Influence of recycled aggregate on flexural behaviour of reinforced concrete beams

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ABSTRACT: Conservation of natural resources and protection of environment is the key to sustainable development. Construction engineers and the researchers have to share this critical responsibility. Research is in progress to explore new civil engineering materials which can contribute to the sustainable development. The research work on flexural behaviour of recycled aggregate concrete beams presented here is one such attempt to establish performance of recycle aggregate concrete (RAC) as structural grade concrete. In the present paper, two grade of RAC, viz., M25 and M30 and two types of sections namely, under reinforced and balanced sections were considered for studying flexural behaviour (ultimate load, ultimate moment, deflections, strains, moment-curvature relations and crack pattern) of beam specimens. For comparative study, corresponding type of natural aggregate concrete (NAC) beam specimens were investigated for flexural behaviour. In all 8 beams of RAC and 8 beams of NAC were tested for flexure under two point loading. The investigations indicated encouraging results for RAC beams in all respects, thus, pointing to recycled aggregate as potential alternative source of aggregate of the 21st Century.

1 INTRODUCTION

Continued growths in population, demand for better quality of life and evolutionary industrialisation have resulted in rapid urbanization. Obviously, this explosion into an urban way of life will demand enormous resources and supply of construction material required to build the infrastructure at a rapid pace. Civil engineering structures such as housing, water supply, transportation, sanitation etc, form a major component of the infrastructure development supporting life in these metropolis and big cities. Concrete is a predominant construction material required for it and obviously, constituents of concrete, namely, cement and aggregates are in high demand. This is evident from the fact that the construction industry consumes 10 billion tonnes of concrete annually. Correspondingly, the quantity of cement and aggregate requirement would be in the range of 1.5 billion tonnes and 10 billion tonnes respectively.

The huge demand for cement and aggregates is obviously alarming in view of growing concern expressed by environmentalist on excessive tapping of natural resources. Conservation of natural resources has become a key word and civil engineering materials are no exception to this reality. Further, in order to maintain ecological balance and to ensure sustainable development, there is an urgent need to restrict the use of natural resources. This means, the engineers and scientists have to explore the possibility of finding alternative materials or to adopt recycling technology. While alternative to the cement in terms of fly ash and other pozzolanic materials were evolved for use in concrete, the alternative materials to natural aggregate are being explored. This research work is a step forward to explore a popular alternative to the natural aggregate for use in concrete. The present work is an attempt to provide solution to the problems and concerns raised by the environmentalist and contribute to the sustainable development.

2 NEED FOR THE PRESENT WORK

Enormous growth in construction industry and consequent to that, the growing demand for natural aggregates is compounded by (i) considerable decline in the availability of good quality natural aggregate in the vicinity of construction site, and (ii) stringent anti pollution and environmental regulation for conservation of natural resources. Simultaneously, there has been enormous increase in the quantities of demolished concrete, the disposal of which posed a serious problem due to shortage of dumping sites and steep rise in dumping cost. The reports indicate that the quantity of concrete discarded every year has reached the staggering figure of about 100 million tonnes in the United States, and European Economic Communities; and 25 million tonnes in Japan, France, and United Kingdom. It is estimated that these quantities of discarded material will increase nearly three fold by 2010 A.D.

