Incorporation of Homogenous Ceramic Tile Waste to Enhance Mechanical Properties of Mortar

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ABSTRACT

The subject of reduce, reuse and recycle of waste material either from industries or agriculture sectors is regarded as very important in the general attempt for sustainable construction. The by-products like fly ash, silica fume, slag and palm oil fuel ash have been studied for the past decade and the findings are very well accepted as new innovative materials in construction. 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 from construction industry. However, part of these wastes and those produced by the construction industry are dumped in landfills. In the present research the effect of homogeneous ceramic tile waste on the harden properties of mortar was investigated. Mortar mixes were prepared focusing on the effect of ceramic aggregate as river sand replacement. Tests were conducted for compressive strength, splitting tensile strength for all mortar specimens. The sand was replaced by ceramic aggregate ranging from 0% to 100% by weight of aggregate. The size of ceramic aggregate used is modified in accordance to ASTM C33-13. All samples were cast in 50mm cubes and cured in water after demoulding until the age of testing. The result shows that by replacing 100% of sand with ceramic aggregate, the compressive strength is very much similar to control sample without showing any negative effect. In general, the incorporation of homogenous ceramic tile waste as river sand replacement can enhance the properties of mortar in fresh and hardened states.

Keywords: homogeneous ceramic waste, splitting tensile strength, strength development.

1. INTRODUCTION

This research is part of an experimental work which focus on the possible use of ceramic waste from a Malaysian ceramic manufacturer. The chemical, physical, and mineralogical characteristics of ceramic waste together with their effect on the properties of mortar is explained in this paper. Applying ceramic waste in mortar reduce cost, energy savings, promoting ecological balance and on the other hand conserve natural resources [1]. Large amount of ceramic waste which is abundant in the landfill and increasing amount of this waste day by day encourage the authors to investigate the potential utilization of ceramic waste in mortar as river sand (fine aggregate) replacement. Replacing natural aggregate such a river sand our crushed granite by ceramic wastes is one of the effective ways to reduce the environmental impact and preserve natural resources [2]. This strategy has the potential to reducing the costs, conserve energy, and waste minimization. Ceramic waste such as ceramic tile and clay brick waste have the potential to be used as aggregate replacement [3].

Many studies have been done on the microstructure of cement paste with or without pozzolanic additive [4,5]. However, not many studies were done regarding the effect of ceramic aggregate on the microstructure and the binding effect between cement and aggregate. The ceramic material has pozzolanic properties which was proved by many researchers. Consequently ceramic aggregates also have pozzolanic properties but because the size of the aggregate this activity is much less than fine ceramic powder. This research investigates the effects of ceramic aggregate on the microstructure and strength properties of mortar.

2. METHODOLOGY

2.1. Materials

Cement. Ordinary Portland Cement (OPC) was used in this experimental work satisfy requirement of ASTM C150-12 [6] for cement Type one, the Ordinary Portland Cement was from Cement Industry of Malaysia. The chemical composition of ordinary Portland cement is shown in Table 1.

Table 1: Chemical composition of OPC

	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

Sand. River sand in saturated surface dry condition (SSD) are used. This is to ensure that it does not reduce the workability of the mixture and hence the strength since this condition of fine aggregates is the best condition in mortar mixes so that it will not absorb water during mixing. The river sand for casting was modified according to ASTM C33-13 Standard Specification for Concrete Aggregates [7]. Figure 1 shows the sieve analysis of river sand which is used in this research. The bulk density of sand was 1614kg/m3.

Ceramic aggregate. The ceramic waste were crushed in jaw crusher machine and after that sieved by a series of sieves according to ASTM standard C33-13.The fine aggregate shall satisfy the limitation which is mentioned in the this standards. The colour of ceramic aggregate after preparation was light cream almost the same colour with normal river sand. After grading, the ceramic aggregate was used as river sand replacement [8,9]. The percentage of replacement were varied in order to get the best mix proportion. The physical properties of fine aggregate including ceramic aggregate and river sand is shown in Figure 1. In this research the ceramic aggregate and river sand are modified so that the sieve analysis of them is almost the same. The physical properties of the fine aggregate show that it satisfied the necessary requirements for the production of mortar.

