Workability and Flexural Strength of Recycled Aggregate Concrete with Steel Fibers

Kashif Hassan Chachar
Department of Civil Engineering, Quaid-e Awam University of Engineering, Science & Technology, Pakistan
kashif19956@gmail.com

Mahboob Oad
Department of Civil Engineering, Quaid-e-Awam University of Engineering, Science & Technology, Pakistan
engrmahboob04@gmail.com (corresponding author)

Bashir Ahmed Memon
Department of Civil Engineering, Quaid-e-Awam University of Engineering, Science & Technology, Pakistan
bashir_m@gmail.com

Zameer Ahmed Siyal
Department of Civil Engineering, Quaid-e-Awam University of Engineering, Science & Technology, Pakistan
zmeerahmedsiyal@gmail.com

Kiran Fatima Siyal
Department of Civil Engineering, Quaid-e-Awam University of Engineering, Science & Technology, Pakistan
kiranf893@gmail.com

Received: 16 April 2023 | Revised: 20 April 2023 | Accepted: 28 April 2023

 DOI: https://doi.org/10.48084/etasr.5921

ABSTRACT

This study examined how concrete workability and flexural strength are affected by steel fibers and recycled aggregates. Steel fibers were used in doses between 1-5%, with an increment of 0.5%, and 50% of the natural coarse aggregates were replaced by recycled. Two mixes of conventional and recycled aggregate concrete without steel fibers were used as control mixes. Concrete mixes were prepared using 1:2:4 and 0.45 water-to-cement ratios. Workability was determined using the slump cone. Three prism specimens sized 500×100×100mm were prepared for each batch and cured for 28 days in potable water. After curing, the specimens were air-dried in the laboratory and tested to evaluate their flexural strength under two-point loading. The load and deflection were monitored at regular intervals until failure. A comparison of results with control mixes showed that as the percentage of steel fiber increased, flexural strength increased by 69% and deflection decreased by 66%. The use of steel fibers improved the flexural strength of the recycled aggregate concrete by 59%.

Keywords-demolished waste; recycled aggregates; green concrete; steel fibers; flexural strength; sustainable development; waste management

I. INTRODUCTION

The construction industry has undergone drastic changes over time and has faced great challenges, particularly for high-rise infrastructures from a strength, safety, and durability points of view. The present global boom of construction is due to the modern development and the increasing accommodation needs in city centers. This increased demand forced the construction industry to opt for vertical instead of horizontal expansion. This requires the demolition of old deteriorated short buildings to construct tall ones. This procedure not only demands excessive use of natural aggregates but also generates a huge quantum of demolition waste. Approximately 450 million tons of demolition waste are generated per year in the European Union [15], of which 50-55% is concrete. Some of this waste is used under floors and in plinth protections but generally goes to landfills for dumping. On the other hand, the shortage of space, particularly in city centers, increases the serious problem of dumping. On-site use of demolition waste still leaves a large amount of waste. Another possible use of it is in new concrete, and several studies investigated its use as a substitute for fine and coarse aggregates. Concrete waste is large in volume compared to the other demolition waste ingredients. As the major space-taking component of concrete is coarse aggregates, the use of concrete waste as coarse aggregates would consume more waste, facilitating waste management and reducing the use of Natural Coarse Aggregates (NCA). Furthermore, the use of demolition waste as coarse aggregate provides an alternative indigenous material as a component for concrete.

Various studies attempted to investigate this problem. One way to increase the strength characteristics of concrete is by using various types of fibers. The use of fibers also aids in the disposal of that material's waste. Fibers in concrete have many advantages. The studies in [1-2] made field investigations to highlight the issue, its impact, and its remedies, pointing out that proper implementation of rules and regulations by governments will help to streamline its use. In [3-5], the tensile strength of concrete with Recycled Coarse Aggregates (RCA) was investigated, showing that it was similar to conventional concrete regardless of its source, quality, or quantity. In [6], waste from laboratory-tested cylinders was used in the preparation of new concrete beams to check their flexural strength, reporting a minimum difference in peak load from their counterparts, regardless of the dosage of RCA. In [7], it was reported that demolition waste can be used as coarse aggregates with minimum loss of flexural capacity if proper design and application limits are considered. In [8], demolition waste was used as coarse aggregates in dosages of 30%, 50%, and 100% to check the flexural capacity of the produced concrete, observing similar crack patterns but a lower flexural strength when varying the tensile reinforcement ratio to 0.5%, 0.79%, and 1.14%. In addition, this study noticed that the ductility of the beams was not influenced by the dosage of the RCA. Adding recycled materials to concrete reduces its flexural strength [9]. In [10], flexural strength was reduced by 8.8% and 5.5% for 7- and 28-day cured normal mix RC beams, respectively, and an 11.68% loss of strength was reported for 28-day cured rich mix concrete beams [11]. Fire not only affects the appearance of reinforced concrete beams but also deteriorates their resisting capacity. In [12-14], a 1000°C fire on reinforced RCA beams reduced bearing capacity by 8%, 22%, and 32.41% for fire exposures of 6, 18, and 24 hours, respectively.

