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PERFORMANCE OF MORTAR INCORPORATING CERAMIC WASTE POWDER AS PARTIAL REPLACEMENT OF CEMENT

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ABSTRACT

As construction industry is growing larger at an extreme rate, the generation of construction waste has increased largely. Ceramic tile is one of the major solid wastes generated from construction activities. The solid wastes generated from construction causes undesirable problem so the reusability of these wastes to enhance environmental safety has drawn attention of many researchers. In this study, ceramic waste powder (CWP) from residual ceramic tile was used as a partial replacement of cement in mortars to understand the effect of CWP on the mechanical properties (compressive and tensile strength) of mortar at different curing period. Cement was replaced by CWP at percentages of 10%, 15%, 20%, 25% and 30% in relevant standard cubes and briquette molds to observe their respective strengths at 3 days, 7 days and 28 days curing. Based on the test results, it has been observed that the compressive strength and tensile strength of mortar decreases gradually with the increases percentage of ceramic waste powder (CWP). However, there is no significant reduction of strength observed up to 20% replacement of cement using CWP. The outcomes of this study suggested that up to 20% cement replacement by ceramic waste powder is feasible in mortar which consequences the reduction of cement consumption in construction.

Keywords: *Construction waste, Ceramic tile, CWP, Compressive strength, Tensile strength.*

1 INTRODUCTION

In the modern world, fast growing population has led to a large consuming requirement. To meet the consumers' need, tremendous amount production is being carried out. Large amount of production results in large amount of waste generation. A major solid waste generated from construction work is ceramic tile. Approximately 12 million m^2 ceramic tile are manufactured worldwide (Mohammadhosseini, et al., 2019). Torkittiku & Chaipanich (2010) reported that approximately 30% of ceramic production is reported to be wasted. In Bangladesh, the wasted ceramic tiles from construction work are generally dumped at roadside or around the construction area. The idea of green construction has attracted researchers to recycle and reuse the ceramic wastes in various engineering field.

In some of the solid wastes, cementitious properties were found and are being used as supplementary materials with cement (LI, Zhuo, Zhu, Chen, & Kwan, 2019). Firing clay, Feldspar and quartz are the basic ingredient of ceramic tile. The main chemical elements of ceramic tile are Silicon dioxide (SiO_2) and Aluminium Oxide (Al_2O_3). Besides, Oxides of Iron (Fe_2O_3), Calcium (CaO), Potassium (K_2O), Sodium (Na_2O) and Zirconium (ZrO_2) are also found (Asiwaju-Bello, Olalusi, & Olutoge, 2017). Ceramic waste can be grinded to form Ceramic waste powder (CWP) to use it as a partial replacement of construction material. Researches have been made to test the ability of CWP to replace binders or aggregates in concrete or mortar. In mortar CWP can be used to substitute cement, cement paste or sand as shown in Figure 1.