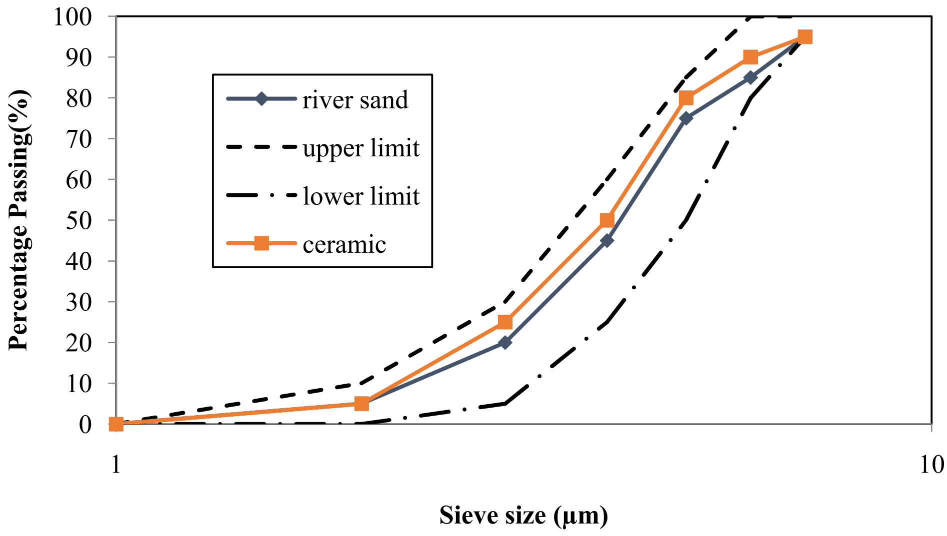

Figure 1: Sieve analysis of river sand and ceramic aggregate

2.2. Preparation of specimens

Mechanical mortar mixer with a rotating speed of 80rpm was used for the preparation of the mortar. All sampling and test were conducted according to ASTM standard C1329 [10]. The cement, ceramic aggregate and river sand 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 [11]. The samples for splitting tensile strength was cast in the cylinder mould 100mm in diameter and 200mm high according to ASTM standard C496[12]. In order to remove the air from the samples, the specimens were compacted by vibrating table for 30 seconds. Then, the specimens were demoulded 24 hours after casting and placed in water tank until the day of testing. The mix proportions of the mortar is shown in Table 2.

Table 2: Mix proportions of mortar

Materials (kg/m^3)	Mortar mix				
	OPC (C0)	25% (C25)	50% (C50)	75% (C75)	100% (C100)
OPC	550	550	550	550	550
Ceramic aggregate	-	1088	725	362	1460
River sand	1460	362	725	1088	-
w/c ratio	0.45	0.45	0.45	0.45	0.45

3. RESULTS AND DISCUSSIONS

3.1. SEM investigation

The SEM image of ceramic powder is shown in Figure 2. It can be seen that the ceramic aggregate show better binding with binder because of the texture of surface. As in the SEM image it is obvious that the surface is harsh and it is like bee house which cause more interface friction between binder and aggregate. This surface and natural angular shape of ceramic aggregate enhanced the interlocking between aggregates and better bonding between binder and aggregates. On the other hand this rough surface, porous texture and angular shape of the ceramic aggregate reduce the workability of mortar mix containing ceramic aggregate.

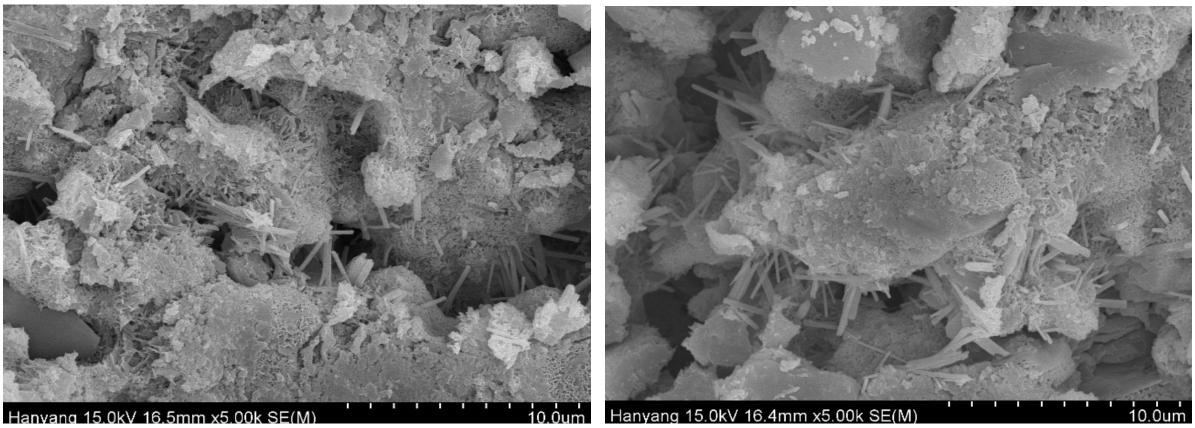

Figure 2: Field Emission Scanning Electron Micrograph of ceramic aggregate.

