Indexed in
Scopus Compendex and Geobase Elsevier,
Geo-Ref Information Services-USA, List B of Scientific
Journals, Poland, Directory of Research Journals

International Journal
of Earth Sciences
and Engineering

www.cafetinnova.org

ISSN 0974-5904, Volume 09, No. 03

June 2016, P.P.415-419

Experimental Investigation on Modulus of Elasticity of Recycled Aggregate Concrete

P S Kulkarni, A Ghatge, O Kank, A Nair and R Aswar
Vishwakarma Institute of Information Technol1ogy, Pune, INDIA
Email: *preeti.kulkarni@viit.ac.in*

Abstract: Use of construction and demolition waste materials in form of aggregates can be an important step towards sustainable development. However utilization of waste construction materials in new construction products must display quality guarantee systems to achieve suitable product properties. With other important characteristics of concrete, Modulus of elasticity (E) of concrete is an important factor which is an indication of stiffness of concrete. E value for conventional concrete is considered as 25 Gpa. However the actual values of conventional concrete can be greater than or less than 25 Gpa. Moreover for Recycled aggregate concrete (RAC), the E value depends on the type of Recycled Aggregates (RA) used and its replacement percentage in concrete. Thus an attempt is made in this project to experimentally determine the Modulus of elasticity of concrete at various percentage replacement of RA. Experimentally it was seen that as the percentage replacement of RA in concrete increases the E value decreases. The alignment of RA in concrete and the E value of RA itself affect the E value of RAC. A comparison of experimental E value and E value calculated using formula devised by earlier researchers was done which shows that the calculated E values of RAC is under or overestimated than experimental values.

Keywords: *Modulus of elasticity, Recycled aggregate concrete (RAC), Recycled aggregates (RA), Percentage replacement*

1. Introduction

Conventional fine aggregates are extracted from river beds and coarse aggregates are produced through blasting, mining of boulders. These activities cause a threat to the environment. On the other hand Construction and Demolition (C&D) waste are generated abundantly in the world. In India approximately 15 million tons of C&D waste is generated of which seven to eight million tonnes are concrete and brick waste and in Pune alone about 100-150 tonnes of construction debris are produced[1,2]. Thus Apart from reducing the mounting problems of waste management to an extent, other reasons which can support adoption of reuse/ recycling of C&D waste in new construction are reduced extraction of raw materials, reduced transportation cost, improved profits and reduced environmental impact.

C&D waste can be used in construction in the form of Recycled aggregates (RA) after processing of the waste. Recycled concrete aggregate (RCA) is generally produced by two-stage crushing of demolished concrete, and screening after the removal of contaminants such as reinforcement, paper, wood, plastics and gypsum. Concrete made with such recycled concrete aggregate is called Recycled aggregate concrete (RAC). RILEM Committee 121-DRG Specifications mentions about three groups of Recycled aggregates. [3].

- Group I- Aggregates mainly from masonry rubble
- Group II- Aggregate obtained from Concrete Rubble
- Group III- A mixture of natural aggregates (>80%) and rubble from the other two groups (with up to 10% of group I.

In the current project Group II aggregates are used and termed as Recycled aggregates (RA).

RAC display strength properties which are different from the conventional concrete. RAC generally display loss in strength characteristics due to the weak RA. Modulus of elasticity (E) of concrete is a key factor for estimating the deformation of structural elements, as well as a fundamental factor for determining modular ratio, n, which is used for the design of structural members subjected to flexure. The modulus of elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracking develops [4].The concrete produced using RA shows diverse properties, and thus understanding E value of RAC is important. The current study presents the experimental results of E value of RAC and compares with the E value of conventional concrete.

