Impact of Partial Replacement of Cement by Coconut Shell Ash and Coarse Aggregate by Coconut Shell on Mechanical Properties of Concrete

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Abstract. India is the third largest coconut cultivating country in the world. South India states are the predominant coconut cultivating area in India. Coconut shell (CS) and coconut shell ash (CSA) are unavoidable by-products from agricultural industry. As a part of solid waste management, the investigation was carried out to evaluate the effect of replacing cement by CSA and coarse aggregate by CS. The replacement level was considered as 5%, 10%, 15%, 20%, 25% and 30% in both cement and coarse aggregate by CSA and CS respectively. Normal strength concrete was considered in this investigation. The density and mechanical properties of concrete such as 28 days cured compressive strength and flexural strength were determined. Using 3D graphical analysis, the optimum replacement of cement and coarse aggregate was predicated in this investigation.

1. Introduction
Concrete is an inevitable man-made material in the world. The fast growth of construction industry demanded accumulative quantity of concrete worldwide. The Indian cement production statistics was clearly mentioned that India’s production capacity is the second largest in the world [1]. The present scenario of Indian construction industry demanded a huge quantity of cement and concrete for sustainable growth. The cement production is one of the highest energy consumed industry and emitted an equal quantity of CO₂ in to the atmosphere. In order to avoid such drawback, the supplementary cementitious materials are utilized and alternate aggregate are identified and being utilized in concrete. The resent research finding suggested that the rich silica minerals obtained from the agricultural waste are an alternate to the industrial by-products such as fly-ash, Ground granulated blast furnace slag, Metakaolin etc., [2, 3, 4]. Utsev and Taku (2012) investigated CSA as partial replacement mineral admixture in concrete and found that 10% replacement of cement was possible without affecting the strength properties [5]. Joshua et al., (2018) were concluded that CSA as potential mineral admixture for developing durable concrete [6]. On the other hand, the research finding were demonstrated that the coarse aggregate can be
replaced by the CS and able to develop lightweight concrete [7]. The strength and durable properties of coconut shell coarse aggregate (CSCA) added concrete were comparable with the conventional lightweight concrete [8, 9, 10]. In this background, this investigation was intended to utilize both CSA and CSCA by replacing cement and coarse aggregate respectively. The density and mechanical properties of the proposed concrete were determine to evaluate the suitability and determined the optimum replacement level of cement and coarse aggregate without compromising the performance of the concrete.

2. Experimental Investigation
2.1 Materials used
2.1.1 Cement and Aggregates
The market available Portland Pozzolana Cement (PPC) was utilized throughout the investigation. The specific gravity of cement was 3.14. Local river sand belongs to grading zone II with fineness modulus of 2.67 was utilized as fine aggregate. 20 mm size granite stones was selected as coarse aggregate and the specific gravity was determined as 2.75. The fineness modulus of coarse aggregate was found as 7.57. The performance of cement and aggregates utilized inthis investigation were found suitable as per the respective codes [11, 12].

2.1.2 Coconut shell coarse aggregate (CSCA)
Sundried crushed coconut shell passing through the 12.5 mm sieve was carefully selected as coarse aggregate. The moisture content and water absorption of CSCA were calculated as 4.28% and 26.78% respectively. The thickness of coconut shell was measured and found in the range of 2 mm to 8 mm. The specific gravity and fineness modulus were found as 1.89 and 7.35. The sample of CSCA used in this investigation is shown in Figure 1.

2.1.3 Coconut shell ash (CSA)
The sundried coconut shell broken pieces were allowed to burnt in the open air (uncontrolled combustion) for three hours and continue with calcination process by placing it in a muffle furnace at a temperature of 800°C for 6 hours to remove the carbonaceous material until a white substance, which had shown the formation of coconut shell ash and due to the calcination process is transform the crystalline form of ash in to amorphous form. The specific surface area of CSA was found as 325 m²/kg which is comparable with other agro based cementitious materials like Sugar cane bagasse ash and rice husk ash [1,3,13]. The specific gravity and bulk density of CSA were determined as 1.78 and 800 kg/m³ respectively. The chemical compositions of CSA is mentioned in Table 1. As per ASTM C618, When SiO₂ + Al₂O₃ + Fe₂O₃ of a mineral admixture is more than 70%, it was considered as a suitable mineral admixture for concrete. The chemical oxide composition combination of CSA used in this investigation (SiO₂ + Al₂O₃ + Fe₂O₃) was found as 72.34% and found suitable as cementitious material [14]. The CSA used in this investigation is shown in Figure 2.

