Flexural Behavior of RC Beams Made with Recycled Aggregates Under 12-Month Long Term Loading

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***Abstract*—In the present era of infrastructure development, demolishing waste management poses serious problems, particularly in urban centers. Vast development requires huge amounts of conventional concrete aggregates resulting in serious environmental problems. Therefore, efforts are carried out in utilizing demolishing waste, particularly demolishing concrete as coarse aggregates used in new concrete. This article presents laboratory investigations of flexural behavior of reinforced concrete beams made with partial replacement of natural coarse aggregates with coarse aggregates from demolished concrete under 12-month long-term loading. Two batches of beams were cast and cured for 28 days. In the first batch three RC beams with partial replacement of natural coarse aggregates were cast, while in the second batch 6 RC beams with all-natural coarse aggregates were prepared. Out of these six beams three beams were tested under short-term loading to determine maximum load. 50% of this load was used as sustained load on the remaining all beams. The beams were mounted on purpose made frames and deflection, strain, and cracking were recorded on daily basis. After the elapse of the defined time the beams were tested under central point load until failure. Result comparison shows a 4.96% increase in deflection and 2.33% reduction in peak load. Based on the results of this study it is concluded that demolished concrete as coarse aggregates in new concrete shows reasonably good performance under 12-month long-term loading.**

Keywords-recyclable aggregates; reinforced concrete beam; demolishing waste; flexural behavior; long-term loading; green concrete

I. INTRODUCTION

Concrete has proved itself as the best material for general construction. But there are several issues related with the production of its ingredients, since they pose problems to the environment. On the other hand, demolishing waste generated from demolishing of old structures, add up to the environmental issues. One way of dealing with both of these problems, at least to some extent, is using the waste in new concrete. The resulting product will be eco-friendly, help in waste management, and help in preserving the natural resources of the ingredients of conventional concrete. The concrete using waste material is termed as green concrete. The use of demolished old concrete as coarse aggregates in new concrete is an active area of research.

The study of any aspect of a material requires comprehensive review of the literature related to it. Author in [1] checked the recent developments about the use of demolished concrete as coarse aggregates in new concrete. The author highlighted different aspects of the material with respect to its use and problems associated with it. He concludes that the material has promising effects, particularly on the strength of concrete. Concrete testing under short-term loading is routine practice to determine its various properties. In this connection authors in [2-5] used 50% replacement of natural coarse aggregates with coarse aggregates from demolished concrete to study flexural stress-strain behavior of RC beams. From the experimental observation, they observed 8.8% and 11.68% reduction in flexural capacity of 28-day cured normal and rich mix beams respectively. Flexural strength, shear strength and bonding of green concrete beams have also been studied by authors in [6]. They used waste from the testing of cylinders as coarse aggregates in 40% and 100% dosages. The comparison of obtained results with control specimens, ACI provisions and findings from literature showed good agreement.

In real structures, the loads mostly are of sustained nature. Therefore, evaluation of material properties and behavior under sustained/long-term loading is essential. To this end authors in [7] used 0%, 50% and 100% dosage of recyclable aggregates from demolished concrete to replace natural coarse aggregates in casting of reinforced concrete beams. The authors tested the beams with sustained load for 1200 days. Using the obtained results, the authors developed a numerical expression for the

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evaluation of long-term deflection by introducing the creep coefficient of recycled aggregates. The analysis of the results revealed that the size of the aggregates has also influence on the final deflection, therefore the authors also introduced the regeneration coefficient to deal with this issue. Using the above two coefficients and laboratory data, they introduced the deflection increase coefficient which simplifies the computation of long-term deflection. Long-term loading effects, creep, and shrinkage of concrete made with old concrete as coarse aggregates under 365 days sustained loading were compared with ACI provisions in [8]. After data analysis, the authors suggested modification in ACI provisions. Testing of the resulting equation showed good agreement between the two sets of the results. Long-term behavior of concrete under different conditions has been quite studied, i.e. service conditions (cracking and induced stress) of fiber reinforced concrete [9], effect of compressive strength and reinforcement ratio on glass-fiber reinforced concrete [10], and a numerical expression for the effect of bending moment on long-term behavior [11].

From the above discussion it may be observed that there is still a need of research regarding the use of the material. Therefore, this article presents a laboratory investigation on the effect of 12-month long-term loading on reinforced concrete beams. The 50% replacement [8, 12] of natural coarse aggregates with coarse aggregates from demolished concrete was used in casting. It is hoped that the outcome of the research will provide detailed understanding of the long-term behavior of the beams for the proposed duration and will not only improve the confidence about the material but also set a landmark for future research in the field.

