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Strength and Uses of Concrete Using Recycled Aggregates

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Abstract—The systematic disposal of construction and demolition debris is a major cause of the civic apathy in Major cities like Mumbai. The use of recycled aggregates obtained from the wastes of construction and demolition is showing prospective application in construction as an alternative to natural aggregates. In the present study, an attempt is made to obtain sand and coarse aggregates from the debris of demolished buildings. Three such sites were considered and concrete was prepared using the recycled aggregates. The values of compressive strength of this concrete at 07 days and 28 days are compared with the strength of concrete obtained by using natural (virgin) aggragates. Based on the results obtained on strength of the concrete, the applications of the concrete prepared using recycled aggregates are suggested.

Keywords-Construction; Recycle; Aggregates; Concrete; Strength

I. INTRODUCTION

This is a research project which aims to make aggregate from recycled aggregates and sand i.e. aggregates and sand obtained from debris at demolition sites. The systematic disposal of construction and demolition of debris is a major cause of the civic apathy in cities like Mumbai. The haphazard disposal of such debris gives rise to the following problems [1].

a) Choking of drains/gutters, leading to water logging during the monsoon.
b) Disposal in green tracts such as mangroves etc. creates environmental concerns.
c) Disposal in open spaces creates legal issues and also deprives the citizens their open spaces for recreation/sports.
d) Leaving such debris at the site (or around it in pockets) creates legal issues as well as spoils the aesthetics of the place.

Hence, it is observed that disposal of such debris is a major cause of concern. Open pits created specially over vast tracts of land to accommodate such debris are an extremely expensive solution in a city like Mumbai, owing to the high land cost. Thus, reusing such debris to make concrete which can then find various uses in construction is the only feasible solution in the near future [1]. As such, it has become a major field of research in India and also been put into practice at small-scale

Also, the rapid expansion of Mumbai (which is concentrated in the suburbs and the satellite city of Navi Mumbai) implies that this issue needs to be addressed much faster than how it is being done now. The space crunch is further limiting the space available to store / dump such derbies. As they have to transport the debris over large distances (sometimes tens of kilometers) for disposal, it increases the cost of work and prompts them to look for shortcuts / illegal means to dispose such debris which may create environmental/legal concerns in one or more ways stated above.

When structures made of concrete are demolished or renovated, **concrete recycling** is an increasingly common method of utilizing the rubble. Concrete was once routinely trucked to landfills for disposal, but recycling has a number of benefits that have made it a more attractive option in this age of greater environmental awareness, more environmental laws, and the desire to keep construction costs down.

Concrete aggregate collected from demolition sites is put through a crushing machine. Crushing facilities accept only uncontaminated concrete, which must be free of trash, wood, paper and other such materials. Metals such as rebar are accepted, since they can be removed with magnets and other sorting devices and melted down for recycling elsewhere. The remaining aggregate chunks are sorted by size. Larger chunks may go through the crusher again. After crushing has taken place, other particulates are filtered out through a variety of methods including hand-picking and water flotation.

Crushing at the actual construction site using portable crushers reduces construction costs and the pollution generated when compared with transporting material to and from a quarry. These systems normally consist of a rubble crusher, side discharge conveyor, screening plant, and a return conveyor from the screen to the crusher inlet for reprocessing oversize materials. Compact, self-contained mini-crushers are also available that can handle up to 150 tons per hour and fit into tighter areas. With the advent of crusher attachments - those connected to various construction equipment, such as excavators - the trend towards recycling on-site with smaller volumes of material is growing rapidly[2]. These attachments encompass volumes of 100 tons/hour and less.

There are a variety of benefits in recycling concrete rather than dumping it or burying it in a landfill [3]. These are-

a) Keeping concrete debris out of landfills saves landfill space.
b) Using recycled material as gravel reduces the need for gravel mining.
c) Using recycled concrete as the base material for roadways reduces the pollution involved in trucking material.

II. PROCEDURE

In this section, visit to the site, collection of the material, preparing the aggregates (coarse and fine) to be used for the preparation of concrete are described.

