Utilization of ceramic waste powder and rice husk ash as a partial replacement of cement in concrete

Bhaskara Rao Nalli¹ and Prudhviraju Vysyaraju²

¹,² Assistant Professor, Department of Civil Engineering, Sri Sivani College of Engineering, Srikakulam, Andhra Pradesh, India 532402.
¹ Email: Bhaskar.nalli40@gmail.com
² Email: vysyaraju.prudhviraju@gmail.com

Abstract. Ceramic waste powder (CWP) and rice husk ash (RHA) are one of the highly produced waste materials from tiles industry and rice processing units respectively. Using these materials in concrete as a partial replacement for cement offers several advantages like reducing the burden on landfills, reducing the construction cost by replacing costly cement and improvement in performance of concrete etc. due to their mineral composition. In the current study, an effort was made to partly replace the cement with CWP and RHA. Concrete design mix was carried out by using 0, 5, 10, 15 and 20% CWP and varied proportions of RHA were tried on the optimum CWP for cement replacement (0, 5, 10, 15, 20%). Tests were carried out on the fresh and hardened concrete specimens to study the mechanical properties of concrete. Analysis of the test results indicate that 15% CWP yielded best results and 10-15% RHA in combine proportion was found to be the optimum replacement of cement offering higher strength when assessed to the conventional concrete. Maximum compressive strength achieved at 15% CWP and 15% RHA whereas, the flexural strength and split tensile strength were attained at 15% CWP and 10% RHA dosage.

Keywords: Control mix, Ceramic waste, Cement Replacement, Mineralogy and Workability

1. Introduction

The continuous infrastructural development resulted in rapid depletion of the building material resources [1] and escalated production of the solid waste [2–4]. Among the elements of the concrete, a crucial one is the cement that imparts strength as a binding agent and is the most expensive one [5]. Various researchers around the world started studying the alternate materials that can substitute this binding agent [6–8]. The huge quantities of the solid waste generated requires disposal which otherwise adversely affects the environment [7,9]. Disposal of this huge solid waste requires a large amount of valuable land which is becoming very scarce in recent days [10]. The utilization of these waste materials in civil engineering offers a great deal of environmental sustainability besides reducing the burden on landfills. Various researchers utilized industrial byproducts like fly ash, silica fumes, GGBS, building demolition waste, recycled concrete aggregate, rice husk ash, ceramic waste, rubber products, etc. as a replacement of building materials in concrete [11–16].

Among the various solid wastes, various materials offer the replacement of cement, the binding agent, due to the pozzolanic characteristics possessed by them. Ceramic waste powder (CWP) is an
industrial by-product generated during the polishing of tiles. Unfortunately, this waste amount to about 1.9kg per polishing of 1m² area tiles [17,18]. CWP though does not offer high strength in its early stages, offers suitable pozzolanic activity after 28 days [19,20]. Partly replacing the cement by CWP not only contributes to sustainable development but also enhances the properties of cement mortar and concrete by reduction in porosity and cracks [21–25]. Sharifi et al. [26] demonstrated that the CWP can be used to improve the acid resistance of cement motors when used as a part replacement of cement. The mechanical strength and the sorptivity tests were performed on the cement mortars prepared by various proportions of CWP replacement [27]. Mechanical and microstructural studies on the cement mortars when partial cement replacement is carried out with CWP shown that the Alkali-silica reaction was reduced besides enhancing the mechanical strength [9,26,28–30]. The properties of fresh and hardened light weight foamed concrete were studied at various proportions of CWP replacement and at different water-cement ratios by Lee et al. [31,32]. Researchers studied the effect of other materials (mostly waste materials/by-products) in addition to the CWP wastes in concrete. Mazenan et al. [33] presented a review of cement replacement with pal oil fuel ash and CWP to improve the characteristics of concrete. Shanmugam et al [34] shown that the corrosion resistance and the acid resistance could be enhanced by partial replacement of cement with CWP and red brick dust. AlArab et al. [35] studied the thermal characteristics of cement mortars prepared with cement replaced with CWP and blast furnace slag. Xiong et al. [36] investigated the effect of ceramic waste and fly ash addition in the engineered cementitious composites.

