Journal of Sustainable Cities and Built Environment (JSCBE)

Original Article

Compressive Strength Evaluation of Cured Cement Mortar including Rubber, Foam, Plastic, and Paper Wastes as Partial Replacement with Sand

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Abstract

Waste materials pollution has instigated a serious environmental problem for decades, therefore new initiatives have been taken around the world to recycle wastes into construction materials in recent years. This study applied the compressive strength as one of the key parameters to examine the characteristics of materials, it was conducted to investigate the efficiency of adding different waste materials to cement mortar mixture as partial replacement with sand. Crumbed rubber, expanded polystyrene (foam), shredded wastepaper, and shredded plastic bags were selected to examine the efficiency of adding them to cement mortar. These waste materials were mixed individually with cement, sand and water proportionally. The produced mixture of each waste materials was casted in standard cubes and cured in water for different ages 3, 7 and 28 days. The compressive strength of the cured cubes was tested, the results showed that over all tested ages, plastic-based mortar provided the lowest compressive strength variance values by -7.4, -6.7%, and -5.4% in comparison with tested reference mortar. Rubber-based mortar showed the highest variance by -58.5 % at 3 days, -58.3% after 7 days and -55.5 % after 28 days. Foam comes next to Plastic-based mortar then Paper-based mortar by -13.7 & -37 % after 3 days, -11.3 & -34 % after 7 days and -14 & -26 % after 28 days respectively. In comparison to ASTM C129, the results ranges supported the possibility of using cement mortar mixed with shredded plastic, foam and shredded wastepaper in producing non-loadbearing concrete masonry units.

Keywords: Cement Mortar; Compressive Strength; Rubber; Foam; Plastic and Paper Wastes; Recycling

Citation: Elbialy, S. (2023). Compressive Strength Evaluation of Cured Cement Mortar including Rubber, Foam, Plastic and Paper Wastes as Partial Replacement with Sand. Journal of Sustainable Cities and Built Environment, 01(01), 24-33. Retrieved from http://jscbe.ku.edu.bh

DOI: https://doi.org/10.58757/jscbe.cseccmir.002

Publisher: [KU] Kingdom University.

Editor-in-Chief: Dr. Ashraf M. Soliman

Managing Editor: Dr. Adeb Qaid

Received: 19 December 2022

Accepted: 05 January 2023

Published: 25 January 2023

1. **Introduction**

Currently, recycling of waste materials is a crucial process that affects both the environment and the economy which is mandatory to protect and preserve the planet for future generations. Globally, paper & cardboard, plastic, and lather & rubber waste are generated by 17%, 12%, and 2% of the total solid waste respectively [1]. The growing consumer population and the growth of non-degradable waste products have led to a waste disposal problem creating an economic and environmental challenge [2]. Bahrain has one of the highest waste generation rates per capita, an annual amount of 1.2 million tons of solid waste is produced by the county yearly [3]. Managing this rapidly growing waste stream cost-effectively and sustainably is a major environmental concern which plays a critical role in the sustainability of economic, social, and environmental factors [4]. Recently, recycling companies had consultations about waste management that support and strengthen the concept of reusing materials. Recycling waste into useful products can help solve this crisis by reducing economic and environmental issues associated with waste disposal and reducing natural resource depletion [5]. Many studies (e.g., [6], [7], [8], [9], [10], [11], [12], [13]& [14]) have demonstrated the possibility of using plastic waste aggregates in place of sand/gravel or cement additive in concrete/mortar. Moreover, other researchers used fly ash to reduce the exothermic reaction between cement and water by replacing Portland cement [15]. Alsalami has studied the effect of adding pistachio shells as partial replacement of sand on the density, absorption, and compressive strength of mortar [16]. Recycling of paper waste has been investigated in many studies; it was concluded that paper waste can be used to prepare plastering mortars with low energy consumption and non-polluting technology [17]. Additional studies used crumb rubber in mortar mix, the results showed that crumb rubber mortar has long-term durability, while there have been differences in its material properties, the studies concluded that it can be used as a construction material in tough environments [18]. Other waste materials such as steel slag was applied as a partial replacement of sand to study the variations in compressive strength after 14 and 28 days of water curing [19]. Furthermore, different waste materials were combined together; waste bottle glass nanoparticles mixed with ground blast furnace slag and fly ash to achieve high-strength alkali-activated mortars [20]. Overall, it is critical to understand how cement mortar behaves when mixed with waste materials in order to optimize recycling and waste reduction. Studying mortar properties is critical to ensure good performance of masonry structures, as mortar is responsible for dividing stresses in building structures [21]. The compressive strength describes the ability of materials to carry loads, which gives an idea of the characteristics of building materials [22]. In this study, the author used the compressive strength as a parameter to examine the possibility of substituting different waste materials as a partial replacement of sand in cement mortar. Among the most common waste materials, four types were selected for mixing with cement mortar individually: paper, foam, plastic bags, and pulverized rubber from damaged tires. The measured compressive strengths of the cement mortar mixed to the applied waste materials were compared to the reference cement mortar (without adding waste materials). This may contribute to reducing wastes and maintaining a cleaner environment. Furthermore, it provides new innovative ways of producing green building.