2.1. Site visit

In the present project, it is planned to segregate the usable materials (aggregates and sand) from the concrete chunks obtained at the demolition site. Three such sites were selected and the row samples were collected, where the existing buildings were demolished. The procedure for achieving this is outlined below.

The site visit must be well planned. Contractors are usually not forthcoming about strangers visiting their sites and hence must be taken into confidence that the visit is for academic purposes. Once demolition has been carried out at the site, the visit should not be delayed as the contractors may not wait for long before moving the material out of site. Also, transportation and storage for 250-300 kilograms of material must be properly arranged for.

2.2. Collection of material

This stage must be carried out very carefully as care exercised during this stage will prove helpful in the later stages. Greater emphasis should be laid on collecting chunks of concrete as breaking them down will yield both aggregates and sand later. Fine material must be avoided as it will eventually be sieved out during the sieving. Handcarts and *ghamelas* must be used for the collection of material.

2.3. Breaking of materials

The chunks of concrete can be broken into smaller components using UTMs (Universal Testing Machines) and hammers. The larger chunks which are heavy and cannot be handled by one person alone need to be crushed under a UTM, while the smaller chunks obtained thereof can then be broken further using hammers. Care must be taken to ensure that the thickness of the mortar film on aggregates is minimized during the breaking as this can affect tremendously the strength of the recycled concrete. The mortar that is obtained after being separated from the aggregates can then be broken further to obtain sand-sized particles, which can be used as recycled sand.

2.4. Sieving of materials

After the first round of breaking/crushing is over, the material is sieved through IS sieves of 20mm, 10mm and 4.75mm size. The materials are then be graded as follows-

Retained on 20 mm sieve -	coarse aggregate
Retained on 10 mm sieve -	coarse aggregate M2
Retained on 4.75 mm sieve -	coarse aggregate M1
Passing through 4.75 mm sieve -	sand

The material passing through 0.15mm sieve is discarded. The aggregate retained on 20 mm sieve is again crushed using hammers and step 2.4 is repeated till the mortar film on the aggregates has been sufficiently minimized and sufficient quantity of the material has been obtained.

2.5. Making of concrete

The material obtained after sieving is batched, mixed (in the calculated proportion) and finally compacted and placed in the cubic and cylindrical moulds as per the number of specimens required. The specimens are air-cured for 1 day and water cured for 6 or 27 days depending on the test [4].

III. TRIALS AND PROPORTIONS

The material collected from site 1 was used for deciding the mix proportion to be used as a standard for the rest of the project. In this regard, the proportion for M-35 grade of concrete was obtained from Lafarge RMC plant at Andheri, Mumbai. The proportion decided was -

1 : 0·24 : 2·32 : 1·24 : 1·35 (cement : fly ash : sand : M1 aggregates : M2 aggregates),
Water/cementitious material ratio= 0.45,
Plasticizer used- 1·2% of the cementitious material ("SUNANDA" brand).

Two mixes were prepared on the proportion stated above. While the first mix used 100% recycled sand, the other used 50% recycled and 50% fresh sand.

Mix 1 - 1 : 0·24 : 2·32 : 1·24 : 1·35
(cement : fly ash : recycled sand : M1 : M2)

Mix 2 - 1 : 0·24 : 1·16 : 1·16 : 1·24 : 1·35
(cement : fly ash : fresh sand : recycled sand : M1 : M2)

Only cube compression test was performed (at 7 days only) and the curing period is inclusive of one day of air curing. The results of cube compression strength of trial mix for Site-1 are given in Table 1.

Table 1. Cube compression strength (7 days) of trial mixes

	Compression Strength			
Trial Mix No.	Cube-1 (MPa)	Cube-2 (MPa)	Cube-3 (MPa)	Average strength (MPa)
1	16·0	14·5	13·0	14·5
2	18·0	14·9	16·8	16·6

As the results show, the mix with 50% recycled and 50% fresh sand gave higher strength. **Hence, this proportion was adopted for the rest of the sites to be surveyed.**

IV. TESTS AND OBSERVATIONS

The present project aims to determine the reuses of the concrete made from recycled aggregates and sand, based on its strength. Hence, the tests carried out on the specimens of these concrete are strength-based only and are described below.