II. MATERIALS AND TESTING

The demolished concrete used in this research work was collected in the shape of large blocks from the demolishing waste of a 45 year old, single story, school building. These blocks were processed manually to reduce to a maximum size of 25mm (Figure 1). Natural coarse aggregates of the same size were also used. The remaining ingredients of concrete used in this investigation are ordinary Portland cement, hill sand, and potable water (pH=6.87). Although good care is exercised in the hammering of the large blocks of the demolished concrete, yet some of the cracked particles were present. These particles if used in concrete will definitely affect its final strength, therefore, cracked particles, organic impurities, etc. have been removed manually, followed by washing of the aggregates. The use of well graded aggregates in concrete ensures proper functionality and strength. Therefore, both natural and recyclable aggregates were sieved as per the relevant procedure and specifications of ASTM. Figure 2 shows the gradation curve of both types of aggregates. It may be observed from the Figure that both curves follow the same trend which ensures that the aggregates are well graded. In addition to sieve analysis, physical and basic properties, i.e. water absorption, specific gravity, and abrasion resistance of the recycled aggregates were examined. Due to the mortar attached with the aggregates, the surface texture of the aggregates was rough and the color was dull in comparison to conventional coarse aggregates. Water absorption of the aggregates was higher than of natural coarse aggregates, while the specific gravity of the recyclable aggregates was less than that of the conventional aggregates. It was also noted that the abrasion resistance of the aggregates was less compared to the abrasion resistance of conventional aggregates. This was primarily due to the old mortar attached with the aggregates and the age of the concrete.

Fig. 1. Demolished concrete

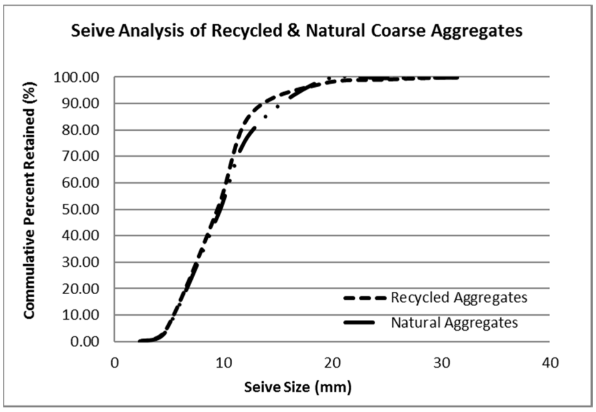

Fig. 2. Sieve analysis of coarse aggregates

The natural and recycled aggregates were used in equal proportion (50%) to cast the reinforced concrete beams. Concrete mix ratio of 1:2:4 with 0.5 water-cement ratio were used. To reinforce the beams, grade 60 deformed steel bars were used. The beams were cast in two batches. In the first batch, three beams were cast with both natural and recycled aggregates, whereas in the second batch six beams were cast with all-natural coarse aggregates. Out of these six beams three beams were used to determine peak load under short-term gradually increasing load. The half of the average of this load was used as sustained load for long-term testing of the beams. The remaining three beams of this batch were treated as control specimen to check and compare the results of the proposed beams. The size of the beams was kept the same and equal to 1875mm×150 mm×300mm. To reinforce the beams four #4 bars were used as longitudinal reinforcement (2 bars in tension and 2 bars in compression zones). Shear reinforcement in the form of stirrup #3 bars was provided at 150mm center to center along the length of the beams. Deformed bars were used for both longitudinal and shear reinforcement. For the batching of the ingredients, weight batching method was adopted. The ingredients were mixed in concrete mixer and placed in moulds following the standard procedure of filling the moulds and to compact the concrete. In all beams, top and bottom concrete cover was kept equal to 25mm. After demoulding, all the specimens were cured for 28 days in water (Figure 3). After curing, the beams were allowed to air dry for 24 hours. To determine the maximum load sustained by the RC beams, three beams made with all-natural coarse aggregates were tested in UTM under central point load (Figure 4). The load was applied gradually at the rate of 0.5KN/s. The peak load of the three beams was recorded and averaged. 50% of this load was used as sustained load during the long-term testing of the proposed beams.

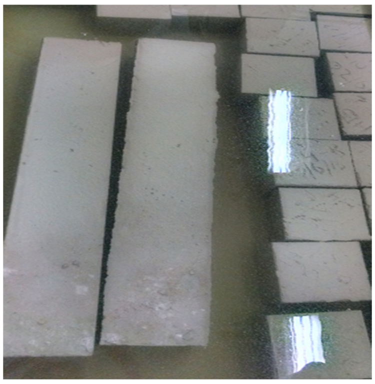

Fig. 3. Curing of specimens

Fig. 4. Short term testing of RC beams

Demic pads were applied on all beams along the depth at center with 25mm center to center distance for strain measurement. All beams were then mounted on purpose made steel frames (Figure 5). The load evaluated earlier was applied on the center with the help of load cell and screw jack system. This load was kept constant and maintained during the testing time. The beams were monitored for deflection, strain and cracking on a daily basis for 12 months. At the end of the required time, the beams were removed from the loading frames and were tested for peak load in UTM in the same fashion that was done to determine the peak load before starting the long-term testing of the beams. The obtained results are discussed in the following section.

