EFFECT OF RECYCLED COARSE AGGREGATES IN PROPERTIES OF CONCRETE

Dr. R. Kumutha and Prof. K. Vijai[1]

ABSTRACT

The properties of concrete containing coarse recycled aggregates were investigated. Laboratory trials were conducted to investigate the possibility of using recycled aggregates from the demolition wastes available locally as the replacement of natural coarse aggregates in concrete. A series of tests were carried out to determine the density, compressive strength, split tensile strength, flexural strength and modulus of elasticity of concrete with and without recycled aggregates. The water cement ratio was kept constant for all the mixes. The coarse aggregate in concrete was replaced with 0%, 20%, 40%, 60%, 80% and 100% recycled coarse aggregates. The test results indicated that the replacement of natural coarse aggregates by recycled aggregates up to 40% had little effect on the compressive strength, but higher levels of replacement reduced the compressive strength. A replacement level of 100% causes a reduction of 28% in compressive strength, 36% in split tensile strength and 50% in flexural strength. For strength characteristics, the results showed a gradual decrease in compressive strength, split tensile strength, flexural strength and modulus of elasticity as the percentage of recycled aggregate used in the specimens increased. 100% replacement of natural coarse aggregate by recycled aggregate resulted in 43% savings in the cost of coarse aggregates and 9% savings in the cost of concrete.

KEY WORDS

recycled aggregates, density, compressive strength, split tensile strength, flexural strength, modulus of elasticity

1. INTRODUCTION

In India, a huge quantity of construction and demolition wastes is produced every year. The disposal of wastes has become a severe social and environmental problem. The possibility of recycling these wastes in the construction industry is thus of increasing importance. In addition to the environmental benefits in reducing the demand of land for disposing the waste, the recycling of demolition wastes can also help to conserve natural materials and to reduce the cost of waste treatment prior to disposal.

The largest proportions of demolition waste are concrete rubbles. It has been shown that the crushed concrete rubble, after separated from other construction and demolition wastes and sieved, can be used as a substitute for natural coarse aggregates in concrete or as a sub-base or base layer in pavements (Hansen 1992, Mehta et al. 1993, Collins 1994, and Sherwood 1995). Successful application of recycled aggregate in construction projects has been reported in some European and American countries, as reviewed by Desmyster et al. (2000). The limited use of recycled aggregate in structural concrete is due to the inherent deficiency of this type of material. In comparison with natural normal weight aggregates, recycled aggregates are weaker, more porous and have higher values of water absorption. The results of research studies by Hendriks et al. (1998) show that, when recycled aggregates obtained from crushed concrete are used to replace up to 20% by weight of the coarse natural aggregate in concrete, little effect on the properties of concrete is noticed.

The concrete strength decreases when recycled concrete was used (Barra et al. 1996) and the strength reduction could be as low as 40% (Katz 2003 and Chen et al. 2003). However, no decrease in strength was reported for concrete containing up to 20% fine or 30% coarse recycled concrete aggregates, but beyond these levels, there was a systematic decrease in strength as the content of recycled aggregates increased (Dhir et al. 1999). The strength characteristics of concrete was not affected by the

[1]Assistant Professors, Department of Civil Engineering, Sona College of Technology, Salem-636 005, TamilNadu, India.
Email: kumuthar@yahoo.co.in; vijai_me@yahoo.co.in.

quality of recycled aggregate at high water/cement ratio, it was only affected when the water/cement ratio is low (Ryu 2002 and Padmini et al. 2002). The higher the water/cement ratio, the lesser is the reduction in compressive strength (Chen et al. 2003, Dhir et al. 1999 and Ryu 2002). Beyond 28 days of curing, the rate of strength development in concrete containing crushed concrete or crushed brick is higher than that of the control indicating further cementing action in the presence of fine recycled aggregate (Khatib 2005).