| Oxide composition (%) | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO  | MgO  | SiO₂ + Al₂O₃ + Fe₂O₃ + LOI |
|-----------------------|------|-------|-------|------|------|-----------------------------|
| Cement                | 23.42| 4.87  | 3.78  | 63.16| 1.85 | 32.07                       |
| CSA                   | 38.54| 19.03 | 14.77 | 5.03 | 1.34 | 72.34                       |
| Utsev&Taku (2012) [5] | 37.97| 24.12 | 15.48 | 4.98 | 1.89 | 77.57                       |
| Joshua et al., (2018) [6] | 66.32| 8.79 | 5.35 | 6.25 | 0.87 | 80.64                       |

Table 1. Chemical composition of cement and CSA
2.2 Mix proportioning
The normal strength (M20 grade) was considered and the mix proportion of the concrete was determined in accordance with the IS: 10262-1982 [15]. The replacement level was considered as 5%, 10%, 15%, 20%, 25% and 30% in both cement and coarse aggregate by CSA and CS respectively. The final mix proportion of the concrete after three trials was arrived and shown in Table 2.

| Mix ID | Cement (kg/m³) | CSA (kg/m³) | Sand (kg/m³) | CA (kg/m³) | CSCA (kg/m³) | w/c ratio | Water (kg/m³) | Density (kg/m³) |
|--------|----------------|-------------|--------------|------------|--------------|-----------|---------------|----------------|
| CC     | 350            | -           | 600          | 1200       | -            | 0.5       | 175           | 2420           |
| C1A1   | 332.5          | 17.5        | 600          | 1140       | 60           | 0.5       | 175           | 2395           |
| C1A2   | 332.5          | 17.5        | 600          | 1080       | 120          | 0.5       | 175           | 2375           |
| C1A3   | 332.5          | 17.5        | 600          | 1020       | 180          | 0.5       | 175           | 2360           |
| C1A4   | 332.5          | 17.5        | 600          | 960        | 240          | 0.5       | 175           | 2335           |
| C1A5   | 332.5          | 17.5        | 600          | 900        | 300          | 0.5       | 175           | 2310           |
| C1A6   | 332.5          | 17.5        | 600          | 840        | 360          | 0.5       | 175           | 2295           |
| C2A1   | 315            | 35          | 600          | 1140       | 60           | 0.5       | 175           | 2410           |
| C2A2   | 315            | 35          | 600          | 1080       | 120          | 0.5       | 175           | 2380           |
| C2A3   | 315            | 35          | 600          | 1020       | 180          | 0.5       | 175           | 2335           |
| C2A4   | 315            | 35          | 600          | 960        | 240          | 0.5       | 175           | 2300           |
| C2A5   | 315            | 35          | 600          | 900        | 300          | 0.5       | 175           | 2280           |
| C2A6   | 315            | 35          | 600          | 840        | 360          | 0.5       | 175           | 2260           |
| C3A1   | 297.5          | 52.5        | 600          | 1140       | 60           | 0.5       | 175           | 2370           |
| C3A2   | 297.5          | 52.5        | 600          | 1080       | 120          | 0.5       | 175           | 2350           |
| C3A3   | 297.5          | 52.5        | 600          | 1020       | 180          | 0.5       | 175           | 2305           |
| C3A4   | 297.5          | 52.5        | 600          | 960        | 240          | 0.5       | 175           | 2265           |
| C3A5   | 297.5          | 52.5        | 600          | 900        | 300          | 0.5       | 175           | 2240           |
| C3A6   | 297.5          | 52.5        | 600          | 840        | 360          | 0.5       | 175           | 2220           |
| C4A1   | 280            | 70          | 600          | 1140       | 60           | 0.5       | 175           | 2345           |
| C4A2   | 280            | 70          | 600          | 1080       | 120          | 0.5       | 175           | 2300           |
| C4A3   | 280            | 70          | 600          | 1020       | 180          | 0.5       | 175           | 2275           |
2.3 Testing methods
The density of the hardened concrete was determined using buoyancy method as per the Archimedes principle [16]. The compressive strength of concrete was carried out using cube of 150 mm size and the flexural strength of concrete was conducted using 100 mm x 100 mm x 500 mm size prism specimen. Both the tests were conducted after the curing period of 28 days in accordance with IS 516-1999 [17].

3. Results and discussion
3.1 Density
The density of hardened concrete specimens of all mixes are summarized in Table1. The density of the control concrete was calculated as 2420 kg/m³. Generally, the density of the concrete is depends up on the specific gravity of coarse aggregate and hence the substitution of CSCA in concrete reduces the density of concrete considerably. The concrete specimens of the replacement level of 30% in CA and cement had shown lowest density varied from 2310 to 2100 kg/m³.

