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Improvement of the Cement Mortar Properties using Recycled Waste Materials

Dalia Adil Rasool[1*], Mais A. Abdulkarem[2*] ,Manal Hamed Jasem[3]

Materials Engineering Department, College of Engineering, Mustansiriayah University, Baghdad, Iraq.

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ABSTRACT

Ceramic tiles as well as brick waste materials from building demolition and black tea waste have caused major environmental issues. As a result, one of the primary objectives of sustainable solid waste management is maximizing their reusing and recycling potential. Therefore, the major goal of this work is to assess the efficacy of using a mixture of waste materials brick powder, ceramic tiles powder, and black tea as a partial substitution for fine aggregate and cement in mortar that was mixed with a 1:3 ratio and a W/C ratio of 0.5. In this work, the cement was substituted by black tea in proportions of 2.5%, 5%, 7.5%, and 10%, while the fine aggregate has been replaced through waste brick powder and ceramic tiles powder in proportions of 0%, 5%, 10%, 15%, and 20% by weight of the mortar mixture. The flexural strength, compressive strength, density and absorption values of the mortar mixtures have been specified in this work. The major findings of this study revealed that in the mortar mixture, cement and fine aggregate might be replaced partially by brick powder, ceramic tiles powder, and black tea, with the best ratio of replacement being M3[(15% brick powder and ceramic tiles) +(7.5% black tea)]. The flexural and compressive strength values increased by adding the modifier brick powder, ceramic tiles powder and black tea, while the density and absorption were reduced. As a result, in order to equilibrium between the environmental sustainability and construction demand, building waste must be utilized.

Keywords: Ceramic tiles, materials wastes, black tea, cement mortar, brick clay, compressive strength, water absorption, density.

1. INTRODUCTION

The industry of construction is accountable for the depletion regarding several non-renewable resources as well as the leaving a considerable volume of industrial waste materials [1]. The use of demolition and industrial buildings waste as partial replacements with regard to fine aggregate and cement in cement mortar and concrete mixture could decrease the demands for natural resources through recycling such wastes as modified materials, the need for economical and safe construction materials [2-3]. Cachim [4] studied the mechanical characteristics regarding hardened and fresh concrete that is made with crushed brick at 15% and 30% replacement levels and 0.45 and 0.50 water cement ratios. According to the author, crushed bricks could be substituted up to 30% with a strength reduction and up to 15% without causing a strength drop. Beemamol et al. [5], utilized ceramic tailing waste sand to replace fine aggregate by 50% and 100%. In addition, fly ash is replacing cement in construction mortar by 25%. The use of ceramic waste sand reduces shrinkage and permeability while increasing durability. Mostafa Samadia et al. [6], looked into the impact of ceramic powder as a cement substitute on the morphology and strength of cement mortar.

*Corresponding author: maisabdulRahman@uomustansiriyah.edu.iq, daliaadilalalali84@uomustansiriyah.edu.iq

Ceramic powder has been used to replace cement from 0% to 60% of the total weight of cement. It was discovered that replacing ceramic powder with 40% yielded the maximum strength. Also, it was discovered that using ceramic powder enhances the mortar's microstructure and strength. Crushed clay brick was utilized by Said Kenai and Farid Debib [7] to partially replace by 25% to100% of coarse and fine aggregates in concrete. The results indicated that coarse aggregate substitution levels of 25% and fine aggregate substitution levels of 50% were reported. Mohammed et al. [8] investigated how to recycle black tea waste ash (BTWA) as a partial substitute for the cement. The experiment was conducted with cement mortar mixes which contain 5 replacement levels of BTWA 0%, 2.5%, 5%, 7.5%, and 10% by weight. The values for compressive strength have been enhanced. At replacement levels of 5%, 7.5%, and 10%, the BTWA had a bad effect on mortar flexure strength. Zheng et al. [9], investigated the impact of recycled brick powder as a partial substitute for the cement in the cement mortar 10 – 30 %. According to the results of the tests, recycled brick powder might be utilized as a partial substitute for cement in mortar without the reduction of its qualities In Iraq, the solid wastes which included ceramic tile , brick produced from demolitions of construction and black tea are resistant to biological, chemical and physical degradation forces and not biodegradable. These large quantities of waste go to landfills without any benefit or recycling. Additionally, landfills are considered as one of the biggest problems faced by the Iraqi government. Thus the main objective of this research is to reduce environmental pollution and sustainable natural resources by recycling these waste materials. The novelty of the research is the usage of hybrid wastes from synthetic and natural waste materials to offer additional information in the field of developing the mortar mix. The fine aggregate is replaced by brick waste and ceramic tiles (synthetic waste), while cement is replaced by black tea waste (natural waste) to explore the possibility of employing these recycled materials and its impact on mortar mixture.