This paper presents a recent study carried out locally to study the feasibility of using recycled coarse aggregates in concrete. The concrete is expected to achieve a 28 day compressive strength of not less than 20 MPa. The effect of replacing the natural coarse aggregates with recycled aggregates on the properties of concrete is reported. Properties include density, compressive strength, split tensile strength, flexural strength and modulus of elasticity.

2. EXPERIMENTAL PROGRAMME

2.1. Materials

Portland pozzolana cement having a specific gravity of 3.3 was used in the casting of the specimens. Locally available river sand having a fineness modulus of 2.42, bulk density of 1701.84kg/m^3 and a specific gravity of 2.62 was used as fine aggregates. Natural coarse aggregates of 20 mm maximum size having a fineness modulus of 6.94, bulk density of 1698.5 kg/m^3 and specific gravity of 2.87 were used. Water conforming to the requirements of water for concreting and curing was used throughout. The recycled aggregates (RA) were crushed concrete that was obtained from demolished structures. They were further crushed in the laboratory to produce coarse recycled aggregates passing through a 20mm sieve and retaining on a 4.75mm sieve as shown in Figure 1. Coarse recycled aggregates have a bulk density of 1426.05 kg/m^3 and a specific gravity of 2.63.

FIGURE 1. Recycled Aggregate (RA).

2.2. Mix Proportions

Six different mixes were used to examine the influence of adding coarse recycled aggregates on the properties of concrete. Details of the mixes are given in Table 1. The control mix CC had a proportion of 1 (Cement): 1.66 (Fine aggregate): 3.46 (Coarse aggregate) for a targeted strength of 20MPa and did not contain recycled coarse aggregates. In mixes RA20, RA40, RA60, RA80 and RA100, the natural coarse aggregates were replaced with 20%, 40%, 60%, 80%, and 100% (by weight) recycled aggregates respectively. The water cement ratio for all the mixes was 0.5.

TABLE 1. Details of Mix proportions (kg/m^3).

S.No	Specimen Designation	Cement	Fine Aggregate	Natural Coarse Aggregates	Recycled Coarse Aggregates	Water
1	CC	372	617.65	1287.78	0	186
2	RA20	372	617.65	1030.22	257.56	186
3	RA40	372	617.65	772.67	515.55	186
4	RA60	372	617.65	515.11	772.67	186
5	RA80	372	617.65	257.56	1030.22	186
6	RA100	372	617.65	0	1287.78	186

2.3. Casting, Curing and Testing

For each mix, six cubes of 150mm in size, nine cylinders of 150mm diameter and 300mm height and one flexure beam of size 100mm × 100mm × 500mm were cast using steel moulds and compacted using a vibrating table. The cast specimens were kept in ambient temperature for 24 hours. After 24 hours they were demoulded and placed in water for curing. Cubes were used to determine the compressive strength of concrete at 7 days and 28 days. Cubes were tested to failure at a loading rate of 140/kg/sq.cm/minute as per IS 516. Before testing for compressive strength, the same cube specimens were utilized to evaluate the density of concrete at 7 days and 28 days. Six cylinders were used to determine the split tensile strength of concrete at 7 days and 28 days while the remaining three cylinders were used to determine the modulus of elasticity of concrete at 28 days. Split tensile test was done as per IS 5816 while the test for modulus of elasticity was carried out as per the procedure given in IS 516. Flexure beam was used to find out the flexural strength of concrete at 28 days by two point bending test with a supporting span of 405mm, using a Universal testing Machine of Capacity 1000kN. Testing was carried out as per IS 516 with a loading rate of 180kg/minute.

3. RESULTS AND DISCUSSION

3.1. Density of Concrete

Table 2 presents the density values in kg/m^3 for all the mixes at 7 days and 28 days curing time. Density values ranges from 2403 to 2570 kg/m^3. A decrease in density can be observed as the percentage of recycled aggregate content increases. There is a slight increase in density with increase in curing period as shown in Figure 2.

