Use of Clay Tile Chips as Coarse Aggregate in Concrete

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Abstract. Roof of majority of old buildings in Kerala is constructed with Mangalore pattern clay tiles. Hence, a large amount of broken clay tiles are produced during the demolition of these old buildings. In this study, the potential of using the broken clay tiles as aggregate in concrete is studied. The crushed natural stone aggregate in concrete is replaced by 25, 50, 75 and 100\% by volume. The control mix containing natural aggregate and mix with clay tile aggregates partially or fully replaced prepared in the laboratory and tested. The compressive strength, modulus of elasticity, modulus of rupture, tensile strength were determined. The test results indicated that replacement of natural aggregate by 25\% by volume with the broken clay tile can be recommended. Thereafter, the reduction in the strength is found to be significant.

Keywords: Clay Tile, Modulus of Rupture, Young’s Modulus, Split Tensile Strength, Compressive Strength

1. Introduction

Use of waste material in construction is a green approach. The alternate materials to replace constituent materials of concrete are a hot research topic today. It provides the value addition to the waste materials and helps to achieve the sustainability goals in the construction. Manglore pattern clay Roof tiles were used for roof construction in majority of the old buildings in Kerala. Hence, large amount of broken roof tile chips are available in the construction and demolition (C&D) waste generated during the renovation and reconstruction work of these old buildings. Hence, it is important to identify a method to utilize the broken clay chips. In this study, potential of the use of these broken clay tile chips in concrete production as coarse aggregate is studied.

Aruna \textit{et al.}\textsuperscript{[1]} studied the potential of use of broken tiles for the part replacement to coarse aggregates in concrete. The percentage replacement used was 0 to 25\% percent. The results showed that the compressive strength is reduced by 3 to 13\% corresponding to replacement ratios between 5 and 25\%. Elci \textit{et al.}\textsuperscript{[2]} studied the use of floor and wall tiles as aggregate in concrete production. The wall tile is reported to have lower density and high water absorption compared to floor tile. Both tile aggregate sowed good adhesive properties. Prasad \textit{et al.}\textsuperscript{[3]} used clay tile aggregate to replace crushed stone aggregate in 25 MPa concrete. The replacement ratios of 10, 20, 30 and 40 \% were tried and the test results indicated that up to 30 \% replacement can be recommended. Saravanakumar and Maruthuchalam \textsuperscript{[4]} used waste clay tile chips for replacing coarse aggregate and fly ash for replacing cement. The test result showed that compressive strength of clay tile aggregate concrete is 82\% and 75\% of control mix.
when the aggregate replacement ratio is 20 and 30% respectively. Ibrahim et al. [5] studied the use of clay brick chips for the production of light weight concrete. The specimens were prepared with varying the percentage of clay bricks aggregate content. The result showed that replacement ratio of 25% yields a compressive strength of 25MPa. Khalaf [6] studied the use of crushed brick as coarse aggregate in concrete. The test results showed that 28-days compressive strength of concrete containing brick aggregate is greater than that of concrete containing crushed stone aggregate.

Yang et al. [7] studied the properties of concrete containing used recycled crushed aggregate (RCA) and crushed clay bricks (CCB). The proportion of CCB: RCA of 0:100, 20:80, 50:50 and 100:0 was used. The strength of the mix containing CCB: RCA of 20:80 was found to be greater than other mixes. Anderson et al. [8] used waste ceramic tiles as coarse aggregate. The aggregate replacement ratios of 20-100% were used. A slight increase in the strength was reported when the percentage replacement ratio of coarse aggregate is 50%. Awoyera et al. [9] used ceramic tile waste as coarse aggregate in concrete. The test results showed that the increase in strength is about 36.1 % corresponding to a replacement ratio of 100%. Kavitha and Sundar [10] carried out experimental study to use ceramic tile waste as partial replacement of coarse aggregate in concrete. It was suggested that the optimum dosage of the ceramic tile aggregate is 25% of the total aggregate in concrete. Isah [11] suggested that the optimum replacement ratio of the waste ceramic tile chips as aggregate in concrete is 10%. Sekar [12] studied the influence of partial replacement of coarse aggregate with ceramic tile waste in concrete. The replacement percentage of 0, 15, 30 and 45 % was used. The test result showed that there is a significant increase in strength up to 15% replacement and beyond which there is no such improvement in the strength. McGinnis [13] studied the strength of concrete with recycled aggregate. The strength was found to decrease by 16.6 and 26.4% corresponding to a replacement ratio of 50 and 100% respectively. Mohammed et al. [14] studied the use of recycled brick aggregate as coarse aggregate in concrete. The replacement percentage between 10-50% was considered in this study. The result showed that there is no significant reduction in the compressive strength due to the addition of brick chip aggregates. Minapuet et al. [15] experimented to use light weight porous pumice stone pieces as the coarse aggregate in 30 MPa concrete. Out of the various coarse aggregate replacement ratios tried in this study, 20 % replacement of pumice aggregate was found to yield best strength. Rajeswari and George [16] studied the use of pumice stone as aggregate in concrete. The crushed stone aggregate was replaced with pumice stone in the ratios of 0, 50, 60 and 70%. The maximum strength was reported for a mix with 60% replacement of coarse aggregate. Abdulla [17] prepared concrete containing construction and demolition waste. The aggregate replacement ratio of 100 % was used. The test results indicated that the use of demolition waste aggregate in concrete does not influence the strength properties of concrete.