2. Literature Review

Researchers working in the field of recycled aggregates have made attempts to understand the feasibility of using RA in concrete. Recycled aggregate concrete (RAC) is concrete made with percentage replacement of RA with conventional coarse aggregates. At a particular water-cement ratio (w/c) ratio 100% RA in RAC shows weaker compressive strength than conventional concrete. Also lower flexural strength, split tensile strength, modulus of elasticity and bulk density can be seen with higher value of shrinkage than conventional concrete [5]. The quality of recycled aggregates ultimately determines a concrete specimens potential for strength, modulus of elasticity and resistance to shrinkage [6]. Strength and modulus of elasticity values tend to be smaller for RAC than for natural aggregate concrete. This is attributed to lower modulus of elasticity (E) of the recycled concrete aggregates themselves and a weaker interface between old mortar and new mortar [7]. A reduction of about 17.7% in the 28 day E value can be seen as comparison to 12.2% reduction in Compressive strength (CS) of concrete with 100% RA [8]. A 22% reduction was seen in E value for RAC as compared to 15% reduction in compressive strength of concrete with 100% RA and w/c as 0.50 [9]. In a study the E value decreases with increase in the replacement ratio of RA in concrete due to the weaker Inter transitional zone (ITZ) between RA and cement [10]. A higher gain of E value can be seen after 5 yrs of curing than that seen in conventional concrete [11]. Smaller size of RA in concrete increases the porosity of RAC and is also the main cause for reduction of E value [12]. Limited applications were seen for use of RAC in structural components. As an important property of concrete, understanding the E value of RAC is very important. IS 456-2000 gives the formula of $5000\sqrt{f_{ck}}$ to calculate E value for conventional concrete [4]. Several expressions were proposed to describe the relationship between E and cubic compressive strength f_{cu} of RAC [3].

$$E=370\text{X } f_{cu}+13100 \quad \text{……………….eq.1}$$

Another expression shown in eq. 2 was proposed to calculate E value of RAC with coarse RA [3].

$$E=909\text{X}f_{cu}+8738 \quad \text{…………..………..eq.2}$$

Literature thus signifies that there is a decrease in E value of RAC. The current research focuses on understanding the experimental E value of RAC with various replacement ratios of RA in concrete. An comparison is made with the calculated values of E using the formulas in Eq. 1 and Eq.2.

3. Materials used in the Study

The methodology of the study was divided into experimentation programme and analytical comparison with experimental E value. For the experimentation programme the materials used were:

a. Conventional materials- Cement, fine aggregates and Coarse aggregates (20mm and 10mm in size), which were purchased from the local vendors.

b. The main source of recycled concrete aggregate (RA) was demolished parking structure mainly the columns and foundation which was free from any reinforcement or other contaminants, and cubes casted and tested in the laboratory. The local crushing plants were not able to crush the concrete waste and thus the crushing and sieving had to be done manually. The concrete rubble remains were broken manually in the initial phase and then sieving was done using Indian standard sieves. The process of crushing and sieving generated, Fine recycled concrete aggregate, recycled concrete aggregate-10mm and recycled concrete aggregate-20mm.

4. Methodology

The methodology for the study was divided in 3 parts:

I. An experimentation program was undertaken in which concrete mixes were designed using IS:10262:2009 for M25, M30, M35 and M40 grade. Each grade of mix was designed with 0%, 30%, 70% and 100% replacement of RA. Table 1 below shows the mix designs with designated mix nos. 20mm and 10mm size of aggregates were used (conventional and RA) in the proportion of 60% and 40% respectively. Compressive strength of each mix was tested at 28 days according to IS 516-1959 [12].

Table 1*: Mix design of mixes*

Sr. No	Mix No	Mix proportion	Replacement % of RA
1	M1	1:2.54:3.94	0
2	M2	1:2.54:3.94	30
3	M3	1:2.54:3.94	70
4	M4	1:2.54:3.94	100
5	M5	1:2.47:3.82	0
6	M6	1:2.47:3.82	30
7	M7	1:2.47:3.82	70
8	M8	1:2.47:3.82	100
9	M9	1:2.25:3.67	0
10	M10	1:2.25:3.67	30
11	M11	1:2.25:3.67	70
12	M12	1:2.25:3.67	100
13	M13	1:2.18:3.56	0
14	M14	1:2.18:3.56	30
15	M15	1:2.18:3.56	70
16	M16	1:2.18:3.56	100

II. The next experimental program undertaken was to test the standard concrete cylinders of each concrete mix to calculate the E values of concrete according to IS 516-1959 [12].

III. Each experimental value of E was compared with E value calculated using eq.1 and eq.2.

5. Results and Discussion

E value of concrete is an important property of concrete which depends on E value of aggregates, stiffness of mortar, concrete porosity and aggregate-cement bonding [3]. The E value of concrete determines the resistance to deflection of the concrete structure. Stronger concrete with a high static modulus of elasticity value would deflect less in a concrete structure. Deflection further is a result of the flexural strains that develop under dead and live loads and this may occur cracking in the tensile zone. In the first part of the current study, each mix was designed and 28 day compressive strength of RAC was tested. Table 2 below shows the 28 day compressive strength of mixes M1 to M16.