In [16], RCA concrete samples were prepared and cured for 1, 2, 7, 28, and 56 days with a compressive strength target between 20-50MPa, and the test results revealed a residual concrete strength of 90% with only a 3% reduction in the modulus of elasticity. In [17-18], fly ash was used in RCA concrete to improve strength, showing that a dosage of 25-35% fly ash allows a larger proportion of NCA to be replaced with RCA made from demolition waste. The studies in [19-22] investigated the mechanical and durability properties of RCA concrete with fly ash and customizable water-binder ratios, demonstrating that the use of large amounts of fly ash in recycled aggregate concrete enhanced its properties in terms of compressive strength, tensile strength, and resistance to chloride action. In [23-24], it was shown that RCA concrete containing biomass bottom ash behaved worse, concluding that it should only be used in non-structural concrete. In [25], the strength characteristics of RCA concrete were positively affected by the quality of the parent concrete, as when the strength of parent concrete was 80-100MPa, RCA concrete exhibited properties almost similar to the NCA.

Several studies have investigated the use of fibers to improve concrete properties. The use of steel fibers from waste steel has been also examined in both concrete types. In [26], the effect of the aspect ratio of steel fibers on the flexural strength of RCA concrete was studied, using steel fibers between 0.5-2.5% and four aspect ratios. The results indicated that the optimum dosage of steel fibers was 1.5% and that an increased aspect ratio resulted in an increase in strength. In [27], the collective effect of fly ash and steel fibers on the tensile and flexural strength of concrete was investigated, using different doses of fly ash and steel fibers. The results showed that using 2% steel fibers and 30% fly ash increased flexural strength to a maximum of 8%. In [28], the effect of steel fibers was studied in reinforced RCA concrete exposed to temperatures of 200, 400, and 600°C, showing that the presence of steel fibers reduced the strength of the concrete but helped in preventing its spalling. In [29], 1-5% steel fibers were used in concrete, showing that the optimal dose was 3% as it provided an 18% and 52% increase in compressive and flexural strength, respectively. In [30], the use of 2.5% steel fibers provided a 61% increase in flexural strength. In [31], it was concluded that using 1% steel fibers in concrete containing 100% RCA increased its strength up to 37%. In [32-34], the effect of normal and equivalent mortar volume methods on RCA concrete containing steel fibers was studied, showing up to 50% and 35% increase in flexural strength for beams failing in shear and flexure, respectively. In [35] the use of polypropylene and steel fibers in RCA was reviewed, concluding that mineral fibers have a better synergistic effect and produce concrete with better properties. In [36], the use of steel fibers in RCA concrete improved the strength characteristics of both reinforced and unreinforced concrete beams. Not only steel fibers, but also GGBF slag and fly ash [37], biomedical waste [38], curing methods [39], and curing types [40] have been investigated to check their effect on the strength properties of RCA concrete. Steel fibers and RCA were also studied in [41]. Although several studies investigated the use of steel fibers in RCA concrete, there is a scattering in the optimum dosage, aspect ratio, and type of steel. A similar scatter appears in the results of studies on the flexural strength of fibrous RCA concrete. This study attempted to laboratory investigate the flexural- strength of fibrous RCA concrete under two-point loading.

II. MATERIALS AND METHODS

A. Concrete Ingredients

This study used ordinary Portland cement under the brand name Pak Land. The fineness of the cement was checked with a #100 sieve and was found to be 94%. The initial and final setting times of cement were 68 and 231 minutes, respectively. The values obtained for cement followed ASTM C150/C150M-18 [42]. Hill sand obtained from approved sources was used as fine aggregate. Figure 1 shows the sieve analysis results of the fine aggregates, while its fineness modulus was 2.375. The percentage passing through various sieves and the fineness modulus of the fine aggregates were within the allowable ranges of ASTM C136/C136M-14 [43].

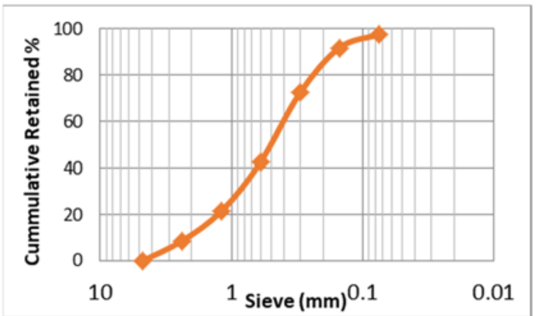

Fig. 1. Sieve analysis of fine aggregates.

