Feasibility of Construction Demolition waste in Concrete as a Coarse Aggregate

Jeyanth Baskaran1*, Prabhakaran Veerasamy and Vijay Manibharathi2

1Assistant Professor, Civil Engineering, Bannari Amman Institute of Technology, Sathyamangalam, Tamilnadu, India
2Assistant Professor, Civil Engineering, Kongunadu College of Engineering Technology, Trichy, Tamilnadu, India

Corresponding author’s e-mail address *jeyanth@bitsathy.ac.in

Abstract. Concrete is an efficient and versatile material for construction. The rapid urbanization results in huge increase in new construction activities which ends with exploitation of natural resources, whereas demolition of structure ends up in the generation of Construction & Demolition wastes (CDW) in a huge amount that causes solid waste disposal issues. This research reveals utilization of CDW effectively in Concrete, to attain the property of natural aggregates as well as to reduce the solid waste disposal issues. Initially, the debris from the building waste is collected, crushed, and separated as C-Coarse and C-Sand. The M40 concrete specimens is done by using the cultivated aggregates in 25, 50, 75 and 100 % replacement with that of the natural aggregates. From the test result the 50% replacement of cultivated aggregate is optimum and M3 mix is a suitable mix. The effective depth of beam is also almost similar with M3 mix makes the use of CDW as a feasible one. Use of CDW will save about 12.075 m³ of fine aggregate and 21.625 m³ of coarse aggregate for every 100 m³ of concreting work makes it as a suitable alternative for the conventional aggregates. Thus, the 50% replacement of CDW for aggregates is feasible in terms of strength characteristics of concrete that makes it as best material for natural aggregates and may decrease its requirement. Further, the rise in the use of CDW will reduce the volume of solid waste generated and corresponding environmental pollution which leads to achieving the sustainability of natural resources.

1. Introduction
Concrete is a composite material with cement, fine and coarse aggregate which is well known for its strength and durability. The rapid growth in urbanization and industrialization increases its consumption to a huge quantity. Since natural aggregate occupies more than 70% of volume, any rise in use of concrete will intensifies its quantity consumed. All over the world every year about 40 billion tons of aggregate is produced in which India contributes 13 % [16]. Further, the increase in concrete consumption makes the concrete into a most non-sustainable material due to maximum consumption of natural resources [11]. The generation of source of natural aggregate requires thousands of years. The rate of generation of natural aggregate is very much smaller compared to its present rate consumption which leads to depletion of natural resource. Many research works are already in progress to identify and use a suitable alternative construction material which is economical as well as
feasible both in terms of strength and durability characteristics. As a result, researches have been increased to recover the recycled aggregates from Construction and demolition waste and various methods for the utilization of derived materials [17]. The demolition of a structure may be done either by conventional method or by selective demolition which results in high economic viability [14].

Rapid growth in urbanization leads construction of new structures by demolishing the old one which results in generation of huge quantity of Construction and Demolition Waste (CDW). Every year India generates about 15-23 million tons of CDW and handling this huge quantity creates lot of problems in the Solid Waste Management. Generally, CDW is disposed by means of land filling technique which occupies huge area and create lot of environmental related issues causing water, soil and land pollution which results in poor fertility of soil due to increase in alkalinity [2].

Since CDW is derived from the construction waste it possesses similar properties with that of the natural aggregates with high water absorption characteristics which can be reduced by adding fine granular particle [12]. The use of CDW as an alternative aggregate for concrete facilitates reduction in consumption of natural aggregates as well as landfill issues. Based on the composition CDW, it has been categorized as Recycled Concrete Aggregate (RCA), Recycled Ceramic Aggregate (CA) or Recycled Mixed Aggregate (RMA). Among those types of CDW the RCA has been utilized by the researchers a lot to know its viability in concrete [4,8]. The Construction and Demolition waste management systems is considerably progressed from 1980’s in the developing countries, particularly Australia, Western Europe and North America. About 98 % of recycled aggregates are used for construction applications in Japan make it as a leading country in recycling concrete waste. The largest producers of CDW aggregates in the present decade are Asia/Pacific, Russia and South American regions [16]. The introduction of Industrialized Building System (IBS), is an improved construction technique in developed countries, has facilitated the increase of recycling rate of Construction waste [10]. Over last decade a significant research on RCA and its application in concrete is carried out [8].

