Flexural Stress-Strain Behavior of RC Beams made with Partial Replacement of Coarse Aggregates with Recyclable Concrete Aggregate

Part-2: Rich Mix

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

Abdul Hafeez Buller
Department of Civil Engineering,
Quaid-e-Awam University of Engineering, Science & Technology,
Nawabshah Pakistan
engrabdulhafeezbuller@gmail.com

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

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

Samiullah Sohu
Department of Civil Engineering,
Quaid-e-Awam University College of Engineering, Science & Technology, Larkano, Pakistan
sohoosamiullah@gmail.com

Abstract-**Crowded city centers pose serious problems of infrastructure and associated facilities. Construction industry is obliged to opt for vertical construction in place of short height structures in order to meet with the needs. This leads to the generation of huge quantities of demolishing waste whose management is a serious issue. One of its best uses is its utilization in new concrete. Concrete is widely used in construction industry. Normally 1:2:4 mix is used, but the use of rich mix is also common in columns and elsewhere. Therefore, this research work focuses on evaluating the flexural stress-strain behavior of rich concrete mix beams made with 50% replacement of natural coarse aggregates with coarse aggregates from old concrete. A total of 12 reinforced concrete beams 1:1.5:3 ratio mix and 0.54 w/c ratio are prepared in two batches in 0.9mx0.15mx0.15m beams. In the first batch, natural coarse aggregates are replaced in 50% with coarse aggregates from demolished concrete and the second batch contains beams made with all-natural coarse aggregates. To reinforce the beams, 2#4 deformed bars are used in compression and tension zone along with #3 stirrups at 15cm c/c all along the length of the beam. In each batch, half of the beams are cured for 7 days and half for 28 days. After curing, all beams are tested for load, deflection, and strain in a universal load testing machine. All parameters are recorded at regular intervals and cracking and failure patterns are monitored. From obtained results, it is analyzed that the beams presented 11.68% reduction in flexural capacity. Cracking pattern and failure mode of the beams is similar to those of the control specimen.**

Keywords-flexural stress; green concrete; old concrete; recycled coarse aggregates; strain

I. INTRODUCTION

Living space and associated infrastructure congestion in urban areas pose serious problems around the globe. Construction industry is forced to opt for vertical constructions particularly for residential purposes in place of short height buildings. Therefore, demolishing of short height buildings and construction of higher buildings has become a need of the day, resulting in huge amounts of construction waste. Unavailability of landfills to deposit this demolishing waste poses another problem. Transportation of this waste to far distances causes loss of time and it is also expensive. Proper disposal of this waste is a serious need. The utilization of this waste in new construction as a remedial measure has been proposed and the relevant research is active. This not only helps in waste management efforts but saves natural aggregates. Different researchers studied properties of concrete by making use of demolished concrete as partial or full replacement of natural coarse and fine aggregates [2-5]. Concrete's behavior with respect to load-deflection, cracking, ultimate load etc. have been studied. Focus has also been made on cleaning and screening of old concrete before using it in new concrete. Although the material has successfully been used in pavements, sideways and walkways yet, different proposals based on the research outcomes show wide scatter, giving room for more research.

The, already completed, first part of this research focuses on the flexural stress-strain behavior of reinforced concrete beams made by replacing 50% natural coarse aggregates with coarse aggregates from old concrete batched with 1:2:4 mix.

The selection of 50% replacement is made following the conclusions of [3]. This research work addresses flexural stress-strain behavior of above mentioned beams made with rich mix (1:1.5:3). Old concrete from RC buildings / RC members demolished in Nawabshah city is collected in the form of large pieces. These large pieces are then hammered down to approximately 25mm size. The smaller objects are then screened and sieved with a 25mm sieve. For the research presented in this paper 6 reinforced concrete beams are prepared using OPC, hill sand, natural coarse aggregates and coarse aggregates from old concrete in 50% proportion in 1:1.5:3 mix. To reinforce these beams two #4 bars are used in both tension and compression zone along with #3 deformed bar as stirrups at 15cm c/c from the left to the right end of the beam. Six reinforced concrete beams using the same specification, except for 100% natural coarse aggregates, are also prepared (control specimen). In both batches three beams are cured for 7-days and another three for 28-days. Normal water curing is adopted. After curing, all beams are tested with central point load up to rupture. Load, deflection and strain are recorded at regular intervals during loading process. From the recorded load, flexural stress is computed by using numerical expression. During the loading process, track of cracking pattern and cracking load was recorded for analysis and comparison. Obtained results were analyzed, compared and presented in tabular and graphical form. Typical and selected images of cracking in beams are also given in relevant sections. It is believed that the results of this research pave way for setting reference for scholars in the field and improve the understanding of using rich mix with 50% replacement of natural coarse aggregates with coarse aggregates from demolished concrete.