The solution to the above problem is found in adopting the recycling technology. Recycling not only solves the waste disposal problem but also reduces the cost and conserves the non- renewable natural resources. Thus, attempts were made by researchers to investigate the properties of recycled coarse aggregate (hereafter referred as recycled aggregate) and study the performance of concrete made out of recycled aggregate. BCSJ 1978, Buck, A.D 1977, Hansen & Narud 1983, Hasaba,et.al. 1981, Ravindrarajah & Tam 1985, Frondistou-Yannas 1977, Malhotra 1976, Mukai 1979, Gerardu & Hendrick 1985, Rasheeduzzafar & Khan 1984, Ravande Kishore & Bairagi 1990 are among the notable researchers who have carried out research work on characteristics of recycled aggregate and short term and long term behaviour of recycled aggregate concrete. All of them have indicated that, attached cement mortar of recycled aggregate particles is the main reasons for its modified characteristics. A common observation is the higher water absorption accompanied by lower specific gravity values for recycled aggregate. Further, the workability of recycled aggregate concrete is found to be lower in view of higher water demand of recycled aggregate due to the porous nature of adhered cement mortar on its surface. However, researchers have observed that a properly proportioned fresh recycled aggregate concrete is cohesive. As regards to properties of hardened recycled aggregate concrete, 5 to 10 percent drop in compressive strength and 10 to 30 percent drop in modulus of elasticity is reported by the investigators. However, reports on the performance of recycled aggregate concrete in indirect tension and flexure are contradicting with, some reporting on par strength, while others indicating 10 to 15 percent lower values. High values of creep and shrinkage strains are other common observation reported by various investigators. A notable research work in this field of research is on development of comprehensive mix design chart and guidelines exclusively for recycled aggregate concrete by Ravande Kishore in 1994.This development has provided the construction engineer with a right solution for proportioning recycled aggregate concrete especially suitable to Indian conditions.

A comprehensive literature review reveals significant work in the field, but most of the research work is on basic properties of recycled aggregate and recycled aggregate concrete. No research work is reported on performance of reinforced recycled aggregate concrete (RRAC) structural elements in flexure. As a matter fact, structural elements subjected to flexure are predominant component of a structural system. Thus, structural performance of RRAC flexural elements needs to be investigated. The present work is an attempt to initilise research investigation on the vital aspect of flexural behaviour of RRAC beam elements.

3 OBJECTIVES

a) To evaluate the load carrying capacity and moment carrying capacity of RRAC beam elements.
b) To examine the load-deflection and load-strain characteristics of RRAC beam elements.
c) To study the moment curvature relationship for RRAC beam elements.

4 EXPERIMENTAL PROGRAMME

The experimental programme was carried out in three phases as indicated below.
Phase 1: Evaluation of physical properties of natural aggregate and recycled aggregate.
Phase 2: Concrete mixture proportioning and preparation of test specimens.
Phase 3: Flexural testing of specimens.

4.1 *Phase 1*

The physical properties of natural fine aggregate (NFA), natural coarse aggregate (NCA), recycled coarse aggregate (RCA) and recycled fine aggregate (RFA) are evaluated to account them in the mixture proportioning. Important physical properties such as specific gravity, water absorption, etc. were investigated by performing tests as per procedure given in Indian standard specifications [IS 2386 1970]. The results of these tests are presented in Table 1.

Table 1. Physical properties of aggregates

Property	NCA	RCA	NFA	RFA
Sp. gravity	2.60	2.32	2.63	2.45
Fineness modulus	6.73	6.64	2.88	2.78
Bulk density, kg/m^3				
a) Loose	1387	1234	1550	1440
b) Comp.	1534	1420	1694	1582
Water absorption, %	0.70	4.50	0.50	1.1
Attached cement mortar, %	-	33.0	-	-

4.2 *Phase 2*

Two grades of concrete viz. M25 and M30 were considered for the investigation. The mixture proportions were worked out as per the guidelines given in Indian standard specifications [IS 10262 1982]. Twenty eight days compressive strength of normal portland cement was taken in to account in design of concrete mixtures. For design of recycled aggregate concrete (RAC) mixtures, RK method of mixture proportioning [Ravande Kishore 1994] was used. Fifty percent of natural fine aggregate was replaced by recycled fine aggregate (RFA). The details of concrete mixtures of each grade are given in Table 2.

Table 2. Mix proportions of concrete

Materials	Grade of concrete			
	M25		M30	
	NAC	RAC	NAC	RAC
Cement, kg/m^3	385	396	429	443
FA, kg/m^3	574	334 + 334*	545	303 + 303*
CA, kg/m^3	1190	1114	1183	1125
Water, kg/m^3	188	202	189	202
W/C	0.49	0.51	0.44	0.45

* RCA + RFA

Eight recycled aggregate concrete (RAC) beams were cast to study the flexural behaviour. For comparative study, eight natural aggregate concrete (NAC) beams of same type were also cast. The details of the types of beam viz., beam notation, and reinforcement details are presented in Table 3. The typical beam reinforcement and loading details are shown in Figure 1.