Low slump value of the concrete is caused by the use of RCA and that can be improved by using saturated surface dry coarse aggregate. Replacing 25% of Natural Coarse Aggregate with RCA has no significant adverse effect on its structural performance. When the replacement ratio increased to 50%, reduction in compressive strength ranges from 7% to 13% with a smaller decrease in splitting and elastic modulus [3]. The flexural strength of the concrete made with RCA is slightly lower comparing to the concrete with natural coarse aggregates [13]. The use of recycled coarse aggregate increases the abrasion resistance of concrete [9, 13]. Acceptability of recycled material for concrete is hampered due to a poor image of recycling activity, and lack of confidence on the products made with it. The recycling operation is directly affected by the cost of disposal of waste from construction industry to the aggregate preparation plant. Even though more number of new construction activities are taking place in developing countries, the low dumping costs and space availability for land filling act as a barrier to recycling activities. To divert more volume of waste for recycling, charges must be imposed on sanitary landfill [1]. The main aim of this research is to check the feasibility of use of CDW in concrete as aggregate which leads the concrete as sustainable material.

2. Methodology
The schematic representation of the methodology adopted for checking the feasibility of CDW in concrete is shown in Figure 1.
2.1. Preparation of Aggregates
The recycled aggregates are collected & segregated from the concrete waste which is known as Cultivated Aggregates. Both coarse and fine aggregates are separated by means of mechanical sieving.
and designated as Cultivated Course (C - Course) and Cultivated Sand (C - Sand). The properties of the C - Coarse and the C - Sand are obtained by means of testing of cultivated aggregates.

2.2. Mix Design and Mix Proportion
The conventional concrete (CC) mix is batched as per the recommendation of IS 10262:2009 which defines the characteristic compressive strength of 40 N/mm² with the water cement ratio of 0.40. Four CDWC mixes are prepared by altering the percentage of Cultivated Fine and Coarse aggregates in 25%, 50%, 75% and 100% and known as M2, M3, M4 and M5 respectively.

2.3. Check for Feasibility and Optimum percentage of Cultivated Aggregates
Samples are casted for testing to know the fresh & hardened properties of concrete. The fresh batched concrete is tested for workability by using the slump cone test. The Compressive Strength, Split Tensile Strength of the concrete are obtained for the age of 7, 14, 28 days of curing. The test results are compared with CC and the feasibility of the CDWC is checked.

2.4. Estimation of Eco-Environmental Benefits
The use of cultivated aggregates results in both economic as well as environmental benefits which can be determined by comparing the dimension of bending member designed based on the characteristic compressive strength of CC and CDWC mixes with the help of analytical method. The total percentage saving in volume of the conventional aggregate is also estimated. The schematic representation of the methodology adopted for checking the feasibility of CDW in concrete is shown in Figure 1.

3. Result and Discussion
3.1. Preparation of Cultivated Aggregates
The concrete waste from the construction and demolition is collected and crushed using Jaw crushers. After crushing the end product is sieved & segregated as coarse and fine aggregates. The aggregates passing through the 20 mm and retained in 12.5 mm sieve is used as Cultivated Coarse aggregates or C-Coarse (Figure 2.). The C-Coarse used are well graded and lay within the particle size ranges recommended as per IS 383-2016. The aggregates passing through the 4.75 mm sieve and retained on 75-micron sieve is collected and named as Cultivated Fine aggregate or C-Sand (Figure 3). Both the aggregates are further washed to remove the dust and finer particles from the surface of aggregate.

3.2. Testing of Aggregates
Both natural and cultivated aggregates must be tested to carry out mix design of CC mix and mix proportions of the CDWC mixes. The testing of aggregate starts with the mechanical sieve analysis to conform the corresponding zone of aggregate. Then the physical properties such as specific gravity, bulk density and water absorption are also measured. Mechanical sieving of C-Coarse is carried to measure the weight and percentage retained on each sieve. The cumulative of percentage retained and
passing is calculated and presented in Table 1 and Figure 4. Finally, the aggregate passing 20 mm and retained in 12 mm are used as C-Coarse.