II. LITERATURE REVIEW

Finding alternative materials for cement, fine and coarse aggregates is an active research area. To this end, the use of demolished concrete in new concrete is also studied but more research is required to make solid conclusions regarding its behavior. Recent development on the use of demolished concrete as course aggregate in new concrete in [1] presents the possibilities of using demolished concrete as coarse aggregate. Author in [1] discusses the difficulties associated with the use of demolished concrete. He concludes that partial use of demolished concrete as coarse aggregate has very good effect on the strength of the new product. Authors in [2] used 50% replacement of natural coarse aggregates with coarse aggregates from demolished concrete. They used mathematical modeling to establish the relationship between the tensile strength and weight of concrete specimen. They compared tensile strength of cylinders made by using 50% replacement by coarse aggregates from demolished concrete and cylinders made by natural coarse aggregates alone. Obtained results show 5% loss of tensile strength in comparison to control specimen. Authors in [3] used replacement of natural coarse aggregate from 0 to 50% with 5% increment and studied the compressive strength of concrete cylinders. For their research, they used 1:2:4 mix and water cement ratio from 0.45 to 0.6. They tested 54 cylinders made with 100% natural coarse aggregates and 324 cylinders with aggregates from demolished concrete. They altogether tested seven batches of the cylinders in three groups of 7, 14 and 28 day curing. Based on the outcome of this testing, they concluded that demolished concrete can be used as an alternative of natural coarse aggregates as they recorded maximum decrease in compressive strength equal to 26% with 50% replacement of natural aggregates.

On the use of demolished concrete as partial replacement of coarse aggregates in new concrete, authors in [4] used 50%, 60%, 70% and 80% replacement of natural coarse aggregates in slabs. Test results showed that 50% replacement is the optimum as with this replacement they observed only 7.1% reduction in maximum load. They also observed maximum deflection at the slab center equal to 4.4mm which is within the allowable limits of ACI 318 [14]. Study of flexural behavior of reinforced concrete beams made with partial replacement of natural coarse aggregates with aggregates from demolished concrete was conducted in [5]. Authors prepared 30, 36"x6"x6" size beams using 1:2:4 mix and 0.45-0.55w/c ratio along with 4#4 deformed bars and #2 bars as stirrups. Authors used 50% to 80% replacement with 10% increment. They used 28-day curing for all beams and performed testing for flexural strength and cracking behavior. From the test results, they recorded 12% as minimum and 26% as maximum reduction in flexural strength. The research outcome also revealed that 88% strength can be obtained using 50% replacement. Thus, they concluded that demolished concrete can effectively be used as coarse aggregates in new concrete, particularly in the areas of moderate or low load. Authors in [6] studied the flexural strength of concrete beams made with preplaced coarse aggregates with colgrout. They called this new material colcrete. They used colgrout to prepare concrete beams of size 750mmx150mmx150mm in two batches. One with 1:2:4 mix and 0.56w/c ratio and other in 1:3:6 mix with 0.58w/c ratio. They also prepared similar beams with natural coarse aggregates as control specimens. After curing for 28 days all beams were tested for flexural strength. The comparison of the results shows that the performance of colcrete in flexure was better than that of concrete. Hence they concluded that the use of colcrete particularly for members predominantly loaded in flexure is more effective than normal concrete. Author in [7], studied the feasibility of using recycled concrete for pavement work, with laboratory testing and finite element analysis. Laboratory results showed that the compressive strength and modulus of elasticity decreased slightly with increase in percentage of recycled concrete aggregates. Using these parameters, finite element analysis was performed to determine the maximum stresses under critical temperature and loading conditions. The obtained results were in good agreement with the theory.