Mangalore pattern roof tiles are burned pressed clay tiles having relatively better properties when compared to the brick aggregates. The use of waste pieces of the clay roof tiles has become practical, since they are cheap and it will reduce environmental pollution. Concrete is one of the most important building materials used in construction industry. Also replacement of raw materials in concrete is also a practical case. Concrete is the mixture of cement, coarse aggregate, fine aggregate and water in a definite proportion. The use of many waste materials as coarse aggregate in concrete are reported in the literature [1-17]. The potential of the use of waste pieces of burned pressed clay roof tiles as coarse aggregate in concrete are not studied in detail. In this study, partial and full replacement of conventional crushed stone aggregate in concrete with clay roof tile chips is examined. The properties such as compressive strength, tensile strength, modulus of rupture, modulus of elasticity were examined.

2. Material Properties

The main constituents of concrete mix are water, cement, coarse aggregate and fine aggregate. Chemical admixture is also used in order to increase the workability of the mix. The properties of the constituent materials are determined.

2.1 Cement

Portland pozzolana cement conforming to IS:1489[18] was used. Portland pozzolana cement is manufactured by mixing 75 % of ordinary Portland cement (OPC) with 25% of fly ash pozzolana. The specific gravity and standard consistency of cement is found to be 2.96 and 32% respectively.
2.2 Fine Aggregate

Fine aggregate fills the voids between the coarse aggregate in the concrete. The specific gravity of the fine aggregate is found to be 2.6. Particle size distribution of the fine aggregate is given in Figure 1 and it indicates that the fine aggregate is conforming to zone II of IS:383 [19].

![Fine aggregate](image1)

**Figure 1.** Particle size distribution of fine aggregate

2.3 Crushed stone aggregate (CSA)

The coarse aggregates occupy about 60% of the total volume of the concrete. Crushed stone aggregate was used as the coarse aggregate in control mix. The specific gravity of the CSA was found to be 2.73. The well graded CSA was used and the particle size distribution curve is given in Figure 2.

![Coarse aggregate](image2)

**Figure 2.** Particle size distribution of coarse aggregate (CA)

2.4 Tile chips aggregate (TCA)

Broken Mangalore Pattern roof tiles were collected from the building demolition site. These tile pieces are further broken into 20 mm down size and used as aggregate in concrete. The specific gravity of the clay tile chip aggregate was found to be 2.1. The particle size distribution curve of the TCA indicates that the aggregate is grades as per IS:383[19].

2.5 Water and chemical admixture

Potable water was used as mixing water in concrete. Sulphonated naphthalene based super plasticiser was used as the chemical admixture to improve the workability of the concrete.

3. Mix Proportion

The weight of the constituent materials were arrived as based on absolute volume method given by IS: 10262[20]. The mixes were designated to indicate the proportion of the crushed stone aggregate
(CSA) and tile chip aggregate (TCA). For example, designation of 75C25T indicates the mix containing CSA of 75% by volume of total aggregate and TCA of 25%. The weight of the materials per cubic meter of concrete is given in Table 1.

| Mix designation | Admixture | Water | Cement | Fine aggregate | Coarse aggregate |
|----------------|-----------|-------|--------|----------------|------------------|
|                |           |       |        | CSA | TCA |
| 100C0T         | 2.8       | 175   | 350    | 723 | 1192 |
| 75C25T         | 2.8       | 175   | 350    | 723 | 894  |
| 50C50T         | 2.8       | 175   | 350    | 723 | 596  |
| 25C75T         | 2.8       | 175   | 350    | 723 | 298  |
| 0C100T         | 2.8       | 175   | 350    | 723 | --   |

