Development of sustainable construction material using construction and demolition waste

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Received 11 September 2013; accepted 19 March 2014

Construction and demolition of old structures generates large quantity of masonry waste in urban areas. This waste is generally diverted towards landfill. In the present study, a sustainable construction material (brick) using construction and demolition (C&D) waste is developed. Cement and fly ash are used as binder and C&D waste is used as fine and coarse aggregates.

Construction and demolition waste bricks (eco-bricks) of size 230 mm × 90 mm × 90 mm are developed for the six different compositions (BR90-1 to BR90-6). Physico-mechanical tests (block density, compressive strength and water absorption) are carried out as per Indian standards and embodied energy for the considered compositions is estimated. The test results are compared to commercially available fly ash bricks. The eco-bricks that achieved the least embodied energy is considered as the best combination of sustainable construction material. Amongst the various trials carried out the brick BR90-6 with the ratio of binder, fine aggregate and coarse aggregate as 1:2.75:2.25 exhibit compressive strength and water absorption within the limits of Indian standards with minimum self weight and embodied energy. The developed sustainable product can be practically implemented over any specific location by the manufacturer which serves the purpose of solid waste management.

Keyword: C&D waste, Eco-bricks, Block density, Compressive strength, Water absorption, Efflorescence, Embodied energy

Increasing population and rapid urbanization contribute towards solid waste generation. Waste in construction activity is generated either in new projects or in the process of demolition of old structures. Globally, the estimated quantity of construction wastes was 12 billion ton in the year 2002. Annually, Asia alone generates 4.4 billion tons of solid waste. Most of the developing Asian countries like India lack in specific regulations for disposal of construction and demolition (C&D) wastes1. India generates about 14.5 MT of solid waste annually from the construction industry that includes waste sand, gravel, bitumen, bricks, masonry and concrete2.

C&D waste may be generated due to various reasons, viz., demolition or dismantling structure, damaged or excess construction material, non use of material due to alteration in specification, changes in design during construction, designers’ inexperience in methods or sequence of construction, errors committed by tradespersons or labourers, improper planning of required quantity, inappropriate site storage, etc. The construction waste is generally diverted towards landfill which occupies useful land. Construction waste management has two major approaches; first minimization of generated quantity and the second is reusing the generated waste. In order to manage the waste properly, assessment of the factors affecting generation of waste at site proves to be helpful3. Recycling is another major productive area in which considerable quantity of waste can be utilized for manufacturing new building materials4.

Composition of C&D waste is complex due to the variety of building materials used in construction. The waste is generally categorized on the basis of its end use (recyclable & non recyclable) and output quantity (major & minor). Major components include concrete, bricks, mortar, steel (from RCC, door/window frames, roofing support, railings of staircase etc.), rubble, stone (marble, granite, sandstone) and timber/wood (especially in demolition of old buildings). Minor components are conduits (iron, plastic), pipes (GI, iron, plastic), electrical fixtures (copper/aluminium wiring, wooden baton, Bakelite/plastic switches, wire insulation), panels (wooden, laminated), and others (glazed tiles, glass panes). Amongst above materials steel, plastic, glass and aluminium are recyclable and...
have scrap value. Waste wood has multiple end usage. Concrete, broken tiles and waste pieces of masonry are generally dumped in landfill. Converting concrete and masonry waste into useful building material helps in conserving land which is otherwise required for dumping wastes.

In past, research studies were carried out to explore the recycling potential of C&D waste. Building enterprises or contractors were identified as a producer of construction waste and also as user of recycled waste. Involvement of all stakeholders, including government is necessary for proper resource utilization of construction waste\(^6\). A study conducted in Turkey explored the potential of waste minimization, necessity of regional and national programs and guidelines for the reduction, reuse, recycling and appropriate disposal of construction waste\(^6\). In the study of evaluation of existing waste recycling methods in Hong Kong, Tam and Tam\(^7\) suggested innovation, technology, balanced supply and proper legislation as measures of improvement in recycling potential of C&D waste. Studies were carried out to identify the most important sources of waste in construction and possible measures towards waste minimization. The relative significance of construction waste sources and a comprehensive waste assessment system was highlighted and it was found that design change in execution phase was the most significant cause of waste generation\(^8\). Study of residential construction projects for analyses of the generation of construction waste had revealed that design and operations activities have maximum impact on generation of waste\(^9\).