Authors in [8] conducted research using lateritic sand and quarry dust as fine aggregates to study flexural and tensile strength of concrete. They used variation of 0 to 100% with interval of 25% against quarry dust and prepared samples using 1:1.5:3 mix with 0.65w/c ratio. The samples were cured for 28 days followed by testing for flexural and tensile strength properties. Test results showed that both flexural and tensile strengths increased with increase in lateritic percentage. Based on the results, they concluded that the mixture of lateritic sand and quarry dust can be used as a replacement of river sand without losing much flexural and tensile strength concrete properties compared to normal concrete. Authors in [9] studied section stress distortion performance and failure characteristics of beams made with recycled concrete. They prepared beams with 50%, 70% and 100% recycled concrete along with 0.68%, 0.69% and 1.13% steel reinforcement. Based on the experimental results, they concluded that the distortion and destruction pattern, cracking moment and ultimate flexural carrying capacity of the beams, in comparison to control beams, was the same, however the beams made with recycled concrete presented more deflection than the control specimens. To study the flexural behavior of reinforced concrete beams strengthened with BFRP bars, authors in [10], conducted experimental work to determine the load-deflection behavior. From the experimental results, they observed that the new material had bonding problem. The deflection of the beams was also larger than that of the control specimens. Therefore, they concluded that the bonding problems affect severely the usage of BFRP bars in concrete.

Flexural behavior of concrete beams using recycled fine aggregate as partial replacement of river sand and steel fibers was evaluated in [11]. Authors used various doses of recycled fine aggregates and based on the research outcome they concluded that the use of recycled fine aggregates in structural concrete has promising effect on the strength of the concrete. Authors in [12] used 100% replacement of course aggregates with coarse aggregates from demolished concrete to study the load-strain behavior of reinforced concrete beams along with the influence of steel fiber reinforcements. Based on the experimental results they observed that addition of steel fibers and recycled aggregates significantly increased the mechanical strength and fracture process in comparison to the control concrete. Authors in [13] conducted flexural loading tests on concrete beams made with recycled concrete aggregates. Both fine and course aggregates were produced from demolished old concrete. They studied and compared basic concrete properties and load-deflection behavior. Based on the test results the conclusion was that the use of demolished concrete as aggregates in the new concrete is possible under the proper design procedures and limits of usage of the aggregates.

III. MODEL AND TESTING

Reinforced concrete beams of 0.9m length and 0.15mx0.15m cross-section were used. A total of 12 beams were prepared, out of which 6 beams were prepared by replacing 50% natural coarse aggregates with coarse aggregates from old concrete and 6 beams were prepared with 100% natural coarse aggregates. The latter are termed as control specimens and are used for result comparison. Large old concrete pieces were collected from demolished concrete structures/reinforced concrete members in the vicinity of Nawabshah city. The pieces were then hammered down to maximum size of 25mm. The resulting dust was then sieved with 25mm sieve to match the natural coarse aggregates in use. To provide reinforcement in the beams 2#4 deformed bars were used both in tension and compression zones along with #3 stirrups all along the length of beam at 15cm c/c. Ordinary Portland cement, fine and coarse aggregates were then batched in 1:1.5:3 proportions with 0.54w/c ratio. A few beams are shown in Figure 1. Table I presents the beam details.

Fig. 1. Model Beams

TABLE I. SPECIMEN DETAILS

Batch No		1		2	
No. of spec:		3	3	3	3
% RCA		50	50	0	0
Mix Ratio		1:1.5:3	1:1.5:3	1:1.5:3	1:1.5:3
W/C Ratio		0.54	0.54	0.54	0.54
Curing Period		7	28	7	28
Main Steel	**Bottom**	2#4	2#4	2#4	2#4
	Top	2#4	2#4	2#4	2#4
Stirrups		#3 @ 6" c/c	#3 @ 6" c/c	#3 @ 6" c/c	#3 @ 6" c/c

All beams were divided in two batches with 6 beams in each batch. Out of these six beams in each batch 3 beams were cured for 7-days and 3 for 28-days. Afterwards, the beams were left for air drying followed by installation of dumic pads on one side of beams in three layers with 37.5mm gap between them (Figure 5). All the beams were tested in a universal load testing machine, using gradually increasing load at the loading rate of 0.25MPa/s (Figure 2).