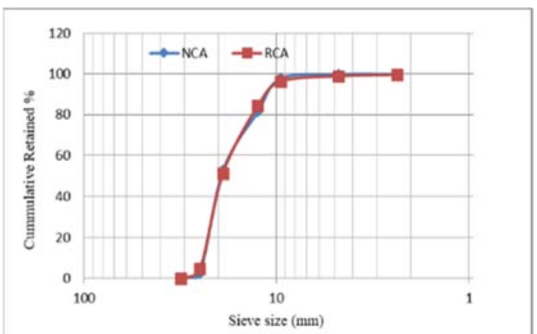

Fig. 2. Sieve analysis of NCA and RCA.

Coarse aggregates were also obtained from approved sources and their maximum size was 25mm. The aggregates were sorted for unwanted substances, washed, and dried, and sieve analysis was performed. Figure 2 shows the results of the sieve analysis, which were within the allowable ranges of ASTM C136/C136M-14 [43]. The fineness modulus of the aggregates was 3.18. Demolished waste was collected from a demolished ground-story reinforced concrete building. Mixed debris, as shown in Figure 3, was brought to the laboratory and hammered to a maximum of 25mm, equal to the maximum size of NCA, as shown in Figure 4. The obtained aggregates were sorted, washed, and dried, and a sieve analysis was performed, as shown in Figure 2. The fineness modulus of the recycled aggregates was recorded at 3.18. Like conventional aggregates, the parameters of the recycled aggregates were within the allowable ranges of ASTM C136/C136M-14 [43]. This study used water, obtained from a water supply, with 7.1 pH.

Fig. 3. Demolished waste.

Fig. 4. NCA and RCA.

Figure 5 shows the steel fibers used, which were cut from steel wire of 1mm diameter. The length of each fiber was 25mm. The tensile strength of the fibers was 1140N/mm^2.

Fig. 5. Steel fibers.

The concrete was prepared in a 1:2:4 ratio. The water-to-cement ratio was 0.5. The steel fiber content used in the concrete was 1-5%, with an increment of 0.5%, resulting in 10 batches (B1 to B10). Additionally, two control mixes were prepared without steel fibers, one with NCA (CC) and another with RCA. Table I provides the details of the mixes.

B. Water Absorption and Specific Gravity

The water absorption and specific gravity of the aggregates were evaluated following the procedures specified in ASTM C-127 [44], and Table II shows the results.

TABLE I. DETAILS OF CONCRETE MIXES

B#	NCA (%)	RCA (%)	Steel fibers (%)	Cement (kg)	FA (kg)	NCA (kg)	RCA (kg)	Steel fibers (kg)
CC	100	0	0.0	10	20	20	0	0
RCA	50	50	0.0	10	20	10	10	0
B1	50	50	0.5	10	20	10	10	0.3
B2	50	50	1.0	10	20	10	10	0.6
B3	50	50	1.5	10	20	10	10	0.9
B4	50	50	2.0	10	20	10	10	1.2
B5	50	50	2.5	10	20	10	10	1.5
B6	50	50	3.0	10	20	10	10	1.8
B7	50	50	3.5	10	20	10	10	2.1
B8	50	50	4.0	10	20	10	10	2.4
B9	50	50	4.5	10	20	10	10	2.7
B10	50	50	5.0	10	20	10	10	3

TABLE II. WATER ABSORPTION AND SPECIFIC GRAVITY

Aggregate type	Specific gravity	Water absorption (%)
Natural Coarse Aggregates	2.57	1.64
Recycled Coarse Aggregates	2.31	3.42

C. Workability

The workability of the designed mixes was evaluated using the slump cone test following ASTM C143 [44]. Cone filling, rodding, lifting, and measurement of the slump were carried out in a standard fashion, as shown in Figure 6. Table III shows the slump values recorded for all mixes.

Fig. 6. Slump cone test.