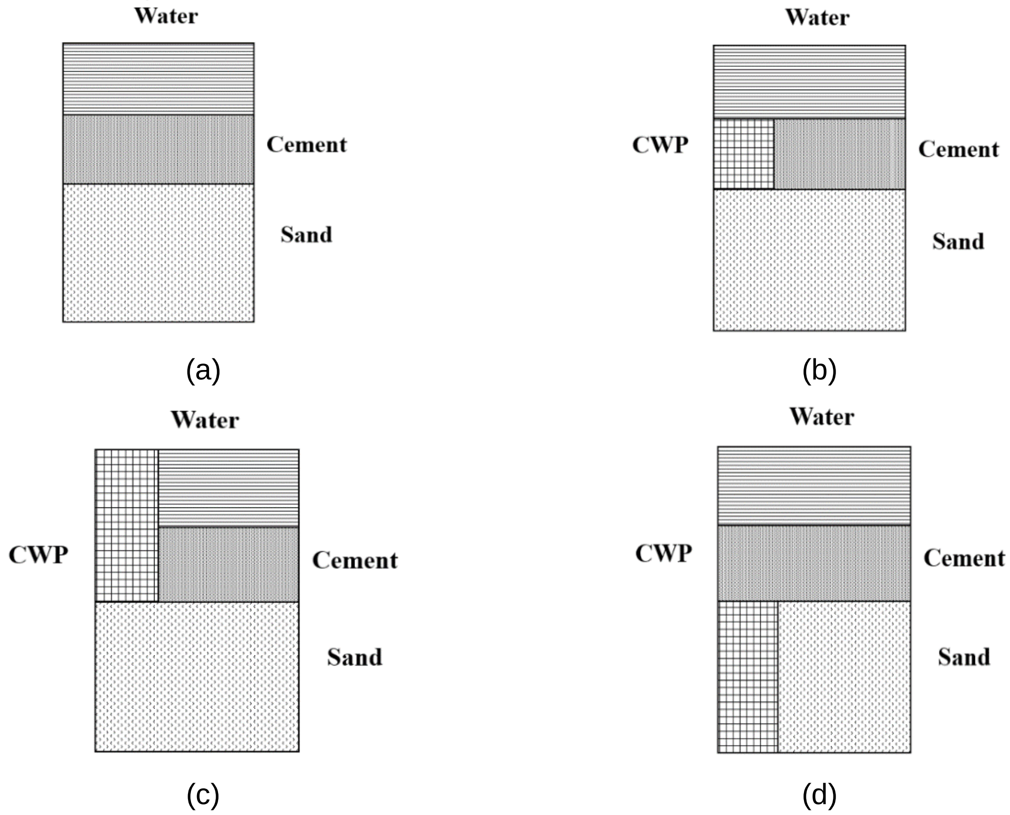


Figure 1: (a) Normal Mortar, (b) CWP replacing cement in mortar, (c) CWP paste is replacing water and cement, and (d) CWP is replacing fine aggregate.

Using CWP as replacement of cement can reduce the amount of cement used. Generally, 1 ton of Portland cement production generates almost equal amount of Carbon dioxide (CO_2) (Najim, Al-Jumaily, & Atea, 2019). It is reported that 5% to 8% of greenhouse gas emission is caused by cement manufacturing (El Dieb & Kanaan, 2018). El Dieb and Kanaan (2018) informed that ceramic waste has potential to be used as concrete ingredient but further research is required. CWP have pozzolanic activity that can contribute to concrete (Rahhul, Irassar, Castellano, Pavslik, & Cerny, 2014). According to Irassar et al. (2014) using CWP as pozzolanic material simulates hydration due to more effective water cement ratio. They also observed good pozzolanic activity after 28 days. The utilization of CWP as cement replacement can decrease thermal property but increase thermal insulation (Pokornŷ, Fort, Pavlikova, Studnika, & Pavlic, 2014). Wang and Tian (2019) showed that incorporating CWP in mortar reduced the heat of hydration and increased shrinkage. Concrete permeability can be reduced through the replacement of cement by CWP (Cheng, Huang, Liu, Hou, & Li, 2016). According to Reiterman et al. (2014), replacement of 10% cement by using CWP can reduce mechanical property of concrete by 3%. When CWP is used as replacement of fine aggregate, there is a great effect on workability due to greater water absorption properties (Matias, Faria, & Torres, 2014). Incorporation of CWP in concrete can also reduce permeability and increase durability (Bignozzi & Bondua, 2011).

In this study, an effort was made to use the CWP as binding material to replace cement. Grinded ceramic tile was used as CWP to replace different percentages of weight of cement in mortar. The main focus of the study was the effect of CWP on the mechanical properties (compressive and tensile strength) of mortar at different curing period. This research mainly accomplished to find scopes to recycle and reuse waste ceramic tiles to develop sustainable and eco-friendly construction.