***Table 2**: 28 Day compressive strength of mixes*

Sr. No	Mix No	28 day compressive strength in N/mm^2	Modulus of elasticity (E) N/mm^2
1	M1	41.280	48733.081
2	M2	29.580	35656.640
3	M3	48.200	27810.401
4	M4	29.500	26563.563
5	M5	48.285	36443.708
6	M6	50.635	33019.579
7	M7	41.310	32370.248
8	M8	33.375	34446.409
9	M9	54.605	43528.653
10	M10	53.425	37528.653
11	M11	44.840	27020.986
12	M12	48.865	28173.258
13	M13	53.275	37647.998
14	M14	53.360	34399.590
15	M15	39.065	30760.358
16	M16	31.150	26420.805

Table 2 shows that as the percentage replacement of RA in mix increases, the 28 day compressive strength of mix shows a decrease. The decrease in strength can be attributed to the higher porosity of RAC which is the result of higher porosity in RA due to adhered mortar. In RAC two interfaces exists, the interface between adhered mortar and the original aggregate, and the new interfacial zone between the new mortar and the RA. Due to presence of attached mortar in RA the interfacial zone becomes weak and thus is of the cause for failure of concrete. A decrease of 28.53% in mix M4 can be seen as compared to M1, decrease of 30.87% in mix M5 as compared to M8, decrease of 10.51% in Mix M12 as compared to M9 and 41.52% in M13 as compared to M16. A decrease in compressive strength of RAC also indicates a decrease in E value of RAC.

In the next part of the experimentation, concrete cylinders made using RA were tested for calculating modulus of elasticity (E). The setup for the same is as shown in the figure 1.

The E value tested for various mixes are shown in table 2. A reduction of Modulus of elasticity is seen in the mixes as the percentage replacement of increases in the mixes (Refer figure 2).

***Figure 1** Setup for modulus of elasticity of concrete*

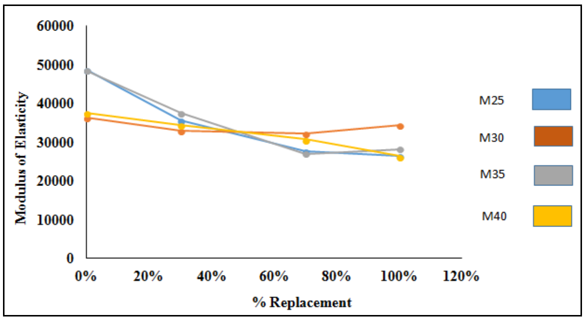

***Figure 2** E value for RAC with different % of RA*

The loss in E value of RAC is 41.92% with 100% RA in M4 as compared to M1, 5.6% reduction can be seen as compared to M8, 24.92% in M12 as compared to M9 and 29.82% in M16 as compared to M13.

Figure 2 shows that the E value decreases with increase in percentage of RA as compared to 0% replacement of RA, however beyond 70% of RA in concrete a slight increase in E value can be seen. The increase can be attributed towards alignment of RA in RAC which could sustain the load applied. Inclusion of RA in concrete reduces the stiffness in concrete which depend on mortar stiffness, concrete porosity and intertransitional zone. The increase in porosity of RA due to adhered mortar also reduces the E value of RAC. The lower modulus of elasticity of RA also contributes towards lower E value for concrete. A typical stress strain curves for (0% to 100%) all grade of RAC are shown in figures 3-7.