### Table 1. Sieve Analysis for C – Coarse

| IS Sieve Designation | % Retained | Cumulative % Retained | Cumulative % Passing |
|----------------------|------------|-----------------------|----------------------|
| 40 mm                | 0          | 0                     | 0                    |
| 20 mm                | 9.36       | 9.36                  | 90.64                |
| 10 mm                | 60.14      | 69.50                 | 30.50                |
| 4.75 mm              | 25.14      | 94.64                 | 5.36                 |
| Pan                  | 5.36       | 100                   | 0                    |

![Figure 4. Sieve Analysis for C Coarse](image)

Both Natural Sand and C-Sand are sieved separately and percentage of passing through each sieve is measured and presented in Table 2. The result shows that the percentage of Natural Sand and C-Sand passing the sieves are conforming the Zone II. The percentage passing of Natural Sand and C-Sand is plotted and shown in Figure 5. Both fine aggregates follow almost similar pattern of passing through each sieve, which shows that there is no significant variation among them in terms of volume of aggregate of each size. Hence, the C-Sand can be used as an alternative for Natural Fine Aggregate.

### Table 2. Sieve Analysis for Sand & C - Sand

| IS Sieve Designation | Grading Zone II | % of Sand Passing | % of C - Sand Passing |
|----------------------|-----------------|-------------------|----------------------|
| 10 mm                | 100             | 100               | 100                  |
| 4.75 mm              | 90-100          | 100               | 99.8                 |
| 2.36 mm              | 75-100          | 98.4              | 95.0                 |
| 1.18 mm              | 55-90           | 72.8              | 55.71                |
| 600 µm               | 35-59           | 46.3              | 36.81                |
| 300 µm               | 8-30            | 21.8              | 13.78                |
| 150 µm               | 0-10            | 7.5               | 5.31                 |
Figure 5. Comparative Analysis of Sieve for Sand and C – Sand

The specific gravity of Natural and Cultivated aggregates is obtained separately. The specific gravity of Natural Coarse and Sand are 2.65 and 2.70 respectively. Similarly, the C-Coarse and C-Sand are having a specific gravity value of 2.48 and 2.57 respectively. The water absorption value of natural and cultivated coarse aggregates is 1.0 and 1.2 respectively. Similarly, Natural and C Sand are having a water absorption value of 2.2 and 2.5 respectively. The values of physical properties of Natural and Cultivated aggregates are presented in Table 3.

Table 3. Physical Properties of Natural and Cultivated Aggregates

| S. No. | Property                  | Natural Coarse | Natural Sand | C-Coarse | C-Sand |
|--------|---------------------------|----------------|--------------|----------|--------|
| 1      | Specific gravity          | 2.65           | 2.7          | 2.48     | 2.57   |
| 2      | Bulk Density (kg/m³)      | 1129           | 1570         | 1478     | 1757   |
| 3      | Water Absorption          | 1.00           | 2.20         | 1.20     | 2.50   |

3.3 Mix Design and Mix Proportion

The mix design for M40 grade concrete is done as per IS 10262 – 2019 for the CC mix. The proportions are given in weight batch mode. The natural aggregate, both coarse and fine, is replaced by cultivated aggregate in 25%, 50%, 75% and 100% of its volume. The quantity of aggregates to be replaced is calculated with the help of specific gravity and the volume to be replaced. Water cement ratio of 0.40 is kept as constant for all the mixes. The mix proportion used for CC and CDWC mixes is shown in Table 4.