Rice husk is generated abundantly during the milling process of rice. This husk is further processed by burning it, separating the impurities and grinding to produce the Rice Husk Ash (RHA). The pozzolanic activity of RHA depends completely on its processing that produces more quantity of amorphous silica, more fineness with specific surface area [37,38]. The pozzolanic reactions of RHA could continue to happen for years based on the dissolution of silica and the availability of Calcium hydrates (CH) from RHA [39–41]. The pozzolanic activity of the RHA was evaluated rapidly as demonstrated by Nair et al. [40]. Many researchers demonstrated the applicability of the RHA as a cement replacement to enhance the strength characteristics of the cement concrete and mortar [42–48]. The density of concrete raised with more fineness of RHA, while the voids decrease, up to the optimum cement replacement [49]. The microstructural characteristics of RHA blended with cement in the concrete present us with beneficial modification of concrete characteristics [38,44,50–56]. The mechanism behind the successive reactions in cement blended with RHA particles was presented by Le and Ludwig [57]. Lo et al. [58] studied the effect of partial replacement of cement on porous concrete that reduced carbon footprint to a considerable extent.

In the current study, an effort is made to analyze the fresh concrete properties and the mechanical characteristics of the concrete prepared from the cement partially replaced with various proportions of CWP and further the mix with optimum CWP content was dosed with various proportions of RHA. This study becomes an initiative to use more solid waste in an advantageous manner. This work aimed primarily at improvement in the performance of concrete material by replacing huge quantities of costly OPC with waste pozzolanic material that required addressing the disposal needs. This article lays a basis for carrying out the innovative design applications of pavement construction, design mix for other concreting works etc.

1.1 Research Significance
This research aims at the reduction of the environmental impact arises from abundant production of waste materials like CWP and the rice husk by utilizing them in concrete production. This also helps in reducing the green house gas Carbon Dioxide (CO₂) through replacement of OPC. Overall the cost of concrete production could also be reduced with this successful replacement of OPC with cementitious materials that required waste disposal.

2. Materials

2.1 Concrete
Concrete on M30 grade was used as the base concrete (control mix) in the current study.
2.1.1 Cement. Commercially available Ordinary Portland Cement of grade 53 was used in this research. The properties (physical) of the cement used were presented in table 1.

Table 1. Physical properties of cement

| Test Parameter          | Result  |
|-------------------------|---------|
| Normal Consistency      | 29.5%   |
| Initial Setting Time    | 105 minutes |
| Final Setting Time      | 220 minutes |
| Specific Gravity        | 3.13    |
| Fineness                | 4%      |
| Soundness               | 1.3 mm  |

2.1.2 Fine Aggregate. As fine aggregate (FA), river sand that was readily available in local area was used for concrete preparation whose physical properties were as presented in the table 2 and the gradation was presented in figure 1. The sand was thoroughly cleaned for removal of any deleterious contents before the testing.

Table 2. Physical properties of fine aggregate

| Test Parameter          | Result  |
|-------------------------|---------|
| Specific Gravity        | 2.64    |
| Zoning of FA            | Zone-II |
| Fineness Modulus        | 2.53    |
| Water Absorption        | 0.86%   |

Figure 1. Gradation of Fine Aggregates

2.1.3 Coarse Aggregate. 20mm and 10mm single sized crushed stone aggregates from the local quarry were used as coarse aggregates (CA) in the ratio of 65% and 35% to satisfy the gradation limits as per IS:383-2016. The physical properties of the CA were presented in table 3.

Table 3. Physical properties of coarse aggregate

| Test Parameter          | Result  |
|-------------------------|---------|
| Crushing Value          | 20.6%   |
| Aggregate Impact Value  | 25.37%  |
Combined Flakiness and Elongation Index 23.85%
Specific Gravity 2.72
Water Absorption 0.86%

2.1.4 Chemical Admixture. Fosroc conplast X421IC was used as a super plasticizer in enhancing the workability of concrete.