3.2. Compressive strength

The compressive strength of mortar with different percentage of ceramic aggregate as river sand replacement is shown in Figure 3. The 100% ceramic replacement showed higher compressive strength at all ages in comparison with other samples. As illustrated in this figure the difference in compressive strength amount of all the samples is not too significant. This may be due to the size distribution and physical characteristic of ceramic aggregate is 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.

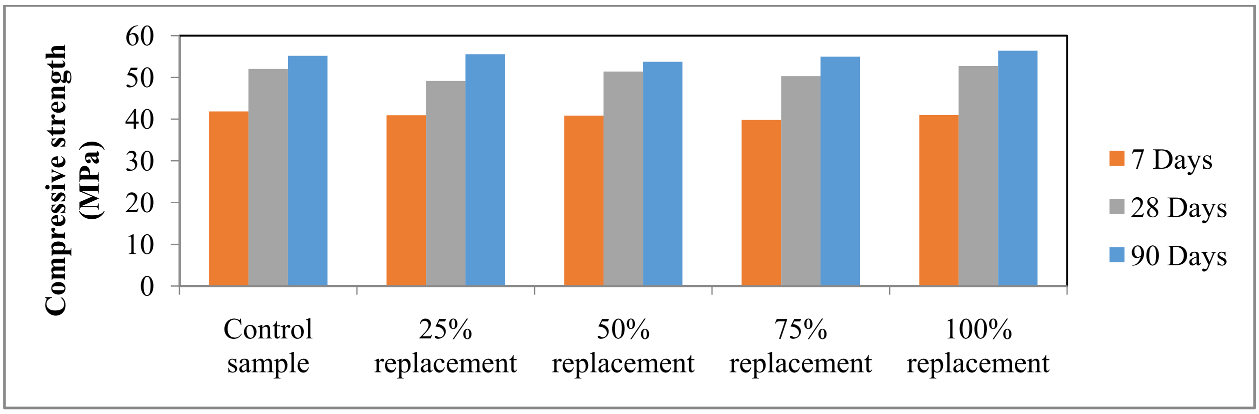

Figure 3: Compressive strength of mortar with sand and ceramic aggregates

3.3. Splitting Tensile Strength

The result of the splitting tensile strength of samples are shown in Figure 4. The strength was determined at the ages of 7, 28 and 90 days. The splitting tensile strength at the age of 7 days was in range of 4.7 to 5.1 MPa. Similar to compressive strength by increasing the age of samples the splitting tensile strength also increase. 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 6.2 to 6.5 and 6.7 to 6.9, respectively. In 28 and 90 days the results are between 6.2 to 6.5 and 6.7 to 6.9 respectively. The splitting tensile strength of the samples with 100% ceramic aggregate as river sand replacement recorded only 6% higher than control samples.