Table 3. Reinforcement details for beam specimens

Beam notation	Main reinf. & stps.	Reinf. (%)	No. of beams
M25 NU	2 nos. - 10φ, 2 nos. - 8φ 6φ@ 110mm c/c	0.90	2
M25 RU	2 nos - 10φ, 2 nos. - 8φ 6φ@ 110mm c/c	0.90	2
M25 NB	4 nos. - 10φ 6φ@ 110mm c/c	1.10	2
M25 RB	4 nos. -10 φ 6φ@ 110mm c/c	1.10	2
M30 NU	4 nos.- 10φ 6φ@ 110mm c/c	1.10	2
M30 RU	4 nos.- 10 φ 6φ@ 110mm c/c	1.10	2
M30 NB	2 nos.- 12 φ, 2 nos. -10φ 6φ@ 110mm c/c	1.34	2
M30 RB	2 nos.- 12 φ, 2 nos.- 10φ 6φ@ 110mm c/c	1.34	2

N-natural, R-recycled, U-under reinforced, B-balanced

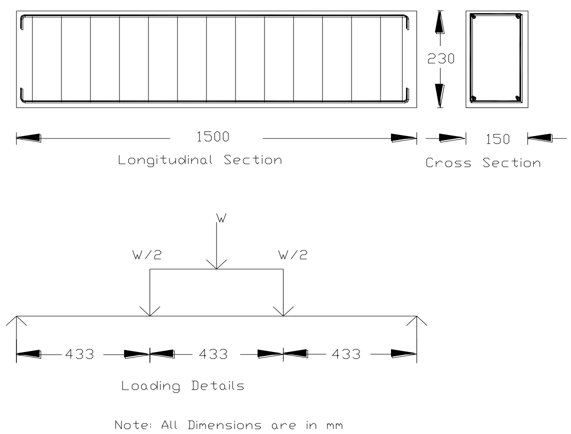


Figure 1. Typical beam reinforcement and loading details

Standard procedure was adopted in preparation of beam moulds, placing of reinforcement and moulding of beam specimens. While, natural aggregate concrete mixing was done as usual, the mixing of recycled aggregate concrete required necessary care about presoaking of aggregate before mixing and other measures as suggested in guidelines on mixing of RAC [Ravande Kishore 1994]. Workability tests in terms of slump and compaction factor were carried out to ensure desired workability. Three standard cubes were cast for each grade of concrete along with moulding of beam specimens to evaluate compressive strength of concrete. The demoulding was done after 24 hours and the specimens were cured by conventional method for 28 days.

4.3 *Phase 3*

Two point transverse load test was performed on beams specimens to evaluate their flexural behaviour. After curing, the specimens were given a white wash and identification number. The white wash was given to enable the detection of cracks during testing at various stages of loading. A steel frame with inner dimensions of 600x200x350mm with bolts at top and bottom to hold dial gauges was fixed to the beams to measure strains over a 200mm gauge length. Three dial gauges were fixed at the top and one-third span sections. The beam deflections were measured by means of three dial gauges set below the beam at mid span and one-third span sections. The dial gauges used has a least count of 0.01mm. The beams were tested on a universal testing machine (2000kN capacity) under two point loading at one-third point of span as indicated in Figure 1.

Dial gauge readings were recorded for every incremental load of 5.0 kN distributed equally over two points. Strains, both in compression and tension zone, and deflections were monitored during the test at various stages of loading. Cracks at various stages of loading were observed and marked on beam specimens. The test results recorded pertaining to load Vs deflection, load Vs strain are presented in graphical forms in Figures 2-3. Further, moment curvature relationship are also plotted and shown in Figure 4. Ultimate load carrying capacity and ultimate moment carrying capacity (theoretical & experimental) of various types of beams (RAC & NAC) are also recorded and presented in Table 4.