4.1 Cube compression test

In any structural member (of concrete), most of the compressive load is taken by concrete, while the tensile load is taken by steel. It is mainly observed that the resistance of concrete to compressive stresses is very high, whereas that to tensile stresses is very low [5]. This test is conducted to determine the load which a cube of concrete of 150 mm size will take before crushing.

Moulds of internal dimensions 150 mm x 150 mm x 150 mm [6] are used for this test. Concrete is to be filled in the mould and has to be properly mixed which is carried out using a mixing machine. The mould is oiled on all sides properly before being filled. The mix is filled in three layers of equal thickness, and tamped with a steel rod of 16 mm dia., 25 times per layer.

The number of cubes required as per codal provision for each testing is three [6]. To compensate for variation, the average value of the strengths obtained is considered. The cubes are kept for one-day air curing and then six-days water curing. The cubes are tested in a compression testing machine (CTM).

The cube compression test results at 07 days and 28 days for Site-1 are given in Table 2. Similarly, the cube compression strength results at 07 days and 28 days are given in Table 3. The average strength of three cubes is also calculated and given in the tables. The schematic repression of average cube strength at 07 days is shown in Figure 1.

Table 2. Results of cube compression test for Site-1

Curing period (days)	Result for cube-1 (MPa)	Result for Cube-2 (MPa)	Result for cube-3 (MPa)	Average strength (MPa)
07	13.86	12.88	16.35	14.30
28	25.24	21.55	23.11	23.37

Table 3. Results of cube compression test for three Sites

Site no.	Curing period (days)	Result for cube 1 (MPa)	Result for cube 2 (MPa)	Result for cube 3 (MPa)	Average strength (MPa)
1	07	13.86	12.88	16.35	14.30
	28	25.24	21.55	23.11	23.37
2	07	16.53	16.00	19.02	17.18
	28	29.64	31.50	32.00	31.05
3	07	18.04	18.66	17.00	17.90
	28	23.51	31.55	30.57	28.54

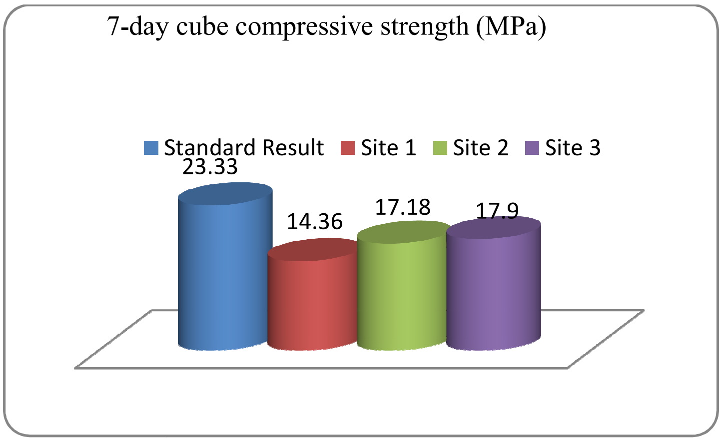

Figure 1. Comparison of results of 7-days cube compression test

4.2. Cylinder compression test

This test is similar to the cube compression test, the only difference being the shape of the specimen. Instead of the standard cubes mentioned earlier, the specimens in this case are cylinders of 300 mm height and 150 mm dia. They are tested in a CTM after 28 days curing (1-day air curing and 27-days water curing). The standard result in this case is expected to be around 0.8 times that in the cube compression test, for the same duration of curing and same mix proportion. The cylinder compression test results at the end of 28 days are given in Table 4. The comparison of 28 days average cylinder compression strengths is shown in Figure 2.