2 MATERIALS AND METHODS

2.1 Ceramic waste powder

Ceramic powder was made from waste tiles. At first tiles were broken at small size. These broken tiles were put on aggregate crushing machine for hydraulic pressure (near 200kN). Then the crushed ceramics were put on "Los Angels Abrasion Machine" for 15 min. The grinded ceramics were sieved by #200 sieve as shown in Figure 2.

Fig 2: Preparation of ceramic waste powder through #200 passing

2.2 Cement

Cement is used in mortar and concrete as a binding material at huge amount. The binding of mortar depends on the binding property of cement. Ordinary Portland Cement is used in this study. The initial and final setting time of cement were measured in accordance with ASTM C191 and found 160 minutes and 285 minutes respectively, which satisfies the standard requirement (ASTM C595) for both Ordinary Portland Cement (OPC) and Portland Composite Cement (PCC).

2.3 Sand

According to ASTM C1329 blended sand needs to be used for the preparation of cement mortar. In this research, Ottawa sand was used to prepare cement mortars. The gradation of blended sand was performed in accordance with ASTM C778.

2.4 Preparation of specimen

Cube specimens (2in x 2in x 2in) with cement sand ratio of 1:2.75 were prepared for compressive strength test. Cement was replaced by ceramic waste powder (CWP) at different percentage such as 10%, 15%, 20%, 25%, and 30%. Water cement ratio was kept constant at 0.485. Total 54 cubes were prepared for compression testing. Some prepared samples for compressive strength test of mortar are shown in Figure 3(a). Nine (09) cubes from each percentage were made for 3 days, 7 days and 28 days curing. Table 1 presents the estimated amounts of materials required for three (03) 2in x 2in x 2in cubes of corresponding percentage.

Table 1: Material quantity for preparation of three (03) 2in x 2in x 2in cubes

ID	Ceramic (gm)	Cement (gm)	Sand (gm)	Water (gm)
0%	0	250	687.5	121.25
10%	25	225	687.5	121.25
15%	37.5	212.5	687.5	121.25
20%	50	200	687.5	121.25
25%	62.5	187.5	687.5	121.25
30%	75	175	687.5	121.25

For tensile strength test, 1:3 mortar was used to prepare the briquette. Here also cement was replaced by CWP at different percentage (10%, 15%, 20%, 25%, and 30%). Water cement ratio was taken 0.485. Total 54 briquettes were prepared among which nine (09) specimens from each percentage were made for 3 days, 7 days and 28 days curing. The estimated amounts of materials required for three (03) briquettes of corresponding percentage is presented in Table 2. Some prepared samples for tensile strength test of mortar are shown in Figure 3(b).

Table 2: Material quantity for preparation of three (03) briquettes

ID	Ceramic (gm)	Cement (gm)	Sand (gm)	Water (gm)
0%	0	125	375	60.625
10%	12.5	112.5	375	60.625
15%	18.75	106.25	375	60.625
20%	25	100	375	60.625
25%	31.25	93.75	375	60.625
30%	37.5	87.5	375	60.625

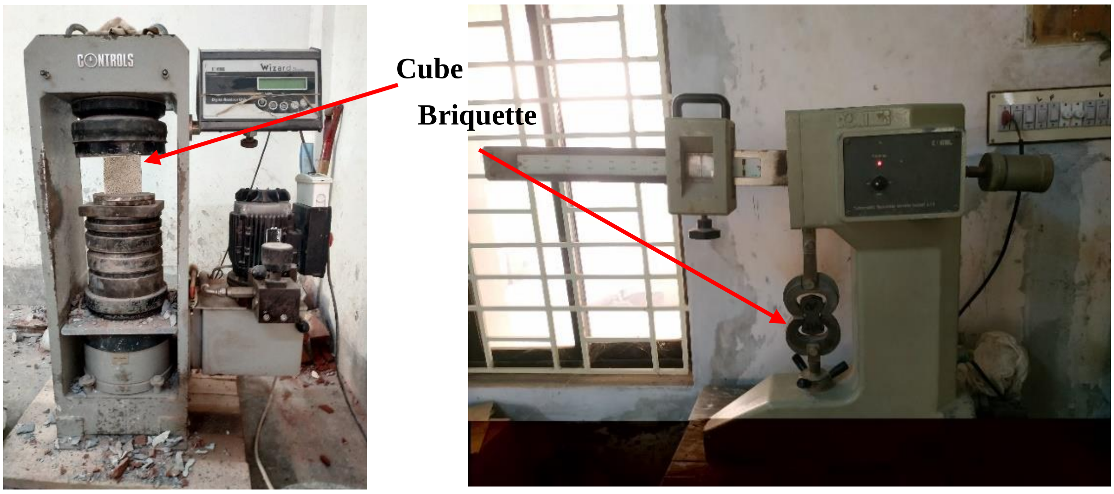
(a) Cube specimens (b) Briquette specimens