4. Casting and Curing of Specimens

The fresh concrete was prepared using a pan mixture. Materials were weigh-batched. The coarse aggregates were taken in saturated surface dry (SSD) condition. The tile aggregates were soaked for 24 hours and then spread on non-absorbing platform for 1 hour to dry the surface. The dry mixture of the materials was prepared initially in the mixing machine. The 90% of the total water was added to the dry mixture and thoroughly mixed. The balance 10% of the water was mixed with chemical admixture. The admixture-water solution was then added and mixing is continued. The homogeneous fresh mix is then filled in the clean oiled moulds. The details of specimens are given in Table 2.

| Sl. No. | Test                  | Shape of specimen | Size of specimen L x B x H | Number of specimens |
|--------|-----------------------|-------------------|-----------------------------|---------------------|
| 1      | Compressive strength  | Cube (7-days)     | 150 mm x 150 mm x 150 mm    | 3                   |
|        |                       | Cube (28-days)    | 150 mm x 150 mm x 150 mm    | 3                   |
|        |                       | Cylinder (28-days)| 150 mm Ø x 300 mm (H)      | 3                   |
| 2      | Split tensile strength| Cylinder*         | 150 mm Ø x 300 mm (H)      | 3                   |
| 3      | Modulus of rupture    | Prism*            | 500 mm x 100 mm x 100 mm    | 3                   |
| 4      | Modulus of Elasticity | Cylinder*         | 150 mm Ø x 300 mm (H)      | 3                   |

*Tested at an age of 28 days

A total of 90 specimens were cast in this study. All the specimens were demoulded after 24 hours of casting and cured by immersing in water for required period.

5. Testing of Specimens

The specimens were tested as per IS:516[21]. The compression test was conducted using a compression testing machine of capacity 2000kN. The modulus of elasticity test was conducted by attaching a compresso-meter of least count of 0.001mm. The modulus of rupture test was carried out using flexure testing machine having a capacity of 100kN. The modulus of rupture specimens were tested over a span of 400mm. Three specimens were tested and the average was reported in this paper.

6. Results and Discussion

The results of the tests of compressive and tensile strength, modulus of rupture and modulus of elasticity test are given in Table 3. The strength loss due to the addition of tile aggregate is computed and is given in Figure 3 and 4. The strength loss is the ratio of difference between the strength of the mix and the control mix to the strength of control mix.
### Table 3. Experimental test results

| Mix Designation | 7-days cube compressive strength (N/mm²) | 28-days cube compressive strength (N/mm²) | 28-days cylinder compressive strength (N/mm²) | Split tensile strength (N/mm²) | Modulus of rupture (N/mm²) | Modulus of Elasticity (kN/mm²) |
|-----------------|----------------------------------------|------------------------------------------|---------------------------------------------|-------------------------------|-----------------------------|-----------------------------|
| 100C0T          | 15.1                                   | 26.3                                     | 21.2                                        | 3.6                           | 4.6                         | 25.4                        |
| 75C25T          | 14.2                                   | 25.6                                     | 20.3                                        | 3.3                           | 4.4                         | 22.8                        |
| 50C50T          | 13.7                                   | 22.7                                     | 18.2                                        | 2.9                           | 3.6                         | 21.1                        |
| 25C75T          | 12.5                                   | 18.4                                     | 15.2                                        | 2.6                           | 3.0                         | 17.0                        |
| 0C100T          | 10.6                                   | 15.3                                     | 12.7                                        | 2.2                           | 2.8                         | 10.5                        |

#### 6.1 Compressive Strength

The compressive strength for all specimens is given in Table 3. With the addition of TCA increases the compressive strength decreases. The strength loss in compressive strength due to the addition of TCAs in concrete is shown in Figure 3. The strength loss in compression was observed for full (100%) replacement of CSA with TCA, which was found to be 41% and 40% for 28-days compressive strength of cylinder and cube respectively. The decrease for 7-days cube compressive strength was found to be 30%. The specific gravity of the tile aggregate was 2.1, which was about 77% of the CSA. This indicates that the tile aggregate contains more voids when compared to CSA. Hence, TCAs are weaker aggregates than the CSAs. This may be reason for having lower strength for TCA concrete when compared to CSA concrete. However, the reduction in the compressive strength due to the replacement of 25% CSA with TCA is found to be nominal (3 to 5%). Hence, the replacement of CSA with TCA up to 25% can be recommended without modification of the mix design procedure. The higher replacement ratios can be considered after incorporating necessary modifications to compensate the strength loss in the concrete.