Table 4. Mix proportion for CC and CDWC Mixes

| Nature of Mix | Type of Mix | Unit | Cement | Fine Aggregate | Coarse Aggregate |
|---------------|-------------|------|--------|----------------|-----------------|
|               |             |      |        | Natural        | Cultivated      |
|               |             |      |        | Natural        | Cultivated      |
| CC Mix        | M1          | K    | 450    | 652            | -               |
|               |             |      |        |                | 1               |
|               |             |      |        | 1.45           | -               |
|               |             |      |        |                | 2.54            |
|               |             |      |        |                | -               |
|               | M2          | K    | 450.00 | 489.04         | 155.16          |
|               |             |      |        |                | 859.59          |
|               |             |      |        |                | 268.15          |
|               |             |      |        | 1.00           | 1.09            |
|               |             |      |        |                | 0.34            |
|               |             |      |        |                | 1.91            |
|               |             |      |        |                | 0.60            |
|               | M3          | K    | 450.00 | 326.03         | 310.33          |
|               |             |      |        |                | 573.06          |
|               |             |      |        |                | 536.30          |
|               |             |      |        | 1.00           | 0.72            |
|               |             |      |        |                | 0.69            |
|               |             |      |        |                | 1.27            |
|               |             |      |        |                | 1.19            |
|               | M4          | K    | 450.00 | 163.01         | 465.49          |
|               |             |      |        |                | 286.53          |
|               |             |      |        |                | 804.45          |
|               |             |      |        | 1.00           | 0.36            |
|               |             |      |        |                | 1.03            |
|               |             |      |        |                | 0.64            |
|               |             |      |        |                | 1.79            |
|               | M5          | K    | 450.00 | 0.00           | 620.66          |
|               |             |      |        |                | 0.00            |
|               |             |      |        |                | 1072.60         |
|               |             |      |        | 1.00           | 0.00            |
|               |             |      |        |                | 1.38            |
|               |             |      |        |                | 0.00            |
|               |             |      |        |                | 2.38            |
3.4. Test for Workability of Concrete
The slump value of concrete defines its workability. For each concrete mix, without and with CDW replacement, the slump value is measured and presented in Figure 6. The difference in slump value between the CC and CDWC is lesser than 5 mm which shows that the partial replacement of Cultivated Aggregates does not affect the workability of the concrete. Particularly the 50% replacement results in slump value almost equal to that of CC mix. Therefore, the M3 mix can be taken as suitable mix in terms of workability.

![Figure 6. Slump Value for different mix](image)

3.5. Test on Hardened Concrete
3.5.1. Compressive Strength Test The progressive increase in compressive strength of hardened concrete is obtained by testing the concrete cubes after proper curing of 7, 14 and 28 days respectively. The CC mix shows an average compressive strength of 26.7 N/mm², 35.4 N/mm² and 43.4 N/mm² for 7, 14 and 28 days of curing respectively. The inclusion of cultivated aggregate modifies the cube compressive strength to the significant level. The CDWC mix shows a slight decrease in compressive strength due to the presence of cultivated aggregates. The use of cultivated aggregates causes this decrease in compressive strength. The comparison of average compressive strength yields a better result for M3 mix obtained by replacing 50% of natural aggregates by cultivated aggregates. The benefits gained by reducing the consumption of natural aggregates and use of construction demolition waste is much higher than that of the problems created due to a small decrease in compressive strength. Hence, the M3 mix can be effectively replaced instead of CC in all construction activity. The average cube compressive strength of each mix at the end of 28 days of curing is taken as a Characteristic Compressive Strength (fck) for the corresponding mix and shown in Table 5.

| S.No. | Type of Mix | Compressive Strength (N/mm²) |
|-------|-------------|-----------------------------|
| 1     | M1          | 43.44                       |
| 2     | M2          | 39.10                       |
| 3     | M3          | 41.80                       |
| 4     | M4          | 37.24                       |
| 5     | M5          | 34.71                       |

3.5.2. Split Tensile Strength Table 6 describes the split tensile strength is carried out for CC and CDWC mixes at the end of 28 days of curing. The result shows that the CC mixes possess maximum tensile strength. The increase in percentage of replacement of cultivated aggregates decreases the tensile strength than that of the CC mix. The maximum reduction in tensile strength is about 25% for
M4; whereas 25 % & 50 % replacements (M2 & M3) produce a minimum reduction of about 9%. Hence, M2 and M3 mixes can be considered for construction applications.

| S. No. | Type of Mix | Tensile Strength (N/mm²) |
|--------|-------------|--------------------------|
| 1      | M 1         | 4.12                     |
| 2      | M 2         | 3.79                     |
| 3      | M 3         | 3.73                     |
| 4      | M 4         | 3.61                     |
| 5      | M 5         | 3.13                     |

4. Optimum Percentage of Replacement of CDW

The CDWC mix is obtained by using various percentage of replacement of cultivated aggregates. Optimum percentage of replacement has been identified based on the test results of both fresh and hardened concrete. From the workability test, M3 mix yields similar result to that of CC mix. The compressive strength test result also reveals that the M3 mix achieves the characteristic compressive strength similar to M40 grade concrete, and hence, it can be replacing the CC mix. Whereas both M2 and M3 mixes shows significantly closer tensile strength characteristics, which makes both of them can be selected as suitable mixes. By considering all the test results it is concluded that the M3 mix is identified as a suitable mix, and hence, 50% of cultivated aggregate as optimum percentage of replacement.

