Behavior of RC Beam under Monotonic and Cyclic Loading using Waste Materials as Fine Aggregate

T.Balasubramaniam, G.S.Thirugnanam

Abstract: Crusher sand or Manufactured sand (M-Sand) obtained from stone aggregate quarries is widely used as fine aggregate in concrete to avoid the depletion of natural river sand. To avoid air and land pollution due to direct dumping of wastes in open land area from granite processing industries and thermal power stations, the behavior of reinforced concrete beam without waste (RC beam) and with waste (RCW beam) materials like granite powder (10%) and bottom ash (10%) as combined partial replacement for M-Sand was carried out. The parameters like load carrying capacity, ductility, energy absorption capacity and stiffness degradation were evaluated. The behavior of all the parameters of both the beams was similar and there was slight decrease (10%) in strength parameters due to increase in fine pore particles. Hence, the granite powder and bottom ash can be used as partial replacement for fine aggregate in building constructions.

Keywords: M-sand, Granite powder, bottom ash, RC beam, behavior

I. INTRODUCTION

Bottom ashes which are considered as waste material generated from thermal power station are normally disposed to an open area. This leads to pollution in surrounding water bodies and also decreases the yield in agricultural land area. The partial replacement of fine aggregate by bottom ash in concrete increased the strength of concrete with age [1]. And also the strength properties of concrete with bottom ash as partial replacement for natural sand were increased with age of concrete [2]. The granite powder waste generated from stone processing industry was increasing every year in India. Generally stone slurry is disposed in landfills, its water content is reduced and the resulting stone dust causes several environmental impacts. The occurrence of stone powder particle in normal concrete enhance the performance of hardened concrete [3].In this investigation, the effect of bottom ash and granite powder waste (GPW) in the behavior of reinforced concrete beam was studied.

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The parameters such as load carrying capacity, ductility, energy absorption capacity and stiffness degradation were calculated and compared with RC and RCW beams

II. EXPERIMENTAL INVESTIGATION

A. Materials

Pozzolana Portland cement conforming to IS 1489 (Part 1): 1991 of specific gravity 3.12 was used as binding material. Silica fume (920-D grade) obtained from Elkem India private limited, Mumbai, India was used as mineral admixture. Manufactured sand (M-Sand) conforming to IS 383:1970 and IS: 2386 (Part 3) of specific gravity 2.8 and fineness modulus 2.6 was used as fine aggregate. Crushed aggregate of specific gravity 2.74 conforming to IS 383:1970 was used as coarse aggregate. Bottom ash (from thermal power plant) and Granite powder (from local granite stone processing industry) was used as partial substitute for fine aggregate. A super plasticizer under the trade name as cera hyperplast was used to maintain medium workability as per IS 456 – 2000.

B. Mix proportions

The control mix (M60) as per I.S 10262-2009 guide lines was used in this research. The specimen for compressive strength at age of 28, 56 and 90 days and for behaviour at the age of 28 days were tested as per IS 516-1959.The quantities for control mix and mix with waste per m^3 of concrete for the two trial mixes were presented in Table 1.

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Table 1 Mix Proportion for Combined Granite powder and Bottom ash concrete

Mix ratios	Silica fume [kg]	Cement [kg]	Granite Powder waste [kg]	Bottom Ash [kg]	F.A. [kg]	C.A [kg]	SP %	Water [litre]
GP0 + BA 0	44	392	0	0	672	1238	0.8	140
GP 10 + BA 10	44	392	67	67	538	1238	1	140

III. EXPERIMENTAL METHOD

A. Workability and Compressive strength

The degree of workability of concrete (slump test) was maintained as medium value (75 mm to 100 mm) as per IS 456 - 2000 by varying the percentage of super plasticizer. Compressive strength of concrete was determined on cubes of size 150 mm x 150 mm x 150 mm at the age of 28, 56 and 90 days using Compression Testing Machine (CTM) of capacity 4000 kN as per IS:516 - 1959.