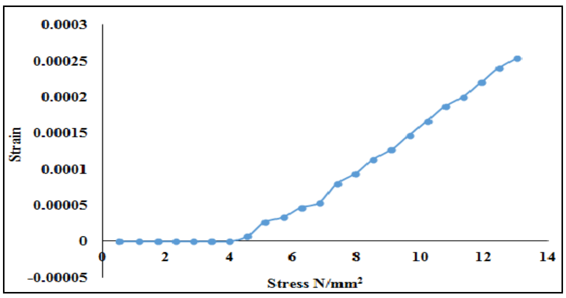

***Figure 3** Stress strain graph for M25 with 0% RA*

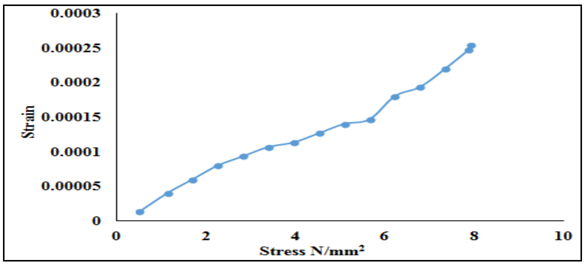

Figure 4 *Stress strain graph for M25 with 100% RA*

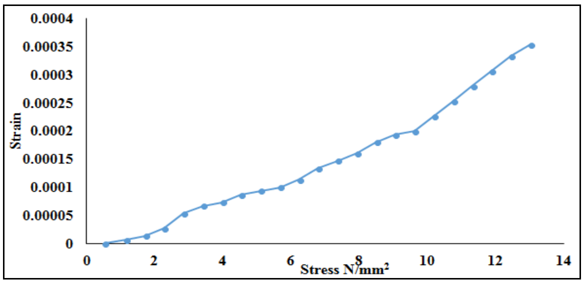

Figure 5 *Stress strain graph for M30 with 100% RA*

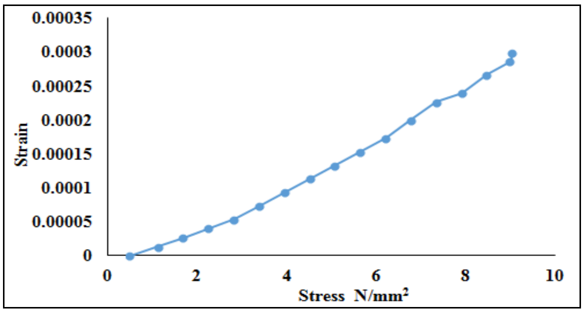

Figure 6 *Stress strain graph for M35 with 100% RA*

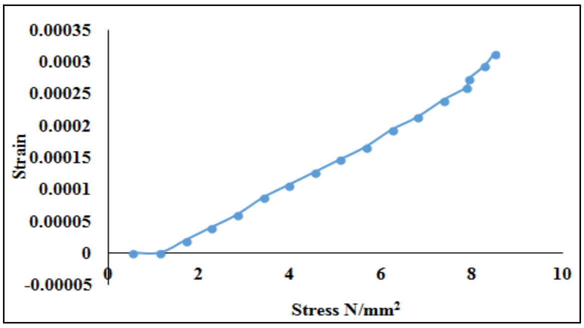

Figure 7 *Stress strain graph for M40 with 100% RA*

Increase in strain with stress in concrete with 100% RA can be seen in figures 3-7 as compared to the same in 0% RA. The stress sustained by 0% RA concrete is also high as compared to that of 100% RA concrete. With application of load on RAC, failure occurs within adhered mortar of aggregate thus making RA weaker. Cracks are initiated in the inter transational zone region which leads to failure of the specimen. Increase in deflection can also be seen in concrete with % increase of RA in concrete. Observing the shape of the stress–strain curve as seen in figures 4-7, it can be concluded that the concretes with 100% RA show similar stress–strain curves as that of 0% RA in the mix. The shape is linear and then it becomes parabolic. With the same unit stress, the recycled concretes develop strains which are higher than the strains achieved with the conventional concretes, and will be higher with the higher replacement percentage of RA. In part II of the research, eq.1 and eq.2 were used to calculate the E value of concrete with RA. Table 3 below shows the calculated values of E using eq.1, eq.2 and the experimented values of E

Table 3 *Experimental and theoretical values of E*

Mix No	Experimental E	E calculated using Eq. 1	E calculated using eq.2
M1	48733.081	28373.600	46261.520
M2	35656.640	24044.600	35626.220
M3	27810.401	30934.000	52551.800
M4	26563.563	24015.000	35553.500
M5	36443.708	30965.450	52629.070
M6	33019.579	31834.950	54765.220
M7	32370.248	28384.700	46288.790
M8	34446.409	25448.750	39075.880
M9	43528.653	33303.850	58373.950
M10	37528.653	32867.250	57301.330
M11	27020.986	29690.800	49497.560
M12	28173.258	31191.150	53183.560
M13	37647.998	32811.750	57164.980
M14	34399.590	32843.200	57242.240
M15	30760.358	27554.050	44248.090
M16	26420.805	24625.500	37053.350

Table 3 shows that the E values calculated using eq. 2 show underestimation as compared to experimental values and an overestimation can be seen in E values when calculated using eq. 2. A graph showing E values calculated using eq.1 and eq. 2 and experimental values is shown in figure 8 and 9 for M25 and M40 grade of concrete.