In the study carried out for production of sand from C&D waste vertical shaft crusher was found to be the most efficient amongst all other methods\(^10\). In a study in Brazil, concrete production waste (CPDW) and lime production (LPW) waste were used together to produce new construction material. Study revealed that amongst various proportions of two wastes, the proportion 60% CPDW and 40% LPW demonstrated good mechanical properties\(^11\). Recycled fresh concrete waste (FCW), when used as coarse aggregates in concrete reduces mechanical properties of concrete. A 30% replacement and low W/C ratio resulted in concrete with a target 28-day compressive strength of 40 MPa\(^12\). Concrete produced with recycled coarse aggregate showed a reduction in the compressive strength and elastic modulus with an increase in replacement ratio of natural aggregate. Whereas, drying shrinkage strain increased with recycled coarse aggregate content.\(^13\) In the study carried out to investigate potential of recycled brick as aggregate for producing concrete flags and paving blocks, change in properties of concrete with respect to the proportion of waste brick aggregate was studied. A 100% replacement of aggregate by waste brick aggregate showed a decrease in density, increase in water absorption and a reduction in compressive strength. However, 32% replacement of aggregate by waste brick showed satisfactory properties confirming to refereed standard\(^14\). In a similar study, recycled concrete aggregate and crushed clay brick were used as coarse and fine aggregates in the manufacturing of paving blocks. Two sizes of crushed clay brick pieces, 10 mm and less than 5 mm were used as aggregate in blocks. Paving blocks with 25% of less than 5 mm crushed clay brick aggregate showed less density, good compressive strength and improved tensile strength\(^15\). Replacement of coarse and fine natural aggregates by recycled aggregates at the levels of 25% and 50% had little effect on the compressive strength (a variation between 40 to 48 MPa) of the brick and block specimens, but higher levels of replacement reduced the compressive strength. However, with the increased percentage of recycled aggregate replacement the transverse strength of the specimens was increased\(^16\).

Currently in India, similar to most Asian countries there are no separate regulations for C&D waste management. There is a need to highlight the importance of recycling construction waste, create awareness about the problem of waste management and explore the availability of technologies for recycling.

In the present study construction waste bricks (eco-bricks) from C&D waste collected from a demolition site were developed. Waste concrete, broken bricks and tile pieces were used as coarse aggregate. Fine dust was used to replace part of fine aggregate. Different proportions were tried physical and mechanical tests were carried out according to Indian standards to compare the developed material with the locally available conventional fly ash brick. Embodied energy in the production of Eco-bricks was also calculated and compared to fly ash brick.

**Experimental Procedure**

**Cementitious material**

Portland Pozzolana cement and fly ash were used as the cementitious materials. Both materials are commercially available in India. Cement was
confirming to IS 1489 (Part 1). Fly ash is locally available as a waste product of thermal power generation plant located at Koradi, near Nagpur, India and was observed as siliceous material confirming to class F.

**Aggregate**

Waste material was collected from a local demolition site of a concrete structure located in Nagpur. Concrete and masonry waste was segregated from recyclable waste, i.e., steel, plastic etc. at the source itself. Bigger pieces of collected C&D waste were crushed manually into small particles. Crushed material was sieved with standard sieve of 4.75 mm size to separate fine and coarse material. Aggregate of size more than 4.75 mm and less than 10 mm was used as coarse aggregate and less than 4.75 mm was used as a replacement to fine aggregate in the mix. Properties of aggregates are given in Table 1. The waste was then transported to brick manufacturing plant site. Transportation distance from thermal power plant to manufacturing plant for fly ash and from the demolition site to manufacturing plant for C&D waste was less than 50 km.