TABLE III. SLUMP CONE TEST

Batch no.	Steel fibers (%)	Slump (mm)	Batch no.	Steel fibers (%)	Slump (mm)
1	0.00	70.0	7	2.50	60.0
2	0.00	62.0	8	3.00	59.5
3	0.50	61.5	9	3.50	57.0
4	1.00	61.0	10	4.00	55.0
5	1.50	62.0	11	4.50	54.5
6	2.00	61.0	12	5.00	54.0

D. Sample Preparation and Curing

Three prism specimens with dimensions of 500×100×100mm were prepared in all 12 batches to check the flexural strength of the concrete. In total, 36 prism specimens were prepared. The concrete ingredients in the required proportion were batched by weight, followed by thorough mixing. Water was then added, and the mixer was run until a uniform paste was formed. The inner side of the molds was oiled, and each mold was filled in 3 layers and compacted with a needle vibrator. The specimens were demolded after 24 hours and left at room temperature to dry for a day. Then all the specimens were cured for 28 days in potable water. Figure 7 shows a few specimens.

Fig. 7. Specimens and curing.

E. Specimen Testing

After curing, the specimens were taken out of the water and left to dry for 24 hours. All specimens were tested on a universal testing machine under a two-point load, at one-third of either support, following ASTM C150. During testing, load and deflection were monitored at regular intervals. The failure of the specimens was checked at the maximum sustained load. Figure 8 shows a few specimens during the test, and Table IV shows the average results of five samples in each mix for both flexural strength and deflection.

Fig. 8. Specimen testing.

TABLE IV. AVERAGE FLEXURAL STRENGTH

Batch no	Steel fiber %	Load (KN)	Mean flexural strength (N/mm^2)	Mean deflection (mm)
1	0.00	8.57	6.43	3.40
2	0.00	7.50	5.62	5.34
3	0.50	8.74	6.56	4.40
4	1.00	9.23	6.92	4.18
5	1.50	10.02	7.52	3.82
6	2.00	10.17	7.63	3.64
7	2.50	10.40	7.80	3.18
8	3.00	10.69	8.02	2.34
9	3.50	10.84	8.13	2.12
10	4.00	11.07	8.30	1.88
11	4.50	11.32	8.49	1.56
12	5.00	11.94	8.95	1.14

III. RESULTS AND DISCUSSION

Both aggregate types satisfied the standard requirements of well-graded aggregates, as shown in the sieve analysis results. RCA absorbed water at a rate of 3.42%, while NCA absorbed 1.64%. A comparison of the specific gravity findings of the two aggregates showed that RCA had 10% lower specific gravity than NCA. This can be attributed to the age of the old concrete and the old mortar connected within the RCA. Both variables contribute to the higher water absorption of RCA.

The slump of the traditional concrete was within the acceptable range for the specific mix. However, the slump of the other mixes remained lower than that of conventional concrete. Figure 9 compares the traditional and the fiber concrete, whereas Figure 10 shows the percentile decrease in the slump of the RCA mixes. Adding more steel fibers to the mixture caused a drop in the slump value. The maximum drop in the slump (22.9%) was noticed when using 5% of fibers. This demonstrates that the water requirement of the blend is higher when using steel fiber, and it should be taken into account when choosing the w/c ratio for the mix, or else more admixture or mechanical effort will be needed to keep the necessary workability.

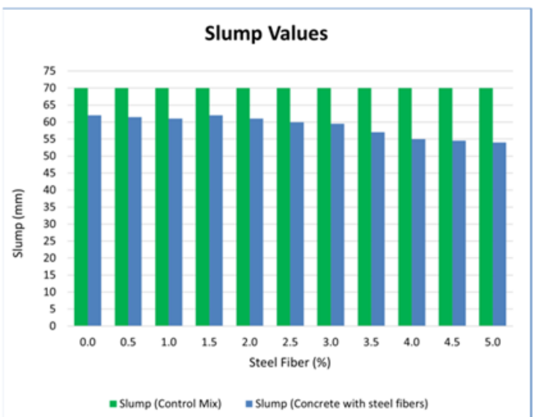

Fig. 9. Comparison of slump values.