Figure 3: Prepared cube and briquette specimens

2.5 Experimental Set-up

2.5.1 Compressive Strength Test

Compressive strength test was performed according to ASTM C109. 2in x 2in x 2in cube mortar was used. Control specimens were made designated as 0%. Cement was replaced by ceramic waste powder at different percentage. 10%, 15%, 20%, 25%, and 30% of ceramic powder was used in mortar. Compressive test was done after 3days, 7days and 28 days curing. The load was applied until failure of the specimen. Figure 4(a) illustrates the compressive strength test set-up for cube specimen.



(a) Compressive strength test set up (b) Tensile strength test set up

Figure 4: Experimental Set-up

2.5.2 Tensile Strength Test

Tensile strength test was carried out in accordance with ASTM 1860. Briquette specimen was used in this test. The briquette was 3" long, 1.75" wide, 1" wide in contracted mid-section and 1" deep as per ASTM standard. Specimen without CWP is designated as control specimens. Here also, 0%, 15%, 20%, 25%, and 30% of cement was replaced by the CWP to prepare mortar. Samples were cured for 3 days, 7 days and 28 days. The tensile strength test set-up for briquette specimen is presented in Figure 4(b). The load was applied until failure of the specimen.

3 RESULTS AND DISCUSSIONS

3.1 Compressive Strength of Mortar

Curing time enhances the compressive strength of mortar as shown in Figure 5. Curing of mortar increase the binding property among the materials. Figure 5 is providing a clear evidence that compressive strength is decreasing gradually with the increasing amount of ceramic waste powder (CWP). The compressive strength for control specimen (0%) was found 17.57 MPa, 27.47 MPa and 40.24 MPa for the curing period of 3days, 7days and 28 days respectively. However, 31.23 MPa and 30.70 MPa compressive strength was gained for 25% CWP and 30% CWP respectively after 28 days curing. In the Figure 5, 25% CWP and 30% CWP specimens had gained 19.98 MPa and 19.17 MPa after 7 days curing which is very marginal according to standard. ASTM C150 reported that the minimum compressive strength for OPC cement at 3days, 7days and 28 days is 12MPa, 19MPa and 28MPa respectively. However, according to ASTM C595, the minimum compressive strength for PCC cement at 3days, 7days and 28 days is 13MPa, 20MPa and 25MPa respectively.