Table 4. Results of 28-days cylinder compression test

Site no.	Duration of curing (days)	Result for cylinder 1 (MPa)	Result for cylinder 2 (MPa)	Result for cylinder 3 (MPa)	Average result (MPa)
1	28	17.54	16.75	15.84	16.71
2	28	22.40	22.57	21.50	22.16
3	28	16.40	19.35	17.90	17.88

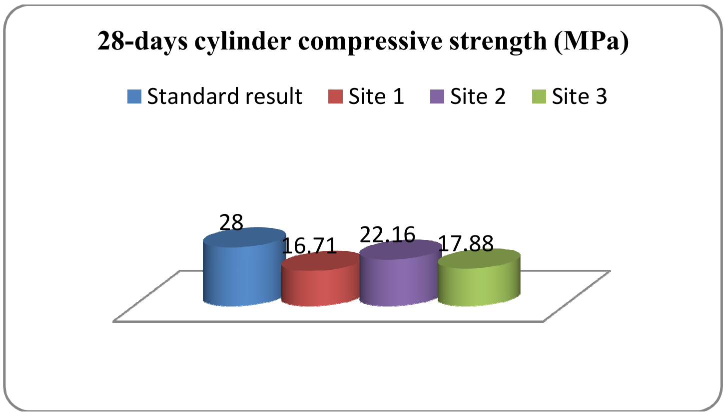

Figure 2. Comparison of cylinder compression test results

V. LOSS IN STRENGTH OF CONCRETE

As the concrete has been made from the recycled materials (aggregates and sand), it is expected to show loss in strength in all the tests. The loss in strength of concrete in the various tests conducted is shown below.

5.1 Cube compression test

The percentage loss in strength of the concrete made of recycled aggregates is calculated for all the three sites. The loss in strengths are calculated at the end of 07 days and 28 days curing. The percentage loss in strength of the concrete after seven days and twenty eight days curing are respectively given in Table 5 and Table 6

Table 5. Loss in strength in 7-days cube compression test

Site no.	Standard result (MPa)	Actual Result (MPa)	Percentage loss in strength
1.	23.33	14.36	39
2.	23.33	17.18	27
3.	23.33	17.92	24

Table 6. Loss in strength in 28-days cube compression test

Site no.	**Standard result (MPa)**	**Actual result (MPa)**	**Percentage loss in strength**
1.	35	23.37	34
2.	35	31.05	12
3.	35	28.54	19

It is observed that the loss in strength in all tests is the highest for concrete recycled from site 1, whereas it is the lowest for concrete recycled from site 2. This loss in strength can be attributed to the age of the structure on site 1 (60 years – Site -1 building being the oldest).

It is found that the loss in strength for the cubes at the end of seven (07) days is found in the range of 24 to 39 % and that at the end of twenty eight (28) days is found in the range of 12 to 34 %. It is found that the percentage loss in strength is reduced at the end of 28 days testing. Similarly, the loss in strength of cylinders at the end of 28 days is observed to be in the same range.

VI. CONCLUSIONS

Based on the tests performed on concrete made from recycled aggregates and sand and the strength test results that have been compiled in the preceding section, the reasons of loss in strength and possible re-use of concrete made using recycled aggregates, following can be concluded.

Reasons for loss in strength

The loss in strength is generally in the range of 20 % to 40 %. Additional research in this area is a continuing need. Other than the reason (regarding age) that has been mentioned in section 5, the loss in strength of concrete can be attributed to the following factors.

a. Due to insufficient breaking of the mortar film on the aggregate, it could not develop the required strength with the fresh paste of cement and sand.
b. The quality of aggregate used at the time of construction
c. Possible chemical attacks on aggregates, resulting in their loss in strength.

Reuse of concrete using recycled aggregate

The concrete obtained after recycling (from all sites) fails to reach the expected strength (35 MPa). The test results show a loss of strength of about 20 % – 40 %. Hence, the concrete can now find use in the following applications.

a. Larger pieces of crushed concrete, such as riprap, can be used for erosion control.
b. With proper quality control at the crushing facility, well graded and aesthetically pleasing materials can be provided as a substitute for landscaping stone.
c. Wire gabions (cages), can be filled with crushed concrete and stacked together to provide economical retaining walls. Stacked gabions are also used to build privacy screen walls (in lieu of fencing).
d. The recycled concrete can be used in PCC filling for foundations and walls as it is mostly a non-structural role.
e. The recycled concrete can be used to construct retaining walls, where high strength is neither needed nor expected.

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