Fig. 2. Load arrangement

During the loading process load, deflection and strain were measured at intervals of 2.5kN. Strain was recorded at the same interval for all three locations set for the purpose. The average was then evaluated and recorded for load value. Table II gives the average values of 7-day cured beams of both batches, whereas the same parameters for 28-day cured beams are listed in Table III.

IV. RESULTS AND DISCUSSION

The beams prepared for this research were tested with gradually increasing central point load in UTM until failure. All parameters under consideration were recorded at load intervals of 2.5kN. First crack appearance and associated load were carefully monitored and recorded. Figures 3-6 show the first crack in some beams. Shear failure of the beams is evident from the above-mentioned figures. The load recorded at regular intervals and was used to compute the flexural stress numerically from (1):

$$\sigma_f = \frac{3PL}{2bd^2} \quad (1)$$

TABLE II. AVERAGE VALUES, 7-DAY CURED BEAMS

#	Beam No	Max load (N)	Deflection (mm)	Flexural stress (N/mm²)	Strain	First crack load (N)
1	RB-1	63361.00	4.15	25.34	0.00321	45002.00
	RB-2					
	RB-3					
2	RB-7	71736.33	7.41	28.69	0.00301	55765.67
	RB-8					
	RB-9					
% Value:		88.32	55.96	88.33	106.57	80.70
% Difference:		11.68	44.04	11.67	-6.57	19.30

TABLE III. AVERAGE VALUES, 28-DAY CURED BEAMS

#	Beam No	Max load (N)	Deflection (mm)	Flexural stress (N/mm²)	Strain	First crack load (N)
1	RB-4	69694.67	4.97	27.88	0.00325	53372.33
	RB-5					
	RB-6					
2	RB-10	71549.33	6.30	28.62	0.00277	48121.33
	RB-11					
	RB-12					
% Value:		97.41	78.93	97.41	117.15	110.91
% Difference:		2.59	21.07	2.59	-17.15	-10.91

Fig. 3. Cracking in beam

Fig. 4. Beam failure

Dial readings were recorded. These reading were then converted into strain by multiplying with dial constant. Average of obtained strains was computed and recorded for all loading intervals. Deflections values for all load intervals except crushing load were also recorded. Table IV gives information of maximum values of all parameters for 7-day cured beams made with 50% replacement of natural course aggregates with coarse aggregates from old concrete. Similar results are given in Table V for 28-day cured beams. Table VI and Table VII show the results for 7-day and 28-day cured beams made with 100% natural aggregates respectively.

Fig. 5. Beam failure

Fig. 6. Beam failure

TABLE IV. 50% RCA, 7-DAY CURED BEAMS

Beam No	Max Load (N)	Deflection (mm)	Flexural Stress (N/mm²)	Strain	First crack load (N)
RB-1	67530	5.13	27.01	0.00335	50000
RB-2	55043	3.28	22.02	0.00314	45000
RB-3	67510	4.03	27.00	0.00314	40006

TABLE V. 50% RCA, 28-DAY CURED BEAMS

Beam No	Max Load (N)	Deflection (mm)	Flexural Stress (N/mm²)	Strain	First crack load (N)
RB-4	67574	4.12	27.03	0.00317	55043
RB-5	67510	5.64	27.00	0.00318	50031
RB-6	74000	5.16	29.60	0.00339	55043

TABLE VI. 0% RCA, 7-DAY CURED BEAMS

Beam No	Max Load (N)	Deflection (mm)	Flexural Stress (N/mm²)	Strain	First crack load (N)
RB-7	71726	7.10	28.69	0.00300	56023
RB-8	71824	7.86	28.73	0.00301	55142
RB-9	71659	7.26	28.66	0.00302	56132