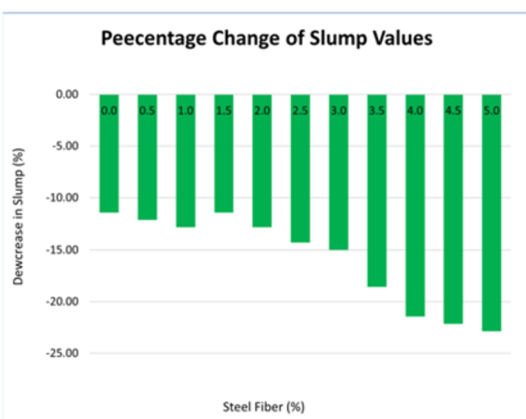

Fig. 10. Change in slump vs control concrete

Figure 11 compares the flexural strength results of the concrete mixes with the control mix. It can be seen that RCA reduced the flexural strength (-12.5%), but the problem was counteracted with the addition of steel fibers. In all mixes, an increase in flexural strength was observed with the increase in steel fiber content. It is also anticipated that a further increase in steel fiber content will further increase flexural strength and reduce workability, and this should be carefully considered when deciding the dosage of steel fibers. The increase in flexural strength is attributed to the strength of the steel fibers plus their function to provide good interlocking between the ingredients of the concrete matrix, leading to a higher load-carrying capacity of the hardened concrete. Therefore, it can be used in new concrete, along with 50% RCA from demolition debris. This will not only lessen the waste management burden but also help in conserving conventional aggregates and protecting the environment. This study used steel fibers made from the new steel wire, but fibers can also be produced from waste steel, further reducing waste issues. Figure 12 shows the percentile deviation of the flexural strength of concrete mixes with steel fibers with the control mix. It can be seen that at the highest dose of steel fibers, the increase in flexural strength was 39% compared to the control mix while the same against the recycled aggregate concrete was 59%.

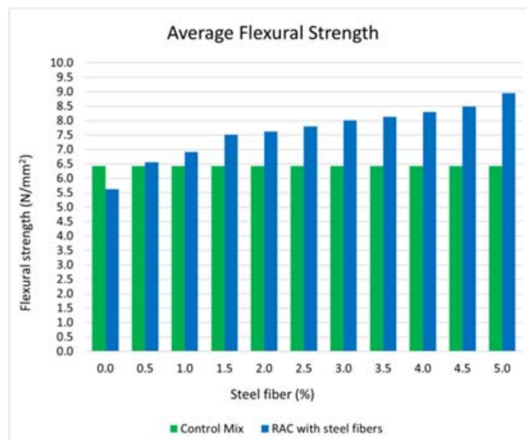

Fig. 11. Mean flexural strength.

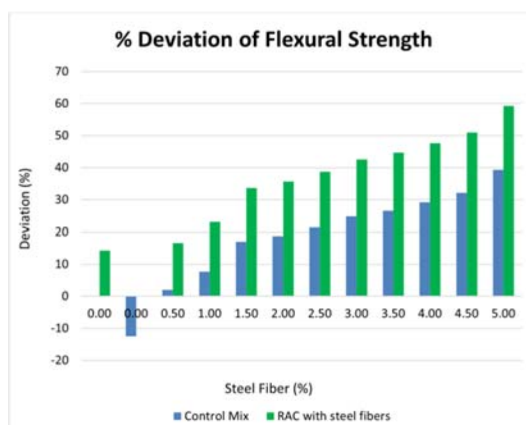

Fig. 12. Deviation of flexural strength.

Figure 13 compares the average deflection for all specimens with the control mix. The pattern of deflection is reversed to flexural strength when increasing steel fiber content. This happens because the addition of steel fibers improves strength and thus reduces deflection. It is also anticipated that further addition of fibers will further decrease deflection, showing that steel fiber content can be used to control strength and deflection. However, it might contribute to the brittleness of the concrete and may result in sudden failure of the member. Therefore, this aspect should be studied and considered before deciding on the required displacement control using steel fibers. It may further be observed that RCA increased deflection by 57%, but when using 3% steel fibers, it was controlled and reduced by 66.5%.

Fig. 13. Mean deflection test.

It was also observed that the specimens failed in flexure which confirms the theoretical failure mode of plain concrete. The analysis of the specimens showed that at failure they did not split into two pieces but the fibers provided an interlocking medium. The same event may have helped improve strength, reduce cracks, and provide the interlocking mechanism to reduce the crack width.

IV. CONCLUSION

This study examined the workability and flexural strength of binary blended concrete with RCA and steel fibers. Based on the observations of laboratory investigations, the following can be concluded:

- RCA had a lower specific gravity and greater water absorption than NCA. This greater water absorption increased the water requirement of the concrete mix, necessitating an adjustment to the design.
- The mechanical properties of the resulting concrete were significantly affected by RCA. Compared to the control mix, the use of 50% RCA resulted in decreased workability and flexural strength and increased deflection. This is because of old, dry, and porous aggregates that are weaker in strength and need more water.
- Using a higher proportion of steel fibers and a consistent dosage of 50% RCA, flexural strength and deflection increased significantly. The maximum strength increase was recorded at the highest dosage of steel fibers. It is also anticipated that a further increase in fiber content will further increase flexural strength, but the brittleness and durability of concrete may be a problem and need to be carefully considered before deciding the optimal dosage.
- In failure, the beams were not split into parts due to the interlocking mechanism of the steel fibers, as they provide a medium to bridge cracks and improve strength.
- The combined mix of steel fiber and RCA can be used to improve concrete strength.

Therefore, this study recommends the use of 50% RCA from demolished waste with steel fibers for producing concrete with good flexural strength and controlled deflection.

