Coconut Shell as a Partial Replacement to Coarse Aggregate in Concrete

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ABSTRACT

Background: In developing countries, to build environmentally sustainable structures, the possibility of using some agricultural wastes and industrial by-products from different industries as construction materials will be highly desirable and has several advantages. Objective: This paper presents a new method to produce structural lightweight aggregate concrete using an agricultural solid waste, namely coconut shell (CS), as a partial replacement to normal coarse aggregate. Results: This method is based on crushing large dried CS. The lightweight concrete mix design is usually established by trial mixes. In this short study, an attempt is made to study the effects of CS in concrete and its applicability for structural use. Reported in the paper are the compressive strength, modulus of elasticity, flexural behavior, workability and density of concrete containing 25%, 50%, 75% and 80% of CS replaced to normal coarse aggregate by volume. The stress–strain behavior and young’s modulus of the concrete mixes were investigated and compared to normal weight concrete (NWC). In general, the properties of concrete mixes compared well with that of normal weight concrete. Conclusion: The results obtained encourage the use of CS as aggregate for the production of structural lightweight concrete.

INTRODUCTION

In view of the rising environmental tribulations faced today and also considering the fast reduction of conventional aggregates, the use of aggregates from by-products and solid waste materials from different industries are highly desirable. One such alternative is coconut shell (CS), which is a form of agricultural solid waste. This aggregate is abundantly available in countries like Indonesia, Philippines and India. The main coconut producers in the global market for 2010 are shown in Table 1. Lightweight aggregate concrete (LWAC) is an essential and versatile material in modern construction. It has gained recognition due to its lower density and superior thermal insulation properties (Weigler and Sieghart, 1980). Lightweight concrete has strengths comparable to normal concrete; yet is typically 25–35% lighter (Lo and Cui 2002). A recent study showed that Lightweight concrete using CS as coarse aggregate is able to produce concretes with compressive strengths of more than 25 N/mm² (Gunasekaran et al., 2011).

CS is lighter than the conventional coarse aggregate, hence the resulting concrete will be light in weight. As per ASTM C 330 (1999) the compressive strength of lightweight concrete used for structural applications should not be less than 17 N/mm². An attempt has been made in the present work to develop Structural Lightweight Concrete in accordance with Indian Standards IS 10262 (2009) with coconut shell as a partial replacement to coarse aggregate.

Table 1: The Top 5 Coconut Producing Countries.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Country</th>
<th>Production 2010</th>
<th>% of World Total</th>
<th>% Change from 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Indonesia</td>
<td>20,655,400 t</td>
<td>33.07%</td>
<td>- 3.691%</td>
</tr>
<tr>
<td>2.</td>
<td>Philippines</td>
<td>15,540,000 t</td>
<td>24.88%</td>
<td>- 0.814%</td>
</tr>
<tr>
<td>3.</td>
<td>India</td>
<td>10,894,000 t</td>
<td>17.33%</td>
<td>+ 6.65%</td>
</tr>
<tr>
<td>4.</td>
<td>Brazil</td>
<td>2,705,860 t</td>
<td>4.33%</td>
<td>- 8.58%</td>
</tr>
<tr>
<td>5.</td>
<td>Sri Lanka</td>
<td>2,238,800 t</td>
<td>3.58%</td>
<td>+ 6.66%</td>
</tr>
</tbody>
</table>

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Experimental Work:

Material used:
The discarded coconut shells were collected from the local oil mills and they were well seasoned. The seasoned CS is crushed manually. Coconut shell passing through 16mm and retained on 4.75mm sieves were collected. Due to higher water absorption capacity CS aggregates were used in saturated surface dry (SSD) condition. Ordinary Portland Cement (OPC) 53 Grade conforming to Indian Standard IS 12269 (1987) was used as a binder. River sand conforming to grading zone III as per IS 383 (1970) was used throughout the investigation as the fine aggregate. The potable water from the College as per standards was used for mixing and curing. Compaction was achieved through the use of a table vibrator.

Mix proportions:
The LWC mix design is usually established by trial mixes (Shetty M S, 2005). Literature shows that the cement content for structural lightweight concrete lies between 285 and 510 kg/m$^3$ (Mannan and Ganapathy, 2004) and the replacement of coarse aggregate to coconut shell have to be done on volume basis (Mannan and Ganapathy, 2001). In the experimental study an attempt is made by designing a concrete mix for a 28 day characteristic compressive strength of 20 N/mm$^2$ as per IS 10262 (2009) and replacing the coarse aggregate with 25, 50, 75 & 80% of coconut shell on volume basis. The details of the mix proportions are given in Table 2. The mix proportion was designated as M0 for control concrete (no replacement), M1, M2, M3 and M4 for 25, 50, 75 and 80% replacements respectively. Based on the mix design, the amount of cement used was 383 kg/m$^3$ for all the trial mixes. The free water cement ratio for all the mixes was 0.50.

