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Improving the abrasion resistance of ordinary and high-performance mortars through utilization of sanitary ware ceramic wastes

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Keywords

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High-performance mortar

Abstract

Waste utilization has been one of the most vital concerns of sustainable development within the past few decades. Concrete is one of the most suitable and, of course due to its nature, efficient options for utilization of different kinds of wastes. Sanitary ware ceramic (SWC) waste utilization, for instance, in concrete has been studied broadly over the past two decades. Due to the rigid structure of most SWCs, utilization of a proper SWC in either concretes or mortars is likely to improve the abrasion resistance of them. In this study, it was endeavored to do so by utilization of fine SWC aggregates in an ordinary mortar (OM) and a high-performance (HPM) mortar. An OM with water/cement ratio of 0.5 and a HPM with water/cement ratio of 0.3 were used in the experimental studies. The SWC-containing mixtures were prepared by replacing of limestone aggregate altogether by fine SWC aggregate. Results showed that the utilization of SWC wastes as fine aggregate could remarkably improve the abrasion resistance of cementitious mortars. The volume losses for the SWC-containing OM and HPM were, respectively, 55.8% and 46.3% lower than those of control mortars. Since the volume loss values were quite similar, it is obvious that aggregate phase was the dominant parameter for the abrasion resistance.

1.Introduction

Today, due to the growing industrialization, the amount of waste has also increased. These wastes pose a threat to the environment and nature. Waste management could be divided into three categories: prevent waste generation, reuse, and recycling [1]. Preventing or minimizing waste production can be achieved by detailed optimization studies of industrial facilities and of production processes. The reuse and, especially, the recycling have been widely investigated in the building/construction materials industry and in the related academic disciplines. Beyond the artificial—and of course waste—pozzolanic additives (like fly ash), many solid waste materials could be utilized as either fine/coarse aggregate or binder in concrete technology such as concrete rubble, different pet bottle wastes, scrap car tires, broken glasses having various compositions, bricks, ceramics, various slags etc. [2]. Furthermore, various agricultural wastes such as bamboo, wheat, barley, corn, olive, banana, sisal, date palm, and elephant grass have also been introduced for that purpose up to now [3].

Ceramics are divided into a wide variety of sub-products within itself. Waste may arise from various ceramic products such as bricks, blocks, roof tiles, SWC, and porcelain insulators [4]. Different production methods and different raw materials are the reasons of the diversity. Depending on the ceramic raw material, various ceramic products can be manufactured by a single firing process of red or white pastes. Red paste is mostly used for structural products such as fired bricks, blocks, and roof tiles, while white paste is used in the production of fired tiles and vitrified ceramics, which are generally more durable. It is known that the chemical compositions of fired ceramics are not so different from their raw materials, but only their mineralogy due the firing process. Generally, SiO_2 and Al_2O_3 constitute the majority of the chemical composition of fired ceramics [5]. Given the aforementioned diversities, the studies dealt with the utilization of the ceramic wastes in cement-based materials vary in objectives, materials, methodology, and, of course, results. Awoyera et al. [6], for instance, have reported considerable improvements in the mechanical properties of their concrete by utilization—even up to 100% replacement ratio—of crushed floor and wall tiles as aggregate. Whilst, the study conducted by Senthamarai and Devadas Manoharan [7] have revealed the ceramic insulator aggregate utilization, no matter the replacement ratio, did not change the mechanical properties of their conventional concrete mixtures having various water/cement ratios. Zegardlo

et al. [8] have showed that SWC could be also used for improving the mechanical properties of high performance concrete. They could obtain a compressive strength of 127 MPa by utilization of SWC coarse aggregate; exactly 32 MPa more than the control mixture.

One of the most important factors determining the quality an aggregate is its surface abrasion resistance. Since most of SWCs have relatively high hardness, they could be utilized as aggregate to enhance the abrasion resistant of mortar and concrete. A few studies have focused on the abrasion performance of concrete containing SWC aggregate. Halicka et al. [9] have stated that the concrete prepared using SWC aggregate had approximately 20% higher surface wear resistance than the control concrete prepared using natural aggregate. Similar improvements in the abrasion resistance has also been reported by Binici [10]. Some of the studies in the related literature have revealed that SWC aggregate could has considerable positive effect on the abrasion resistance of mortar and concrete. In this study, the possible abrasion-enhancing effect of fine SWC aggregate was examined also on a HPM alongside with on an OM mixture.