B. Behavior of R.C beam

The aim for this investigation was to study the flexural behaviour of reinforced concrete beam with two point load system under monotonic and cyclic loading with the optimum percentage replacement mix of both Granite powder and Bottom ash. The flexural behaviour of reinforced concrete beam with the combined mix of 10% Granite powder and 10% Bottom ash were compared with the control mix. The dimension of the RC beam was 120mm breadth, 200 mm thick and 2000 mm length was used. Three numbers of 10mm diameter bars as tension reinforcement and two numbers of 10mm diameter bars as hanging bars were used. Two legged 8 mm diameter vertical stirrups with equal spacing were used as shear reinforcement. The test specimens were cast in cast-iron moulds. The inside of the mould were applied with oil to facilitate the easy removal of specimens. The concrete was placed in between the steel reinforcements positioned in the moulds in three layers of equal thickness and each layer was vibrated. After 24 hours, the test specimens were remoulded. The set of specimens was placed in normal water curing, till the age of test. Four sets of test beam were cast for monotonic and cyclic loading for control mix and the combined mix of Granite powder and Bottom ash. The cast RC specimens were loaded under two point loading system for pure bending with simply supported condition over the span of 1800mm using a loading frame of capacity 750 kN. Three dial gauge of least count 0.01mm were placed on the tension face of the beam to measure the deflection along the length. The loading was done with the hydraulic jack that is placed centrally over the channel section and this channel transfer's load to the beam with the help of two steel rollers of 30mm diameter placed at L/3 span from either side of support. The testing arrangement of the beam specimen was shown in Figure 1.The parameters like load carrying capacity, ductility, energy absorption capacity and stiffness degradation were calculated.

Fig 1 Loading arrangement of RC beam

C. Flexural parameters under monotonic loading

1. *Load deflection behavior*

All the beams were tested under two point loading condition shown in Fig1. The monotonic load was applied by using hydraulic jack and to record the load precisely, proving ring was used.

2. *Stiffness Characteristics*

The procedure for calculating stiffness was as follows. (a) An initial tangent was drawn on curve at origin. (b) Determine the slope of the tangent drawn to curve, which gives the stiffness of the beam.

3. *Ductility Characteristics*

The ratio of maximum deformation (Δu) to the yield deflection (Δy) can give a measure of displacement ductility.

4. *Energy Absorption Characteristics*

When the RC beam was subjected to loading, some energy was absorbed. It was equal to the work in straining. The energy absorption capacity of the beam was calculated as the area below the load deflection curve.

D. Flexural parameters under cyclic loading

1. *Load Deflection Behavior*

The forward cyclic load was applied by using Hydraulic jack and to record the load precisely, proving ring was used. Totally seven cycles were imposed. The beam was gradually loaded by increasing the load level in each cycle such as 5, 10, 15, 20,25kN etc., up to the maximum load of that cycle. At the end of each cycle the load was gradually released and deflections during unloading were noted. The beam was loaded up to failure and the values of load at first crack and ultimate failure state and crack pattern were noted.

2. *Stiffness Characteristics*

The procedure for calculating stiffness was as follows.(a) A tangent was drawn for each cycle of the hysteric curves at a load of P = 0.75 P_u, Where P_u was the maximum load of that cycle.(b)Determine the slope of the tangent drawn to each cycle, which gives the stiffness of that cycle.

3. *Ductility Characteristics and Cumulative Ductility Factor*

A quantitative measure of ductility has to be with reference to load deformation curve (Bilinear). The first yield deflection was determined from the assumed bilinear behaviour of beams. The ratio of maximum deformation of a particular cycle of that of the yield deflection can give a measure of displacement ductility.

4. *Energy Absorption Characteristics*

The cumulative energy absorption capacity of the beam was obtained by adding the energy absorption of the beam during each cycle considered.

IV. RESULTS AND DISCUSSION

A. Workability and compressive strength

The workability of concrete mixture was decreased when M sand was replaced with 20 % combined replacement of granite powder and bottom ash. The slump value was maintained as 80 mm (Table 2) for the combined replacement of GP and BA to get the medium workability using super plasticizers for pumped concrete as per IS 456 – 2000.The compressive strength was higher at fixed slump value for bottom ash concrete[4]. The compressive strength of replaced mix was reduced at all ages while compared with the control mix (GP0+BA0). The compressive strength was reduced due to increase of voids in concrete for the increase of granite powder and bottom ash replacement and also due to delay in the formation of C-S-H gel while replacing bottom ash. The compressive strength was increased slightly with granite fines as fine aggregate [5] [6]. The strength of bottom ash concrete was increased at later age [7].