**Admixture**

Even though coarse aggregates were used in saturated surface dry (SSD) state, water absorption due to C&D waste fines resulted in dry mix and in turn poor finishing of bricks. Thus, water reducing sulfonated naphthalene formaldehyde polymer based super plasticizer confirming to IS 9103 was used in appropriate proportion to improve cohesiveness of mix.

**Fabrication process**

The mix notations BR90-1 to BR90-6 indicate mixes for different proportions of ingredients for 230 mm × 90 mm × 90 mm brick (Table 2). The process adopted for manufacturing the eco-brick is given in Fig. 1. In the mixes BR90-1 to BR90-3

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**Table 1 – Physical properties of aggregates**

<table>
<thead>
<tr>
<th>Fine aggregates</th>
<th>Sand</th>
<th>C&amp;D waste fines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>2.67</td>
<td>2.6</td>
</tr>
<tr>
<td>Fineness modulus</td>
<td>2.9</td>
<td>3.2</td>
</tr>
<tr>
<td>Water absorption</td>
<td>1%</td>
<td>12%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C&amp;D waste coarse aggregates</th>
<th>Specific gravity</th>
<th>2.4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fineness modulus</td>
<td>6.67</td>
</tr>
<tr>
<td></td>
<td>Water absorption</td>
<td>13.31%</td>
</tr>
<tr>
<td></td>
<td>Elongation index</td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td>Flakiness index</td>
<td>11.2%</td>
</tr>
<tr>
<td></td>
<td>Adhered mortar</td>
<td>35%</td>
</tr>
</tbody>
</table>

**Table 2 – Compositions of raw materials for fly ash brick and eco-bricks (by wt)**

<table>
<thead>
<tr>
<th>Mix Notations</th>
<th>Cement</th>
<th>Fly ash</th>
<th>Sand and crusher dust</th>
<th>Gypsum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fly ash brick</td>
<td>10%</td>
<td>55%</td>
<td>30%</td>
<td>5%</td>
</tr>
<tr>
<td>Mix notations</td>
<td>Cement</td>
<td>Fly ash</td>
<td>Sand</td>
<td>C&amp;D waste fines</td>
</tr>
<tr>
<td>BR90-1</td>
<td>1</td>
<td>0.4</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>BR90-2</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>BR90-3</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>BR90-4</td>
<td>1</td>
<td>1</td>
<td>1.4</td>
<td>3.6</td>
</tr>
<tr>
<td>BR90-5</td>
<td>1</td>
<td>1</td>
<td>1.5</td>
<td>4</td>
</tr>
<tr>
<td>BR90-6</td>
<td>1</td>
<td>1</td>
<td>1.5</td>
<td>4</td>
</tr>
</tbody>
</table>

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Fig. 1 – Process of manufacturing of eco-bricks
proportion of cement to fly ash was gradually reduced, and natural sand and C&D waste were used as fine and coarse aggregate respectively. In BR90-4 to BR90-6 proportion of cement and fly ash was kept 1:1, sand and crushed C&D waste fines were used as fine aggregate whereas, C&D waste was used as coarse aggregate. Ingredients were weighed and mixed in different compositions. Mechanical mixing unit was used for mixing of constituents in different proportion. After mixing, the mix was loaded on the conveyor belt through which it was fed into automatic brick making machine mould and pressed. A pressure of 40 Ton was applied through the machine. The mould was then lifted, and bricks pallet containing bricks was removed. The bricks were then placed on wooden pallets and dried for 2 days (Fig. 2). Dried bricks were cured for 28 days. Bricks were checked for finishing of surfaces and cracks. Random check was done for size and dimensions. Brick was cut to check homogeneity of mix (Fig. 3) and was found homogeneous in grain structure. Dose of plasticizer was 1.5% by weight of cement and fly ash together. Ratio of water to binder (cement and fly ash) was kept as 0.6.