2. Materials and Methods

A CEM I 42.5 R type Portland cement, with a fineness (Blaine value) of 395 m^2/kg, was supplied from Soma Cement Factory. Crushed limestone aggregate having a maximum particle size of 5 mm was used as the reference aggregate. The SWC waste were collected from a local sanitary ware ceramic manufacturer's landfill (Serel SWC plant, Manisa). The SWC waste had been broken into smaller pieces by a hammer; and then, those SWC pieces were crushed in a jaw crusher to have a gradation similar to that of the limestone aggregate. To adjust the workability of HPM mixtures, a new generation of Polycarboxylic ether-based superplasticizer (MasterGlenium® SKY 608, BASF) was used in this study.

The chemical compositions of the cement, the SWC, and the limestone aggregate are presented in Table 1. The particle size distributions of the SWC aggregate and the limestone aggregate are shown in Figure 1. The specific gravity and the water absorption of the limestone aggregate were 2.59 and 1.63%, respectively. These values for the SWC aggregate were 2.38 and 1.53%, respectively.

Table 1. Chemical Compositions of Materials Used in This Study

Chemical Composition (%)	Cement	SWC	Limestone
SiO_2	19.79	72.41	1.41
Al_2O_3	4.78	20.16	0.38
Fe_2O_3	3.39	0.18	0.35
CaO	63.71	0.88	55.10
MgO	1.78	0.52	0.50
Na_2O	0.32	4.37	-
K_2O	0.78	0.64	0.20
SO_3	2.84	-	0.06
Cl^-	0.0098	-	-
Free CaO	-	-	-
Loss on Ignition	2.09	-	40.3

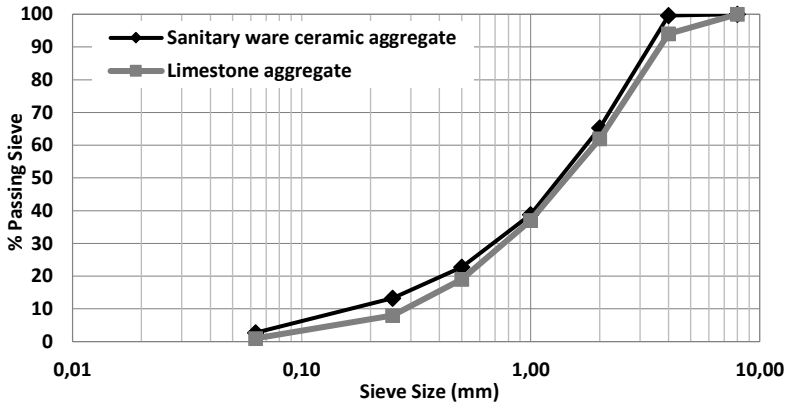


Figure 1. Particle size distributions of the SWC aggregate and the limestone aggregate

An OM having water/cement (w/c) ratio of 0.5 and a HPM having w/c ratio of 0.3 were designed as the reference mixtures. In both of the mixtures, 100% (by volume) of the limestone aggregate was replaced by the SWC aggregate (Table 1). The workability of mortars, the mini flow table test, were assessed according to the TS EN 1015-3 standard [11] with 15 drops. The superplasticizer was used only in the HPM mixtures the flow value was adjusted to be 190 mm because OM mixtures had the required consistency for an adequate molding and compacting processes. The mix designs and the flow values are presented in Table 2.

Table 2. Mix Designs

Mixture	Cement (kg/m^3)	Water (kg/m^3)	Limestone (kg/m^3)	SWC (kg/m^3)	SP (kg/m^3)	Mini flow test value (mm)
OM-Ref	495	248	1488	0	0	220
OM-SWC	495	248	0	1362	0	165
HPM-Ref	700	210	1396	0	4.5	190
HPM-SWC	700	210	0	1283	4.9	190

The abrasion resistance of mortars was assessed by the Böhme abrasion test carried out according to TS 2824 EN 1338 [12] standard using cube specimens having 71 mm sides. The machine consists of a 750-mm diameter steel disc—the wear dust, 20 ± 0.5 g of corundum crystalline Al_2O_3, is spread on it—rotating at a speed of 30 ± 1 rpm, a counter, and a lever, which applies 300 N load on specimens. After 28 days of the standard water curing, all specimens were kept in an oven at 105 °C until achieving a constant weight. Then, 16 periods of the disc rotation (wearing) having 22 rotation cycles each were applied on specimens as specified in the standard. After each period, the edge length and weight of the specimens had been measured; and then, they were rotated 90° on the disk for the following abrasion period. The abrasion vales were calculated according to Equation 1.

$$\Delta V = \frac{\Delta m}{\rho_R} \quad (1)$$

Where; ΔV is the volume loss (mm^3) after performing the 16 rotation cycles, Δm is the mass loss (g) after the cycles and, ρR is the density of the specimen.