2. Materials and Methods

2.1. Applied Materials

The applied materials in this study are ordinary Portland cement (ASTM C-150 Type-I) [23], fine aggregate (sand) passing through 2.36 mm sieve and four waste materials; crumbed rubber obtained from scrap car tires sized into 3-5 mm, expanded polystyrene (foam) collected from electronic store wastes and crushed into 3– 8 mm particles, shredded wastepaper spreader into 3 by10 mm peace, and shredded plastic bags sliced into 3 by 10 mm. The applied waste materials are illustrated in Figure 1. The density of each waste material was determined experimentally by dividing the mass of the material filling a standard box of 0.3mx0.3mx0.07m dimensions by the volume of the box of 0.0063 m3. These waste materials were mixed individually using a concrete mixer machine with cement and sand in a weight-based ratio of 1:2:1 (cement: sand: waste material) and constant water to cement ratio w/c of 0.40 [24]. Another reference mortar with no waste materials was prepared using cement and sand in a weight-based ratio of 1:3 (cement: sand) and 0.40 w/c ratio. The prepared mortar mixes are listed in Table 1. The mixtures were casted in three well compacted layers sequentially and vibrated using vibrating table machine (Figure 2) through the molding in standard cubes of 70.6 x 70.6 x 70.6 mm dimensions.




Rubber Foam Paper Plastic

Figure 1. The experimented waste materials.

Table 1. Mortar mix proportions

Mortar mix	Density of waste material (kg/m^3)	Wet mix proportions per cubic meter (kg)		
		Cement	Sand	Waste material
Reference cement mortar	-	1050	3150	0
Rubber-based mortar	450.0	1050	1575	170
Paper-based mortar	120.32	1050	1575	45
Plastic-based mortar	49.5	1050	1575	18
Foam-based mortar	15.0	1050	1575	5.7

Figure 2. vibration process

2.2. Compressive Strength Test

The essential purpose of this work was to assess the feasibility of using waste materials as mixing material in cement mortar by testing the compressive strength of the produced mixture. For this study, a total number of 45 specimens were prepared to examine their compressive strength after 3, 7 & 28 days with curing. Nine cubes of reference mortar and nine cubes of each mortar mix combined with one of the applied four waste materials were cast as illustrated in Figure 3. The cubes were demolded after 24 hours and cured in a potable water tank for 3, 7 & 28 days as in Figure 4. The water inside the tank was changed each week routinely to avoid any probable pollution.

a. Plain mortar b. Mixed mortar with waste materials.

Figure 3. The experimented mortar cubes.

Three cubes were tested for each casted set of cubes to investigate the compressive strength using a standard universal testing machine (Figure 5) at each tested age. The compressive strength of the mortar cubes was tested according to ASTM C109 [25]. The load on a cube was applied at a uniform rate of 0.15-0.35 N/mm² per second. An average value is calculated from the observed values of three specimens for higher accuracy of the compressive strength tests.