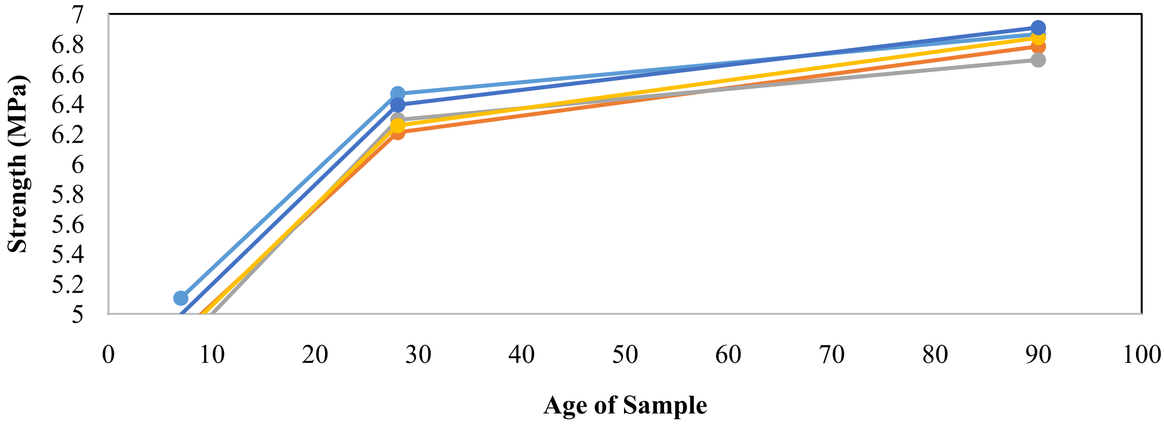

Figure 4: Splitting tensile strength of mortar samples

3.4. Termo Gravimetric Analysis (TGA)

Figure 5 shows the Termo Gravimetric Analysis of samples containing different percentage of ceramic aggregate as river sand replacement. This figure shows that the TGA results of all the samples is the same and hump and bump in graph almost similar. Similar behaviour of the different samples indicate that the aggregate do not have reaction with the binder. In other word there is no chemical reaction between ceramic aggregate and cement. In addition the binder which was used in all samples is ordinary Portland cement and same hydration in all the samples show that only cement react in the mix.

The evaporation of moisture cause first weight lost happened at the temperature of 100 to 110 ^{0}C. At this temperature the weight of samples was sharply decreased because the physical water (H2O (L)) inside the samples vaporized. After that reduction in the weight is slightly until the point which dehydration happened [13].

The dehydration of Ca(OH)2 occurs at a temperature in the range of 400 to 600 °C. The following chemical reaction usually takes place in this region: in the temperature between 400-600 °C Calcium hydroxide (Ca(OH)2) will be dehydrated. Calcium oxide (CaO) and water (H2O) are the results of dehydration of calcium hydroxide in which water is in gas phase and evaporated.

The decarbonation of samples occurred at temperature in the range of 600 to 800 C°. At this temperature the calcium carbonate ($Ca(CO_3)$) decomposed to calcium oxide (CaO) and carbon dioxide (CO_2).

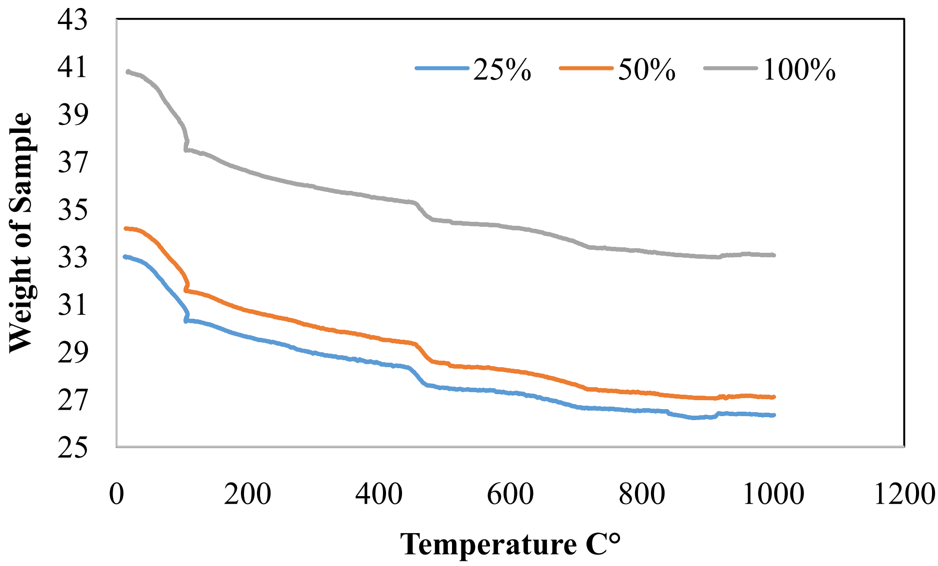

Figure 5: Termo Gravimetric Analysis (TGA) of samples containing 25%, 50% and 100% ceramic aggregate

4. CONCLUSIONS

The use of ceramic aggregate as replacement for river sand has positive effect on the compressive strength and splitting tensile strength of samples. The results show that this waste material can be a good alternative as river sand replacement. The FESEM images proved from the experimental results that the existing of strong bonding between ceramic aggregate and binder. This is due to the shape, surface texture and microstructure characteristic of the ceramic aggregate. The TGA result of samples show even after 28 days there is not any chemical reaction between ceramic aggregate and cement. By replacing river sand with ceramic aggregate up to 100% it can preserve the natural resources and reduce impact on the environment.

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