3. Results and Discussion

The 7-day and 28-day compressive strengths of the OM and HPM mixtures are presented in Figure 2. Although OM-SWC mixture had slightly lower 7-day compressive strength than the OM-Ref, it was approximately the same at 28 days. This recovery could be explained by the pozzolanic effect of SWC aggregate's finer particles [13,14]. In the previous study conducted by the authors, the pozzolanic effect of finer particles of this SWC aggregate was found to be so noteworthy that it could even mitigate the alkali-silica reaction expansions [15]. On the other hand, SWC-containing HPM mixture had higher compressive strengths than the reference HPM mixture at both of 7-day and 28-day. This can be attributed to the better SWC-matrix interfacial characteristics—specifically to the higher bond strength—of HPM owing to its lower W/C ratio.

The 7-day and 28-day flexural strengths of OM and HPM mixtures are presented in Figure 3. It can be seen that there were not meaningful differences between the SWC-containing and the reference mixture neither in the OM nor in the HPM mixtures.

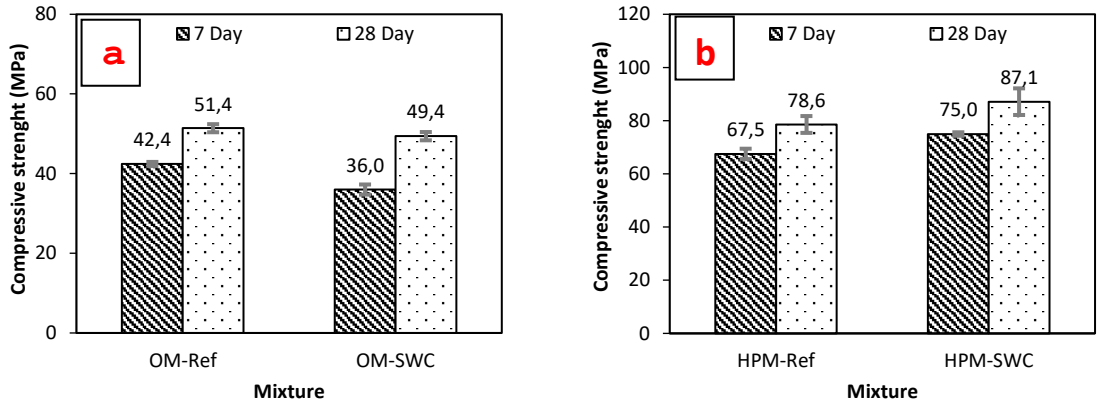


Figure 2. Compressive strengths of OM (a) and HPM (b) mixtures at the age of 7 and 28 days.

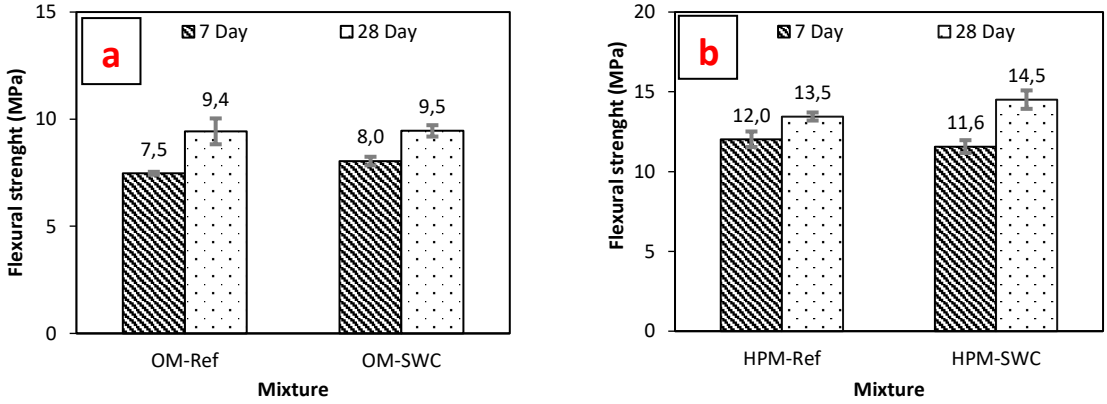


Figure 3. Flexural strengths of OM (a) and HPM (b) mixtures at the age of 7 and 28 days.