2. EXPERIMENTAL DETAILS

2.1 The Materials

i. Cement: The specimens for the presented work were made with Iraqi ordinary Portland cement. The chemical parameters of fine aggregate, cement, and brick powder have been verified to IQ.S (No5/1984) where Table 1 and 2 show their physical characteristics [10].
ii. The fine aggregate: The fine aggregate employed in this work came from Al-Nabaey region. Table1 shows the grading of the fine aggregate that corresponds to IQ.S (No45/1984), zone 3 specifications [11].
iii. Ceramic tiles: The ceramic wastes resulting from the building's demolition were immersed in water for 24 hours, then dried and crushed, followed by milling the crushed particles to obtain particles which cross from the sieve 1.18 mm, replacing fine aggregate. The chemical characteristics of these ceramic tiles are shown in Table 1.
iv. Clay brick: The use of brick waste from building demolition, where bricks were immersed in water for 24 hours, after that dried as well as crushed to obtain particles that pass through a sieve of 1.18 mm, replacing fine aggregate. The chemical characteristics regarding brick powder are shown in Table 1.
v. Black tea waste: Black tea wastes were collected from domestic use. Also, the black tea wastes were dried and replaced with cement. Table 1 shows the chemical characteristics of black tea wastes.

2.2. Mixture proportioning

The mortar mixtures have been made with Portland cement, fine aggregate which was mixed with a ratio of 1:3 and w/c ratio of 0.5 as can be seen in Table 3. The modified mortar's specimens were obtained by substituted the cement by black tea in proportions of 2.5%, 5%, 7.5%, and 10% while the fine aggregate has been replaced through waste brick powder and ceramic tiles powder in proportions of 0%, 5%, 10%, 15%, and 20% by weight of the mortar mix simultaneously.

Table 1 The chemical compound of cement, fine aggregate, ceramic tiles, brick powder and black tea waste

Chemical Compound	Cement (%)	Fine aggregates (%)	Ceramic tiles (%)	Brick powder (%)	Black tea waste (%)
Magnesia, MgO	3.62	0.81	3.6	3.74	2.15
Lime, Cao	64.53	5.4	3.64	9.99	11.14
Ferric oxide, Fe2O3	2.95	0.59	1	5.67	0.37
Alumina, Al2O3	4.58	0.5	31	13.7	0.79
Silica, SiO2	19.51	83.52	65	48.7	0.83
Sulfuric Anhydride, SO3	0.97	2.67	-	0.21	0.44
Loss on Ignition	4	5.56	-	13.4	75.02

Table 2 The physical properties of cement

Properties	Results
Soundness (Autoclave Method), %	0.09
Specific Gravity	3.34
Compressive strength, MPa 3 days 7 days	 25.13 34.6

Table 3 Mix proportions of the modified waste –cement mortar mixtures

Proportion Mix. % (Ceramic & Brick)+ Black tea		Cement (gm)	Fine aggregate (gm)	Waste Materials		W/C
				Ceramic& brick from fine aggregate	Black tea by from cement	
M0	0%	250	750	-	-	0.5
M1	5%+2.5%	243.75	712.5	37.5	6.25	0.5
M2	10%+5%	237.5	675	75	12.5	0.5
M3	15%+7.5%	231.25	637.5	112.5	18.75	0.5
M4	20%+10%	225	600	150	25	0.5

3. Tests Methods

3.1 Compressive Strength

The test has been carried out based on ASTM:C109M-07e1 [12] using 50×50×50 mm testing cubes. The testing cubes were examined using a compressive digital machine (ELE-Auto test) with a capacity of 200 KN. The test was conducted after ageing for 28 days.