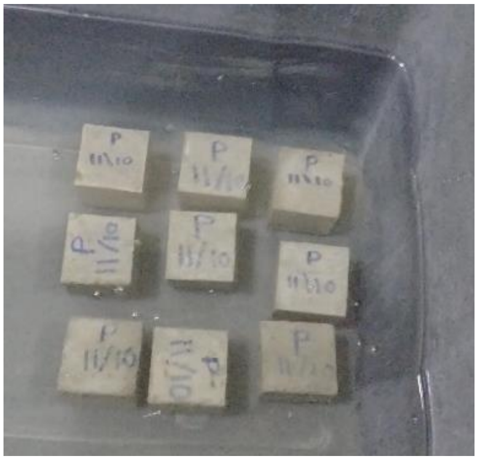

Figure 4. Curing process

Figure 5. The testing machine

3. Results and Discussion

After proper curing, mortar cubes were tested for compressive strength at 3, 7 and 28 days. The compressive strength of the cured mortar cubes was calculated by dividing the crushing load applied to the cube (in Newtons) over the cross-sectional area of the cube (70.6 mm x 70.6 mm). The collected average values at each age are listed in Table 2 and shown in Figure 6.

Table 2. Compressive Strength at testing ages.

Mortar mix	Average Crushing Load (KN)			Average Compressive strength (N/mm²)		
	3 days	7 days	28 days	3 days	7 days	28 days
Reference	36	40	42.67	7.35	8.16	8.71
Plastic	33.33	37.33	40.33	6.80	7.62	8.23
Foam	34	36.33	36.67	6.34	7.24	7.48
Rubber	15.1	16.67	19	3.05	3.40	3.87
Paper	22.67	26.33	34.67	4.63	5.37	6.45

Overall tested ages, the compressive strength of all the types of the mortars contain waste materials was decreased in comparison to the reference mortar. There was a good match between the recorded results and findings in many of the literatures such as [14], [17] & [18]. Plastic-based mortar provided the lowest compressive strength variance values by -7.4, -6.7%, and -5.4% in comparison with the reference mortar. Rubber-based mortar showed the highest variance by -58.5 % at 3 days, -58.3% after 7 days and -55.5 % after 28 days. Foam-based mortar comes next to Plastic-based mortar then Paper-based mortar by -13.7 & -37 % after 3 days, -11.3 & -34 % after 7 days and -14 & -26 % after 28 days respectively. The analyzed variance values are illustrated in Figure 7. In terms of compressive strength, the results show that plastic wastes perform better than other tested waste materials however, foam and paper provided reasonable variances compared to the plain/reference mortar. In addition, it was recorded that the curing process increased the compressive strength of all mortar types except for the rubber-based mortar in which the increase of compressive strength was nearly constant; it ranged from 3.1 N/mm² at 3 days to 3.8 N/mm²at 28 days by 2 % increasing rate. On contrast the compressive strength of the paper-based mortar was increased by 39 %. However, the studies concluded that rubber-based mortar can be used as a construction material in tough environments [18].