The abrasion test results of the OM and HPM mixtures are presented in Figure 4. It is obvious that the abrasion resistances of both mixtures were enhanced by the utilization of the SWC aggregate. The volume loss for the reference OM mixture was 5.4% while it was only 2.4% for the OM-SWC mixture. In other words, the abrasion-induced volume loss for SWC-containing mixture was 55.8% less than that of OM-Ref mixture. It should be noted that the volume and weight losses were very close to each other. The results in the HPM mixtures were quite parallel to those of the OM mixture. The loss for the reference HPM was 4.0% while it was 2.2% for the HPM-SWC mixture. So, it was 46.3% less than that of HPM-Ref mixture. The matrix volume and W/C ratio of both HPM mixtures were the same; therefore, it was the utilization of the SWC aggregate that enhanced—mostly due to the higher hardness of the SWC compared to the limestone—the abrasion resistance of the mortar.

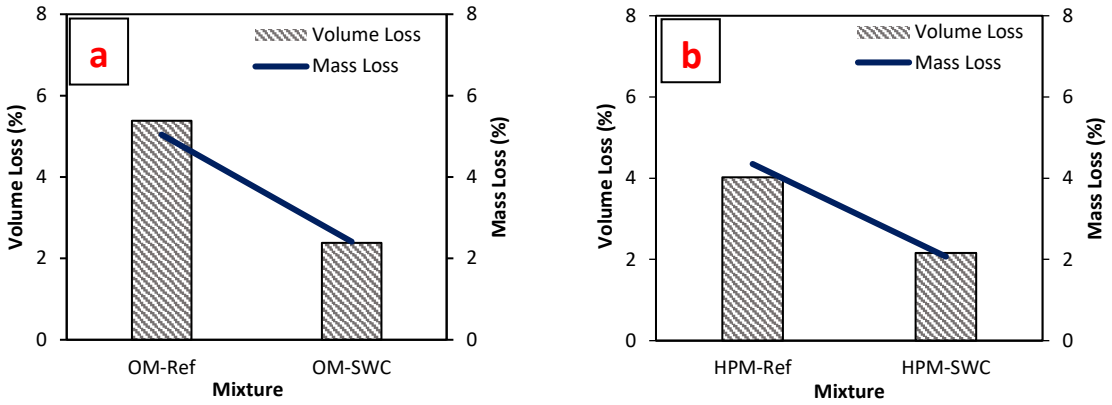


Figure 4. Volume and mass losses results of OM (a) and HPM (b) mixtures

It is known that the densification of cementitious matrix can improve the abrasion resistance [16]; therefore, there could be a meaningful correlation between compressive strength of concrete and its abrasion resistance [17]. Thus, the difference between the reference mixtures of OM and HPM could be explained by the matrix densification. On the other hand, since OM-SWC and HPM-SWC mixtures exhibited similar performances, it could be concluded that the SWC aggregate, regardless of matrix strength or densification, improved the abrasion resistance of the mortars. In other words, it is obvious that the dominant factor determining the abrasion performance was aggregate phase.

4. Conclusion

- Even though compressive strength of SWC aggregate bearing OM mixture at 7 days had been behind the reference mixture, OM-SWC mixture gained more strength than reference mixture at 28 days likely due to the pozzolanic reaction of finer particles of SWC aggregate.

- No matter the age of specimens, HPM-SWC mixture had higher compressive strengths than reference HPM mixture probably because it had higher aggregate-matrix bond strength.

- SWC bearing OM and HPM mixtures showed excellent abrasion resistance due to the higher hardness of the SWC, of course, compared to the limestone.

- Abrasion resistance differences between the reference OM and HPM mixtures revealed that matrix densification was a noteworthy factor for the abrasion resistance. However, the dominant factor was, certainly, the aggregate phase.

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Declaration of Conflict of Interests

The author(s) declare(s) that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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