3.2 Flexural Test

Modulus of rupture was tested by using 40×40×160 mm prism prepared according to ASTM C-192. In the design codes, the flexural strength is typically expressed as rupture modulus (σ). This test shows the importance of bends and breakage that occurs in the material:

$$\sigma \text{ (flexural strength)} = 3PL/(2bd^2) \quad (1)$$

where:

P= load (force) at the fracture point (N), L= length of the support span
b= width, d= thickness

3.3 Water Absorption Test

According to ASTM C642-97[13], the water absorption has been specified through drying specimens in oven with 100° -110°C temperature for a 24h period, cooled in room temperature then weighed. In addition, the specimens have been immersed in the water at 20°∓5°C for a period of 28 days. Furthermore, the specimens have been weighed after drying their surfaces with a towel. Water absorption has been estimated based on the following equation:

$$\text{Water absorption} = \frac{\text{Weight after immersion (Kg)} - \text{Dry weight (Kg)}}{\text{Dry weight (Kg)}} \times 100 \quad (2)$$

3.4 Density Test

The density g/cm3 of the cement mortar cubes was determined by weighing the cubes and dividing the values (mass in grams) by volume 50×50×50 mm.

4. Test Results and Discussion

4.1 Compressive strength

A compressive strength study was carried out on 50mm cube specimens at the ages of 7and 28 days through compressive testing machine. Each batch of mixture had 3 samples to obtain an average of compressive strength. It can be seen from Figure 1 that the compressive strength of reference was improved by the replacement with ceramics, brick waste & black tea waste together for all curing ages, where the increased ratio of compressive strength to the control mix was, respectively, 6.42%, 12.45%, and 22.56% for M1, M2, and M3 mixtures at 28 days. This may be attributed to pozzolanic reaction [14]. SiO_2 reacts chemically with alkalis in cement and form a cementitious product that contributes to the strength development, due to the very fine powder of ceramics waste and brick waste and, also, they may be effectively filling the voids and giving rise to dense mortar microstructure. Tea waste also improved the compressive strength where it increased with the increasing of tea waste content in the mix, but it started to decline after M3 by weight at all curing ages but it was still higher than that of the reference. This may be due to the lack of plasticity of the fresh mixture as a result of increasing of added materials waste percent that causes the air voids to be increased within the matrix (difficulties in compaction) and thus leads the compressive strength to be reduced.

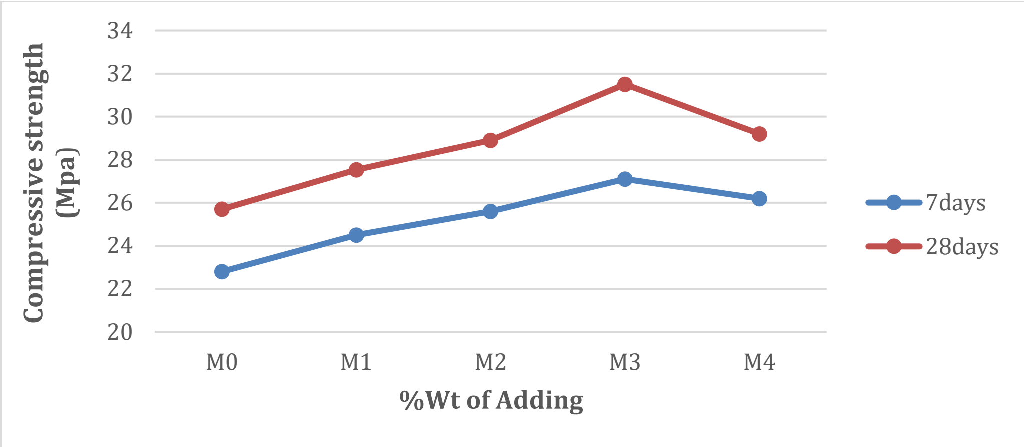

Figure 1. The compressive strength of mortar mix ceramic tiles powder, brick powder and black tea waste at 7 and 28 days