(a)

(b)

Fig. 5. Beams under sustained loading

III. RESULTS AND DISCUSSION

During the long-term testing of the beams, deflection, strain, and cracking were monitored on a daily basis. Deflection and strain recorded at eleven locations along the depth of beams at center were averaged. The weekly results of deflection of both beam groups are shown in Figures 6 and 7. Similarly, Figures 8 and 9 show the weekly strain of beams cast with all-natural and recycled aggregates. The average values of both parameters for all beams are listed in Table I. It may be noted that the deflection in beams cast with recyclable aggregates exhibited 5.6% increase when compared to the deflection exhibited by control specimens. The comparison of average strain results shows that the proposed beams exhibited 5.64% increase when compared to control specimens. The observed deflection was found within the limits of the approximate maximum deflection allowed by ACI 318.

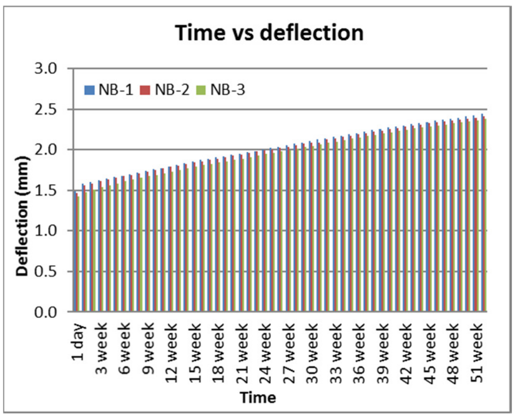

Fig. 6. Weekly deflection (natural aggregate beams)

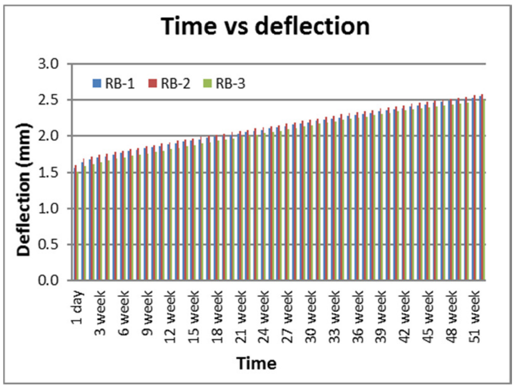

Fig. 7. Weekly deflection (recycled aggregate beams)

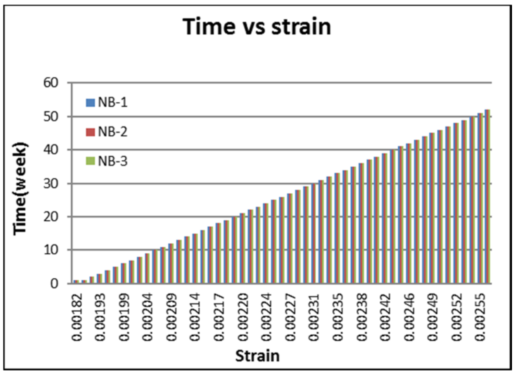

Fig. 8. Weekly strain (natural aggregate beams)

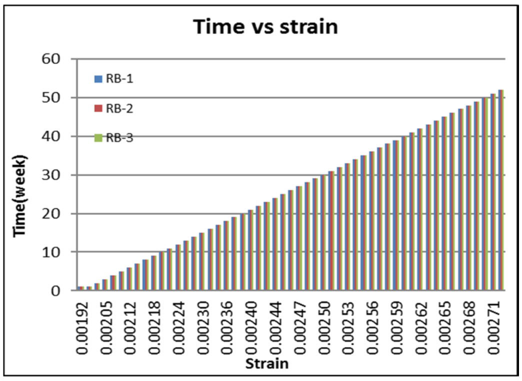

Fig. 9. Weekly strain (recycled aggregate beams)

TABLE I. AVERAGE DEFLECTION AND STRAIN

Aggregate type	Deflection (mm)	Strain
Natural	2.408	0.002606
Recycled	2.543	0.002753

