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An Experimental Investigation into the Mechanical Performance and Microstructure of Cementitious Mortars Containing Recycled Waste Materials Subjected to Various Environments

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ABSTRACT: This paper deals with an experimental investigation into the mechanical performance and microstructure characteristics of cementitious mortars containing recycled waste materials subjected to acidic, neutral, and alkaline environments. The recycled waste materials include glass, eggshell, iron, and rubber powder in various amounts, namely 7, 14, and 21% by volume, as the replacement for ordinary Portland cement (OPC). In this respect, to examine the mechanical performance of the specimens, the compressive, tensile, and bending strength tests as well as water absorption tests were carried out at the ages of 7, 28, and 90 days. Moreover, to study the microstructure of the specimens, scanning electron microscopy (SEM) and x-ray diffraction (XRD) tests were conducted accordingly. For curing the specimens, three different environments with PH values of 2.5, 12.5, and 7 representing the acidic, alkaline, and neutral environments, were taken into account. Promisingly, it was observed that the inclusion of recycled waste materials significantly enhanced the mechanical properties of the mortar when exposed to acidic curing conditions. Lastly, the results derived from the microstructure tests revealed that as a result of replacing cement with glass, iron, and eggshell powders, the width of cracks and volume of the pores decreased by three times, and importantly, the bonding between the cement paste and additives was strengthened.

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1- Introduction

Durability is one of the most important criteria to be considered for designing reinforced concrete (RC) structures. Durable concrete can help the environment by preserving natural resources and minimizing the need for repair. The optimal life of the cement materials could be shortened due to exposure to aggressive environments. The acidic attack is one of the significant deteriorating environmental mechanisms [1]. When the concrete is exposed to an acidic environment, calcium ions are hydrated from the calcium-containing phases in the hardened cement paste such as portlandite and calcium silicate to form calcium salts, which increases the total porosity of the concrete and significantly reduces the mechanical strength and durability [2].

The speed and mechanism of acid attack on concrete depend on various factors such as the type of cement-based materials, water-to-cement (W/C) ratio, the type and pH of the acidic solution, temperature, etc. Therefore, it is indispensable to thoroughly study the impact of exposure to acid on the mechanical and microstructure properties of cement-based materials [3,4]. To date, many researchers have investigated the effect of the corrosive environments on the strength characteristics of the concrete and mortar [5-8].

2- Methodology

In the present study, a number of cementitious mortar specimens containing recycled wastes including glass powder, eggshell powder, rubber powder, and iron powder as the replacement for cement, in amounts of 7, 14 and 21% by weight, were built. The specimens were exposed to acidic (HCL), neutral (Water) and alkaline (Ca (OH)2 + NaOH) environments with pH values of about 2.5, 7 and 12.5 at the ages of 7, 21 and 90 days, respectively. It should be noted that due to the chemical actions that occurred in the specimens (especially the cement in the specimens) during the curing (especially in the early days), the pH of the environment must be constantly controlled until the environmental conditions follow the research assumptions. The pH meter used in this study can be measured with an accuracy of 0.1 and is of digital type.

The water used in the specimens is drinking water and the cement used is type II from Shahroud Cement Factory. Moreover, the sand is double-washed and has been prepared from the Tighab mine in Pakdasht city. Physical and chemical analyses of the cement by Iran's National Standard 389 and the factory standard are presented in Tables 1 and 2. The particle size distribution curve of the sand is presented in Figure 1. The recycled wastes to be partially replaced with

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Table 1. Physical Analysis of the Cement

test method	Factory standard	National Iranian 389 Standard	Test results	Description of test
390	At least 2900	At least 2800	3055	Blin surface (cm/g)
391	Maximum 0.6	Maximum 0.8	0.036	Autoclaving test (percent)
Wicket Needle Time				
392	At least 70	At least 45	145	Elementary (min)
392	Maximum 5	Maximum 6	3:45	Ultimate (Speed)
Compressive strength (kg / cm^2)				
393	-	-	-	1 days
393	-	-	-	2 days
393	At least 170	At least 100	245	3 days
393	At least 250	At least 175	310	7 days
393	At least 350	At least 315	411	28 days
Heat of hydration (calories per gram)				
394	-	-	-	7 days
394	-	-	-	28 days