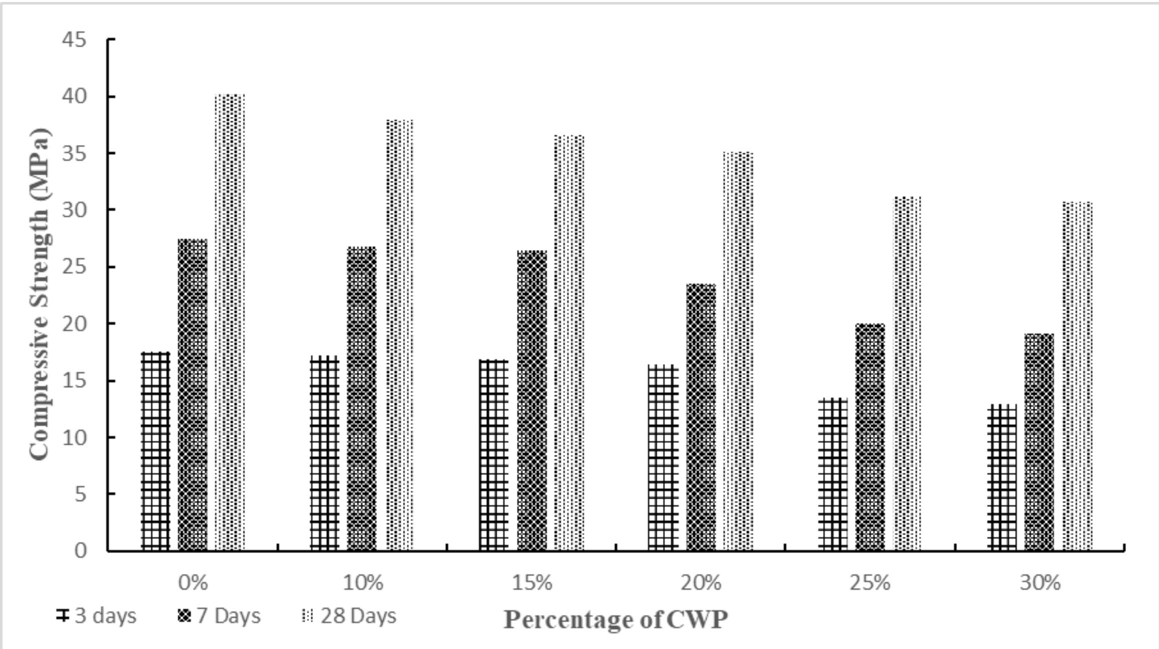


Fig 5: Variation of strength of mortar with curing time

Table 3 represents the reduction in compressive strength with respect to control specimen. Using 25% CWP in mortar results 23.24%, 27.27% and 22.38% strength reduction at 3 days, 7 days and 28 days curing respectively. The strength also decreases by 26.7%, 30.23%, and 23.7% at 3 days, 7 days, and 28 days curing correspondingly due to 30% replacement of cement by CWP. However, the reduction of compressive strength is not observed to be significant up to 20% cement replacement by CWP as illustrated in Table 3. Strength reduction may occur due to reduced proportion of binding material. The CWP induced disturbance in the binding property of cement up to a certain proportion. Compressive strength for 20% CWP containing specimen is 16.42 MPa, 23.55 MPa and 35.07 MPa for 3 days, 7 days and 28 days respectively which are fulfilling the standard requirements for both OPC and PCC cement used in construction.

Table 3: Compressive strength reduction with respect to reference specimen

Curing (days)	Strength (MPa)	Strength reduction with respect to reference specimen (%)				
	0%	**10%**	**15%**	**20%**	**25%**	**30%**
3	17.57	2.06	3.68	6.55	23.24	26.7
7	27.47	2.31	3.91	14.29	27.27	30.23
28	40.24	5.84	9.09	12.85	22.38	23.7

3.2 Tensile Strength of Mortar

The tensile strength of mortar increases with the increase of the curing period as shown in Figure 6. Figure 6 also illustrates that the reduction of strength is gradual with respect to increasing percentage of CWP. Tensile strength of control specimen was found 2.48 MPa, 2.76 MPa and 3.1 MPa for the curing period of 3days, 7days and 28 days respectively. At 28 days, the tensile strength of 25% CWP and 30% CWP containing mortar is 2.41 MPa and 2.34 MPa respectively. Table 4 represents the reduction in tensile strength with respect to control specimen. Replacement of 25% and 30% of cement by CWP cause 22.22% and 24.44% reduction of tensile strength of mortar at 28 days. It has been observed that the tensile strength reduction is not significant up to 20% replacement of cement by ceramic waste powder as presented in Table 4. Strength reduction due to using 20% CWP in mortar is 16.61%, 17.5% and 15.56% after 3 days, 7 days and 28 days of curing respectively. While 20% CWP was used in specimen, tensile strength was gained 2.07 MPa, 2.28 MPa and 2.62 MPa at 3 days, 7 days and 28 days curing respectively which can be fulfilled requirements for both OPC and PCC cement used in construction.

