Jurnal
Teknologi

Full Paper

INCORPORATION OF HOMOGENOUS CERAMIC TILE WASTE TO ENHANCE MECHANICAL PROPERTIES OF MORTAR

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Article history
Received
2 July 2015
Received in revised form
20 October 2015
Accepted
23 October 2015

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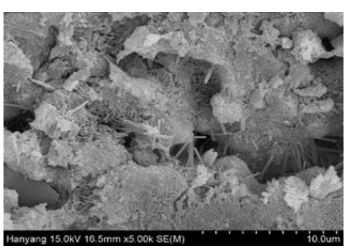
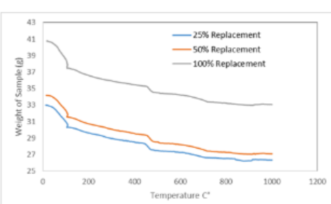
Graphical abstract





Abstract

Reduction, reuse and recycle of industrial and agricultural waste materials are regarded as very important to provide sustainable construction. The by-products such as fly ash, silica fume, slag and palm oil fuel ash, etc., have been studied for the past few decades and the findings are very well accepted as new innovative materials in construction. Currently, ceramic materials are widely used in many parts of the world. Consequently a large quantities of wastes are produced simultaneously by brick and tile manufacturers and from construction industry. Most of these wastes are dumped in landfills that cause environmental problem. In the present research the effect of homogeneous ceramic tile waste as sand replacement was investigated on the harden properties of mortar. The tests conducted under laboratory ambient condition were compressive and splitting tensile strengths. The percentage replacement of sand by ceramic aggregate by weight was in the range of 0% to 100%. The size of ceramic aggregate used is modified in accordance to ASTM C33-13. All samples were cast in a 50mm cube and cured in water until the age of testing. The results showed that the compressive strength values of the control sample and 100% ceramic aggregate as sand replacement at the age of 7days were 41.9 MPa and 40.9 MPa, respectively; almost similar. In addition, the splitting tensile strength of the mortar sample with 100% ceramic aggregate was found to be 6% higher than the control sample. Thus, the homogenous ceramic tile waste can not only be used as sand replacement for normal application in mortar mix but also to enhance its hardened properties.

Keywords: Homogeneous ceramic waste, splitting tensile strength, compressive strength, sand replacement

1.0 INTRODUCTION

This research is a part of an experimental work which focused on the possible use of ceramic waste from a Malaysian ceramic manufacturer. Its chemical, physical, and mineralogical characteristics together with its effect on the properties of mortar are presented in this paper. Incorporating waste aggregate in mortar reduces cost, saves energy, promotes ecological balance as well as conserves natural resources [1-4].

Large amount of ceramic waste is abundantly available in the landfills and is increasing day by day. This encouraged the authors to investigate the potential utilization of ceramic waste as replacement of river sand (fine aggregate) in mortar. This can be one of the effective ways to reduce environmental impacts and preserve natural resources [5-10]. This strategy has the potential to reduce cost, conserve energy, and waste minimization. Ceramic waste such as ceramic tile and clay brick wastes have the potential to be used as aggregate replacement [11-16].

Many studies have been conducted on the microstructural characterization of cement paste with or without pozzolanic additive [17, 18]. However, rare studies were reported regarding the effect of ceramic aggregate on the microstructural characterization and the binding effect between cement and aggregate. The ceramic material has pozzolanic properties and was proved by many researchers. Consequently ceramic aggregates also have pozzolanic properties but because of their size this was not studied much less compare to fine ceramic powder. This research investigates the effects of ceramic aggregate on the microstructural and strength properties of mortar.

2.0 EXPERIMENTAL

2.1 Materials

Ordinary Portland Cement (OPC) was used in this experimental work as per ASTM C150-12 requirement for cement Type I. The OPC was taken from Cement Industry of Malaysia and its chemical composition is shown in Table 1.