TABLE VII. 0% RCA, 28-DAY CURED BEAMS

Beam No	Max Load (N)	Deflection (mm)	Flexural Stress (N/mm²)	Strain	First crack load (N)
RB-10	71267	6.21	28.51	0.00276	48095
RB-11	71321	6.34	28.53	0.00278	48130
RB-12	72060	6.35	28.82	0.00278	48139

Figure 7 shows the flexural stress-strain graphs of beams made with 50% replacement of natural aggregates with coarse aggregates from old concrete. The flexural stress-strain pattern of the three beams is almost the same. It is further observed that except minor differences in strain, all three beams present similar patterns. Maximum flexural stress and strain values observed in beam RB-1 are equal to 27.01N/mm^2 and 0.00335 respectively. The other two beams showed 18.4% and 0.34% less flexural stress. The average flexural stress and strain in all three beams is 25.34N/mm^2 and 0.00321 respectively. The deflection in the beams is recorded in the range of 3.28mm–5.13mm. The highest deflection value is about 2.6% higher than the approximate allowable value as per ACI-318 [14].

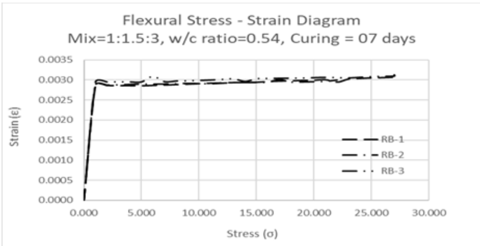

Fig. 7. Flexural stress-strain behavior of 7-day cured beams with 50% natural aggregates

Figure 8 shows the flexural stress vs strain behavior of 28-day cured beams made with 50% replacement of natural coarse aggregates with coarse aggregates from old concrete. The average values of flexural stress and strain were 28.69N/mm^2 and 0.00301 respectively. The average deflection for these beams is recorded in the range of 4.12mm-5.64mm which is 12.8% higher than the approximate allowable value of ACI-318 [14]. The average flexural stress of these beams is about 13.2% higher than those cured for 7 days. The average strain of these beams is about 10.1% lower than those cured for 7 days. Figurer 9 and 10 show flexural stress vs strain behavior for 7-day cured beams and 28-day cured beams made with 100% natural coarse aggregates respectively.

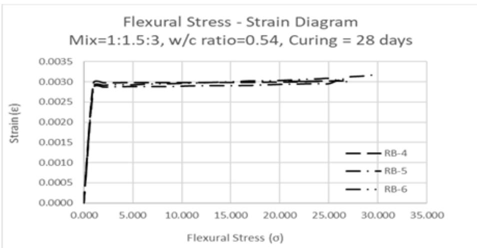

Fig. 8. Flexural stress-strain behavior of 28-day cured beams with 50% natural aggregates

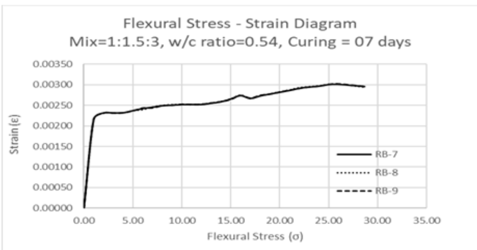

Fig. 9. Flexural stress-strain behavior of 7-day cured beams with 0% natural aggregates

Figure 11 gives comparison of control parameters of all 7-day cured beams. It is evident that beams made with 50% coarse aggregates from old concrete gained less flexural stress and more strain than control specimens cured for the same time. The maximum values for all parameters under study are given above. It is observed that 7-day cured beams failed at 11.68% less load. The same percentage reduction occurred in flexural stress. However, these beams showed 6.57% less strain than the control specimens. Contradictory to theoretical analysis, these beams showed 44.04% more average deflection than the control specimens. It is also observed that the first crack in 7-day cured beams appeared at 19.3% more load than in control specimen.