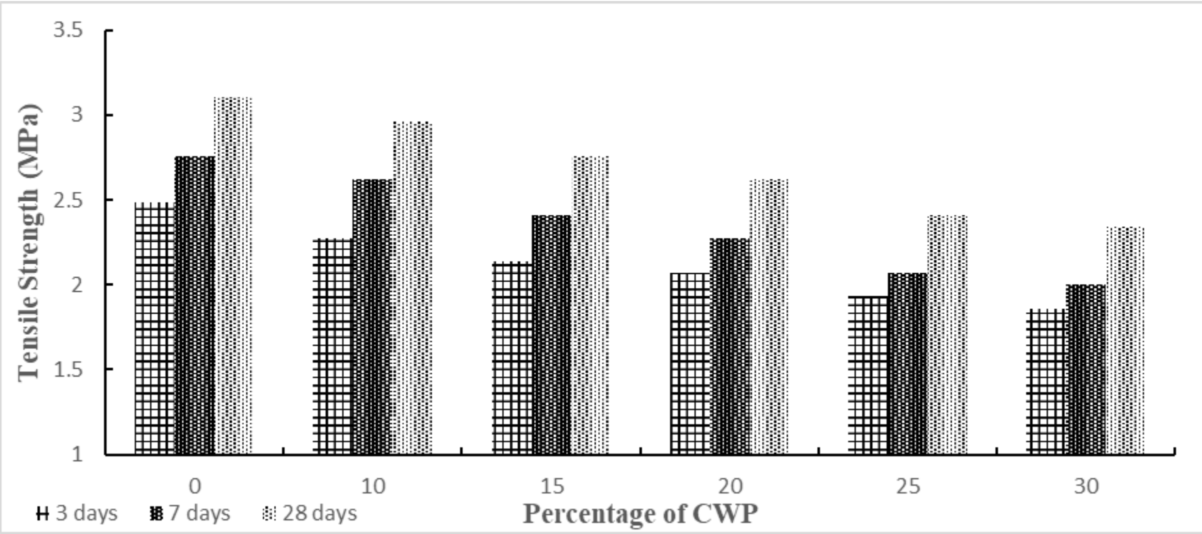


Figure 6: Variation of Tensile of Mortar with Curing Time

Table 4: Tensile Strength reduction with respect to reference specimen.

Curing (days)	Strength (MPa)	Strength reduction with respect to reference specimen (%)				
	0%	**10%**	**15%**	**20%**	**25%**	**30%**
3	2.48	8.33	13.89	16.67	22.22	25.0
7	2.76	5.0	12.5	17.5	25.0	27.5
28	3.10	4.44	11.11	15.56	22.22	24.44

4 SUMMARY AND CONCLUSIONS

Construction waste management is one of the major concern for sustainable construction. Ceramic is widely used in construction. This study emphases on reusing of broken ceramic tiles in the form of ceramic waste powder as binding material to replace cement. Grinded ceramic tile was used as CWP to replace different percentages of weight of cement in mortar. The main focus of the study was to investigate the effect of CWP on the mechanical properties (compressive and tensile strength) of mortar at different curing period. Based on the compressive and tensile strength of mortar, it can be concluded that there is no significant reduction of strength up to 20% replacement of cement using CWP. Moreover, when desirable strength can be gained in mortar or concrete by effective replacement of cement using CWP, then it would be economically beneficial as well as environmentally friendly. Therefore, it is recommended that up to 20% cement replacement by ceramic waste powder is feasible in mortar which consequences the reduction of cement consumption in construction. In excess of the study, micro-structural characterization can provide better understanding of the binding property of CWP.

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