Table 2 Slump value and Compressive strength

Mix	SP (%)	Slump (mm)	Compressive strength (MPa)		
			28 Days	56 Days	90 Days
GP 0 + BA 0	0.8	80	69.89	73.24	78.45
GP 10 + BA 10	1	80	66.9	70.12	75.34

B. Flexural parameters under monotonic loading

1. *Load Deflection Behavior*

The load deflection behaviour of RC and RCW beams were shown in Figure 2.The deflection of RCW beam was slightly higher than the RC beam at all the increment of load values. As the load level was increased, the observed deflection was greater for both the mixes.

2. *Load Carrying Capacity*

The comparison of load carrying capacity of the mixes was shown in Figure 3. The ultimate load carrying capacity of RCW beam was marginally lower than the RC beam.

3. *Stiffness characteristics*

The stiffness of RC beam was reduced slightly from 12.5 kN/mm to 12 kN/mm when the waste was incorporated in mix. The comparison of stiffness value of the mixes was shown in Figure 4.

4. *Ductility factor*

The comparison of ductility of the beams was shown in Figure 5.The ductility factor of RCW beam was reduced slightly when compared with RC beam.

5. *Energy Characteristics*

The Energy absorption of RCW beam was reduced marginally when compared to RC beam. The result was shown in Figure 6.
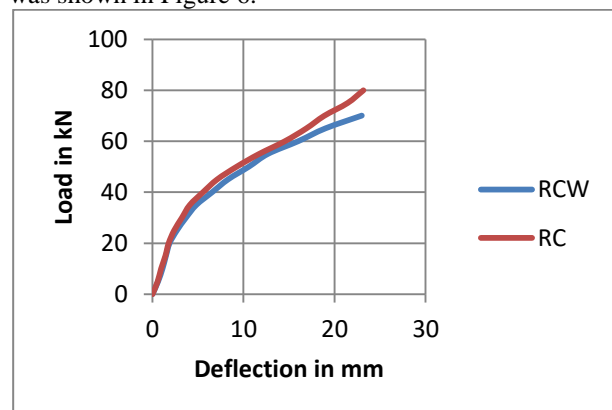

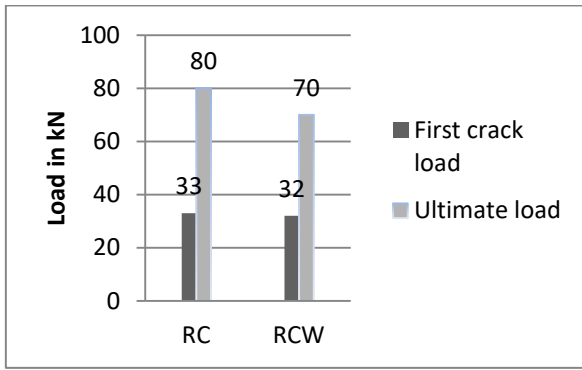**Fig 2 Comparison of Load deflection behavior**
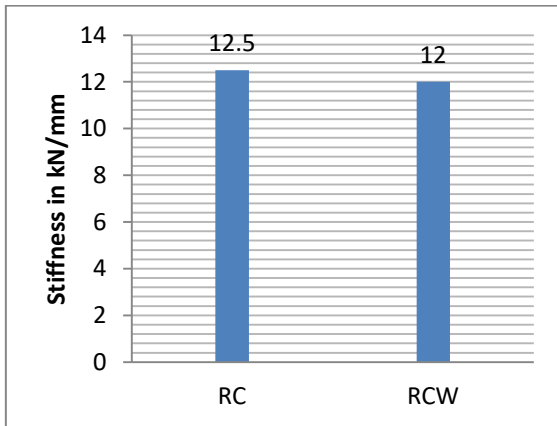
Fig 3 Comparison of Load carrying capacity