Table 2. Chemical Analysis of the Cement

test method	Factory standard	National Iranian 389 Standard	Test results	Description of test	
1692	At least 20.5	At least 20	21.11	(٪) SiO_2	
	Maximum 5	Maximum 6	4.42	(٪) Al_2O_3	
	Maximum 5	Maximum 6	3.96	(٪) Fe_2O_3	
	-	-	63.36	(٪) CaO	
	Maximum 25	Maximum 5	1.51	(٪) MgO	
	Maximum 2.9	Maximum 3	2.70	(٪) SO_3	
1695	-	-	0.32	(٪) Na_2O	
	-	-	0.51	(٪) K_2O	
1692	Maximum 2.9	Maximum 3	2.02	(٪) L.O.I	
	Maximum 0.70	Maximum 0.75	0.32	Acid remaining insoluble (٪)	
	-	-	1.23	Free lime (٪)	11
	-	-	53	C_3S (٪)	12
	-	-	20.8	C_2S (٪)	13
	Maximum 6.5	Maximum 8	5	C_3A (٪)	14

cement, are glass powder, eggshell powder, rubber powder and iron powder.

3- Compressive Strength Test

Three cube specimens with the size of 50mm (ASTM C109) were chosen from each mix design and, nine specimens, were exposed to the acidic, alkaline and neutral (ordinary water) conditions and then, at the ages of 7, 28, and 90 days, respectively, were broken using a hydraulic jack with capacity and loading speed of 2000 kN and MPa/s, respectively. The loading process continued until reaching the rupture limit and the maximum load that could be undergone was recorded.

4- Tensile Strength Test

To perform the tensile strength tests, the direct tension method was adopted according to ASTM C348. The hydraulic jack had a capacity of 150dN, applying the load with a speed of 0.2MPa/s. The briquette specimens from each mix design were exposed to environments with various pH values and then broken at the ages of 7, 28, and 90 days.

5- Results and Discussion

To better understand the results obtained from the findings of this study, the best possible case in the results of this study is compared with the best possible case in the results of other researchers in Table 3. All issues mentioned in the Table are in percentage and are presented in comparison with the reference specimen related to the same paper. Notably, all research mentioned in the Table has used the same additives. Therefore, the results of the following research are not merely limited to the cement mortars. Accordingly, the importance of the results obtained in this paper could be more comprehensively understood. In almost all cases, the results obtained from this paper are better than other studies and have improved the properties of the mortar several times more. Also in this paper, as well as in another paper by Gholhaki et al [9], a simultaneous comparison of four types of additives has been done, but the scope of research in other studies is more limited.

Also, the standard deviation of all the results presented in this paper and the research mentioned in Table 3 for compressive, tensile, and bending strength tests and water absorption tests are 16.65, 0.42, 3.01, and 6.31, respectively.

6- Conclusions

* The results of the flow-mini-slump test indicated that by increasing the particle size of the additives and reducing their adhesion to the cement paste, the slump number increased

