Role of construction industry wastes on the properties of mortars

Niyazi Ugur Kockal

Department of Civil Engineering, Akdeniz University, Turkey

e-mail:ukockal@yahoo.com

Abstract : This study investigated the performance of cement mortars prepared by substituting 30% and 60% of crushed calcareous fine aggregate (CNA) with waste fine aggregates namely, crushed brick aggregate (CBA), crushed marble aggregate (CMA) and crushed ceramic aggregate (CCA). For this purpose, absorption, unit weight, compressive strength, flexural strength, resistance to high temperature up to 400 ^oC and resistance to freeze-thaw cycles were determined for these mortars. In addition, XRF analysis was performed on cement and waste aggregates. From the experimental results, it is found that CBA mortars exhibited the lowest strength values and worst durability properties. However, CBA and especially CCA mortars were more effective in relative strength gain at 56 days.

Key words: Strength, high temperature, freeze-thaw, morphology.

Introduction

More than 25 billion tons of concrete are produced each year all around the world. Aggregates, usually provided from natural resources, occupy up to 80% of volume of concrete. Unfortunately, the available natural aggregate used in concrete and mortar production will soon remain insufficient to supply all the demands of the construction industry. Therefore, construction industry is seeking for other alternatives in order to meet the needs in concrete manufacturing.

Using construction based waste materials in cementitious mixtures have been seen revived interest in recent years. Many researchers (Böke, Akkurt, İpekoğlu, & Uğurlu, 2006; Bektas, Wang, & Ceylan, 2009; Gonçalves, Tavares, Toledo Filho, & Fairbairn, 2009; O'Farrell, Sabir, & Wild, 2006) analyzed some properties mainly strength and durability of mortars containing different types of ground brick (calcined clays) subjected to various treatments. The properties of mortars and/or concretes containing ceramic waste aggregates were examined in some investigations (Higashiyama, Sappakittipakorn, Sano, & Yagishita, 2012; Medina, Sánchez de Rojas, & Frías, 2012; Pacheco-Torgal, & Jalali, 2010; Senthamarai, Devadas Manoharan, & Gobinath, 2011). Mortars and concretes containing marble waste were also studied by evaluating their fresh and hardened state properties (Aruntas, Guru, Dayı, & Tekin, 2010; Belaidi, Azzouz, Kadri, & Kenai, 2012; Hebhoub, Aoun, Belachia, Houari, & Ghorbel, 2011).

The main aim of this work is to compare the mortars manufactured with common construction wastes and evaluate the effects of wastes on performance employing mortar specimens. Knowing these effects will aid in assessing the physical–mechanical performance and the resistance of mortars to different treatments and also their compatibility with other building materials.

Materials and Method

Cement used in the mixtures was CEM II/A-M (P-L) 42,5N complying with TS EN 197-1 with a specific gravity of 3.05. All wastes (brick, marble and ceramic) were collected from construction sites [Figure 1] and ground until a similar grading as of natural crushed sand was obtained. Natural crushed fine aggregate utilized in the study was calcareous sand provided from Dirmil, Burdur. Chemical admixture used for providing consistency of mortars constant was a modified lignin sulphonate based water reducing/plasticizer admixture consistent with TS EN 934-2.

Figure 1: Wastes disposed in the construction site

As fundamental physical material characteristics, water absorption, specific gravity, rodded and loose bulk density of crushed aggregates were determined by following the test procedures in the relevant standards [Table 1].

Table 1: Physical characteristics of waste materials.

Materials	Water absorption (%)	Specific gravity (Dry)	Rodded bulk density (Dry)	Loose bulk density (Dry)	Void content (%)
Sand	2.24	2.71	1741	1589	35.63
Brick	14.08	2.57	1093	1210	57.39
Marble	2.96	2.63	1571	1399	40.15
Ceramic	2.57	2.49	1196	1305	51.87

Specific gravity and water absorption of fine aggregates were determined according to ASTM C 128. Aggregates were tested in oven-dry condition utilizing the shoveling and rodding procedure to determine the unit weight (loose and rodded) and void content according to ASTM C 29-97. Chemical compositions of cement and waste aggregates are given in Table 2.

Table 2: Chemical compositions of materials used in mortar preparation by weight (%).