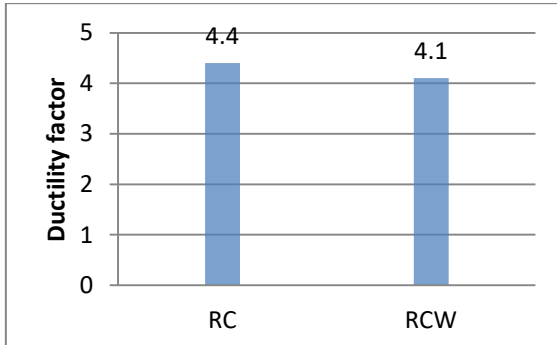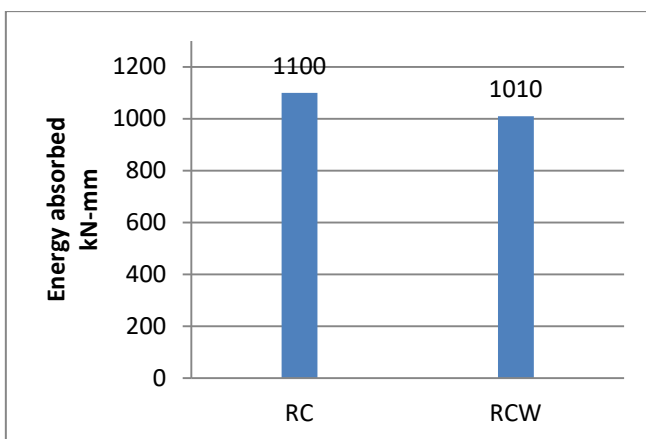Fig 4 Comparison of Stiffness

Fig 5 Comparison of ductility

Fig 6 Comparison of energy absorption capacity

C. Flexural parameters under cyclic loading

1. *Load Deflection Behavior*
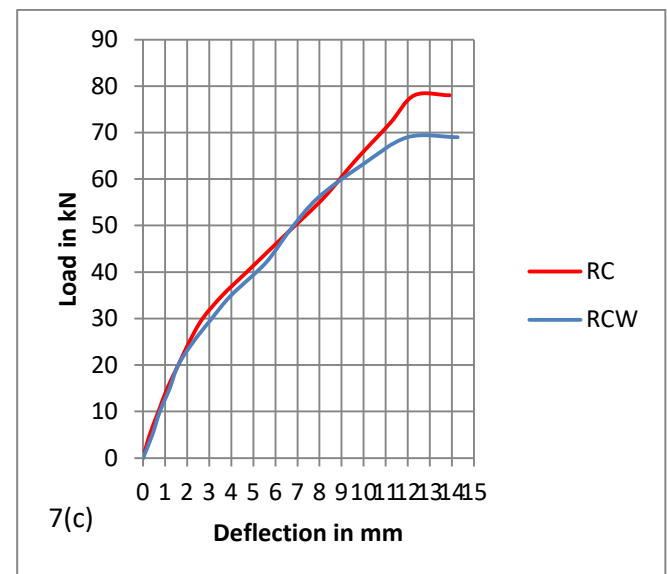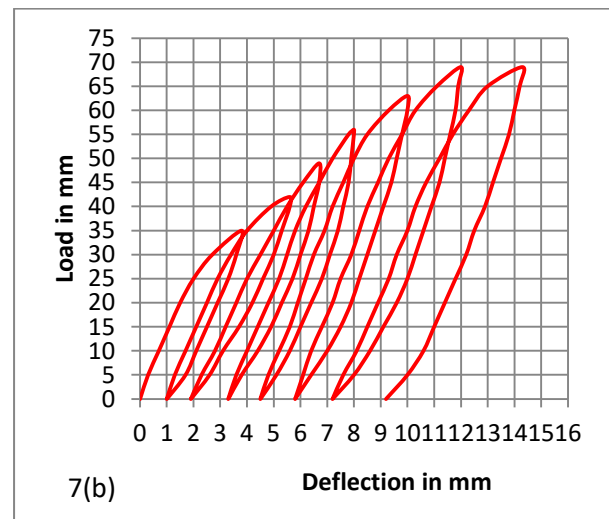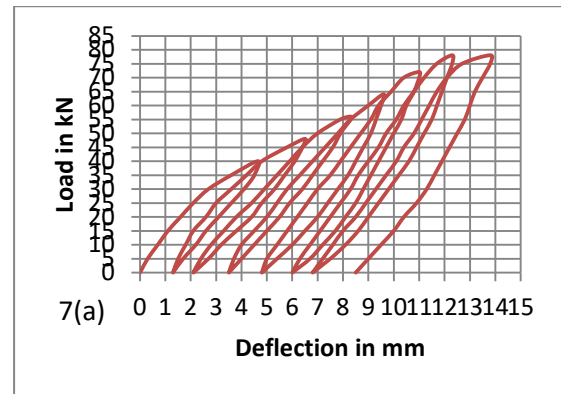

7(a)

7(b)

7(c)

Fig7(a) and 7(b) General load deflection behavior of RC and RCW beam, 7(c) Comparison of Equivalent load deflection behavior

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The general load deflection behavior and equivalent load deflection behavior of RC and RCW beams were shown in Figures 7a, 7b and 7c.The behavior of both the beam was similar in bending and the deflection was slightly higher in RCW beam when compared to RC beam.