<table>
<thead>
<tr>
<th>Mix no.</th>
<th>Mix proportion (C:FA:CA:CS)</th>
<th>Cement Content (kg/m$^3$)</th>
<th>W/C ratio</th>
<th>Slump (mm)</th>
<th>28-day air dry density (kg/m$^3$)</th>
<th>Compressive Strength (N/mm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M0</td>
<td>1:1:4:3.21:0</td>
<td>383</td>
<td>0.5</td>
<td>75</td>
<td>2482</td>
<td>23.33</td>
</tr>
<tr>
<td>M1</td>
<td>1:1:4:2.19:0.31</td>
<td>383</td>
<td>0.5</td>
<td>61</td>
<td>2218</td>
<td>17.30</td>
</tr>
<tr>
<td>M2</td>
<td>1:1:4:1.60:0.67</td>
<td>383</td>
<td>0.5</td>
<td>55</td>
<td>1988</td>
<td>15.80</td>
</tr>
<tr>
<td>M3</td>
<td>1:1:4:0.75:0.93</td>
<td>383</td>
<td>0.5</td>
<td>52</td>
<td>1674</td>
<td>12.86</td>
</tr>
<tr>
<td>M4</td>
<td>1:1:4:0:1.00</td>
<td>383</td>
<td>0.5</td>
<td>50</td>
<td>1563</td>
<td>10.12</td>
</tr>
<tr>
<td></td>
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</tbody>
</table>

Test Methods:
Due to the high water absorption of coconut shell, they were pre-soaked for 24 hours in potable water prior to mixing and were in saturated surface dry (SSD) condition. The concrete was hand mixed on a water tight, non absorbent platform as per IS 516 (1959). Slump cone test was performed to know the workability of the mix. The obtained slump values were between 50 and 75mm showed that this concrete has a medium degree of workability and is within the range of workable concrete (IS 456, 2000). The specimens were cast in 150mm cubes for compressive strength test, 100 x 100 x 500mm beams for flexural strength test and 100mm diameter x 200mm long cylinders for modulus of elasticity test. Compaction was done using a vibrating table to ensure adequate compaction. The specimens were demoulded after 24 ± 3hours in the laboratory and were cured in potable water till the tests were performed. Figure 1 shows the cube casting and curing. The compressive strength, flexural strength and modulus of elasticity were determined in accordance to IS 516 (1959). The compressive strength of the specimen was determined on the 7th, 28th, 90th and 365th day in accordance to IS 516 (1959) to study the development of strength at later ages. The splitting tensile strength was determined as per IS 5816 (1999). The oven dry density was calculated as per ASTM C 567.

Fig. 1: Casting and curing of cubes and cylinders.
Discussions on test results:

Density:
The 28-day air dry density of the mixes M1 to M4 concrete specimens varied from 2318 to 1563 kg/m³. M2, M3 and M4 concrete mixes are within the range of structural lightweight concrete. It was observed that the minimum unit weight of concrete specimen was 1563 kg/m³ for M4 mix. The savings in weight is about 37% for M4 mix compared to control concrete of 2482 kg/m³. The hardened densities of the mixes are shown in Table 2.

Compressive Strength:
The compressive strength developed for 28-day samples is in the range of 25.61 to 16.52 N/mm² depending upon the mix proportion. The results are quite above the required strength of 17 N/mm² for structural lightweight concrete (ASTM C330, 1999) except for mix M4. Lower the density of concrete lower is the strength (Mannan and Ganapathy, 2002), concrete partially replacing coarse aggregate with CS is lighter than control concrete. The development of compressive strength is approximately 26% to 52% compared to control concrete for the mixes M1 to M4. The results obtained are also similar to that reported for oil palm shell concrete (Mannan and Ganapathy, 2002).

Flexural Strength:
The flexural strength is very much dependent on the physical compressive strength of coarse aggregate (Mannan and Ganapathy, 2002). Table 3 presents the flexural strength of all the mixes. As per IS 456 (2000) the flexural strength is equal to 0.7fck where fck is the characteristic compressive strength of conventional concrete. The flexural strength of control concrete is identified as 10% of the compressive strength and for the other mixes it varies from 8% to 6.5%. The results show that the behavior of mixes M1 to M4 is similar to control concrete.