Materials	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	Fe_2O_3
Cement	1.25	2.33	6.38	21.77	1.06	56.66	2.68
Brick	2.00	6.51	14.92	54.24	2.27	8.79	5.82
Marble	0.58	1.10	0.35	1.62	0.06	52.94	0.15
Ceramic	2.73	5.07	15.14	63.99	1.68	4.88	2.33

Cement: water: aggregate proportions in mixes were 1: 0.50: 3, respectively. Natural crushed sand was replaced with waste aggregates in a ratio of 30 % and 60 %. All substitutions were made in volume. The flow diameter values of fresh mortar mixtures were remained constant as 210±14 mm by adjusting the percentage of plasticizer used. All sample preparations were processed in a similar manner, according to European Standard EN 196-1. The mortars were cast into 40x40x160 mm prismatic moulds and kept for 24 h. The hardened mortar specimens were then demoulded and maintained under lime-saturated water at 20 ± 2 ^{o}C until the age of testing.

40x40x160 mm prismatic specimens were subjected to temperature of up to 400 ^{o}C at an incremental rate of 10 ^{o}C per minute from room temperature, using an electrically-heated furnace and exposed to a treatment involving freeze in air and thaw in water in a cabinet from -20 C to +20 C for 10 cycles completed in 2 days.

The consistency test involves placing the mould in the center of the flow table and filling it in two layers each layer being tamped 20 times with the tamper according to ASTM C 270. The table was then jolted 25 times, and the diameter of the spread mortar was measured in two directions at right angles to each other using callipers.

The bulk density, water absorption and porosity values were obtained by testing 100 mm cube specimens according to ASTM C 642. The flexural and compressive strength of hardened mortar specimens were determined in accordance with EN 1015-11. The flexural strength of a hardened mortar was evaluated by three point loading of a 160x40x40 mm prism specimen, subsequent to the failure and breakage of this specimen the compressive strength was determined on each half of the prism specimen. Three specimens of each formulation were prepared for each test.

Results and Discussion

The bulk density, water absorption and porosity test results are shown in Table 3. In contrast to CNA mortars, CBA mortars had the highest porosity and thus water absorption. However, the lowest apparent bulk density and dry bulk density were obtained by CCA and CBA mortars, respectively. The corresponding values dropped while the replacement ratios increased due to the high porosity of brick and ceramic aggregates.

Table 3: Bulk density, absorption and porosity of mortars.

Age	Specimen	Dry bulk density	Water absorp. (% wt.)	Apparent bulk density	Apparent porosity (%)
28 Days	CNA	2.09	5.72	2.37	11.93
	CBA30	1.96	7.98	2.32	15.61
	CMA30	2.03	6.28	2.32	12.73
	CCA30	2.02	5.96	2.30	12.07
	CBA60	1.88	10.50	2.34	19.76
	CMA60	2.05	6.08	2.34	12.47
	CCA60	2.01	5.26	2.24	10.56
56 Days	CNA	2.08	5.48	2.35	11.42
	CBA30	1.94	7.96	2.29	15.41
	CMA30	2.10	6.04	2.40	12.66
	CCA30	2.04	5.61	2.30	11.42
	CBA60	1.94	8.78	2.34	17.03
	CMA60	2.07	5.71	2.34	11.79
	CCA60	2.01	4.09	2.19	8.24

Table 4 gives the mechanical properties of 28 and 56-day mortars with and without treatments. The strength loss ratios due to the various treatments were higher for flexural strength than those for compressive strength. Generally, for all situations, CBA mortars exhibited the lowest mechanical properties and these properties worsened with the substitution level owing to the high water absorption and open porosity percentages of brick aggregates. Although other mortars prepared with CNA, CCA and CMA showed close values, the best performance was observed by CCA mortars when considering reduction in strength values at overall situations. The resistance to high temperature was high for the CCA mortars when analyzing the relative residual compressive strength values. Besides, analyzing the relatively residual flexural strength values presented the superiority of CBA mortars. This fact can be attributed to the higher temperatures experienced by the bricks and ceramics previously in the manufacturing process. In addition, generally one face of ceramic aggregates was glazed, thus the proper adherence could not be achieved leading to lower flexural strength compared to CBA mortars. Exposing the freeze-thaw cycles to mortars weakened CBA mortars mostly rather than the other mortars. Despite similar behavior could be expected for CCA mortars, CCA mortars deteriorated less than CBA mortars. The reason of this result could be the structure of voids in the aggregates.

In contrast to CBA, CCA had mostly closed porosity seen also in SEM images (not presented in this study). The strength gain was more pronounced in the case of CBA and especially CCA mortars as relevant to the pozzolanic behavior of these mentioned aggregates containing amorphous silica and alumina phases. As compared to test results of specimens subjected to high temperature, the strength loss ratios of specimens exposed to freeze-thaw cycles were lower. The reason of this result could be the less number of cycles applied on specimens.

