STRENGTH OF CONCRETE INCORPORATING AGGREGATES RECYCLED FROM DEMOLITION WASTE

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ABSTRACT

The properties of concrete containing recycled aggregates were investigated. Recycled aggregates consists of either crushed concrete (CC) or crushed bricks (CB) from the demolition wastes available locally. Laboratory trials were conducted to investigate the possibility of using recycled aggregates as the replacement of natural coarse aggregates or fine 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. Natural coarse aggregates in concrete was replaced with 0%, 20%, 40%, 60%, 80% and 100% of crushed concrete aggregates. Natural fine aggregate in concrete was replaced with 0%, 20%, 40%, 60%, 80% and 100% of crushed brick aggregates. 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.

Keywords: concrete, strength, recycled aggregates, crushed concrete, crushed bricks, demolition wastes.

INTRODUCTION

In India, a huge quantity of construction and demolition wastes is produced every year. These waste materials need a large place to dump and hence the disposal of wastes has become a severe social and environmental problem. On the other hand scarcity of natural resources like river sand is another major problem which results in increasing the depth of river bed resulting in drafts and also changes in climatic conditions. Hence it becomes necessary to protect and preserve the natural resources. The possibility of recycling demolition 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 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). Higher the water/cement ratio, 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 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 crushed concrete and the natural fine aggregates with crushed brick aggregates on the properties of concrete is reported. Properties include density, compressive strength, split tensile strength, flexural strength and modulus of elasticity.

MATERIALS AND METHODS

Materials

Portland pozzolana cement having a specific gravity of 3.3 was made use of, 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.

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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 through out. The recycled aggregates were crushed concrete (CC) or crushed bricks (CB) that was obtained from demolished structures. CC and CB were further crushed in the laboratory to produce recycled coarse aggregates passing through 20mm sieve and retaining on 4.75mm sieve and recycled fine aggregates passing through 4.75mm sieve, respectively. CC has a bulk density of 1426.05 kg/m^3 and a specific gravity of 2.63. CB has a bulk density of 1427 kg/m^3 and a specific gravity of 2.40

Mix proportions

Eleven different mixes including one control mix were used to examine the influence of adding CC coarse aggregates and CB fine aggregates on the properties of concrete. Details of the mixes are given in Table-1. The control mix (CM) 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 aggregates. The water cement ratio for all the mixes was 0.5. In mixes CC20, CC 40, CC60, CC80 and CC100, the natural coarse aggregates were replaced with 20%, 40%, 60%, 80%, and 100% (by weight) crushed concrete aggregates respectively. In mixes CB20, CB40, CB60, CB80 and CB100, the natural fine aggregates were replaced with 20%, 40%, 60%, 80%, and 100% (by weight) crushed brick fine aggregates, respectively.

Table-1. Details of mix proportions.

S. No.	Specimen designation	Cement	Natural fine aggregate	Natural coarse aggregates	Recycled aggregates (CC / CB)	Water
1.	CM	372	617.65	1287.78	0	186
2.	CC20	372	617.65	1030.22	257.56	186
3.	CC 40	372	617.65	772.67	515.55	186
4.	CC 60	372	617.65	515.11	772.67	186
5.	CC80	372	617.65	257.56	1030.22	186
6.	CC100	372	617.65	0	1287.78	186
7.	CB20	372	494.12	1287.78	123.53	186
8.	CB40	372	370.59	1287.78	247.06	186
9.	CB60	372	247.06	1287.78	370.59	186
10.	CB80	372	123.53	1287.78	494.12	186
11.	CB100	372	0	1287.78	617.65	186

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 100mmx100mmx500mm were cast using steel moulds and compacted using 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. 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 made use of to determine the modulus of elasticity of concrete at 28 days. 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.

RESULTS AND DISCUSSIONS

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 2454 to 2610 kg/m^3 for concrete containing CC aggregates and 2396 to 2610 kg/m^3 for concrete containing CB aggregates. A decrease in density can be observed as the percentage of recycled aggregate content increases. There is a reduction in density with increase in recycled aggregates content as shown in Figure-1.

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Table-2. Density of concrete.