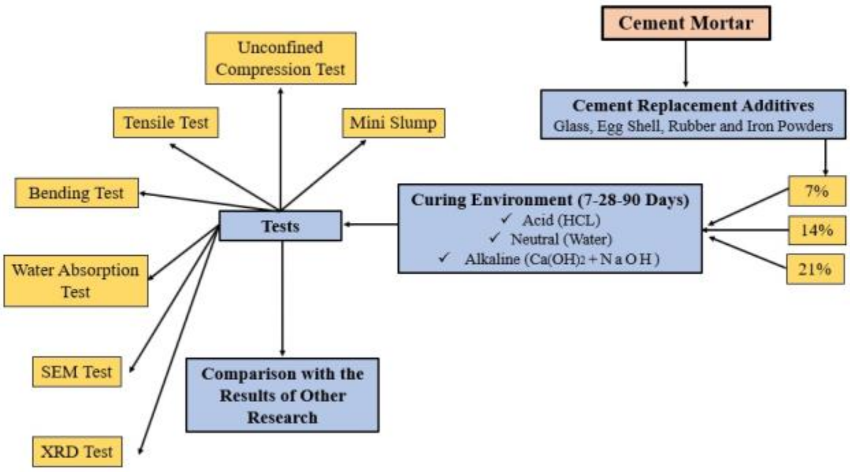

Fig. 1. Particle Distribution Curve of the Sand

due to the presence of empty spaces in the specimens. The highest and lowest adhesions were related to the specimens containing eggshell (due to the presence of calcium) and rubber powder, respectively.

* Based on the results of the compressive strength tests on the specimens, the increase in compressive strength occurred for all specimens (except those containing rubber powder). However, because in some cases with replacement ratios of 7 and 14%, the compressive strength decreased (at most 23% decrease) or did not increase significantly (at most 22.7%), the replacement ratio of 21% was recommended.

* The results of the tensile strength test showed that the trend of changes is almost similar to the compressive strength. Although the values of tensile strength in the replacement ratio of 21%, were close to each other, the highest tensile strength was related to the IP-21 specimen (2.49 MPa). In addition despite the fact that the tensile strength of the specimens containing rubber powder significantly decreased, in some cases with and replacement ratio of 7%, the tensile strength increased to 13.7%. Therefore, it was concluded that by changing the amount of rubber powder used and the amount of water, cement, and sand in the desired mixing design, the desired strengths for the specimens containing rubber powder can be achieved.

* Regarding the flexural performance, it was found that in the replacement ratio of 7% rubber powder, the flexural strength increased. However, with increasing amounts of rubber powder, the flexural strength decreased to 21%, and with increasing amounts of the other powders, the flexural strength increased to 92%.

Table 3. Comparison of the results obtained in this paper with those of other research

	Details	Compressive Strength				Tensile Strength			
		EP	GP	IP	RP	EP	GP	IP	RP
This Paper	CM-AE	+67.3	+57.8	+41.8	-14.9	+90	+91.8	+91.9	+13.7
[9]	CM-AE	-3.8	-	-	-		-	-	-
[10]	CM-AE	-14.1	-	-	-	-	-	-	-
[11]	CM	-	-	-	-22	-	-	-	-
[12]	C-AE	-	-	-	0	-	-	-	-
[13]	CBC-AE	-	-	-	0	-	-	-	-
[14]	CM	-	-	-	-2.3	-	-	-	0
[15]	C-AE	-	-	-	-2.8	-	-	-	-
[16]	CM	-	+3.5	-	-	-	-	-	-
[17]	CM-AE	-	+8.4	-	-	-	-	-	-
[18]	GCM-AE	-	0	-	-	-	-	-	-
[19]	CM	-	-	+10.1	-	-	-	-	-
[20]	CM	+28	+36	-	+17	+49	+30	-	+14
[25]	CM	+29.6	-	-	-	-	-	-	-
[26]	CM	-22.2	-	-	-	-	-	-	-
[27]	C-AE	-	-2.9	-	-	-	-	-	-
[28]	C	-	-	-	+12.9	-	-	-	-
[29]	C	-	+8.8	-	-	-	-8.3	-	-
[30]	C	-	+21.8	-	-	-	-	-	-
[31]	C-AE	-	+16.7	-	-	-	+32	-	-

* CM: Cement Mortar
* AE: Aggressive Environment
* C: Concrete
* CBC: Cement-Based Composites
* GCM: Geopolymer Cement Mortar

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