Influence of Waste Brick Powder on Properties of Masonry Mortar and its Impact on the Masonry Strength

P Murthi, K Poongodi and N Kottiswaran

1 Centre for Construction Methods and Materials, S R University, Warangal, India
2 Department of Civil Engineering, S R Engineering College, Warangal, India
3 Department of Civil Engineering, Info Institute of Engineering, Coimbatore, India
Email: dr.murthi@srecwarangal.ac.in

Abstract. The rapid urban development leads the exponential growth of construction and demolition waste in India. The handling and disposal strategies of building debris are not properly developed and create more threats to environment. Brick and concrete materials are the main wastes generated during demolition. As an alternate measures of recycling the brick waste, it is proposed reusing the waste brick powder particles in to the development of masonry mortar. The waste brick powder is used as cement replacement material and four different level of replacement was considered in this investigation as 5%, 10%, 15% and 20%. The strength of masonry mortar with three ratios (1:4, 1:6 and 1:8)at 7 days, 28 days and 90 days were determined. Further, the impact of innovative masonry mortar on masonry prism strength and bond strength were determined. The results obtained from this investigation had concluded that the cement can be replaced 12% to 15% by brick powder without affecting the compressive strength and shear bond strength performance of brick masonry.

1. Introduction

The solid waste management is one of the important and inevitable social task in order to avoid the environmental imbalance situation [1]. In India, a huge amount of construction activities are in progress to meet the housing needs and infrastructural demand according to the population growth and urbanization. The infrastructural development has been accounted as an important contribution in the Indian economy and amounted to more than 9% of the GDP. Owing to the rapid growth of construction sector, the demand of natural resources for construction is exponentially increased. On the other hand, construction and demolition (C&D) waste materials are generated when demolishing the existing building for re-construction or renovation works. The regulation mechanism of handling the C&D waste is not yet properly adopted and hence it develops the environmental threat [2]. The majority of the C&D waste materials are dumped in the low level areas, road side and illegally dump in rivers and water bodies. This kind of practice is naturally affecting the sustainable development of environment and causing an extra burden to the local administration on solid waste management [3]. In India, it was estimated as per the statistics presented by the Union Ministry of Urban Development that the annual construction waste generated is around 175 million tons. It is estimated that the C&D waste is accounted
as 14% of total municipal solid waste generation. The C&D waste is a composite nature which comprises of concrete, bricks, steel, timber, bitumen and a mixture of site clearance materials.

The brick and masonry waste alone is estimated as 25% - 31% of total wastes generated in C&D and found as the highest waste from C&D debris [3]. In some places, the brick residues reaches more than 50% [4]. As a part of recycling this waste brick in the form of fine powder by replacing cement without compromising the properties of concrete and mortar is an alternate way to make the sustainable concrete and mortar. The studies performed by various authors with recycling of waste bricks as lightweight aggregate [5, 6, 7] and supplementary cementitious materials in concrete [8, 9, 10]. The substitution of more than 10% waste brick powder (WBP) causes reduction of fresh concrete properties significantly. As the replacement level increases, the compressive strength of WBP blended mortar in the early period was decreased [10]. However the compressive strength of WBP blended mortar improved gradually during the later curing period and the mortar contain 20% of WBP had achieved the higher compressive strength at 90 days curing [8-10]. The pozzolanic activity of WBP and properties of WBP blended cement was investigated by Zhao et al. and concluded that while increasing the grinding time, the WBP particles refined in to spherical shape and increase the specific surface area and its pozzolanic activity [11]. Strength and durability properties of WBP blended mortars were evaluated by Schackow et al [12] and their conclusions show that the improvement in durability properties of mortar up to 40% replacement level of WBP was found as a result of combined physical and pozzolanic pore filling effect of WBP. The WBP could also effectively minimize the mortar expansion due to alkali silica reaction [13].

The partial replacement of cement by various mineral admixtures were experimented to minimize the environmental unkind effect and also reduce the utilization of natural resources. The mineral admixtures are suitably blended for making dense concrete and mortar due to the pozzolanic reaction [14, 15, 16]. Enormous research findings were published for finding the suitability of WBP as partial replacement of cement in concrete and mortar similar to other mineral admixtures. The application of WBP blended mortar in the development of masonry mortar is currently limited. However, the consumption of cement is dominant in masonry construction from rural sector to skyscrapers [17]. With this background, this investigation is intended to evaluate the impact of WBP blended cement on compressive strength and shear bond strength of brick masonry and predict the optimum replacement level of WBP without affecting the mechanical properties.