2.2 Ceramic Waste Powder (CWP)
CWP was obtained from the nearby Ceramics company in E.G. District of Andhra Pradesh for the use in current investigation, with its specific gravity being 2.47 and fineness about 2% (98% passed through 90 microns sieve).

2.3 Rice Husk Ash (RHA)
Commercially available RHA was procured for the purpose of current research. The sp. gravity of RHA was calculated to be about 2.08 and fineness of about 1.8% (98.2% passed through 90 microns sieve). The pozzolanic activity of RHA as per the method demonstrated by Nair et al. [40] was found to be about 84% which was above the index suggested by ASTM C618 [59] for the use in concrete.

2.4 Mix Proportions
In the current study, the design mix for control mix was made as per the codal specifications of IRC:44 [60] based on the material properties. A slump of 25-50mm was chosen for the mix design which shall be common in pavement construction. The design mix proportions decided after the trail mixes were as mentioned in the table 4.

| Constituent   | Weight (kg/m$^3$) |
|---------------|-------------------|
| Cement        | 390.06            |
| FA            | 610.57            |
| CA            | 1286.73           |
| Water         | 148.22            |
| Super Plasticizer | 3.90    |

3. Experimental methodology
Initially, the control mix specimens made of the proportions mentioned in table 4 were used as the base mix for comparison. Two different waste materials were chosen to be supplementary materials for cement, namely CWP and RHA as mentioned earlier. Based on the literature survey, it was understood that both CWP and RHA were used as cement replacement materials with optimum quantity varying from 15-20% depending on the pozzolanic activity of the material. Firstly, CWP was used as replacement material in various proportions as 0, 5, 10, 15 and 20% by weight of cement and optimum CWP replacement is decided based on the compressive strength (7 and 28 days) of cubes. 15% CWP was found to be the optimum cement replacement which was in line with the literature. Later, along with the optimum CWP content, RHA was also used to replace additional cement in different proportions as 0, 5, 10, 15 and 20%. The slump was measured in each mix and the variation in the workability of fresh concrete was studied. The mechanical properties of the hardened concrete were studied from the hardened concrete specimens as per IS:516 which include compressive strength of cubes, flexural strength of beams and split tensile strength of cylinder specimens. The different mixtures were designated as mentioned in table 5 for the purpose of this study.

| Designation for various mixtures |
|----------------------------------|
| Cement + CWP                     |
| Cement + CWP + RHA               |

Table 5. Designations for various mixtures

| Designation | Constituents |
|-------------|--------------|
| Cement      | CWP          |
| Cement      | CWP + RHA    |

4
4. Results and discussions

4.1 CWP replacement

4.1.1 Slump. The slump was measured for the control mix concrete and the partially CWP replaced mixtures as specified in table 5 immediately after the water was added and mixed together. The results of slump test for various mixtures were presented in figure 2. Observation of results from figure 2 indicates that the slump of concrete mixed with CWP increased drastically indicating that CWP is acting as a plasticizer which was in line with the observations made by Abubakr et al. [22].

![Figure 2. Slump variation with various CWP replacements for cement](image)

4.1.2 Compressive Strength of Concrete. Compressive strength of the concrete specimens made from the various mixtures specified in table 5 with CWP replacement of cement and cured properly as per the specifications was measured at 7- and 28- days curing period. The test results were presented in figure 3 which indicate that the maximum result was attained at 15% CWP replacement. This optimum value is further used for RHA mixed proportions and thus the designations shown in table 5 were chosen for RHA variations.
4.2 CWP + RHA Replacement