REFERENCES

[1] B. A. Memon and A. H. Buller, "Recent development on use of demolished concrete as coarse aggregates," *International Journal of Emerging Technology and Innovative Engineering*, vol. 2, no. 1, pp. 1–11, 2016.

[2] K. P. Verian, W. Ashraf, and Y. Cao, "Properties of recycled concrete aggregate and their influence in new concrete production," *Resources, Conservation and Recycling*, vol. 133, pp. 30–49, Jun. 2018, https://doi.org/10.1016/j.resconrec.2018.02.005.

[3] R. V. Silva, J. de Brito, and R. K. Dhir, "Tensile strength behaviour of recycled aggregate concrete," *Construction and Building Materials*, vol. 83, pp. 108–118, May 2015, https://doi.org/10.1016/j.conbuildmat.2015.03.034.

[4] R. V. Silva, J. de Brito, and R. K. Dhir, "Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production," *Construction and Building Materials*, vol. 65, pp. 201–217, Aug. 2014, https://doi.org/10.1016/j.conbuildmat.2014.04.117.

[5] L. Wang, J. Wang, X. Qian, P. Chen, Y. Xu, and J. Guo, "An environmentally friendly method to improve the quality of recycled concrete aggregates," *Construction and Building Materials*, vol. 144, pp. 432–441, Jul. 2017, https://doi.org/10.1016/j.conbuildmat.2017.03.191.

[6] B. S. Hamad, A. H. Dawi, A. Daou, and G. R. Chehab, "Studies of the effect of recycled aggregates on flexural, shear, and bond splitting beam structural behavior," *Case Studies in Construction Materials*, vol. 9, Dec. 2018, Art. no. e00186, https://doi.org/10.1016/j.cscm.2018.e00186.

[7] R. Sato, I. Maruyama, T. Sogabe, and M. Sogo, "Flexural Behavior of Reinforced Recycled Concrete Beams," *Journal of Advanced Concrete Technology*, vol. 5, no. 1, pp. 43–61, 2007, https://doi.org/10.3151/jact.5.43.

[8] I. H. Yang, J. Park, K. C. Kim, and H. Lee, "Structural Behavior of Concrete Beams Containing Recycled Coarse Aggregates under Flexure," *Advances in Materials Science and Engineering*, vol. 2020, Jul. 2020, Art. no. e8037131, https://doi.org/10.1155/2020/8037131.

[9] B. A. Memon and G. S. Bhatti, "Flexural Behavior of Beam made by Partial Replacement of Natural Aggregates with Coarse Aggregates from Old Concrete," *International Journal of Engineering Sciences & Research Technology*, vol. 3, no. 5, pp. 52–61, May 2014.

[10] M. Oad, A. H. Buller, B. A. Memon, and N. A. Memon, "Flexural Stress-Strain Behavior of RC Beams Made with Partial Replacement of Coarse Aggregates with Coarse Aggregates from Old Concrete: Part-1: 1:2:4 Ratio," *Engineering, Technology & Applied Science Research*, vol. 8, no. 3, pp. 3048–3053, Jun. 2018, https://doi.org/10.48084/etasr.1982.

[11] M. Oad, A. H. Buller, B. A. Memon, N. A. Memon, and S. Sohu, "Flexural Stress-Strain Behavior of RC Beams made with Partial Replacement of Coarse Aggregates with Coarse Aggregates from Old Concrete: Part-2: Rich Mix," *Engineering, Technology & Applied Science Research*, vol. 8, no. 5, pp. 3338–3343, Oct. 2018, https://doi.org/10.48084/etasr.2129.

[12] A. H. Buller, M. Oad, and B. A. Memon, "Flexural Strength of Reinforced Concrete RAC Beams Exposed to 6-hour Fire – Part 2: Rich Mix," *Engineering, Technology & Applied Science Research*, vol. 9, no. 1, pp. 3814–3817, Feb. 2019, https://doi.org/10.48084/etasr.2494.

[13] A. H. Buller, M. Oad, and B. A. Memon, "Flexural Behavior of Reinforced RAC Beams Exposed to 1000°C Fire for 18 Hours," *Engineering, Technology & Applied Science Research*, vol. 9, no. 3, pp. 4225–4229, Jun. 2019, https://doi.org/10.48084/etasr.2733.

[14] A. H. Buller, M. Oad, B. A. Memon, and S. Sohu, "24-hour Fire Produced Effect on Reinforced Recycled Aggregates Concrete Beams," *Engineering, Technology & Applied Science Research*, vol. 9, no. 3, pp. 4213–4217, Jun. 2019, https://doi.org/10.48084/etasr.2764.

