Effect of Homogeneous Ceramic Tile Waste on Properties of Mortar

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Abstract. The subject of reduce, reuse and recycle of waste material either from industrial or agricultural sectors is considered very important in the general attempt for sustainable construction. In relation to that, ceramic materials are widely used in many part of the world and consequently, large quantities of wastes are produced simultaneously by brick and tile manufacturers and construction industry. However, part of these wastes and those produced by the construction industry are dumped in landfills. In this present research, the effect of homogeneous ceramic tile waste on harden properties of mortar was investigated. Mortar mixes were prepared focusing on the effect of ceramic aggregates as river sand replacement. Tests were conducted for compressive strength, splitting tensile strength for all mortar specimens. The cement was partially replaced by ceramic powder by 20 %, 40 % and 60 %, respectively by weight of cement. The sand was replaced by ceramic aggregates ranging from 0% to 100% by weight of aggregates. The size of ceramic aggregates used is modified in accordance with ASTM C-33 while the cement was partially replaced by 40 % of ceramic powder by weight of cement. All specimens were cast in 50 mm cubes and cured in water after demoulding until the age of testing. By replacing 100 % of sand with ceramic aggregates, it was found that the compressive strength was very much similar to the control specimen without showing any negative effect. Similarly, by replacing cement with ceramic powder, the strength of mortar shows 10% increment as compared to control specimen. In conclusion, incorporation of homogenous ceramic tile waste either as sand replacement or cement replacement both can enhance the properties of mortar in fresh and hardened states.

Introduction

Nowadays, pozzolanic materials have been used as construction material, especially for their effect on improving of microstructure and durability of concrete [1]. Recently, concern about environment pollution because of the environmental protection regulations, that motivate researches to focus on the possibility of using pozzolanic materials from industrial waste like ceramic wastes, fly ash and silica fume [2]. Partial replacement of cement by waste materials would help to solve the landfill problem and lead to improve the durability, workability and strength of concrete [3].

Recycled aggregates, sometimes referred to as crushed concrete, come from the demolition of Portland cement concrete elements of buildings and other infrastructures. Due to the preservation of natural resources, prevention of environmental pollution, and cost-saving considerations of construction projects, the recycled concrete aggregates have been widely used for making different construction concretes and producing high-strength/high performance concretes [4]. The use of inorganic industrial residual products in making concrete will lead to sustainable concrete design and a greener environment. The need to develop concrete with non-conventional aggregates is urgent for environmental as well as economic reasons.

This research is part of an experimental work which focuses on ceramic waste from a Malaysian ceramic manufacturing industry. The physical characteristics of ceramic waste and its effect on the properties of mortar is explained in this paper.

Methodology
Materials

Cement. Ordinary Portland Cement (OPC) was used in this experimental work satisfying the requirement of ASTM C150-12 for cement Type I, the Ordinary Portland Cement was obtained from Cement Industry of Malaysia.

Ceramic powder. The ceramic waste were crushed in jaw crusher and after that was sieved by sieve size of 1.18mm to remove the bigger particles. Then, the ceramic was ground in the modified Los Angeles abrasion test machine with 8 stainless steel bars of 18 mm in diameter and 800 mm long. Only fine ceramic particles that passing through 40 μm sieve were collected and was used in the mixing [5, 6]. The chemical composition of ordinary Portland cement and ceramic powder are shown in Table 1.

Table 1: Chemical composition of OPC and ceramic powder

	Chemical composition (%)						
	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	TiO_2	LOI
OPC	16.40	4.24	3.53	68.30	0.22	0.09	2.4
Ceramic Powder	74.1	17.8	3.57	1.11	2.69	0.46	0.1

Sand. The river sand that is locally available in Malaysia was used in this experimental work. The river sand for casting was modified according to ASTM C33-13 Standard Specification for Concrete Aggregates. Modification of the river sand to reduce the amount of fine particle less than 150 µm (No. 100) to satisfy the standard for graded sand according to the standard.

Ceramic aggregates. The ceramic waste was crushed in jaw crusher machine and after that it was sieved. The fine aggregates shall satisfy the limitation which is mentioned in the ASTM standard C33-13. After grading, the ceramic aggregates was used as river sand replacement [7]. Sand was replaced by ceramic aggregates ranging from 0 % to 100 % by weight of aggregates. There is not too much difference between bulk density of river sand and ceramic aggregates so that replacing the aggregates by weight does not have an effect on ratio of binder to aggregates.