4.2.1 Slump. The constituents as presented in table 5 were mixed together and the slump was measured immediately for the control mix and the 15% CWP & various proportions of RHA replacing cement. The slump values were presented for various mixtures in figure 4. The test results indicate that the slump reduced upon the addition of RHA to the mixture containing 15% CWP (CCWP03) which was originally increased as compared to the control mix value. This conforms to the findings of Miller et al. [61] that indicates the workability of concrete declines with addition of RHA due to its specific surface area.
4.2.2 Compressive Strength of Concrete. Compressive strength of the concrete specimens made from the various mixtures specified in table 5 with 15% CWP & various proportions of RHA replacement of cement and cured properly as per the specifications was measured at 7- and 28- days curing period. The results were presented in figure 5 which indicate that the maximum value was attained at 15% CWP + 15% RHA (CCWPRHA03) replacement. Observation of the results indicate that the 28 days compressive strength was enhanced by about 30% and 2% when compared to the control mix and CCWP03 mix values respectively. This indicates that the combination of CWP and RHA could be used up to the optimum extent for replacing cement with improvement in strength. The 7-days curing compressive strength of the cement supplement specimens was initially less than that of control mix specimens which was due to the physical filler effect as presented by Siddika et al. [38]. Due to the increased pozzolanic activity, the compressive strength increased at the later stages suppressing the physical filler effect.

![Figure 5](image)

**Figure 5.** Compressive strength variation with 15% CWP and different proportions of RHA replacements for cement

4.2.3 Flexural Strength of Concrete. Flexural strength of the concrete specimens made from the various mixtures specified in table 5 with 15% CWP & various proportions of RHA replacement of cement and cured properly as per the specifications was measured at 7- and 28- days curing period. The results were presented in figure 6 which indicate that the maximum value was attained at 15% CWP + 10% RHA (CCWPRHA02) replacement. The flexural strength of the CCWPRHA03 mix was also equivalent to that of CCWPRHA02. Observation of test results indicate that the 28- days flexural strength value was enhanced by about 28% when compared to the control mix value. This indicates that the combination of CWP and RHA could be used up to the optimum extent for replacing cement with improvement in flexural strength. The 7- days flexural strength was also found to be less than the control mix values as similar to the compressive strength.
Figure 6. Flexural strength variation with 15% CWP and different proportions of RHA replacements for cement

4.2.4 Split Tensile Strength of Concrete. Split tensile strength of the concrete specimens made from the various mixtures specified in table 5 with 15% CWP & various proportions of RHA replacement of cement and cured properly as per the specifications was measured at 7- and 28- days curing period. The results were presented in figure 7 which indicates that the maximum value was attained at 15% CWP + 10% RHA (CCWPRHA02) replacement. The flexural strength of the mix CCWPRHA03 was also equivalent to that of CCWPRHA02. Observation of test results indicates that the 28 days split tensile strength was enhanced by about 15% when compared to the control mix value. This indicates that the combination of CWP and RHA could be used up to the optimum extent for replacing cement with improvement in flexural strength. The split tensile strength at 7- days curing period was also found to be less than that of the control mix values as similar to the compressive strength.

Figure 7. Split tensile strength variation with 15% CWP and different proportions of RHA replacements for cement
5. Conclusions
This study uses two industrial waste materials to be blended combinedly replacing a proportion of cement in concrete. Interestingly when CWP was used alone, the slump of the concrete mix increased rapidly acting as a plasticizer besides increasing the compressive strength up to 15% CWP replacement of cement which was considered to be the optimum CWP replacement. The compressive strength was found be increased by about 27% compared to that of control mix after 28-days curing. Further, the investigation was continued to replace the additional amount of cement with RHA at different proportions mentioned earlier. Addition of RHA caused the reduction in the slump which is above the actual slump of control mix concrete that could be offered by the presence of CWP. At 7 days curing period, the strength of concrete attained by replacing cement with CWP and RHA (compressive, flexural and split tensile strengths) was less compared to that of the control mix that was attributed to the RHA presence. The Compressive strength of cement rose up to 15% CWP and 15% RHA replacement of cement (30% enhancement) whereas the flexural and split tensile strengths increased up to 15% CWP and 10% RHA replacement of cement (28% and 15% respectively). Also, the flexural and split tensile strengths of the mix CCWPRHA03 (15% CWP and 15% RHA replacement of cement) was comparable to that of the mix CCWPRHA02 (15% CWP and 10% RHA replacement of cement). Based on the observation of the test results, it could be concluded that the cement can be replaced with 15% CWP and 15% RHA blending which results in strength improvement and waste utilization.

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