2. Experimental program

2.1 Materials

This experimental investigation utilized Portland Pozzolana cement (PPC) specified in IS:1489-1991 (Part-1) [18]. The discarded waste clay brick was obtained from the local brick chamber. The collected waste bricks were crushed and ground in to fine particles using a laboratory model ball mill. The crushed WBP was sieved using 75 micron sieve. The SEM image and EDS spectrum of cement and WBP are shown in Figure 1 to Figure 4. The physical properties and chemical compositions of cement and WBP are shown in Table 1. The grading limit of cement and WBP is shown in figure 5. The local river was employed as fine aggregate whose specific gravity of 2.67 and the fineness modulus of 2.79. Three different category of clay bricks were used and the selection of bricks was made based on the compressive strength. The strength of brick units were determined in accordance with procedure laid down in IS 3495 (Part I):1992 [19] and the mean value of 12 specimens were reported with the standard deviation and co-efficient of variations as presented in Table 2. The water absorption and efflorescence of selected bricks were determined and the results are mentioned in Table 2 [19].
Figure 1. SEM image of cement

Figure 2. SEM image of WBP

Figure 3. EDS spectrum of cement

Figure 4. EDS spectrum of WBP

Figure 5. Grading limit of cement and WBP
Table 1. Chemical compositions and physical properties of PPC and WBP

| Characteristics | OPC  | WBP  |
|-----------------|------|------|
| Chemical Compositions (%) |      |      |
| SiO₂            | 23.42| 24.57|
| Al₂O₃           | 4.87 | 2.43 |
| Fe₂O₃           | 3.78 | 0.76 |
| CaO             | 63.16| 29.16|
| MgO             | 1.85 | 1.53 |
| LoI             | 1.16 | 29.28|
| Physical properties |      |      |
| Specific gravity | 3.15 | 2.75 |
| Fineness (cm²/g) | 2950 | 3170 |

Table 2. Properties of clay bricks

| Brick | Size (mm) | Compressive strength (MPa) | Water absorption (%) | Efflorescence (%) |
|-------|-----------|----------------------------|----------------------|------------------|
|       |           | Mean | SD   | COV(%) |             |                   |
| B1    | 190 x 90 x 80 | 7.042| 0.333| 4.73    | 10.33          | Less than 10      |
| B2    | 190 x 90 x 80 | 5.708| 0.293| 5.10    | 11.87          | Less than 20      |
| B3    | 190 x 90 x 80 | 4.414| 0.221| 5.35    | 14.05          | Less than 25      |

2.2 Experimental design
The masonry mortar was developed by replacing PPC with 5%, 10%, 15% and 20% of WBP by weight of cement. Three mortar mixes (1:4, 1:6 and 1:8) were considered as a variable parameter in this investigation. The strength of control mortar specimens with 0% replacement in all the three mixes were determined to compare the impact of WBP blended masonry mortar. The mortar specimens were prepared in four different occurrence when masonry prisms were prepared and three specimens were casted in each occurrences. The mean value of 12 mortar cube specimens and its standard deviations were reported. The masonry prism and triplet specimens were prepared for finding the compressive strength and shear bond strength of masonry [20]. The height to thickness (h/t) ratio and the mortar thickness were maintained as 1.5 and 12 mm respectively. The tests for masonry specimens were tested after 7 days, 28 days and 90 days of curing period.

2.3 Testing methods
The compressive strength of masonry mortar was tested using mortar cubes of 70.7 mm size and it was determined after the curing period of 7, 28 and 90 days. The samples of the mortar cubes used in this study is shown in figure 6. The strength of masonry prism was determined using compression testing machine. The testing of masonry prism is shown in Figure 7. The mean value of compressive strength of three prism were determined and the normalized compressive strength of prism \( f_p \) were calculated considering a shape modification factor based on the slenderness ratio as per IS: 1905-1987 [21].

Normalized compressive strength of prism = shape modification factor x mean strength of prism. The shear bond strength of brick triplet was tested to evaluate the suitability of the masonry mortar.
developed in this investigation [22]. An average of three triplet results were reported and testing of triplet specimen is shown in Figure 8.

![Figure 6. Masonry mortar samples](image)

(a) Masonry prism  
(b) Testing under progress

**Figure 7. Compressive strength test on masonry prism**

![Figure 8. Shear bond strength test on masonry triplet](image)

(a) Triplet specimen  
(b) Shear bond strength test in progress

**Figure 8. Shear bond strength test on masonry triplet**
3. Results and discussion

3.1 Effect of WBP on compressive strength of masonry mortar

The compressive strength of masonry mortar mixes selected in this investigation with and without WBP after the curing period of 7 days, 28 days and 90 days are presented in Table 3. The results were obtained as the mean value of 12 specimens and hence the standard deviation (SD) and coefficient of variation (COV) were also determined in order to check the consistency in results from the mortar cube specimens casting in different occasions. Though the mortar cube specimens were prepared whenever the masonry prism casted, the uniformity of strength development was observed from SD and COV since SD varies mostly less than 0.126 MPa and COV varies less than 1.2%. It can be seen from the results that the mortar strength at 7 days curing was significantly lower than the brick unit strength due to the slow strength development of PPC in the early age. Further it can also be noted that the compressive strength of mortar at 28 days curing and brick strength were mostly identical and the stronger mortar than the brick was obtained after 90 days curing period. This strength variations of the control cement mortar can be attributed due to the use of blended cement (PPC) and it can be concluded that the prolonged curing is essential when PPC is used for masonry mortar preparation.