Preparation of specimens

That was done in two phases; in the first phase ordinary Portland cement was replaced by ceramic powder from 20 %, 40 % and 60 % by weight of cement. In the second phase the amount of cement replacement was constant and the river sand was replaced by ceramic aggregates ranging from 0 % to 100 % by weight of aggregates. All specimens and tests were conducted according to ASTM standard C1329/C1329M-12. Cement, ceramic powder, river sand and ceramic aggregates were mixed for around two minutes before adding water to the mix. Finally water was added to the mixture and continuous mixing was done for another five minutes. The mortar specimens were placed in the mould of 50 x 50 x 50 mm cubes according to ASTM standard C109/C109M-13. The specimens for splitting tensile strength were cast in the cylinder mould of 100 mm in diameter and 200 mm height according to ASTM C496-11. In order to remove the air from specimens, specimens were compacted using vibrating table for 30 seconds. Then, specimens were demoulded 24 hours after casting and placed in water tank until the day of testing. The mix proportion of the mortar is shown in Table 2.

Table 2: Mix proportions of mortar in first phase

Materials (kg/m^3)	Mortar mix			
	OPC (C0)	20% (C25)	40% (C50)	60% (C75)
OPC	550	440	330	220
Ceramic Powder	-	110	220	330
Sand	1460	1460	1460	1460
Ceramic aggregate	-	-	0%,25%,50%,100%	-
w/c ratio	0.45	0.45	0.45	0.45

Results and Discussions

Effect of ceramic powder in compressive strength

Compressive strength of mortar with different percentage of ceramic powder as cement replacement is shown in Figure 1. The 20 % and 40 % ceramic powder replacement showed higher compressive strength compared with normal mortar at 90 days. This may be due to the pozzolanic reaction occurred between of silicon oxide (SiO_2) and calcium hydroxide $Ca(OH)_2$ from hydration process. Ceramic mortar shows increment of compressive strength at later age compared to normal mortar. But this increase of compressive strength of specimens with replacement is not too much compared with control specimens which may be due to the amount of active silicate in ceramic powder. Study on the microstructure of ceramic powder shows that the amount of amorphous (Non-Crystalline) silicate is not too much and majority of silicate are crystal and non-active. In addition, the amount of Aluminum oxide (Al_2O_3) is high in ceramic powder which cause the gain of strength at early age of casting.

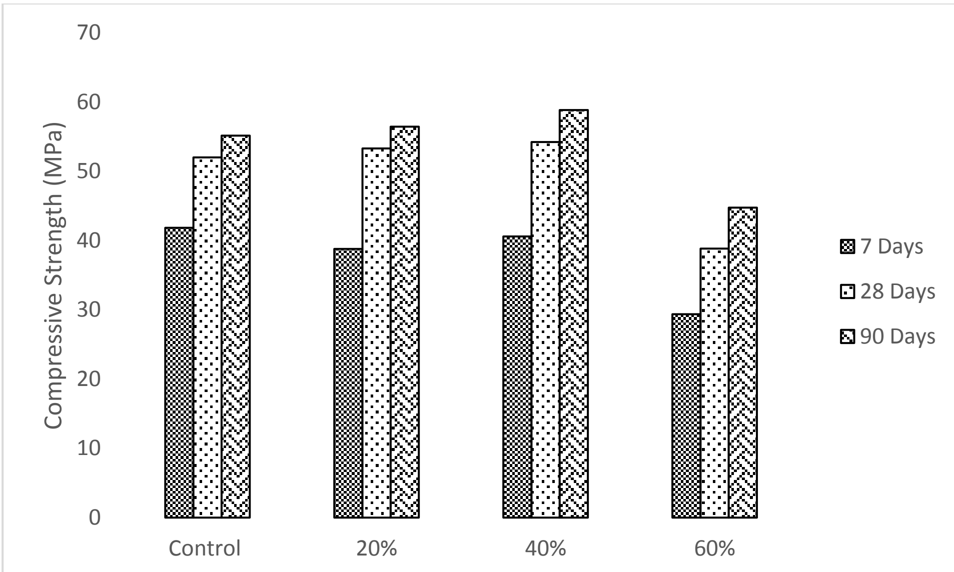

Figure 1: Effect of ceramic powder in compressive strength of mortar.

Effect of ceramic aggregates on compressive strength

Compressive strength of mortar with different percentage of ceramic aggregates as river sand replacement is shown in Figure 2. 100 % ceramic replacement showed higher compressive strength at all ages in comparison with other specimens. As illustrated in this figure, the difference in compressive strength of all the specimens is not too significant. This may be due to fact that the size distribution and physical characteristic of ceramic aggregates are almost similar to the river sand. It was also found that the compressive strength of the ceramic mortar at later ages was relatively similar with the normal mortar. The results indicates that the ceramic aggregates can be used to replace sand in mortar mix.