**Physical and mechanical Tests**
Various physical and mechanical tests, viz., block density, efflorescence, water absorption and compressive strength were conducted to check the suitability of developed material as recommended in prevalent Indian standard codes. Similar tests were carried out on commercially available fly ash bricks to compare the properties of developed bricks.

**Compressive strength**
A set of three specimens for each mix of eco-bricks was tested for compressive strength. Test was carried out as recommended by IS 3495(1). Dimensions were measured to the nearest 1 mm and recorded. Samples were immersed in water at room temperature for 24 h. On removal of the specimen after 24 h, surplus moisture was drained out. Frog and voids on bed faces were filled with cement-sand mortar (1:3). Samples were then stored under the damp jute bags for 24 h and then immersed in clean water for 3 days. Before testing, the samples were removed and excess moisture was wiped off. Samples were then placed in compression testing machine and load was applied axially at a uniform rate of 14 N/mm²/ min. Maximum load at failure was recorded.

**Water absorption**
Water absorption test was carried out as per IS 3495(2). Three specimens were tested for water absorption. The specimens were dried in a ventilated oven at a temperature of 105°C to attain constant mass. The samples were then cooled to room temperature and weighed \(w_1\). Completely dried specimens were immersed in clean water at a temperature of 27±2°C for 24 h. Specimens were removed and traces of water were wiped out with a damp cloth and weighed \(w_2\). Water absorption was calculated as the percentage reduction in weight \(w_2\) over weight \(w_1\).

**Efflorescence**
The efflorescence potential of eco-bricks was evaluated according to IS 3495(3). Three specimens of eco-bricks were partially submerged in distilled water for a period of 7 days. After that the products were dried in an oven and evaluated for the presence
of efflorescence. When viewed from a distance of 10 feet, if there is no difference in the appearance of the test samples and the standard sample the rating was “not effloresced”. If samples show a perceptible difference due to efflorescence, the rating is “effloresced”.

**Embodied energy**

Embodied energy of developed bricks was calculated (Eq.1) using cradle to gate approach.

$$E_{brk} = E_{pr} + E_{tr} + E_{mfg} \quad \ldots (1)$$

where $E_{brk}$ is embodied energy of brick, $E_{pr}$ is energy in production and processing of raw material, $E_{tr}$ is energy in transportation of raw material and $E_{mfg}$ is energy in mixing of raw material and pressing of brick.

Quantity of raw material was calculated for different proportions and values of embodied energy of basic building material such as cement and sand were taken from literature. Since construction waste was crushed and sieved manually thus no energy was considered in production and processing of fine and coarse waste aggregate. However, embodied energy in mechanical mixing of material and pressing of bricks was considered in the calculation. For the transportation energy component, distance of 100 km for cement and 50 km for fly ash, and C&D waste was taken.

**Results and Discussion**

Bed and edge finishing of bricks was inspected and found to be good with proper edge finishing. Hardness of brick was tested by dropping it from a height of 90 cm and brick was found to be hard and developed no cracks. A specimen of brick was cut to check its microstructure. It was found that the structure showed homogeneity and was free from cavities and lumps. Results of laboratory tests are shown in Table 3.