5 DISCUSSIONS

5.1 *Properties of recycled aggregate*

Important physical properties of both natural aggregate and recycled aggregate are presented in Table 1. The test results indicate that recycled aggregate exhibited lower specific gravity and higher water absorption, when compared with corresponding values of natural aggregate. While, fineness modulus of recycled aggregate is more or less same as that of natural aggregate, bulk density of recycled aggregate is found to be on lower side. This significant change in specific gravity and water absorption values in case of recycled aggregate has bearing on the properties of RAC. This is obviously discussed in detail in the following text.

5.2 *Flexural behaviour of recycled aggregate concrete*

5.2.1*Ultimate Load*

Ultimate load for each of the four types of M25 grade beam specimens and four types of M30 grade beam specimens (RAC and NAC) are shown in Table 4.The test results show that RAC type beams failed at relatively lesser loads in both cases i.e. under reinforced section and balanced section. The percentage reduction of ultimate load is in the range of 5.6% to 7.0% for under reinforced section and 2.7% to 2.9% for balanced section. It may be noticed that, again balanced section indicated slightly better performance when compared with under reinforced section. As shown, the range of ultimate load for M25 grade RAC concrete is 118kN to 133 kN and for M30 grade NAC, it is 132 kN to 142 kN. Thus, RAC beams exhibited almost on par performance in terms of load carrying capacity.

5.2.2 *Ultimate moment*

The values of ultimate moment carrying capacity of four types of M25 grade beams and four types of M30 grade beams (RAC and NAC) are presented in Table 4. As indicated in Table 4, the range of ultimate moment carrying capacity of M25 grade RAC beams is 25.6 kNm to 28.8 kNm and for M30 grade RAC beam, it is 28.6 kNm to 30.8 kNm. Theses values are on lower side by 5.5% to 3.0% for M25 grade concrete beams and 7.1 to 2.5% for M30 grade concrete beams when compared to corresponding values for NAC. Further, it may be noted that balanced section beams of all types exhibited slightly better performance with lower percentage reduction in ultimate moment carrying capacity of beams.

A comparison of theoretical and experimental values of ultimate moment carrying capacity of beams presented in Table 4 show that all types of beams exhibited satisfactory performance. The experimental values are found to be 26.7% to 48.9% more than the theoretical values. Even RAC beam exhibited 26.7% to 42.6% higher experimental values compared to corresponding theoretical values. This clearly indicate that structural performance of RAC beams is more than satisfactory and hence recycled aggregate may be encouraged as alternative aggregate in place of natural aggregate.

5.2.3 *Load Vs deflection*

Load verses Deflection curves for beams namely (i) M25 NU & M25 RU, (ii) M25 NB & M25 RB, (iii) M30 NU & M30 RU, and (iv) M30 NB & M30 RB are presented in Figure 2 (a to d). It may be noted that, load Vs deflection curves of natural aggregate concrete (NAC) and recycled aggregate concrete (RAC) beam specimen of a particular grade are plotted in one figure to bring out comparative behaviour of NAC and RAC beams. For both M25 and M30 grades of concrete, the load Vs deflection profile of NAC & RAC beams is identical. Further, it can be observed that, both NAC and RAC under reinforced beams of M25 grade concrete indicate almost same deflections up to a load of 80 kN. The same trend is observed for M30 grade under reinforced beams. As regards to balanced section beams of both NAC and RAC types, the deflection were almost same up to a load of 120kN for M25 and M30 grade concrete. However, it may be noticed that, in general, RAC beams indicated 2.2 to 15.6% higher deflection at the same load when compared with corresponding values for NAC beams. Another significant observation is that balanced sections beam of all types indicated relatively higher stiffness. This is obvious from the fact that, the maximum deflection of 16mm is observed at 118 kN at mid span section for M25 grade RAC under reinforced beam. The corresponding deflection for balanced section beam of same grade and type of concrete is 7.0mm. Like wise, for M30 grade RAC under reinforced beam, the mid span deflection is found to 17.8mm at 132 kN. The corresponding deflection for balanced section of same grade and type of concrete is 10.3 mm.

Although, RAC beam specimens indicated higher deflection, compared to NAC beam specimens, the deflections are within acceptable limits. All the load Vs deflection curve reflect this fact at 50% of the failure load. Thus, performance of RAC beam specimens in terms of deflection criteria is quite encouraging.