After 12-month observation under sustained loading, beams were un-mounted from the loading frames and tested in UTM under central point load following the specification provided by ASTM for the purpose. Both load and deflection were monitored in each beam until failure. The average weekly deflections versus time are plotted in Figure 11. It may be observed that up to deflection of 1.5mm, the stiffness of both materials remained the same. Beyond this value, the beams cast with recyclable aggregates exhibited more deflection than control specimens. It may be observed that all the beams exhibited similar pattern except for peak values. The average ultimate load observed by beams made with all-natural aggregates was recorded equal to 83.38kN. At ultimate load, the average deflection in all three beams of the group was recorded equal to 14.72mm. The average of both parameters for beams cast with recyclable aggregates was recorded equal to 81.44kN and 15.45mm respectively. It may be observed that recycled aggregate beams showed 2.33% reduction in load and 4.96% increase in deflection than control specimens. Almost similar trend and behavior was observed for strain. The deflection and strain observed during the 12-month period of the proposed beams is compared with the results presented in [12]. The authors used the same material and configuration to study deflection and strain for 6-month sustained loading. The deflection of recyclable concrete beams under 12-month sustained loading exhibited 17.73% more deflection than the beams under 6-month sustained loading. Similarly, an increase of 12.83% was observed in strain.

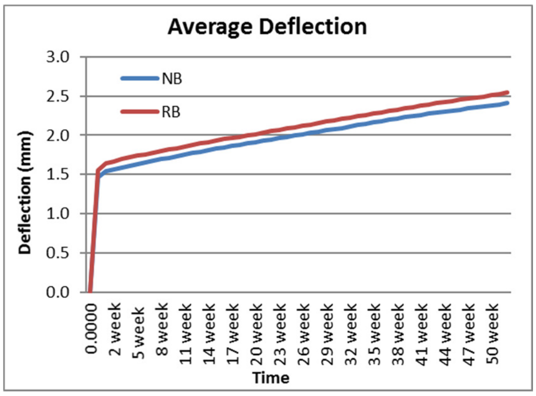

Fig. 10. Average deflection vs time

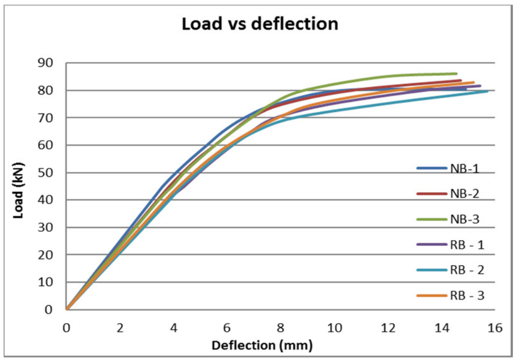

Fig. 11. Load vs deflection

Cracking due to sustained loading was monitored. The progression of cracks was marked and recorded. Figures 12 and 13 show a beam from each group. It may be observed that the crack pattern of the proposed beams (Figure 13) is almost similar to that of beams cast with all-natural aggregates. Also, it is recorded that the crack width at the end of the 12-month observations was less than 1mm. Further, the crack pattern at failure in the beams was also recorded and is displayed in

Figures 14 and 15 for a beam from each group. From the results it can be observed that the response of the proposed beams under 12-month loading matches well with the control specimens'. Hence, 50% replacement of natural coarse aggregates with aggregates from demolished concrete may be used in new concrete.

Fig. 12. Cracking of natural aggregate beam (12-month loading)

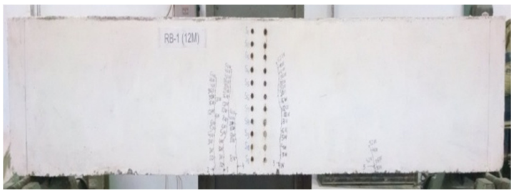

Fig. 13. Cracking of recycled aggregate beam (12-month loading)

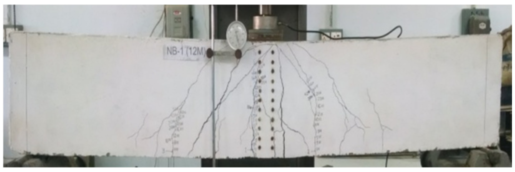

Fig. 14. Cracking of natural aggregate beam (at failure)

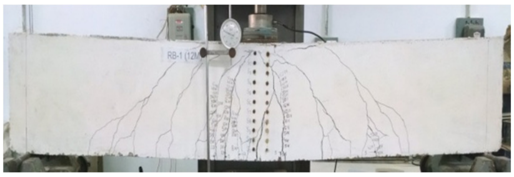

Fig. 15. Cracking ofrecycled aggregate beam (at failure)

IV. CONCLUSION

In this article, the effect of 12-month sustained loading on reinforced concrete beams made with 50% replacement of natural coarse aggregates with aggregates from demolished concrete is presented. Deflection and strain measured on a daily basis show a good agreement with control specimens with a deviation under 10%. Also, the crack pattern of the proposed beams showed good agreement with the control specimens'. The maximum crack width after 12-month sustained loading was recorded less than 1mm. Therefore, it is concluded that the use of demolished concrete as coarse aggregates in new concrete is a promising area of research.

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