The impact of WBP substitution as partial replacement of PPC on the compressive strength of masonry mortar after the curing period of 28 days and 90 days are shown in Figure 9 and Figure 10 respectively. The results evidenced that the sustained compressive strength of mortar was discovered up to 15% replacement of PPC by WBP in all the proposed mortar mixes in both 28 days and 90 days cured specimens. This may be attributed to the pore filling nature of WBP and promote the hydration of available cement particle by maintaining the water requirements for chemical reaction. Sajanthan et al (2019) found that the presence of fine particle in cement-soil mortar could leads to reduce the porous nature and make the mass as dense which promotes the strength of mortar [23]. A reduction of compressive strength of mortar with more than 15% WBP was noticed and it may due to lower the reaction products in the presence of higher amount of inert particles in the mortar.

Table 3. Compressive strength of masonry mortar

| Mortar Mix | WBP Level (%) | 7 Days | CoV (%) | 28 Days | CoV (%) | 90 Days | CoV (%) |
|------------|---------------|--------|---------|---------|---------|---------|---------|
| 1:4        |               |        |         |         |         |         |         |
| 0          | 4.37          | 0.072  | 0.932   | 7.37    | 0.061   | 0.823   | 8.85    | 0.072   | 1.132   |
| 5          | 4.31          | 0.083  | 0.905   | 7.47    | 0.078   | 1.051   | 9.03    | 0.081   | 1.092   |
| 10         | 4.26          | 0.079  | 0.917   | 7.62    | 0.073   | 0.975   | 9.17    | 0.077   | 1.107   |
| 15         | 4.22          | 0.093  | 0.922   | 7.61    | 0.085   | 1.093   | 9.23    | 0.082   | 1.135   |
| 20         | 4.05          | 0.091  | 0.949   | 7.33    | 0.081   | 0.991   | 9.07    | 0.073   | 1.033   |
| 1:6        |               |        |         |         |         |         |         |
| 0          | 3.77          | 0.085  | 0.974   | 6.24    | 0.077   | 0.912   | 7.73    | 0.081   | 0.945   |
| 5          | 3.59          | 0.089  | 0.937   | 6.29    | 0.083   | 0.838   | 7.97    | 0.079   | 0.897   |
| 10         | 3.47          | 0.095  | 0.921   | 6.33    | 0.088   | 0.911   | 8.03    | 0.073   | 1.102   |
| 15         | 3.35          | 0.102  | 0.978   | 6.37    | 0.092   | 0.934   | 8.11    | 0.083   | 1.095   |
| 20         | 3.19          | 0.113  | 0.915   | 5.79    | 0.096   | 1.057   | 7.89    | 0.087   | 1.102   |
| 1:8        |               |        |         |         |         |         |         |
| 0          | 3.53          | 0.095  | 0.845   | 5.03    | 0.084   | 1.022   | 6.65    | 0.079   | 1.117   |
| 5          | 3.37          | 0.099  | 0.822   | 5.15    | 0.093   | 1.017   | 6.73    | 0.071   | 1.109   |
| 10         | 3.15          | 0.112  | 0.807   | 5.19    | 0.105   | 0.921   | 6.83    | 0.113   | 1.005   |
| 15         | 3.09          | 0.119  | 0.811   | 5.21    | 0.112   | 0.933   | 6.71    | 0.126   | 1.121   |
| 20         | 2.87          | 0.122  | 0.769   | 4.97    | 0.108   | 0.998   | 6.23    | 0.167   | 1.108   |
3.2 Effect of WBP blended masonry mortar on compressive strength of masonry prism