Table 4. Ultimate load and ultimate moment of various types of beam specimens

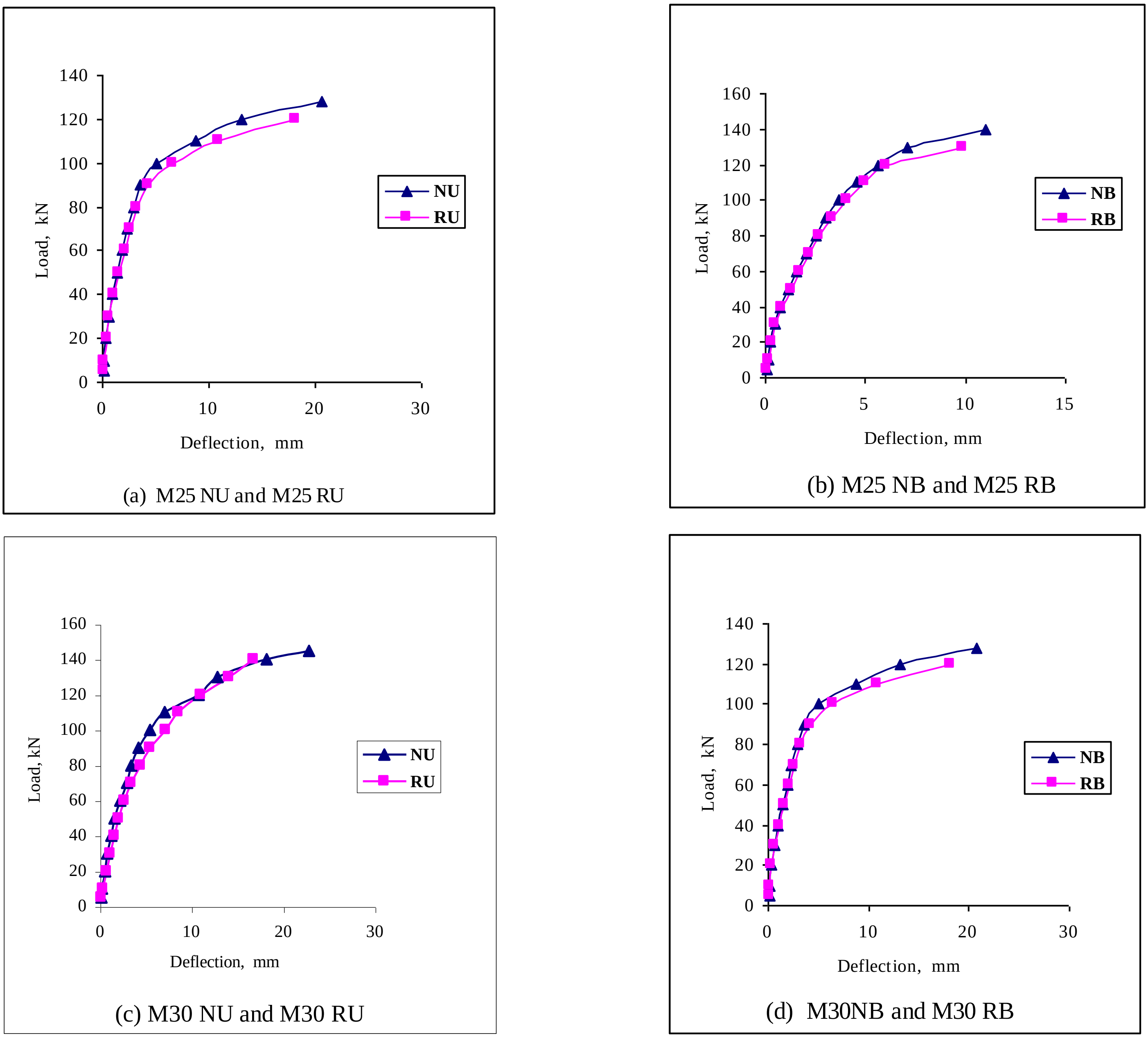
Beam notation	Ultimate load, kN	Percentage reduction of load over NAC, %	Exp. ultimate moment, kN-m	Percentage reduction of moment over NAC, %	Theo. ultimate moment, kN-m	Percentage increase over theoretical moment, %
M25 NU	125	5.60	27.10	5.50	18.20	48.9
M25 RU	118		25.60			40.6
M25 NB	137	2.90	29.70	3..03	20.20	47.0
M25 RB	133		28.80			42.6
M30 NU	142	7.00	30.80	7.14	20.70	48.8
M30 RU	132		28.60			38.2
M30 NB	146	2.70	31.60	2.53	24.30	30.0
M30 RB	142		30.80			26.7