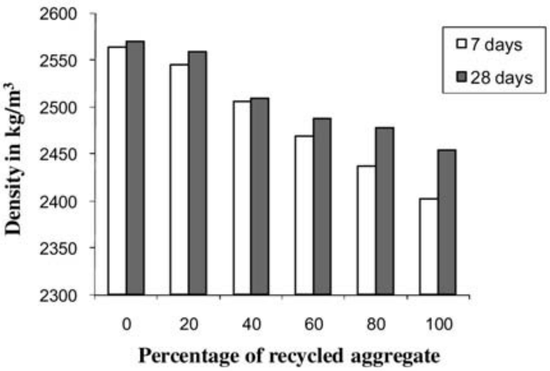
3.2. Compressive Strength

The cube compressive strength for all the mixes at 7 and 28 days of curing is presented in Table 3. The results show that the concrete specimens with more replacement of recycled aggregate have the lowest compressive strength when compared to the concrete specimens with less recycled aggregate for both 7 and 28 days of curing. Figure 3 shows a graphical representation of variation of compressive strength for different mixes. The compressive strength for 20%

TABLE 2. Density of Concrete.

S.No	Specimen Designation	Density (kg/m^3)			
		7 days	Average	28 days	Average
1	CC	2540 2537 2614	2564	2560 2577 2572	2570
2	RA20	2537 2590 2507	2545	2587 2530 2560	2559
3	RA40	2498 2525 2494	2506	2471 2480 2580	2510
4	RA60	2459 2488 2459	2469	2488 2488 2488	2488
5	RA80	2448 2421 2442	2437	2471 2453 2509	2478
6	RA100	2453 2405 2351	2403	2444 2459 2459	2454

FIGURE 2. Effect of RA Content on Density.



replacement of recycled aggregate had dropped around 3.6%. Even up to 60% replacement, the compressive strength gets reduced only to a maximum of 10% with respect to that of control concrete. There is a drop of 28% compressive strength for the 100% recycled aggregate. The compressive strength of the concrete specimens for 100% recycled aggregate is 20.43 MPa, which met the target strength of 20MPa. From the obtained results, it is clear that it is possible to use 100% recycled aggregate in applications like concrete blocks and concrete pavements as they are primarily compression members.

3.3. Split Tensile Strength

The split tensile test indicates a decreasing trend of split tensile strength at both 7 and 28 days of curing, when the percentage of recycled aggregate is increased. Table 4 presents the tensile strength values for all the mixes at 7 and 28 days of curing. Figure 4 shows a graphical representation of variation of tensile strength of concrete. The concrete specimen with 100% recycled aggregate had the lowest tensile strength, which was only 2.09MPa. It is around a 36% drop when compared to a control concrete specimen. There is a drop in tensile strength of 5%, 14%, 16% and 31% for the concrete specimen with 20%, 40%, 60% and 80% recycled aggregate respectively. Even up to 60% replacement, the split tensile strength gets reduced only to a maximum of 16% with respect to that of control concrete.

TABLE 3. Compressive Strength of Concrete.

S.No	Specimen Designation	Compressive strength (N/mm²)			
		7 days	Average	28 days	Average
1	CC	17.53 18.05 19.45	18.34	27.69 28.56 28.51	28.25
2	RA20	17.26 18.40 18.84	18.17	28.86 25.03 27.77	27.22
3	RA40	18.05 18.09 18.05	18.06	26.64 26.55 26.42	26.54
4	RA60	18.15 17.00 18.40	17.85	23.63 28.17 24.45	25.42
5	RA80	21.32 14.39 16.96	17.56	23.72 26.33 25.20	25.08
6	RA100	15.35 12.91 16.39	14.88	21.10 20.84 19.36	20.43