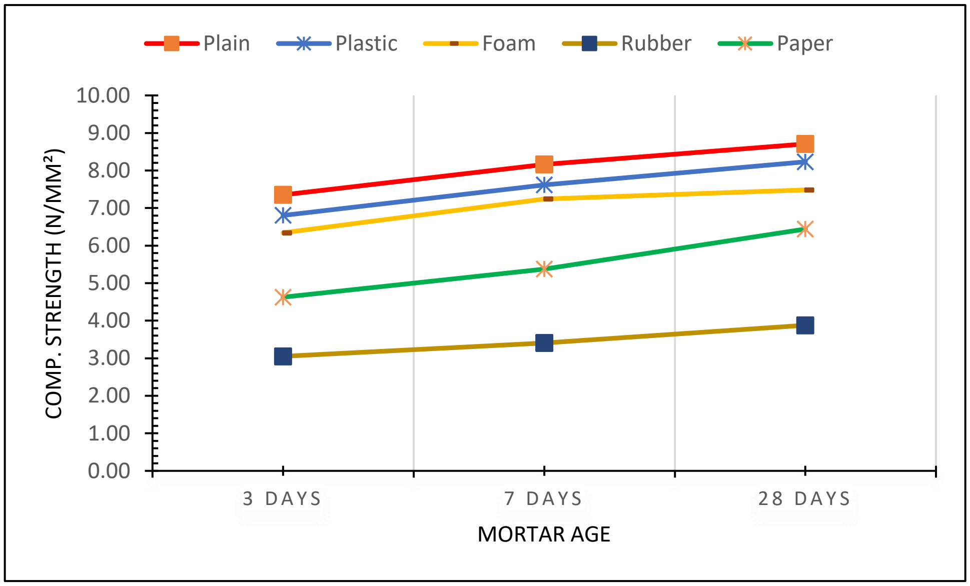

Figure 6. Compressive strength of mortar mixes at tested ages

As per ASTM C129 [26] which covers the hollow and solid non-loadbearing concrete masonry units, used in nonloadbearing partitions, the required compressive strength is 3.45 N/mm² for an individual unit and 4.14 N/mm² average for three units which meet the obtained compressive strength results of the Plastic, Foam and Paper mortar mixes after 28 days as listed in Table 2.

Accordingly, the results show that the possibility of using the mortar mixed with shredded plastic, foam and shredded wastepaper in producing specific types of CMU based on the mix density.

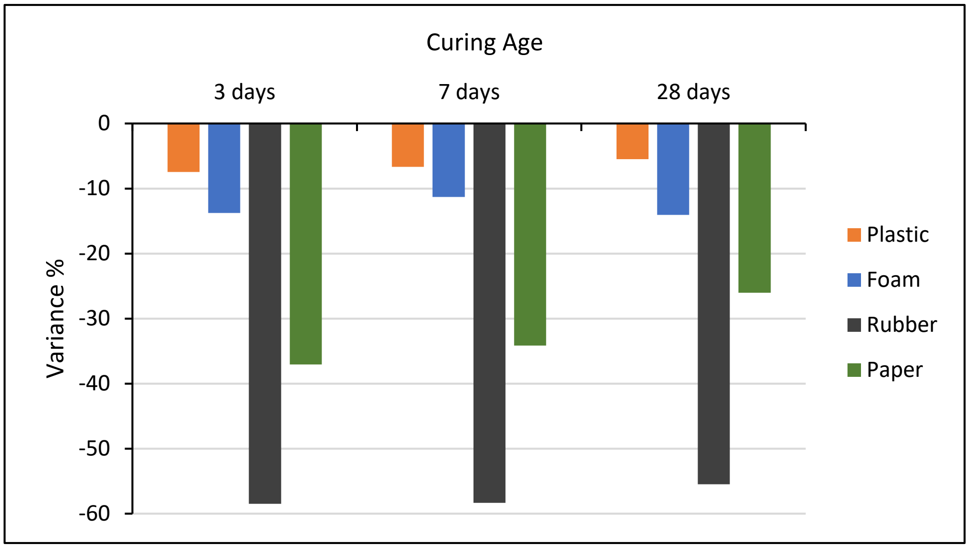

Figure 7. Compressive strength variance in comparison to the reference mortar.

4. Conclusion

In this study, experiments were conducted to assess the compressive strength of the cured cement mortar when waste materials were partially substituted for sand. Crumbed rubber, expanded polystyrene (foam), shredded wastepaper, and shredded plastic bags were selected for this purpose. In comparison with the reference mortar, the tested compressive strength of the cured mortar cubes showed that over 3, 7 and 28 days, plastic-based mortar provided the lowest compressive strength variance values and the rubber-based mortar presented the highest variances. Foam comes next to plastic-based mortar then paper-based mortar. Moreover, over all mortar types, curing increased the compression strength of the tested cubes except for mortar-rubber mixes, which experienced slight increases.

It is recommended based on the presented results to use mortar mixes including shredded plastic, shredded plastic and foam wastes in particular construction purposes such as non-load bearing and light weight concrete block. Conversely, rubber-based mortar showed the lowest compressive strength records that did not meet ASTM C129 standards. Extra investigations are needed to examine different mixture content ratios of cement mortar to waste materials and w/c ratio.

Furthermore, it is recommended to investigate the effect of curing process on the compressive strength of rubber-based mortar containing rubber wastes less than 50% of sand content.

Acknowledgments The Author acknowledge support given by Eng. Moath Majdi Zaki, the laboratory technician at Kingdom University. His collaboration during the experimental tests of this study was greatly appreciated.

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