Table 4: Flexural and compressive strength values of mortars with and without treatments.

Age	Specimen	Flexural Strength (MPa)			Compressive Strength (MPa)		
		No treatment	High Temperature	Freeze-Thaw	No treatment	High Temperature	Freeze -Thaw
28 Days	CNA	8.6	5.8	8.0	43.8	36.2	42.3
	CBA30	7.7	6.2	6.7	39.0	33.1	34.2
	CMA30	8.1	5.6	7.4	42.1	34.2	40.4
	CCA30	8.5	6.3	7.8	43.0	38.1	41.2
	CBA60	6.8	5.7	5.8	37.4	32.4	32.5
	CMA60	7.8	5.1	7.2	40.2	34.7	37.4
	CCA60	7.9	5.6	7.5	42.8	38.9	41.7
56 Days	CNA	8.8	6.3	8.2	46.4	38.6	44.9
	CBA30	8.1	6.6	7.0	44.1	37.6	39.0
	CMA30	8.3	6.1	7.6	42.9	35.5	41.5
	CCA30	8.6	6.7	8.3	45.1	40.4	43.4
	CBA60	7.6	6.4	6.8	41.1	37.9	37.6
	CMA60	8.1	5.5	7.4	41.4	37.2	39.1
	CCA60	8.3	6.3	8.0	44.2	42.1	42.9

Conclusions

Following conclusions can be drawn from the experimental results:

Strength loss ratios after high temperature exposure tests of CCA and CBA mortars were lower than those of CMA and CNA mortars. However, particularly CBA had highest strength loss in the case of freeze-thaw cycle exposure due to the open void structure allowing high penetrability of water. Strength development was higher for CCA and CBA mortars at later age probably owing to the pozzolanic reactions resulting from high glassy phase content produced by sintering during manufacturing process.

Acknowledgements

This work was supported by Akdeniz University Scientific Research Center with Project number 2011.01.0102.009.

References

Aruntas, H. Y., Guru, M., Dayı, M., & Tekin, I. (2010). Utilization of waste marble dust as an additive in cement production. *Materials and Design*, *31*, 4039–4042.

Bektas, F., Wang, K., & Ceylan, H. (2009). Effects of crushed clay brick aggregate on mortar durability. *Construction and Building Materials*, *23*, 1909–1914.

Belaidi, A. S. E., Azzouz, L., Kadri, E., & Kenai, S. (2012). Effect of natural pozzolana and marble powder on the properties of self-compacting concrete. *Construction and Building Materials*, *31*, 251–257.

Böke, H., Akkurt, S., İpekoğlu, B., & Uğurlu, E. (2006). Characteristics of brick used as aggregate in historic brick-lime mortars and plasters. *Cement and Concrete Research*, *36*, 1115–1122.

Gonçalves, J. P., Tavares, L. M., Toledo Filho, R. D., & Fairbairn, E. M. R. (2009). Performance evaluation of cement mortars modified with metakaolin or ground brick. *Construction and Building Materials*, *23*, 1971–1979.

Hebhoub, H., Aoun, H., Belachia, M., Houari, H., & Ghorbel E. (2011). Use of waste marble aggregates in concrete. *Construction and Building Materials*, *25*, 1167–1171.

Higashiyama, H., Sappakittipakorn, M., Sano, M., & Yagishita F. (2012). Chloride ion penetration into mortar containing ceramic waste aggregate. *Construction and Building Materials*, *33*, 48–54.

Medina, C., Sánchez de Rojas, M. I., & Frías, M. (2012). Reuse of sanitary ceramic wastes as coarse aggregate in eco-efficient concretes. *Cement & Concrete Composites*, *34*, 48–54.

O’Farrell, M., Sabir, B. B., & Wild, S. (2006). Strength and chemical resistance of mortars containing brick manufacturing clays subjected to different treatments. *Cement & Concrete Composites*, *28*, 790–799.

Pacheco-Torgal, F., & Jalali, S. (2010). Reusing ceramic wastes in concrete. *Construction and Building Materials*, *24*, 832–838.

Senthamarai, R. M., Devadas Manoharan, P., & Gobinath, D. (2011). Concrete made from ceramic industry waste: durability properties. *Construction and Building Materials*, *25*, 2413–2419.