[15] A. Kanellopoulos, D. Nicolaides, and M. F. Petrou, "Mechanical and durability properties of concretes containing recycled lime powder and recycled aggregates," *Construction and Building Materials*, vol. 53, pp. 253–259, Feb. 2014, https://doi.org/10.1016/j.conbuildmat.2013.11.102.

[16] K. Rahal, "Mechanical properties of concrete with recycled coarse aggregate," *Building and Environment*, vol. 42, no. 1, pp. 407–415, Jan. 2007, https://doi.org/10.1016/j.buildenv.2005.07.033.

[17] S. C. Kou and C. S. Poon, "Enhancing the durability properties of concrete prepared with coarse recycled aggregate," *Construction and Building Materials*, vol. 35, pp. 69–76, Oct. 2012, https://doi.org/10.1016/j.conbuildmat.2012.02.032.

[18] K. H. Younis and K. Pilakoutas, "Strength prediction model and methods for improving recycled aggregate concrete," *Construction and Building Materials*, vol. 49, pp. 688–701, Dec. 2013, https://doi.org/10.1016/j.conbuildmat.2013.09.003.

[19] C. Lima, A. Caggiano, C. Faella, E. Martinelli, M. Pepe, and R. Realfonzo, "Physical properties and mechanical behaviour of concrete made with recycled aggregates and fly ash," *Construction and Building Materials*, vol. 47, pp. 547–559, Oct. 2013, https://doi.org/10.1016/j.conbuildmat.2013.04.051.

[20] S. C. Kou and C. S. Poon, "Long-term mechanical and durability properties of recycled aggregate concrete prepared with the incorporation of fly ash," *Cement and Concrete Composites*, vol. 37, pp. 12–19, Mar. 2013, https://doi.org/10.1016/j.cemconcomp.2012.12.011.

[21] D. Matias, J. de Brito, A. Rosa, and D. Pedro, "Mechanical properties of concrete produced with recycled coarse aggregates – Influence of the use of superplasticizers," *Construction and Building Materials*, vol. 44, pp. 101–109, Jul. 2013, https://doi.org/10.1016/j.conbuildmat.2013.03.011.

[22] Y. N. Sheen, H. Y. Wang, Y. P. Juang, and D. H. Le, "Assessment on the engineering properties of ready-mixed concrete using recycled aggregates," *Construction and Building Materials*, vol. 45, pp. 298–305, Aug. 2013, https://doi.org/10.1016/j.conbuildmat.2013.03.072.

[23] L. Butler, J. S. West, and S. L. Tighe, "Effect of recycled concrete coarse aggregate from multiple sources on the hardened properties of concrete with equivalent compressive strength," *Construction and Building Materials*, vol. 47, pp. 1292–1301, Oct. 2013, https://doi.org/10.1016/j.conbuildmat.2013.05.074.

[24] M. G. Beltrán, F. Agrela, A. Barbudo, J. Ayuso, and A. Ramírez, "Mechanical and durability properties of concretes manufactured with biomass bottom ash and recycled coarse aggregates," *Construction and Building Materials*, vol. 72, pp. 231–238, Dec. 2014, https://doi.org/10.1016/j.conbuildmat.2014.09.019.

[25] S. Kou and C. Poon, "Effect of the quality of parent concrete on the properties of high performance recycled aggregate concrete," *Construction and Building Materials*, vol. 77, pp. 501–508, Feb. 2015, https://doi.org/10.1016/j.conbuildmat.2014.12.035.

[26] P. Shweta and R. Kavilkar, "Study of Flexural Strength in Steel Fibre Reinforced Concrete," *International Journal of Recent Development in Engineering and Technology*, vol. 2, no. 5, May 2014.

[27] P. R. Singh, A. Goel, S. Thakur, and D. N. D. Shah, "An Experimental Approach to Investigate Effect of Steel Fibers on Tensile and Flexural Strength of Flyash Concrete," *International Journal of Scientific Engineering and Applied Science*, vol. 2, no. 5, pp. 384–392, May 2016.

[28] G. M. Chen, Y. H. He, H. Yang, J. F. Chen, and Y. C. Guo, "Compressive behavior of steel fiber reinforced recycled aggregate concrete after exposure to elevated temperatures," *Construction and Building Materials*, vol. 71, pp. 1–15, Nov. 2014, https://doi.org/10.1016/j.conbuildmat.2014.08.012.

[29] Mehran University of Engineering and Technology, Shaheed Zulfiqar Ali Bhutto Campus, Khairpur Mir's, Sindh, Pakistan *et al.*, "Effect of steel fibres on the compressive and flexural strength of concrete," *International Journal of Advanced and Applied Sciences*, vol. 5, no. 10, pp. 16–21, Oct. 2018, https://doi.org/10.21833/ijaas.2018.10.003.

