Civil Engineering Department, Pakistan
E-mail: tariqdehraj@gmail.com

Samreen SHABBIR, Lecturer
Dawood University of Engineering and Technology,
Civil Engineering Department, Pakistan
E-mail: samreen.shabbir@yahoo.com

Irum Naz SODHAR, Assistant Professor
Shaheed Benazir Bhutto University, Shaheed Benazirabad,
Department of Information Technology, Pakistan
E-mail: irumnaz@sbbusba.edu.pk