5.2.4 *Load Vs strains*

Mean values of strain measured at mid span section are shown in Figure 3 (a to h) for each of the four types of M25 grade beams and M30 grade beams (RAC and NAC). All the four types of RAC beams indicated relatively higher strain when compared with corresponding NAC beams. Similarly, beams with balanced section have lesser strains when compared with corresponding under reinforced sections. Although, the figures indicate the strain differential up to 29% for the range of maximum load of 120 to 145 kN, there is hardly any difference in strain values at 50% of the maximum load for each of the beam specimens. It may be noted that, strain differential increase as the magnitude of load applied increase. Thus, RAC beam specimens exhibit satisfactory performance in terms of strains.

5.2.5 *Moment – curvature relationship*

Moment curvature relationship for both M25 and M30 grades of RAC under reinforced and balanced beam sections are presented along with the corresponding moment curvature relationship for NAC beam specimens in Figure 4 (a to d), (M25NU & M25RU, M25NB & M25RB, M30NU & M30RU, and M30NB & M30RB respectively). The figures clearly depict that both RAC and NAC beams follow the same trend. However, it may be noticed that for the same value of moment, curves for RAC beam specimen indicate higher curvature up to 31% indicating less ductility for RAC beams. Further, moment curvature relationship depict that curvature tends to be almost same as beam approach its ultimate moment carrying capacity, with NAC beams having up to 10% higher ultimate moment value. Thus, the moment curvature relationships for RAC beam specimens are comparable with that of NAC beam specimens.