2. *Load Carrying Capacity*

The first crack load carrying capacities of the beams without waste RC and with waste RCW were observed as 35 kN and 33 kN respectively. Ultimate load carrying capacity of the beams RC and RCW were witnessed as 77kN and 69kN respectively. Figure 8 shows the comparison of first crack and ultimate load values.
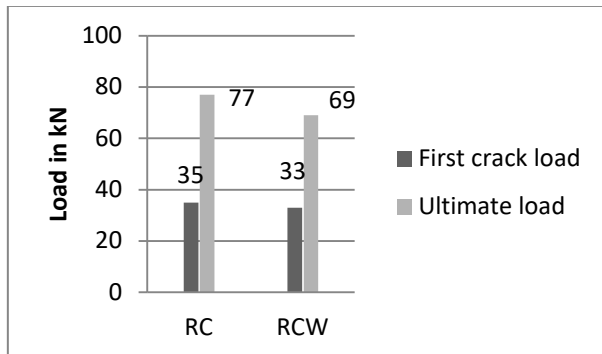

Fig 8 Comparison of Load carrying capacity

3. *Cumulative Ductility Factor Characteristics*

During the final cycle of loading, the cumulative ductility was 17.01 for RC beam, whereas it was 15.07 for RCW beam. The cumulative ductility factor value for RCW was slightly reduced when compared to RC beam. A figure 9a and 9b shows the comparison of the values.
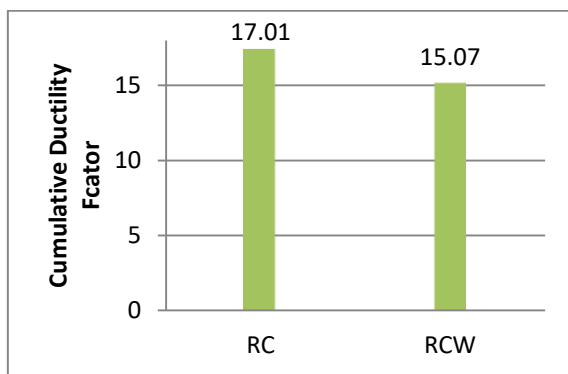

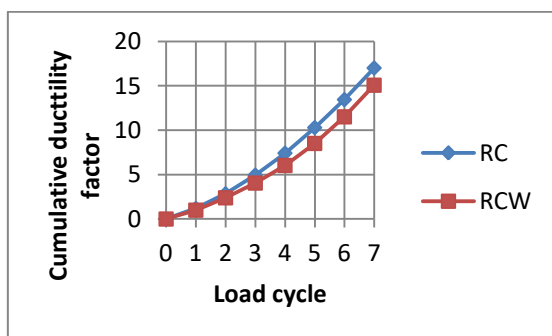Fig 9 a Comparison of Cumulative Ductility Factor

Fig 9 b Comparison of Cumulative Ductility Factor for different load cycle

4. *Cumulative Energy Absorption Characteristics*

The Cumulative energy absorption capacity of the RC and RCW beams was shown in the Figures 10a and 10b.The cumulative energy absorption value of RCW beam was decreased slightly when compared to RC beam.
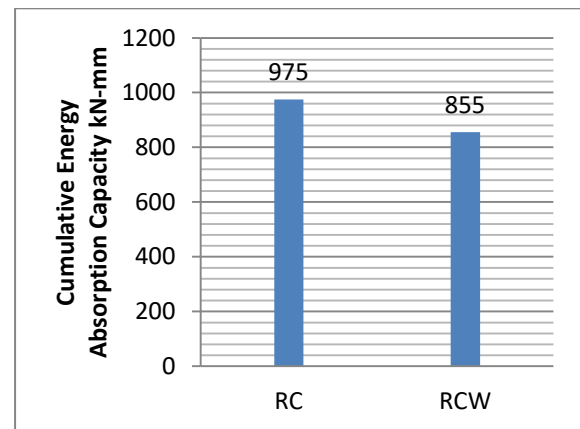