3.2 Compressive strength
The compressive strength variations after the curing period of 28 days with respect to the various dosage levels of CSCA and CSA are shown in Fig.3. The results of compressive strength were obtained an average of three concrete cube specimens. Fig.3 is clearly demonstrated that the gradual improvement in strength up to the replacement level of 15% CSCA due to the enhancement of paste aggregate bond in the transition zone. Further increase the dosage of CSCA level had shown decrease in compressive strength due to increases the contact surface area between aggregate and paste which caused insufficient bond [18]. From Fig.3, it can be observed that optimum replacement of coarse aggregate by CSCA was predicted as 15%. The substitution of CSA were also increased the compressive strength of concrete due to the pozzolanic reaction of CSA and pore confinement of concrete mass [19]. The strength development was observed up to 10% dosage level of CSA. Since the selected cement is fly-ash based PPC, further increase the CSA dosage of cementitious material reduced the cement content in concrete which leads to reduce the primary hydration products. The combined optimum level of CSCA and CSA was predicted from the 3D graph as shown in Fig.3 and found as 15% and 10% respectively.

| C4A4 | 280 | 70  | 600 | 960 | 240 | 0.5 | 175 | 2240 |
|------|-----|-----|-----|-----|-----|-----|-----|-----|
| C4A5 | 280 | 70  | 600 | 900 | 300 | 0.5 | 175 | 2210 |
| C4A6 | 280 | 70  | 600 | 840 | 360 | 0.5 | 175 | 2190 |
| C5A1 | 262.5 | 87.5 | 600 | 1140 | 60  | 0.5 | 175 | 2305 |
| C5A2 | 262.5 | 87.5 | 600 | 1080 | 120 | 0.5 | 175 | 2280 |
| C5A3 | 262.5 | 87.5 | 600 | 1020 | 180 | 0.5 | 175 | 2235 |
| C5A4 | 262.5 | 87.5 | 600 | 960  | 240 | 0.5 | 175 | 2190 |
| C5A5 | 262.5 | 87.5 | 600 | 900  | 300 | 0.5 | 175 | 2165 |
| C5A6 | 262.5 | 87.5 | 600 | 840  | 360 | 0.5 | 175 | 2150 |
| C6A1 | 245 | 105 | 600 | 1140 | 60  | 0.5 | 175 | 2275 |
| C6A2 | 245 | 105 | 600 | 1080 | 120 | 0.5 | 175 | 2250 |
| C6A3 | 245 | 105 | 600 | 1020 | 180 | 0.5 | 175 | 2210 |
| C6A4 | 245 | 105 | 600 | 960  | 240 | 0.5 | 175 | 2180 |
| C6A5 | 245 | 105 | 600 | 900  | 300 | 0.5 | 175 | 2150 |
| C6A6 | 245 | 105 | 600 | 840  | 360 | 0.5 | 175 | 2100 |

Where, C = Cement, A = Aggregate, Numerical = replacement level in the order of 5% increasing
3.3 Flexural strength
The flexural strength variations of 28 days cured concrete prism specimens were determined and shown in Fig. 4. The substitution of CSCA and CSA are confirmed to increase the flexural strength up to the replacement level of 12-15% and 10-12% respectively. The flexural strength improvement may be due to the increasing the bond between the paste form and the aggregate portions. However the increasing the surface area of aggregate by adding more CSCA can cause the reduction of bond which leads to reduction of flexural strength of concrete. Similarly the reduction of flexural strength was observed due to the increasing the substitution level of more than 12% due to the presence of more un-hydrated cementitious particle at 28 days curing [20,21]. Considering both compressive strength and flexural strength results obtained from this investigation, the replacement of CA by CSCA has to restrict up to 15% and the cement replacement by CSA has restricted to 10% and considered as optimum replacement. The final combination of the selected grade concrete can be developed in the form of 90% PPC + 10% CSA + 100% Sand + 85% Granite CA + 15% CSCA

4. Conclusion
The following conclusions were obtained from this experimental investigation:

- The density of concrete was decreased due to the substitution of CSCA instead of CA and CSA instead of cement. The density of concrete with optimum replacement level of cement and CA was found a reduction of more than 4% and more than 13% reduction in density was identified at 30% replacement of both cement and CA.
- The compressive strength of concrete was increased up to the replacement level of 15% CA by CSCA and 10% of cement by CSA and further substitution of CSCA and CSA can cause the reduction of compressive strength gradually.
- The flexural strength of concrete was increased similar to the compressive strength of concrete up to 15% of CSCA and 12% CSA and found the flexural strength of the concrete was 11% of the respective compressive strength.
- The final combination of the concrete considered in this investigation can be developed in the form of 90% PPC + 10% CSA + 100% Sand + 85% Granite CA + 15% CSCA
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Fig. 4 Flexural strength variations of concrete after adding of CSCA and CSA
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