S. No.	Specimen designation	Density (kg/m^3)	
		7 days	28 days
1.	CM	2604	2610
2.	CC20	2545	2559
3.	CC40	2506	2510
4.	CC60	2469	2488
5.	CC80	2437	2478
6.	CC100	2403	2454
7.	CB 20	2588	2602
8.	CB 40	2579	2582
9.	CB 60	2540	2558
10.	CB 80	2481	2538
11.	CB 100	2396	2423

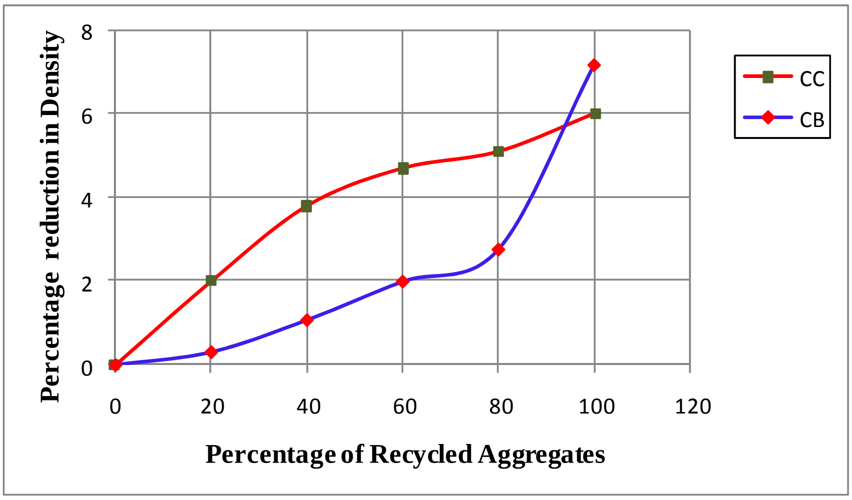

Figure-1. Effect of recycled aggregates content on density.

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. A graphical representation of reduction in compressive strength for different mixes is shown in Figure-2. The compressive strength for 20% replacement of CC aggregate had dropped around 3.6%. Even up to 60% replacement by CC coarse aggregate, 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% CC aggregate. The compressive strength of the concrete specimens for 100% CC aggregate is 20.43 MPa, which met the target strength of 20MPa. From the obtained results, it is clear that there is a possibility to use 100% CC coarse aggregate in applications like concrete blocks and pavements. In the case of replacement of natural fine aggregate by CB fine aggregate the compressive strength for 20% replacement had dropped around 6.5%. Even up to 60% replacement by CB fine aggregate, the compressive strength gets reduced only to a maximum of 17% with respect to that of control concrete. There is a drop of 61% compressive strength for the 100% CB fine aggregate. The compressive strength of the concrete specimens for 60% crushed brick fine aggregate is 23.54 MPa, which met the target strength of 20MPa. From the obtained results, it is clear that there is a possibility to use 60% CB fine aggregate in applications like concrete blocks and concrete pavements.

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Table-3. Compressive strength of concrete.

S. No.	Specimen designation	Compressive strength (N/mm^2)	
		7 days	28 days
1.	CM	21.48	28.25
2.	CC20	18.17	27.22
3.	CC40	18.06	26.54
4.	CC60	17.85	25.42
5.	CC80	17.56	25.08
6.	CC100	14.88	20.43
7.	CB 20	19.85	26.42
8.	CB 40	18.86	25.91
9.	CB 60	16.45	23.54
10.	CB 80	10.93	15.35
11.	CB 100	8.75	11.05

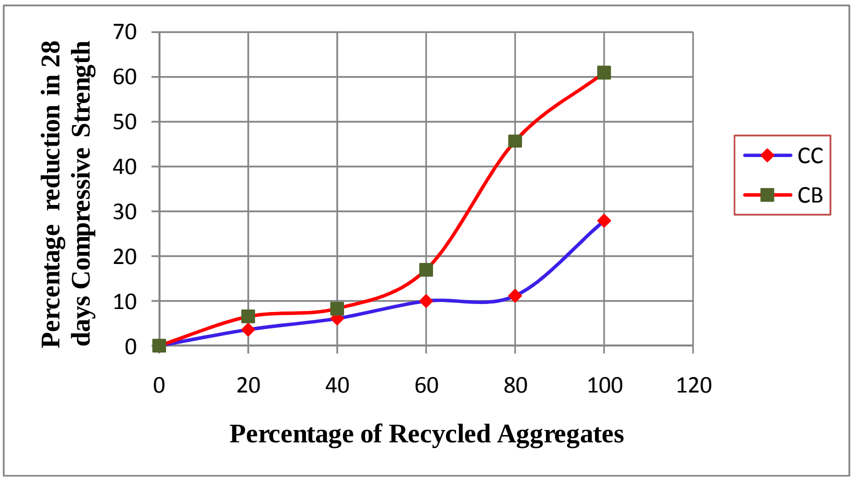

Figure-2. Effect of recycled aggregates content on compressive strength.