When compared to commercially available fly ash bricks, developed eco-bricks exhibited improvement in compressive strength, reduction in water absorption and reduction in embodied energy (Fig. 4). Average density of eco-brick was found to be 2150 kg/m$^3$. It was observed that density reduces with increase in aggregate to binder ratio and BR90-6 brick was the lightest amongst all proportions with an average density of 1866 kg/m$^3$. Compressive strength of developed eco-bricks was in the range of 32.12-6.74 N/mm$^2$ which is well in accordance with IS 3495(1). As compared to commercially available fly ash bricks, compressive strength of Eco-bricks varied from 897% (BR90-1) to 116% (BR90-6). With reduction in cement and fly ash ratio in binder, the compressive strength of eco-bricks was reduced. It was found that compressive strength for BR90-1 with 70% cement was around 20% more than BR90-2 (50% cement) and around 60% more as compared to BR90-3 (30% cement). Replacement of fine aggregates by stone dust and C&D waste as coarse aggregate resulted in to further reduction in compressive strength. This variation was attributed to addition of C&D waste fines and increase in aggregate to binder ratio. In the composition BR90-4, for a ratio of binder, fine aggregate and C&D waste aggregate as 1:2.5:2, the average compressive strength of eco-brick was found to be 9.56 N/mm$^2$. A 10% increase (BR90-5) in the proportion of waste fines resulted in to 15% reduction in compressive strength of eco-bricks. Similarly, around 12% increase (BR90-6) in waste coarse aggregates resulted into further 14% reduction in compressive strength. Increase in both fine and coarse waste aggregates resulted in significant reduction of compressive strength by 30%. However, compressive strength results for developed material were higher than the recommended minimum strength of brick as per Indian standard (3.5 MPa).

Average water absorption was less when compared to fly ash bricks and varied from 6-12% which is 56%
With increase in aggregate to binder ratio, water absorption in developed material was increased but was within the limit specified by Indian standard (20%). Eco-bricks showed no sign of efflorescence for any of the composition.

With respect to fly ash bricks, embodied energy for the mixes BR90-1 and BR90-2 was 28.88% and 6.9% more respectively. Increase in embodied energy was observed because of high proportion of cement which is an energy intensive material. With increase in binder to aggregate ratio, embodied energy was reduced for BR90-3 to BR90-6. Embodied energy of BR90-6 was least amongst all proportions (1.93 MJ/brick) and was estimated as 16.8% lesser than the fly ash brick. The criteria for the best composition brick was decided as Eco-brick with least embodied energy, lesser density and the compressive strength and water absorption in accordance with IS standard; which resulted as BR90-6 as the optimum composition.

Conclusions
The possibilities of using C&D waste as aggregate for development of eco-bricks were presented in this paper. From results of this study, the following conclusions can be drawn:
1. Reuse of C&D materials in development of new building material answers the issue of solid waste management as well as contributes to the increasing demand for the construction material in a sustainable way.

2. C&D (concrete and masonry) can be successfully used to produce bricks, which develop properties at par conventional building bricks.
3. With increase in the proportion of fly ash in binder, reduction in density and increase in water absorption for the eco-bricks was observed.
4. With an increase in aggregate to binder ratio, density of bricks was decreased and water absorption of brick was increased. For similar size of bricks average density of eco-brick was higher than fly ash brick. When compared to fly ash bricks, average water absorption was found to be lesser.
5. Compressive strength of bricks reduced with increased percentage of fine aggregates. A 10% increase in proportion of waste fines, resulted in 15% reduction in compressive strength. Similarly, around 12% increase in waste coarse aggregate resulted into further 14% reduction in compressive strength.
6. Increase in both fine and coarse waste aggregates resulted in reduction of compressive strength by 30%.
7. Use of recycled material in the brick resulted into reduction in embodied energy of brick. Embodied energy of eco-brick with 5:1 aggregate to binder ratio was found to be 16.8% lesser as compared to fly ash bricks.
8. Eco-brick composition BR90-6 had achieved least embodied energy (1.93 MJ/brick), which is 16.8% lesser as compared to fly ash brick. The
density (1866 kg/m³) was observed to be the least amongst all eco-brick compositions. The compressive strength (6.74 N/mm²) and water absorption (12.18%) were observed to be in accordance with IS standard. Thus, it is concluded that the BR90-6 is the optimum composition.

The recommended sustainable product can be practically used to meet the demand of new building material in non-load bearing masonry applications.

Acknowledgement
Authors are thankful to Department of Science and Technology, New Delhi, India for encouraging and extending the facilities for the ongoing research project.

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