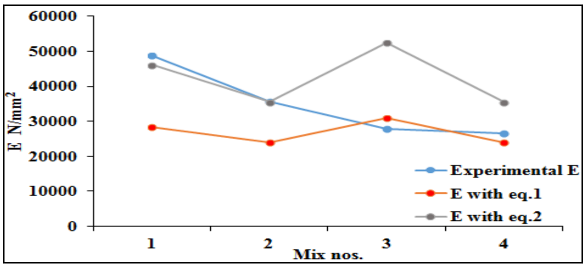

Figure 8 *Experimental and calculated values of E for M25 grade of concrete*

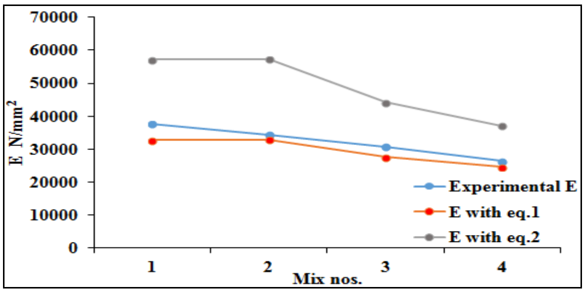

Figure 9 *Experimental and calculated values of E for M40 grade of concrete*

5. Conclusion

The work presented in this paper evaluates experimentally the effect of Recycled aggregate concrete (RAC) on the compressive strength of concrete and the Modulus of elasticity (E) of concrete with 0%, 30%,70% and 100% replacement of RA in RAC. A comparison of E values estimated using 2 published formulas (eq. 1 and eq. 2) with experimental E values is done. Following are the major conclusions of the study:

1) Compressive strength of RAC decreases with increase in percentage replacement of RA in concrete. However the characteristic strength can be achieved by RAC for respective grades of concrete.
2) Modulus of elasticity of RAC decreases with increase in RA percentage in concrete. The alignment of RA in concrete influences the E value. The stress strain diagrams show that the deflection in RAC starts at an early stage of load application.
3) E values calculated using published models show either under or over estimation and thus experimentation to calculate the E value is necessary.

References

[1] M. Jain, "Economic Aspects of Construction Waste Materials in terms of cost savings – A case of Indian construction Industry", *International Journal of Scientific and Research Publications*, 2. 10, pp. 1-7, 2010.

[2] NIIR Project Consultancy services. "Good prospects in waste tyre pyrolysis." *http://www.niir.org/profiles/profile/1727/good-prospects-in-waste-tyre-yrolysis.html.*

[3] B. Jorge de and S. Nabajyoti, *Recycled Aggregate in Concrete*, 1st edition, Springer London Heidelberg, New York, 2011.

[4] M.S. Shetty, *Concrete Technology*, 17th Edition, S. Chand and Company, New Delhi, 2005.

[5] K. Amnon, "Properties of concrete made with recycled aggregate from partially hydrated old concrete", *Cement and Concrete Research*, 33, pp. 703-711, 2003.

[6] K. McNeil, and T.H-K. Kang, "Recycled Concrete Aggregates: A Review", *International Journal of Concrete Structures and Materials*, 7.1, pp. 61–69, 2013.

[7] Y. Tsung, Y.C.Yuen, and L.H. Chao, "Properties of HPC with recycled aggregates", *Cement and Concrete research*, 36, pp. 943-950, 2006.

[8] M. Safidddin, U. J. Alengaram, M.A. Salam, M. Z. Jumaat, F. F. Jaafar and H. B. Saad "Properties of high workability concrete with recycled concrete aggregates", *Materials Research*, 14.2, pp. 248-255, 2011.

[9] H.J. Chen, T. Yen, and K.H. Chen, "Use of building rubbles as recycled aggregates", *Cement and Concrete Research*, 33.1, pp. 125-132, 2003.

[10] M.C. Rao, S.K. Bhattacharyya and S.V. Barai, "Influence of field recycled coarse aggregate on properties of concrete", *Materials and Structures*, 44.1, pp. 205-220, 2010.

[11] C.H. Poon, S.C.Kou and D. Chand, D, "Influence of fly ash as a cement addition on the hardened properties of recycled aggregate concrete", *Materials and structures*, 41.7, pp. 1191-1201, 2008.

[12] A.K. Padmini, K. Ramamurthy and M.S. Matthews, "Relative moisture movement through recycled aggregate concrete", *Cement and Concrete Research*, 54.5, pp. 377-384, 2003.

[13] Bureau of Indian Standards. (1959). Method of tests for strength of concrete. IS: 516:1959.