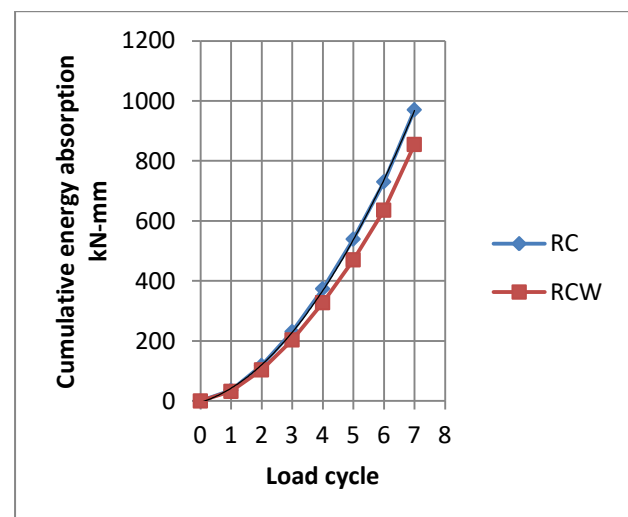Figure 10a Comparison of Cumulative energy absorption capacity

Fig 10b Comparison of Cumulative energy absorption capacity for different load cycle

5. *Stiffness Characteristics*

The stiffness for the beams were compared and shown in Figure 11 .The stiffness of RCW beam was slightly lower than that of RC in all the load cycle. The initial stiffness of RCW was marginally reduced compared to RC beam calculated from equivalent load deflection curve.
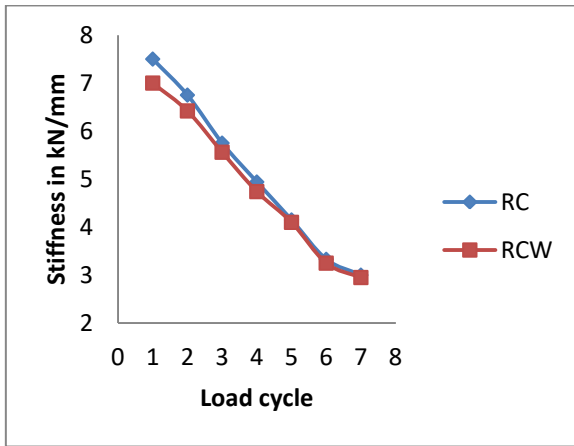
Fig 11 Comparison of Stiffness degradation

6. Behavior and Mode of Failure

In both the HSC mixes GP0+BA0 (RC beam) and GP10+BA10 (RCW beam), the failure was initiated by yielding of steel in tension zone. The crushing and spalling of concrete in compression zone occurs after the yielding of steel in tension zone. In both mixes, the failure occurs due to yielding of steel in central zone

Fig 12 Failure pattern of GP0+BA0 (RC beam)

Fig 12 Failure pattern of GP10+BA10 (RCW beam)

V. CONCLUSIONS

A. Monotonic loading

The ultimate load carrying capacity of RCW beam (GP10+BA10) was 10% less that of control RC beam.

The stiffness, ductility factor and energy absorption of RCW beam (GP10+BA10) was 4%, 6.8% and 8.2% less than that of control RC beam.

Based on the above test results it was concluded that the behaviour all the parameters of both the beams were similar and there was slight decrease in strength parameters due to increase in fine pore particle. Since the deviation of results of RCW beam for all the parameters was less than 10% when compared to RC beam, the usage of the industrial waste materials in concrete as partial replacement for M-sand was increased and also safe disposal of waste materials.

B. Cyclic loading

The ultimate load carrying capacity of RCW beam was slightly (10%) less than that of RC beam.

The cumulative ductility factor value and cumulative energy absorption of RCW beam was 0.9 times that of RC beam.

The stiffness of RCW beam was slightly lower than that of RC beam (1% - 7%) in different load cycles.

In general the use of industrial waste materials in concrete causes marginal decrease in strength parameters. Hence from the environmental point of view it was safe to use the waste materials as partial replacement in concrete for its proper disposal and also for effective use of important minerals in waste materials.

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