Table 3: Flexural Strength of the mix at 28-days.

<table>
<thead>
<tr>
<th>Mix no.</th>
<th>Compressive Strength 28-days (N/mm²)</th>
<th>Flexural Strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M0</td>
<td>34.66</td>
<td>3.65</td>
</tr>
<tr>
<td>M1</td>
<td>25.61</td>
<td>3.23</td>
</tr>
<tr>
<td>M2</td>
<td>19.74</td>
<td>2.87</td>
</tr>
<tr>
<td>M3</td>
<td>17.78</td>
<td>2.71</td>
</tr>
<tr>
<td>M4</td>
<td>16.52</td>
<td>2.59</td>
</tr>
</tbody>
</table>

Modulus of Elasticity (E):
The modulus of elasticity of the mixes is observed to be approximately half to one-sixth of control concrete. The E value is mainly influenced by the type of cement, aggregate, water cement ratio of the mix and curing age (Alexander and Milne, 1995). Figure 2 shows the testing of cylinder specimen for Youngs modulus using a extensometer. The E value of the control concrete is approximately 2.5x10⁶ N/mm². Similar result on modulus of elasticity for control concrete was reported by Alexander and Milne (1995). Figure 3 shows the comparison of modulus of elasticity values of the mixes with those predicted by various equations given by BS 8110 (1985) (eqn. 1), Alengaram et al. (2011) (eqn. 2) and pauw (1960) (eqn. 3). The equations are given below

\[ E = 0.0017 w^{0.33} F_{cu}^{0.33} \]  
\[ E = 5 F_{cu}^{0.33} (w/2400)^2 \]  
\[ E = 0.04 w^{1.5} F_{cu}^{0.5} \]  

where, E is the modulus of elasticity, w is the density of concrete (kg/m3) and Fcu is the cube compressive strength (N/mm²). We can see that among the three equations (eqn. 1) and (eqn. 3) overestimates the value of E, similar result was reported by Payam et al. (2012).

Long-term compressive strength:
Figure 4 presents the relationship between compressive strength and curing time. A very slow rate of increase in compressive strength is observed between 90 and 365 days. For control concrete the increase in strength between 28 and 365-day is 35% and between 90 and 365-day is 16%, whereas for the other mixes it is 30% and 11% respectively. At the early ages the compression failure is due to the breakdown of bond between CS and cement paste. In the later ages 90 and 365 days the failure was due to CS aggregate itself, this shows the improvement of bond over time. The CS mixed concrete continues to develop its compressive strength with age but always remained below control concrete.

Conclusion:
In general the utilization of coconut shell waste provides a good alternate to the conventional crushed stone. The use of coconut shell in concrete can help in overcoming the dependence on costly resources, especially in...
areas where coconut shell are in abundant supply. Considering the results of the short study mentioned in this paper, the following observations and conclusions can be made.

Fig. 2: Youngs Modulus test being performed with an extensometer.

Fig. 3: Experimental and theoretical modulus of elasticity of mixtures.

Fig. 4: Development of compressive strength of the concrete mixes.

1. The specific gravity of coconut shell is about 1.12. This shows CS are approximately 60% lighter than conventional coarse aggregates. Coconut shell can be used as a partial replacement for the conventional coarse aggregate in the production of concrete.
2. The 28-day compressive strengths of concrete for the mixes M2 and M3 are between 19.74 and 17.78 N/mm² which satisfies the requirement for structural lightweight concrete (ASTM C330, 1999).
3. The 28-day compressive strength of the mix M4 is 16.52N/mm² which is less that the requirement of 17 N/mm² and hence cannot be used for structural purpose.
4. The flexural strength varies by 10% of its compressive strength for control concrete and by 8 to 6.5% for the mixes M1 to M4 respectively.
5. The 28-day modulus of elasticity of the mixes M2, M3 and M4 are 8490 to 6844 N/mm² respectively which is approximately 0.35 to 0.28% of the E value of control concrete in this study.
6. The predictive value of E using the equations given by Alengaram et al. (2011) was similar with the test results of the mixes M2, M3 and M4.
7. The obtained slump values were between 50 and 75mm without adding superplaticiser, this study showed that this concrete has a medium degree of workability and is within the range of workable concrete [IS 456, 2000].

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