(a) M25 NU and M25 RU

(b) M25 NB and M25 RB

(c) M30 NU and M30 RU

(d) M30NB and M30 RB

Figure 2. Load-deflection curves at mid span section for various types of beam

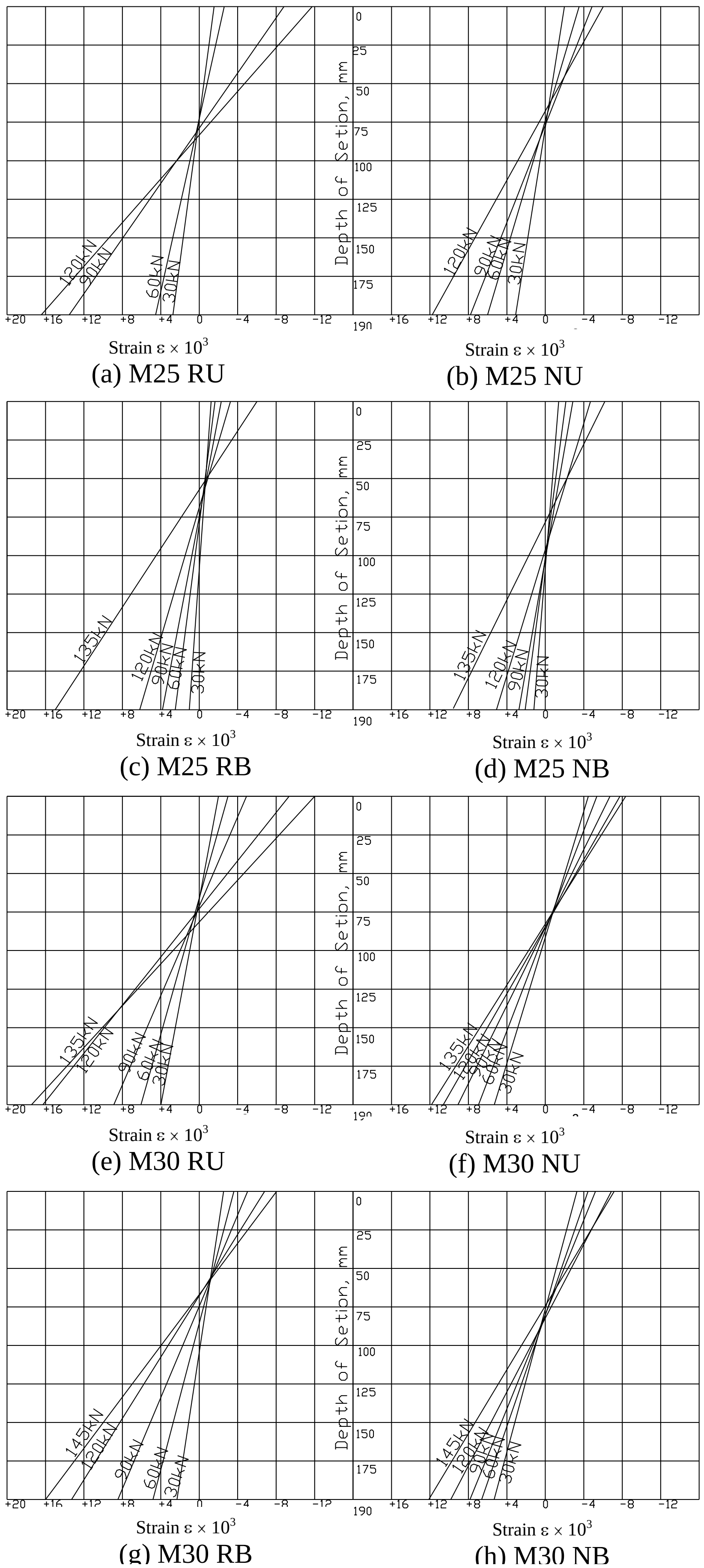
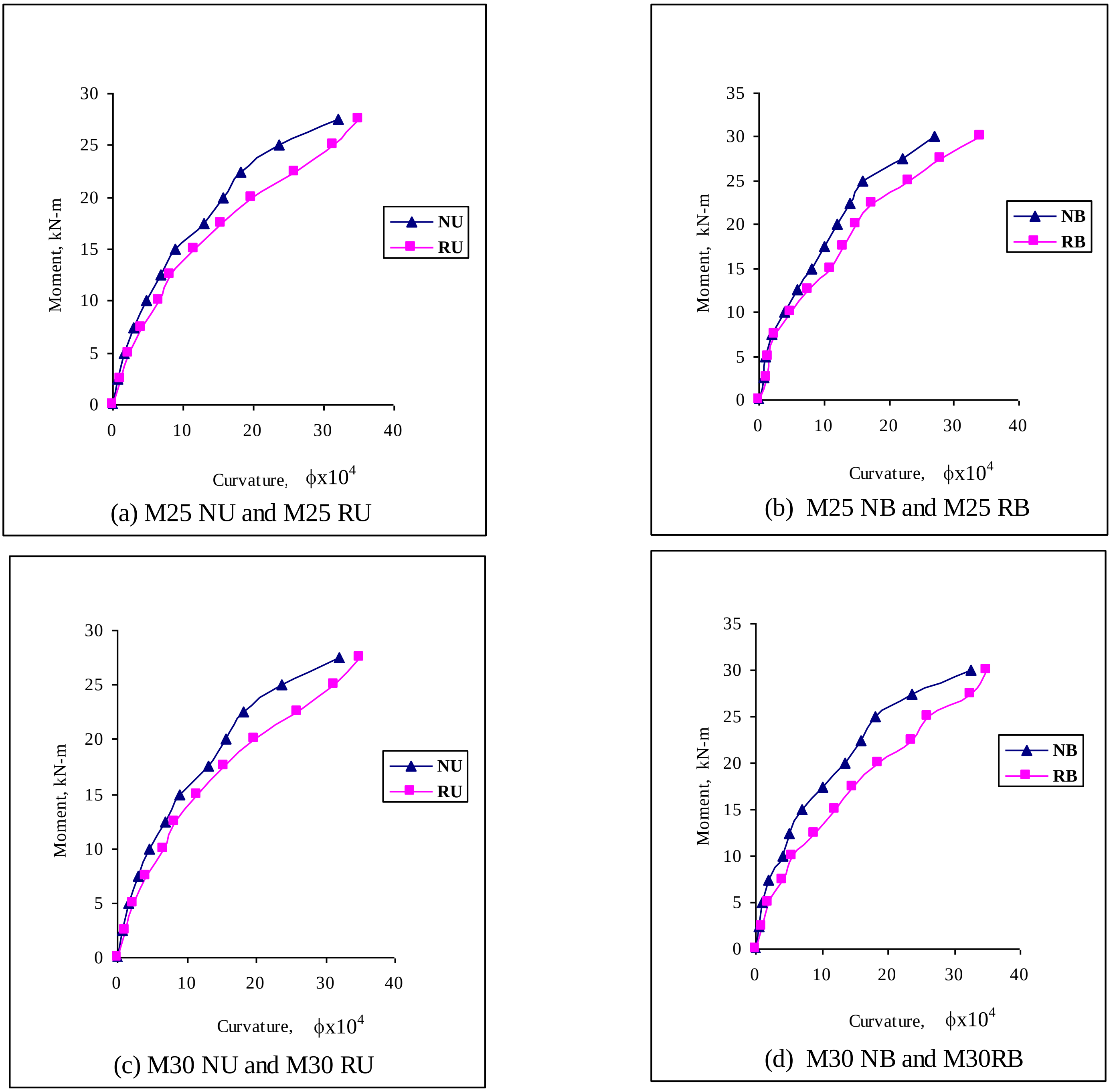