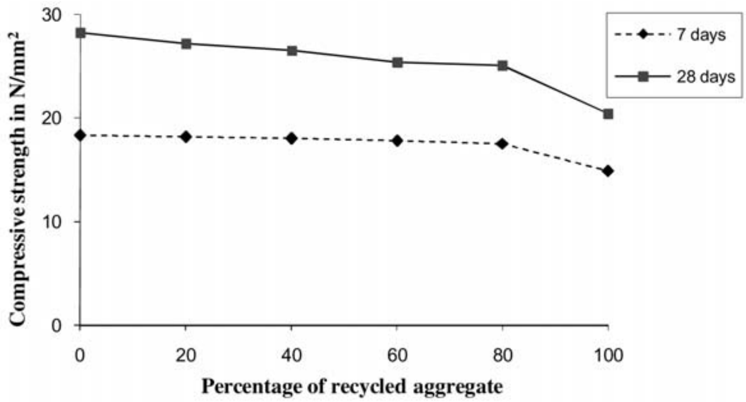


FIGURE 3. Effect of RA Content on Compressive Strength.

TABLE 4. Split Tensile Strength of Concrete.

S.No	Specimen Designation	Split Tensile strength (N/mm^2)			
		7 days	Average	28 days	Average
1	CC	2.23 1.71 1.85	1.93	3.19 3.25 3.32	3.25
2	RA20	2.11 1.75 1.86	1.91	3.25 2.97 3.03	3.08
3	RA40	1.66 1.82 1.55	1.68	2.39 3.11 2.94	2.81
4	RA60	1.27 1.30 1.21	1.26	2.58 3.08 2.53	2.73
5	RA80	1.36 1.14 1.22	1.24	2.29 2.10 2.29	2.23
6	RA100	1.26 1.42 0.95	1.21	2.37 1.74 2.17	2.09

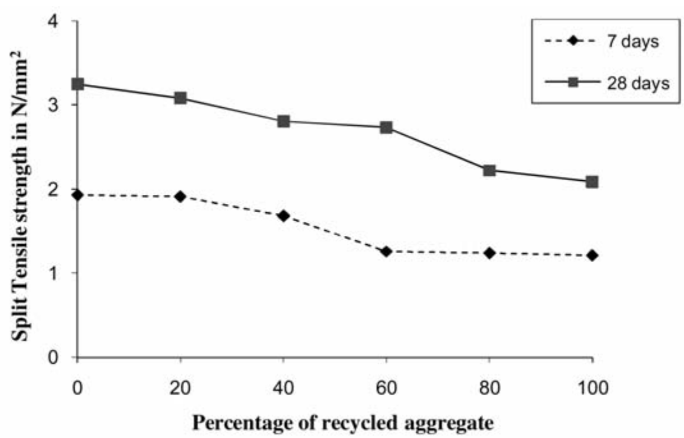


FIGURE 4. Effect of RA Content on Split Tensile Strength.

3.4. Flexural Strength

The flexural strength for all the mixes at 28 days of curing is presented in Table 5. The results show that the concrete specimens with more replacement of recycled aggregate have the lowest flexural strength when compared to the concrete specimens with less recycled aggregate. Figure 5 shows a graphical representation of variation of flexural strength for different mixes. There is a drop in flexural strength of 20%, 41%, 44%, 47% and 50% for the concrete specimen with 20%, 40%, 60%, 80% and 100% recycled aggregate respectively.

TABLE 5. Flexural Strength of Concrete.

S.No	Specimen Designation	Ultimate Load in kN	Flexural strength (N/mm^2)
1	CC	12.0	4.86
2	RA20	9.6	3.89
3	RA40	7.1	2.88
4	RA60	6.7	2.71
5	RA80	6.4	2.59
6	RA100	6.0	2.43

3.5. Modulus of Elasticity

By comparing all the mixes as given in Table 6, the specimen with natural coarse aggregates has the highest value of modulus of elasticity, while the specimens with 100% recycled aggregate has the lowest. Figure 6 shows a graphical representation of variation of Modulus of Elasticity for different mixes. From the experimental results, the modulus of elasticity of full natural aggregate specimens was 27665MPa, while the modulus of elasticity of full recycled aggregate specimens was 22681MPa. It indicates a drop of 4984MPa, which is a 18% difference between the 0% and 100% recycled aggregate batches. There is a drop in modulus of elasticity of 2%, 5%, 8% and 9% for the concrete specimen with 20%, 40%, 60% and 80% recycled aggregate respectively.