The effect of brick strength and WBP replacements in mortar on the masonry prism strength are shown in Figure 11 to Figure 13. From the results, it can be noticed that the curing period of the prism specimen had contributed the strength development of masonry in addition to the brick strength. The usage of blended cement can give the improvement in strength beyond 28 days in the presence of water due to the pozzolanic reaction of the mineral admixture presence in the cement. Accordingly, the compressive strength of prism after 90 days curing period had shown higher values in all the mixes considered in this investigation. The results obtained from a single mix showed that the higher strength
brick demonstrated the higher prism strength. The compressive strength of the prism when B1 bricks were used in all the mixes had shown the higher strength between the WBP replacement levels of 10% to 15%. Though the same mortar mix mortar with the optimum replacement of WBP between 10% to 15% were considered, the lower strength brick causes the significant reduction of masonry strength. The combination of the brick B1 and mix 1: 4 had shown the strength of prism at 10% WBP replacement level as 5.28 MPa at the age of 90 days and interestingly the results of the same 1:4 mortar mix and WBP replacement showed 3.79 MPa which is 28% lower. However, the reduction of prism strength due to poor mortar mix considered in this investigation (1:8) had shown less than 9% than the rich mortar mix. It can be concluded that the strength of masonry prism is governed by brick unit strength and mortar strength. As a result, the brick strength offers greater strength to the prism than the mortar. Thaickavil and Thomas [24]was found that an average of 70% in prism strength was attributed by the brick strength [12]. It may be endorsed to the bulk volume of brick offered the direct load transmission of brick masonry. The effectiveness of load transfer can be obtained by the brick-mortar bond in the masonry, however the roughness of the brick surface is credited the brick-mortar interface mechanism[25,26]. The results are validated by developing the relationship between the compressive strength of control mortar and compressive strength of prism with various brick strength as shown in Figure 14. The effect of 10% to 15% replacement of cement by WBP on the relationship between masonry strength and mortar are shown in Figure 15. The higher correlation coefficient in this relationship was noticed which showed the correctness of the relationship. It was found that the sustained compressive strength of prism and there is no negative influence on the strength of masonry prism due to the optimum usage of WBP in mortar. However, from the Figure 14 and Figure 15, it can be concluded that the compressive strength of brick unit was found to be more impact than the mortar strength in masonry.

Figure 11. Strength development of masonry prism using 1: 4 mix
Figure 12. Strength development of masonry prism using 1: 6 mix

Figure 13. Strength development of masonry prism using 1: 8 mix
3.3 Influence of WBP blended masonry mortar on shear bond strength of masonry

Masonry triplet specimens were performed to ascertain the effects of WBP in shear bond strength of masonry. The 12 mm thickness of masonry mortar was considered. The shear bond strength variation were determined and compared with the results obtained from control mortar specimens. The results obtained from 28 days cured were reported as shown in Figure16. [23,28]. The shear bond strength of masonry using the brick B1 with 1:4 control mix was determined as 0.105 MPa. With the reduction of compressive strength of brick such as B2 and B3 bricks, the reduction of shear bond strength in the
same mix was noticed. In the same way, the reduction of shear bond strength of masonry was noticed when decreasing the compressive strength mortar using 1:6 and 1:8 mixes. From the results it was found that shear bond strength values were governed by both brick strength and mortar strength in the control specimens [20].

Further, the investigation was carried out with the masonry mortar at 10% and 15% WBP replacement level of cement. From the Figure 16, it can be observed that the bond strength of brick masonry were increased significantly with the substitution of 10% WBP in the masonry mortar in all the mixes and bricks considered in this investigation. In contrast, the bond strength of 15% WBP mortar decreases than the results of 10% WBP. However, the results obtained from 15% WBP had shown almost similar bond strength compared with control mortar specimen. The effect of bond strength was also measured with the lower strength brick specimen (B2 and B3) and observed that the reduction of bond strength was found in the same mix. The results show that 10% WBP blended masonry mortar were higher in all the category of bricks and mixes. This might be attributed to the pore filling effect of WBP in the early period and contribute the strength development in the later stage with the presence of water. The higher the WBP level leads to delay the cement hydration process causes the lower bond strength of brick masonry. The low strength bricks are relatively higher water absorption in nature. It causes the reduction of water content in mortar and routes to reduce the hydration process similar to higher WBP. This physical characteristics was ascribed to reduce the bond strength of masonry.

![Figure 16. Shear bond strength variation of masonry triplet specimens.](image)

4. Conclusions
The following concluded points were obtained from this investigation:
- There was no significant variations in compressive strength of WBP blended mortar detected after 28 days curing of mortar specimens up to 15% replacement level.
- The compressive strength of brick masonry prism was influenced by both brick strength and mortar strength. However the brick strength was dominate than the mortar strength and hence the
replacement of cement up to 15% is not affecting in the compressive strength of prism though the mortar was developed by PPC.

- The relationship between the compressive strength and mortar strength was established with higher correlation coefficient in all the mixes considered in this investigation.

- The results of shear bond strength of WBP blended had shown the maximum results up to 10% replacement of PPC. However, the results of 15% WBP replacement has shown an equivalent results to the control mortar.

- It can be concluded that the PPC was replaced up to 15% by WBP and found as optimum replacement level.

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