Figure 3. Variation of strain with load at mid span section



(a) M25 NU and M25 RU
(b) M25 NB and M25 RB
(c) M30 NU and M30 RU
(d) M30 NB and M30RB

Figure 4. Moment-curvature relationships at mid span section for various types of beam

5.2.6 *Crack width*

The cracks width were measured by conventional means and it was found that the crack width were in the range of 0.25 to 1.3 mm. Since crack width for different cracks were varying in each of RAC and NAC beams, no specific conclusion can be drawn about either RAC or NAC beam cracking relatively wider. Further, the pattern of crack development was found to be identical in all types of beam specimens. It may therefore be said that, structural performance of RAC beams in terms of cracking is at par with NAC beams.

5.2.7 *Influence of recycled aggregate on flexural behaviour*

Although, flexural behaviour of RAC beams is relatively inferior when compared with NAC beams, their performance level is comparable. However, the main reason for relatively inferior flexural behaviour of RAC beams can be attributed to the attached mortar component of recycled aggregate. Weak bond between old mortar and the virgin aggregate together with porous nature of attached mortar component may have caused detrimental effect in respect of structural behaviour. Relatively inferior but acceptable level of performance in flexure at greatest advantage of attaining sustainable development is certainly a positive feature of this research investigation.

6 CONCLUSIONS

- A maximum of 7.0% reduction in ultimate load and ultimate moment is observed for RAC beam specimens. Further, the experimental values of ultimate moment for RAC beams are 26.7% to 42.6% higher than the theoretical values.
- Up to 15.6% higher deflections are observed for RAC beam specimens.
- No significant change in strain values are noted at 50% of ultimate load for any type of RAC beam specimens. However, up to a 29% more strain is noted for RAC beam specimen at ultimate load.
- Moment curvature relationship of RAC beams follow same trend as that of NAC beams with almost same curvature at ultimate moment values.
- No significant change in development of crack and crack width is noted for RAC beam specimens.

7 CLOSING REMARKS

The discussions and conclusions presented above favour the use recycled aggregate as alternative material in place of natural aggregate. The increasing environmental awareness together with earnest need of conserving natural resources certainly encourage the use of recycled aggregate for making concrete. Recycled aggregate concrete is indeed a construction material of 21st Century for sustainable development.

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