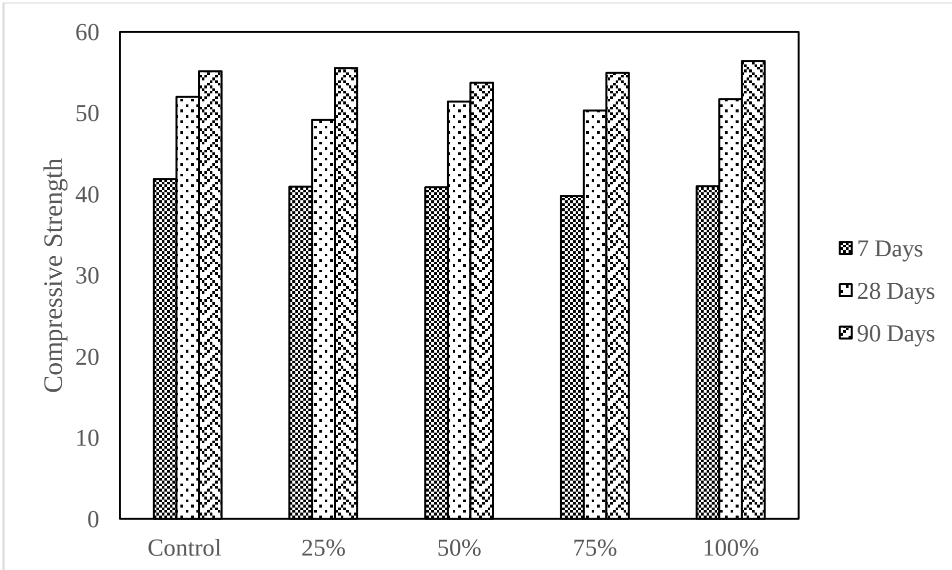

Figure 2. Compressive strength of mortar with sand and ceramic aggregates

Splitting Tensile Strength

The result of the splitting tensile strength of specimens are shown in Figure 3. The strength was determined at the ages of 7, 28 and 90 days. In all of the specimens, the amount of cement replacement was constant at 40 % and only river sand was replaced by different percentage of ceramic aggregates. The splitting tensile strength at the age of 7 days was in the range of 5.5 to 7 MPa. Similar to compressive strength by increasing the age of specimens, the splitting tensile strength was also increased. This was due to the strength generation as a results of the continuous cement hydration process. The splitting tensile strength results at the ages of 28 and 90 days were in the range of 6.1 to 8.5 and 6.9 to 8.8, respectively. The splitting tensile strength of the specimens with 100 % ceramic aggregates as river sand replacement recorded 25 % higher than control specimens.

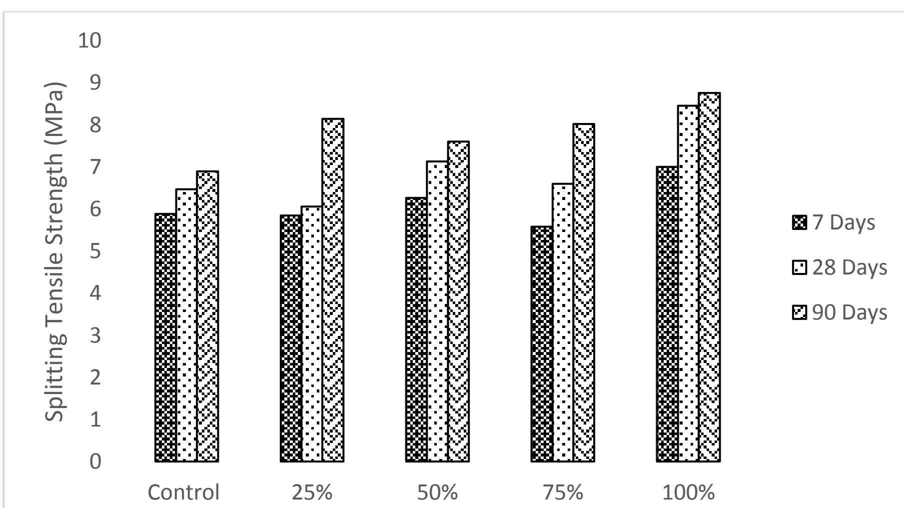

Figure 3. Splitting tensile strength of mortar with sand and ceramic aggregates

Conclusions

The experimental results shows that adding ceramic powder as cement replacement was found to improve compressive strength. This might be due to the effect of ceramic powder as filler as well as pozzolanic material. By replacing cement with ceramic powder up to 40 %, the total amount of calcium silicate hydrate gel increased. So in other word the rate of pozzolanic reaction increased. The use of ceramic aggregates as replacement for river sand has positive effect on the compressive strength and splitting tensile strength of specimens. The results show that this waste material can be a good alternative to river sand replacement. This is due to the shape, surface texture and microstructure characteristic of the ceramic aggregates. By replacing river sand with ceramic aggregates of up to 100 % it can preserve the natural resources and reduce impact on the environment.

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