#### 6.2 Split Tensile Strength

The average split tensile strength of concrete containing TCA is given in Table 3. The split tensile strength is found to decrease with increase in replacement ratio of the coarse aggregate. The strength loss in tension is given in Figure 4. The loss in split tensile strength due to 100% replacement of CSA with TCA is found to be 38%. The reduction in the split tensile strength due to the replacement of 25% CSA with TCA is found to be 8 - 9%. In the cracked surface of the specimen, both splitting of the aggregate and failure of the aggregate interface was visible. The water absorbed on the surface of the tile aggregate cause the reduction in the alkalinity of the cementatious compound at the aggregate interface. Hence, the aggregate interface of the tile aggregate is weaker than CSA. This is the reason for failure of the aggregate-mortar interface in the concrete containing TCA. The weak aggregate and weak
interface fail during the splitting and this resulted in lower magnitude of splitting tensile strength of the concrete containing TCA.

![Graph showing strength loss](image)

**Figure 4.** Strength loss due to the addition of tile aggregate

### 6.3 Modulus of Rupture

The modulus of rupture test result is given in Table 3. The modulus of rupture was found to decrease with the increase in the replacement ratio of CSA with TCA. The strength loss of the modulus of rupture due to replacement of CSA with TCA is given in Figure 4. The maximum strength loss of modulus of rupture is found to be 39% and it was found for the mix with aggregate replacement ratio of 100%. The reduction in the modulus of rupture due to the replacement of 25% CSA with TCA is found to be 5%. The adhesion of TCA with the surrounding mortar is relatively low due to the dispersion of absorbed water in TCA in pre-soaking stage. This leads to the easy braking of the interface when subjected to tensile force in the bottom fibres of the prism specimen, which may be attributed to the strength loss in modulus of rupture in concrete containing TCA.

### 6.4 Modulus of Elasticity

The modulus of elasticity of all specimens is given in Table 3. The modulus of elasticity was found to decrease with increase in the replacement ratio of the coarse aggregate. The strength loss corresponding to modulus of elasticity was determined and is given in Figure 4. The strength loss in modulus of elasticity due to the full (100%) replacement of CSA with TCA was found to be 58%. The reduction in the modulus of elasticity due to the replacement of 25% CSA with TCA is found to be around 10%. The modulus of elasticity is recorded in the re-cracking stage. The CSA being a strong aggregate, the modulus of elasticity of specimen containing CSA was found to be relatively greater in magnitude when compared to the TCA. The deformation of the weak tile aggregate and the aggregate-mortar interface collectively responsible for the reduction in the modulus of elasticity of the concrete.

### 7. Prediction Model

The models for predicting the strength properties of TCA concrete is proposed by carrying out the regression analysis. The independent variable is taken as the 28-days cube compressive strength ($f_{cu-28d}$) and coarse aggregate replacement ratio ($R$). $R$ is taken as the independent variable. The magnitude of $f_{cu-28d}$ to be substituted in MPa and $R$ is equal to 0, 0.25, 0.5, 0.75 or 1.0. The prediction models are given in Table 7. The proposed prediction models can be used to estimate the various strength properties of TCA concrete, if the cube strength test data and replacement ratio are known.
8. Conclusion.
Clay tile chips can be used as a satisfactory aggregate in concrete to get good quality concrete and will give a satisfactory strength. The replacement of crushed stone aggregate (CSA) with clay tile chip aggregate (TCA) yielded a 7th day compressive strength of up to 14.2 N/mm². The test results indicated that the replacement ratio up to 25% can be adopted without modifying the mix design procedure because the reduction in compressive strength would be as 3 to 5%. Higher replacement ratios are also permitted provided appropriate adjustments in the mix design procedure may be incorporated. It is expected that the test results of this study would help the concrete engineers to arrive at the appropriate replacement ratio of TCA in concrete for making sustainable concrete. The mix design procedure using tile aggregate can be developed in future. It is expected that the test data will be useful for formulating code provisions to permit the use of tile aggregate.

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Table 4. Prediction of strength property of TCA concrete

| Property                              | Proposed Model                                      | Predicted/ experimental Mean | SD* |
|---------------------------------------|-----------------------------------------------------|-----------------------------|-----|
| 7-days cube compressive strength (MPa) | $f_{cu-7d} = 0.62f_{cu-28d}$                        | 0.89                        | 0.09|
| 28-days cylinder compressive strength (MPa) | $f_{cy-28d} = 0.81f_{cu-28d}$                      | 0.97                        | 0.01|
| Split tensile strength (MPa)          | $f_{sp} = (0.71 - 0.13R)\sqrt{f_{cu-28d}}$         | 0.98                        | 0.02|
| Modulus of rupture (MPa)              | $f_{r} = (0.89 - 0.21R)\sqrt{f_{cu-28d}}$          | 0.94                        | 0.04|
| Modulus of elasticity (GPa)           | $E_{c} = (5.12 - 2.03R)\sqrt{f_{cu-28d}}$          | 1.16                        | 0.19|

*SD=Standard Deviation
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