3.6. Cost Impacts

In Indian rupees, the cost of one cubic metre of concrete using natural coarse aggregates is 2915 out of which coarse aggregates alone costs 644. On the other hand, when the recycled aggregates are used, the cost of one cubic metre of concrete is reduced to 2640 Indian Rupees in which the cost of recycled aggregates is only 370 (including transportation and labour charges for crushing). This resulted in a 43% reduction in cost of coarse aggregates and a 9% reduction in cost of concrete.

4. CONCLUSIONS

Research on the usage of waste construction materials is very important as the quantity of waste materials is gradually increasing due to increased population and urban development. Furthermore, with the cheaper price of recycled aggregate compared to natural aggregate, builders can carry out the construction task with lesser material costs. From the present experimental investigation it was found that the recycled aggregates will influence much in hardened properties of concrete. As the

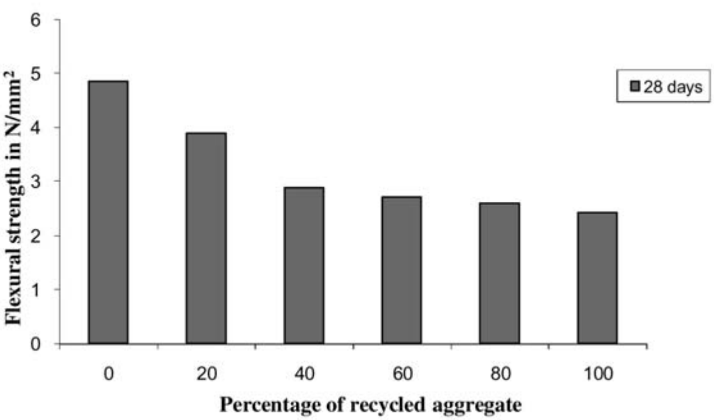


FIGURE 5. Effect of RA Content on Flexural Strength.

TABLE 6. Modulus of Elasticity of Concrete.

S.No	Specimen Designation	Modulus of Elasticity (N/mm^2)
1	CC	27665
2	RA20	27078
3	RA40	26222
4	RA60	25527
5	RA80	25250
6	RA100	22681

percentage of the recycled aggregate is increased, strength of the concrete gets decreased. From the obtained results, it is clear that it is possible to use 100% recycled aggregate in compression elements like concrete blocks and concrete pavements since the target compressive strength can be achieved. Utilization of recycled aggregates in concrete resulted in overall saving of 43% in the cost of coarse aggregates and 9% in the cost of concrete. More studies are required to understand the long term durability characteristics of concrete made using recycled aggregates. As there is considerable reduction in flexural strength with recycled coarse aggregates, further research is needed to explore the usage of recycled aggregates in combination with different fibrous materials with special reference to its applications on structural elements like concrete slabs, beams, columns and walls.

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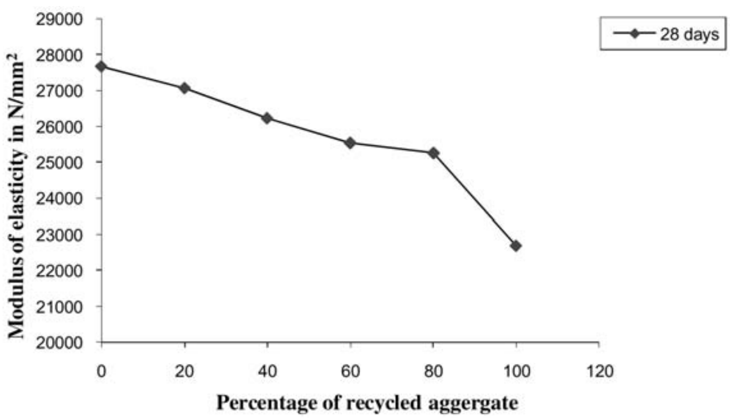

FIGURE 6. Effect of RA Content on Modulus of Elasticity.

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