4.2 Flexural strength test

Flexural strength study was carried out on 40mm×40 mm × 160 mm bar specimen at the ages of 7and 28 days. The flexural strength for reference was improved by the replacement of M3 by weight materials waste as well as it tends to increase with increasing curing age from 7 to 28 days. The maximum value of flexural strength was 12.87Mpa at 28 days. This shows that significant pozzolanic reaction had taken place during this period of time. After M3 the reduction of the flexural strengths of the curing could be due to a lower development of the bond between the aggregates and the cement paste when materials waste is used. This behaviour may be attributed to the role of the materials waste in reducing the plasticity of fresh mortar, so, the escaping of air voids is restricted during compacting and consequently lead to weakness of the interfacial transition zone. These findings are in agreement with J. Martina and M. Usha Rani [15].

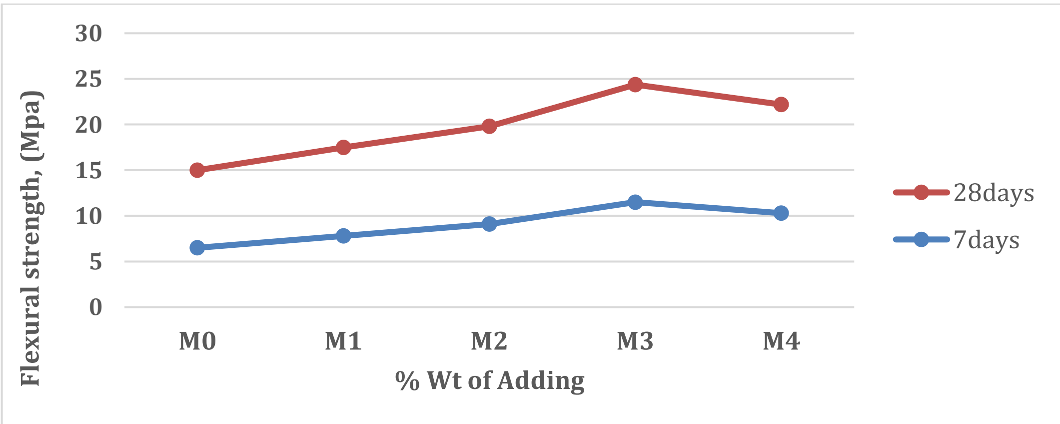

Figure2. The flexural strength of mortar mix ceramic tiles powder, brick powder and black tea waste at 7 and 28 days

4.3 Density test

Figure 3 shows results of the density of mortar, which decreased with the increase in the proportion of additives ceramic tiles powder, brick powder and black tea waste. Typically, density is backward proportional to replacement, because the additives ceramic tiles, brick powder and black tea waste have less specific gravity compared to fine aggregate. This may indicate that the materials waste in the mortar is contributing on the C-S-H gel formation in the mortar due to the pozzolanic reaction. However, the density tends to decrease from replacement of the materials waste in mortar as shown in the same figure. It is probably due to the higher percentage of additive to make binding with the sand particles which results in voids in the sample and thus decreasing the density of the mortar.

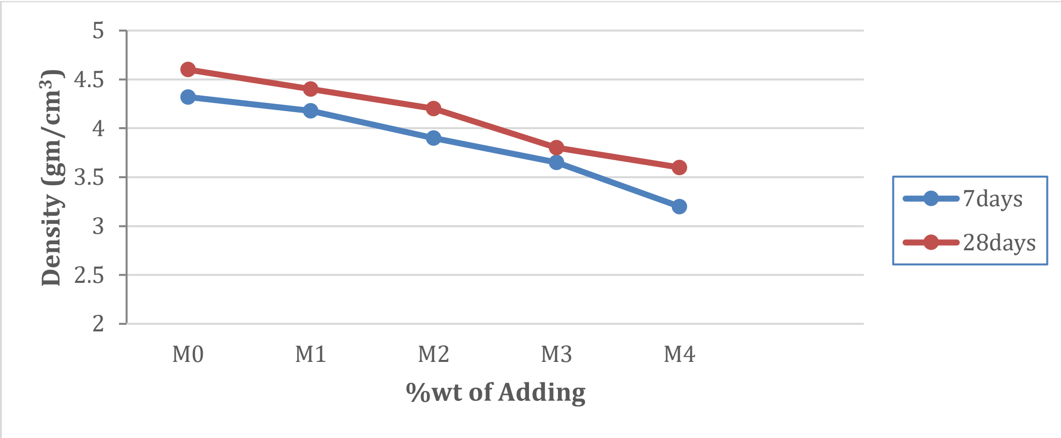

Figure 3. Effect of density of mortar mix ceramic tiles powder, brick powder and black tea waste at 7 and 28 days