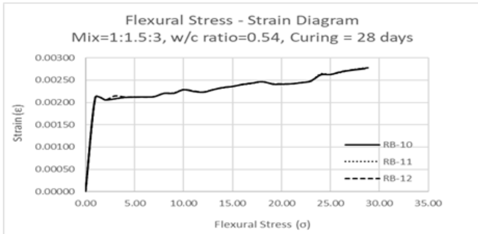

Fig. 10. Flexural stress-strain behavior of 28-day cured beams with 0% natural aggregates

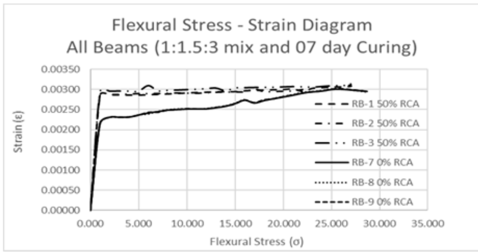

Fig. 11. Flexural stress-strain behavior of all beams cured for 7-days

In Figure 12, the comparison of control parameters of all 28-day cured beams is given. Beams made with 50% coarse aggregates from old concrete showed 2.59% less flexural stress and 17.15% more strain than control specimens. Table III shows that these beams failed at 2.59% less load. Similarly to 7-day cured beams, these beams deflected more than what was theoretically anticipated and deflected up to 21.07% more than control. It is also observed that 28-day cured beams showed first crack at 10.91% less load than the control specimens. Figures 13 to 15 show the comparison of peak load, deflection and load at which first crack appeared for both 7 and 28-days cured beams.

It is concluded that new rich mix concrete made with 50% partial replacement of natural coarse aggregates with coarse aggregates from old demolished concrete results in good strength, flexural stress, and strain without much compromise on the concrete quality, as it is evident that the loss of flexural stress for 28-day cured beams is only 2.59%. This can be controlled by better screening techniques, control of aggregates size and control of steel percentage. Although cracking pattern and load at first crack are in good agreement with the control specimens, yet rich mix beams have showed more deflection than control. This should be addressed properly by tuning steel percentage to bring the deflection in allowable limits.