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. A graphical representation of reduction in tensile strength of concrete is shown in Figure-3. The concrete specimen with 100% CC coarse aggregate had the lowest tensile strength, which was only 2.09MPa. It is around 36% drop when compared to control concrete specimen. There is a drop in tensile strength of 5%, 14%, 16% and 31% for the concrete specimens with 20%, 40%, 60% and 80% CC coarse 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. In the case of concrete specimen with 100% CB fine aggregate tensile strength was only 2 MPa. It is around 38% drop when compared to control concrete specimen. There is a drop in tensile strength of 22%, 24%, 28% and 37% for the concrete specimens with 20%, 40%, 60% and 80% CB fine aggregate, respectively.

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Table-4. Split tensile strength of concrete.

S. No.	Specimen designation	Split tensile strength (N/mm^2)	
		7 days	28 days
1.	CM	1.93	3.25
2.	CC20	1.91	3.08
3.	CC40	1.68	2.81
4.	CC60	1.26	2.73
5.	CC80	1.24	2.23
6.	CC100	1.21	2.09
7.	CB 20	1.70	2.55
8.	CB 40	1.69	2.48
9.	CB60	1.47	2.34
10.	CB80	1.36	2.04
11.	CB100	1.24	2.00

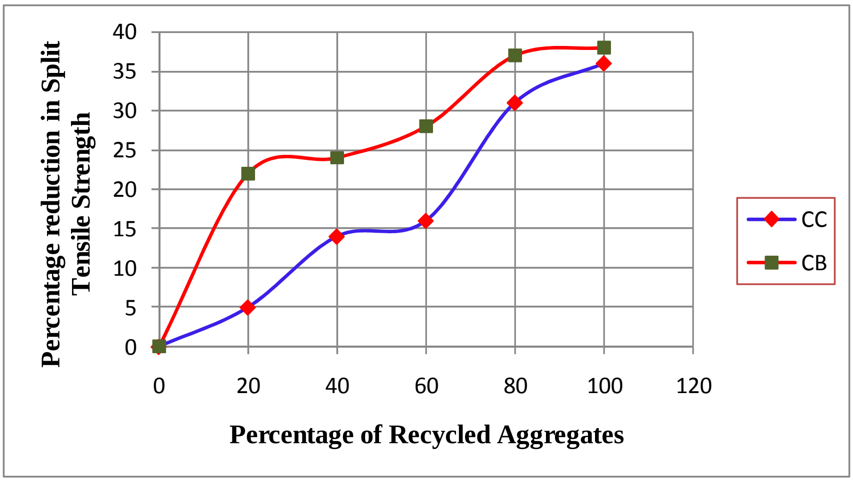

Figure-3. Effect of recycled aggregates content on split tensile strength.

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-4 shows a graphical representation of reduction in flexural strength for different mixes. There is a drop in flexural strength of 20%, 41%, 44%, 47% and 50% for the concrete specimens with 20%, 40%, 60%, 80% and 100% CC coarse aggregate respectively. In case of concrete with CB fine aggregates drop in flexural strength is 10%, 15%, 22%, 30% and 35% for the specimens with 20%, 40%, 60%, 80% and 100% CB fine aggregate, respectively.

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Table-5. Flexural strength of concrete.

S. No.	Specimen designation	Ultimate load (kN)	Flexural strength (N/mm^2)
1.	CM	12.0	4.86
2.	CC20	9.6	3.89
3.	CC40	7.1	2.88
4.	CC60	6.7	2.71
5.	CC80	6.4	2.59
6.	CC100	6.0	2.43
7.	CB20	10.2	4.37
8.	CB40	10.8	4.13
9.	CB60	9.4	3.81
10.	CB80	8.4	3.40
11.	CB100	7.8	3.16