[30] Z. Xu *et al.*, "Experimental study on mechanical properties and microstructures of steel fiber-reinforced fly ash-metakaolin geopolymer-recycled concrete," *Reviews on Advanced Materials Sciences*, vol. 60, no. 1, pp. 578–590, Jan. 2021, https://doi.org/10.1515/rams-2021-0050.

[31] Q. Su, "Strengths of Recycled Concrete Added with Steel Fiber," *Archives of Civil Engineering*, vol. 66, no. 3, pp. 693–703, https://doi.org/10.24425/ace.2020.134421.

[32] E. E. Anike, M. Saidani, A. O. Olubanwo, M. Tyrer, and E. Ganjian, "Effect of mix design methods on the mechanical properties of steel fibre-reinforced concrete prepared with recycled aggregates from precast waste," *Structures*, vol. 27, pp. 664–672, Oct. 2020, https://doi.org/10.1016/j.istruc.2020.05.038.

[33] F. L. Raoof, A. S. Resheq, and E. K. Sayhood, "Behavior of Recycled Aggregate Fibrous Reinforced Beams Under Flexural and Shear Loading," *Engineering and Technology Journal*, vol. 37, no. 3 part(c) special, 2019.

[34] V. Venugopal, "Experimental Investigation of Concrete with Steel Fiber and Study of the Mechanical Properties of Recycled Aggregate Concrete," *International Journal of Scientific & Engineering Research*, vol. 11, no. 3, 2020.

[35] P. Zhang, Y. Yang, J. Wang, S. Hu, M. Jiao, and Y. Ling, "Mechanical Properties and Durability of Polypropylene and Steel Fiber-Reinforced Recycled Aggregates Concrete (FRRAC): A Review," *Sustainability*, vol. 12, no. 22, Jan. 2020, Art. no. 9509, https://doi.org/10.3390/su12229509.

[36] G. Kaplan, O. Y. Bayraktar, A. Gholampour, O. Gencel, F. Koksal, and T. Ozbakkaloglu, "Mechanical and durability properties of steel fiber-reinforced concrete containing coarse recycled concrete aggregate," *Structural Concrete*, vol. 22, no. 5, pp. 2791–2812, 2021, https://doi.org/10.1002/suco.202100028.

[37] F. George and S. Anil, "Study on Properties of Self Compacting Concrete Made with Recycled Coarse Aggregate," *International Research Journal of Engineering and Technology*, vol. 05, no. 04, pp. 3255–3259, Apr. 2018.

[38] G. M. Khanzada, B. A. Memon, M. Oad, M. F. A. Khanzada, and A. M. Lashari, "Effect of Bio-Medical Waste on Compressive Strength of Concrete Cylinders," *Quaid E-Awam University Research Journal of Engineering, Science & Technology*, vol. 18, no. 1, pp. 29–35, Jun. 2021.

[39] M. Oad, A. H. Buller, B. A. Memon, N. A. Memon, Z. A. Tunio, and M. A. Memon, "Effect of Water-Cement Ratio on Flexural Strength of RC Beams Made with Partial Replacement of Coarse Aggregates with Coarse Aggregates from Old Concrete," *Engineering, Technology & Applied Science Research*, vol. 9, no. 1, pp. 3826–3831, Feb. 2019, https://doi.org/10.48084/etasr.2499.

[40] A. Raza, B. A. Memon, and M. Oad, "Effect of Curing Types on Compressive Strength of Recycled Aggregates Concrete," *Quest Research Journal*, vol. 17, no. 2, pp. 7–12, Jul. 2019.

[41] O. Yavuz Bayraktar, G. Kaplan, J. Shi, A. Benli, B. Bodur, and M. Turkoglu, "The effect of steel fiber aspect-ratio and content on the fresh, flexural, and mechanical performance of concrete made with recycled fine aggregate," *Construction and Building Materials*, vol. 368, Mar. 2023, Art. no. 130497, https://doi.org/10.1016/j.conbuildmat.2023.130497.

[42] "Standard Specification for Portland Cement," American Society for Testing and Materials, West Conshohocken, PA, USA, ASTM C150/C150M-18, 2018.

[43] "Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates," American Society for Testing and Materials, West Conshohocken, PA, USA, Standard ASTM C136/C136M-14, 2014.

[44] "Standard Test Method for Slump of Hydraulic-Cement Concrete," American Society for Testing and Materials, West Conshohocken, PA, USA, Standard ASTM C143/C143M-20, 2020.