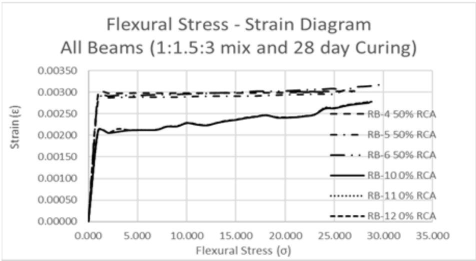

Fig. 12. Flexural stress-strain behavior of all beams cured for 28 days

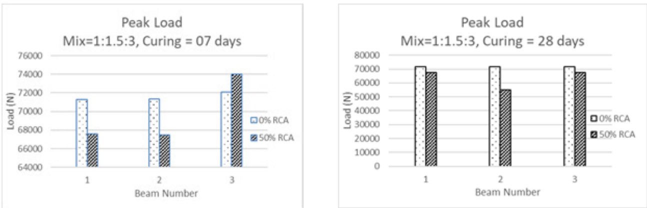

Fig. 13. Comparison of peak load

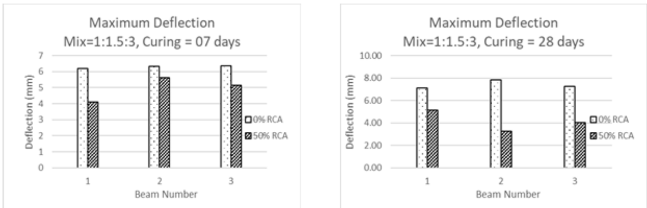

Fig. 14. Comparison of average deflection

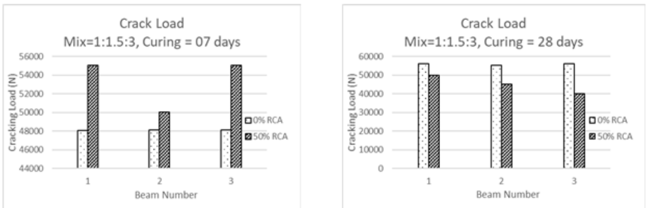

Fig. 15. Comparison of load at which first crack appeared

V. CONCLUSION

An experimental study for flexural stress vs strain was done for rich mix (1:1.5:3) concrete using reinforced concrete beams made with 50% replacement of natural coarse aggregates from demolished concrete. Result analysis shows that only 11.68% reduction is observed in beams cured for 7 days whereas 28-day cured beams showed 2.59% flexural stress reduction. More strain than control is recorded in both groups of beams. Cracking pattern for all beams remained in good agreement with control. 7-day and 28-day cured beams presented 44.04% and 21.07% more displacement than control. This parameter should be controlled before using rich mix concrete beams made with partial replacement of coarse aggregates with coarse aggregates from demolished concrete. Therefore, it is concluded that further work is required in order to bring the displacement within allowable limits. Whereas, strength and flexural stress-strain behavior show that demolished concrete can comfortably be used in rich mix concrete without quality loss of reinforced concrete beams.

VI. RECOMENDATIONS

It is recommended that more concrete mix ratios, different water cement ratios, and old concrete aggregates from different sources may be used in order to come up with better conclusions.

REFERENCES

[1] B. A. Memon, "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] S. Tanwani, B. A. Memon, "Relationship Between Weight and Tensile Strength of Concrete Cylinders Made by Partial Replacement of Coarse Aggregates from Old Concrete", International Journal of Engineering Inventions, Vol. 5, No. 6, pp. 1-9, 2016

[3] M. Oad, B. A. Memon, "Compressive Strength of Concrete Cylinders using Coarse Aggregates from Old Concrete", 1st National Conference on Civil Engineering (NCCE 2013-14) - (Modern Trends and Advancements), April 28-29, 2014

[4] A. A. Bhatti, B. A. Memon, "Strength, Deflection and Cracking Behavior of Concrete Slab Using Demolished Concrete as Coarse Aggregates", International Journal of Engineering Sciences & Research Technology, Vol. 3, No. 6, pp. 492-506, 2014

[5] B. A. Memon, G. S. Bhatti, "Lexural 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, 2014

[6] M. O. A. Mtallib, A. I. Marke, "Comparative Evaluation of the Flexural Strength of Concrete and Colcrete", Nigerian Journal of Technology, Vo. 29, No. 1, pp. 13-22, 2010

[7] P. A. Bekoe, Concrete Containing Recycled Concrete Aggregate for use in Concrete Pavement", MSc Thesis, University of Florida, 2009

[8] J. O. Ukpata, M. E. Ephraim, "Flexural and Tensile Strength Properties of Concrete using Lateritic Sand and Quarry Dust as Fine Aggregates", ARPN Journal of Engineering and Applied Sciences, Vol. 7, No. 3, pp. 324-331, 2012

[9] W. Bai, B. Sun, "Experimental Study on Flexural Behavior of Recycled Coarse Aggregate Concrete Beam", Applied Mechanics and Materials, Vol. 29-32, pp. 543-548, 2010

[10] G. N. Yang, B. R. Huo, M. X. Zheng, "Flexural Behavior of Reinforced Concrete Beams Strengthened with BFRP Bars", International Conference on Power Electronics and Energy Engineering (PEEE 2015), Hong Kong, China, April 19-20, 2015

[11] M. Kaarthik, K. Subrmanian, "Flexural Behavior of Concrete Beams using Recycled Fine Aggregates and Steel Fibers", International Conference on Biological, Civil and Environmental Engineering, Dubai, UAE, March 17-18, 2014

[12] M. Kosior-Kazberuk, M. Grzywa, "Recycled Aggregate Concrete as Material for Reinforced Concrete Structures", Journal of Sustainable Architecture and Civil Engineering, Vol. 2 No. 7, pp. 60-66, 2014

[13] R. Sato, I. Maruyama, T. Sogabe, M. Sogo, "Flexural Behavior of Reinforced Recycled Concrete Beams", Journal of Advanced Concrete Technology, Vol. 5, No. 1, pp. 43-61, 2007

[14] ACI 318, Building Code Requirement For Structural Concrete, American Concrete Institute, 2005