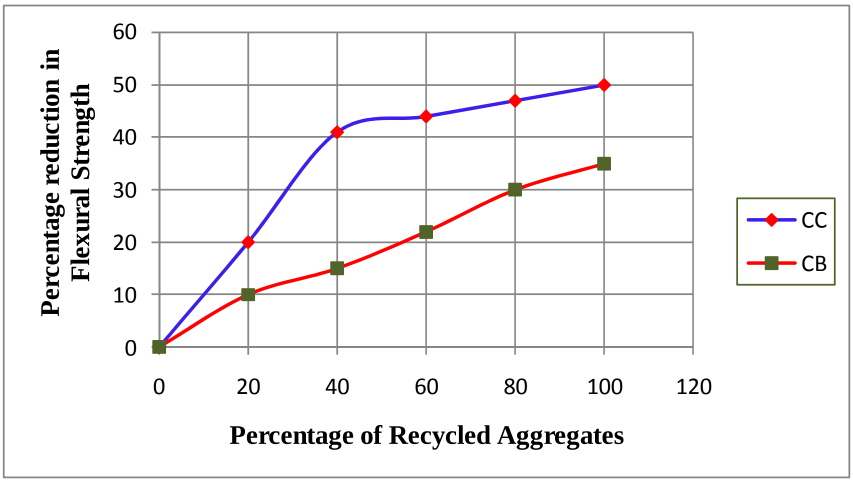

Figure-4. Effect of recycled aggregates content on flexural strength.

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-5 shows a graphical representation of reduction in modulus of elasticity for different mixes. From the experimental results, the modulus of elasticity of full natural coarse aggregate specimens was 27665MPa, while the modulus of elasticity of full CC coarse aggregate specimens was 22681MPa. It indicates a drop of 4984MPa, which is 18% difference between the 0% and 100% CC coarse aggregate batches. There is a drop in modulus of elasticity of 2%, 5%, 8% and 9% for the concrete specimens with 20%, 40%, 60% and 80% CC coarse aggregate respectively. The modulus of elasticity of full natural fine aggregate specimens was 27665MPa, while the modulus of elasticity of full CB fine aggregate specimens was 16441MPa. It indicates a drop of 11224MPa, which is 41% difference between the 0% and 100%, CB fine aggregate batches. There is a drop in modulus of elasticity of 6%, 7%, 9% and 35% for the concrete specimens with 20%, 40%, 60% and 80% crushed brick fine aggregate respectively. Even up to 60% replacement, modulus of elasticity gets reduced only to a maximum of 9% with respect to that of control concrete.

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Table-6. Modulus of elasticity of concrete.

S. No.	Specimen designation	Modulus of elasticity (N/mm^2)
1.	CM	27665
2.	CC20	27078
3.	CC40	26222
4.	CC60	25527
5.	CC80	25250
6.	CC100	22681
7.	CB20	25927
8.	CB40	25782
9.	CB60	25113
10.	CB80	18048
11.	CB100	16441

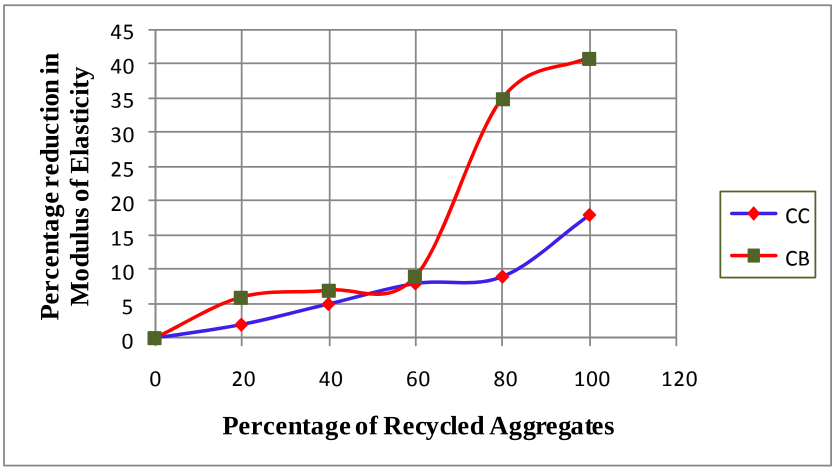

Figure-5. Effect of recycled aggregates content on modulus of elasticity.

CONCLUSIONS

Research on the usage of waste construction materials is very important as the quantity of waste materials is gradually increasing as a result of increase in population and increase in urban development. Furthermore, with the cheaper price of recycled aggregates compared to natural aggregates, the 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 percentage of crushed concrete coarse aggregates and crushed brick fine aggregates is increased, strength of the concrete gets decreased. From the obtained results, it is clear that there is a possibility to use 100% crushed concrete coarse aggregates and 60% crushed brick fine aggregate in compression elements like concrete blocks and concrete pavements since the target strength can be achieved. As there is considerable reduction in flexural strength with recycled aggregates, further research is needed to explore about 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. Apart from this more studies are required to understand the long term durability characteristics of concrete made using recycled aggregates

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