4.4 Water Absorption

The water absorption of mortar specimens has been measured after 7 and 28 days of curing. The addition of ceramic tiles powder, brick powder and black tea waste decreases the water absorption compared with control specimens due to the additives filled the void between the particles of cement mortar. In general, superior protection of reinforcement additives within composite materials is achieved when water absorption is minimal. This reduction in water absorption and water accessible porosity is attributed to the pozzolanic reaction of brick waste, ceramics waste which can refine the pore structures and decrease in the connectivity. The transport of water is governed by factors like pore connectivity and pore size distribution, other than water accessible porosity, indicating that pozzolanic reaction can refine the capillary pores for water transport due to more fineness property of particles than cement and the capacity of the pozzolanic towards fixing $Ca(OH)_2$ generated during the reactions of hydration of cement.

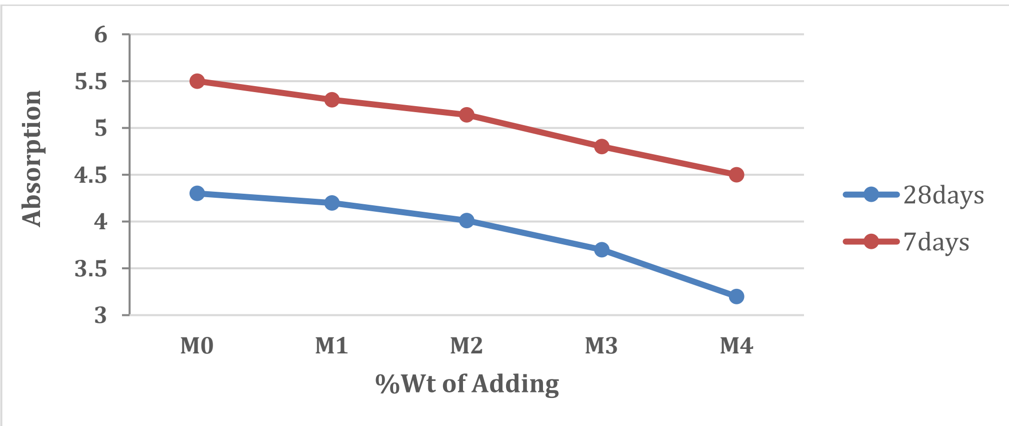

Figure 4. Effect of absorption of mortar mix ceramic tiles powder, brick powder and black tea waste at 7 and 28 days

5. CONCLUSION

The impact of using wastes mixed brick powder, ceramic tiles powder and black tea waste as partial substitution materials for cement and sand at the same time on the mechanical properties related to the cement mortar was investigated in this work. The following are the key conclusions according to the results of the experimental work for the conventional and waste modified cement mortar:

1-The inclusion of brick powder, ceramic tiles powder, and black tea waste improves the strength at 28 days, with the largest improvement 22.56% obtained for samples with M3 [(15% brick powder and ceramic tiles) +(7.5% black tea)] as partial substitutional materials of fine aggregate and cement by mortar mix weight concurrently.

2- The ideal replacement percentage was M3 [(15% brick powder and ceramic tiles) +(7.5% black tea)] %). Above this ratio, the results of cement mortar tests began decreasing due to the weak bonding regarding cement mortar components as replacement percentages increase.

3- For a 28-day period, the flexural strength of mortar mixes modified with (brick powder, ceramic tiles powder, and black tea waste) was high compared to that of control samples. These improvements are approximately 51.41% at M3 [(15% brick powder and ceramic tiles) +(7.5% black tea)].

4- When brick powder, ceramic tiles powder, and black tea waste are added, the absorption ratio and density decrease, resulting in improved water insulation of cement mortar mixture.

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