5. Calculation of Effective Depth of the Beam

In a structural member effective depth of the beam controls moment resisting capacity, deflection characteristics and construction cost. The depth of the beam influences on consumption of material, self-weight of the beam and overall economy of the structure. The effective depth of the beam mainly depends upon the characteristic compressive strength of concrete. Any variation in the characteristic strength will alter the effective depth of beam. The effective depth of the beam is evaluated for the concrete with different mixes. The depth varies depending on the characteristic compressive strength of the concrete, which is obtained from the experimental results. The required effective depth (d) is obtained by using the following moment equation as per IS 456 – 2000. \[ M_u = 0.138 f_{ck} bd^2. \]

The width of beam (b) is assumed as 250 mm and span (l) as 4 m subjected to an UDL of 100 kN/m over the entire length. Assuming the beam as a simply supported, the maximum bending moment developed is 200 kN·m. The effective depth of beam for this bending moment is calculated for each type of mix and presented in Table 7.

| S. No. | Type of Mix | Characteristic Compressive Strength (N/mm²) | Effective Depth (mm) |
|--------|-------------|---------------------------------------------|----------------------|
| 1      | M 1         | 43.44                                       | 365                  |
| 2      | M 2         | 39.10                                       | 385                  |
| 3      | M 3         | 41.80                                       | 372                  |
| 4      | M 4         | 37.24                                       | 395                  |
| 5      | M 5         | 34.71                                       | 409                  |

The effective depth of beam for the given maximum bending moment is 365 mm for CC mix and 372 mm for the CDWC mix with optimum percentage of replacement. From this result, there is no significant increase in effective depth of the beam with 50% CDW aggregate replacement. Hence, the use of CDW in concrete is feasible in terms of effective depth of beam.

6. Volume of Aggregate Saved

The use of cultivated aggregate reduces the consumption of natural aggregates which results in solid waste management. Hence, the calculation of volume of aggregates saved must be calculated accurately. The volume of natural aggregates saved for every 100 m³ of concreting work by utilizing the optimum CDWC mix (M3) is calculated as 12.075 m³ (about 2 trucks) of fine aggregate and 21.625 m³ (about 3.60 trucks) of coarse aggregate.
7. Conclusion
This study reveals the feasibility of using cultivated aggregates for the sustainability of natural aggregates. The physical properties of cultivated aggregates were tested and compared with the conventional aggregates. Both Natural Sand and C-Sand are conforming to the Zone II and the sieve analysis results an almost similar pattern of % passing through each sieve. The workability of the CDWC was not affected by the partial replacement of the cultivated aggregate up to 50%. The strength of the CDWC was evaluated by comparing the conventional concrete mix with different mixes of CDWC. The test result clearly shows that M3 mix which was obtained by using 50% of cultivated aggregates yields a better compressive and tensile strength. Even there is slight reduction in the strength compared to Conventional Concrete it does not have an adverse effect. Thus from the study it is concluded that M3 is a suitable mix for CDWC.
Further the study has been extended to determine the effective depth of the beam by using the cultivated aggregates. And it confirms that there No significant increase in effective depth of the beam with M3 mix which results in less consumption of materials. About 12.075 m3 of fine aggregate and 21.625 m3 of coarse aggregate can saved for every 100 m3 of concreting work by utilizing CDWC. Hence, the CDW will be a suitable alternative for the conventional natural aggregates. The use of CDWC will reduce the volume of solid waste generated highly and corresponding environmental pollution. Further, the volume of saving of natural aggregate and use of CDW will reduce the cost of construction as well as solid waste management issues.

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