The river sand used for casting was modified according to ASTM C33-13 "Standard Specification for Concrete Aggregates" [19]. The homogenous ceramic tile waste was crushed in jaw crusher machine followed by sieving through a series of sieves as per ASTM standard. The fine aggregate satisfied the limitation as mentioned in the standards. The color of ceramic aggregate after preparation was light cream - almost the same as the river sand. After grading, the ceramic aggregate was used as river sand replacement [17, 18]. The percentage of replacement varied to get the best mix design. The physical properties of fine aggregate including ceramic aggregate and river sand are shown in Figure 1. In this research the ceramic aggregate and river sand are modified so that their sieve analysis is almost the same. The physical properties of the fine aggregate showed that it satisfied the necessary requirements for the production of mortar.

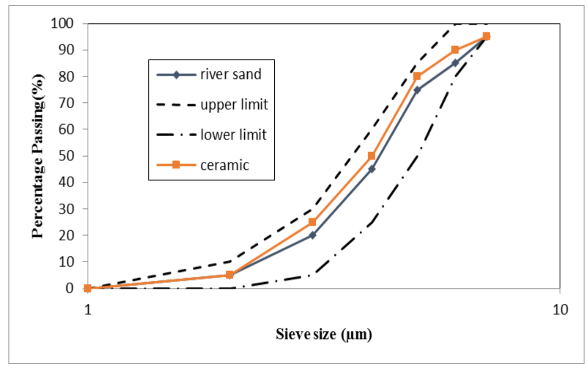


Figure 1 Sieve analysis of sand and ceramic aggregate

2.2 Specimens Preparation

Mechanical mortar mixer with a rotating speed of 80rpm was used for the preparation of mortar. All sampling and tests were conducted according to ASTM standard C1329/C1329M-12. The cement, ceramic aggregate and river sand were mixed for about two minutes before adding water to the mix. Finally the balance of 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 "Standard test method for compressive strength of hydraulic cement mortars". The samples for splitting tensile strength were cast in the cylinder mould: 100mm in diameter and 200mm high according to ASTM C496-11. 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 mortars are shown in Table 1.

Table 1 Mix proportions of mortars

Materials	Mortar mix				
	OPC (C0)	25% (C25)	50% (C50)	75% (C75)	100% (C100)
OPC (kg/m³)	550	550	550	550	550
Ceramic Aggregate (kg/m³)	-	362	725	1088	1460
Sand (kg/m³)	1460	1088	725	362	-
w/c ratio	0.45	0.45	0.45	0.45	0.45

2.3 Test Methods

In accordance with ASTM C109-11, the compressive strength test was conducted at ages of 7, 28 and 90 days. Three specimens were tested to obtain the average value for each test condition.

3.0 RESULTS AND DISCUSSION

3.1 SEM Results

The SEM images of ceramic powder are shown in Figures 2 and 3. It can be seen that the ceramic aggregate showed better binding with binder because of the surface texture. As shown in the SEM image it is obvious that the surface is rough 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.

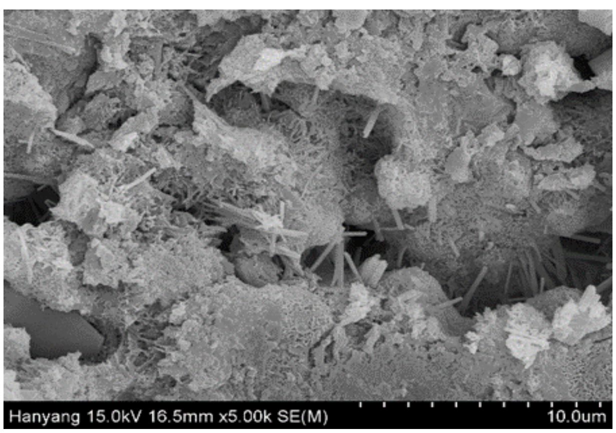


Figure 2 Field emission scanning electron micrograph of sample with ceramic aggregate as sand replacement

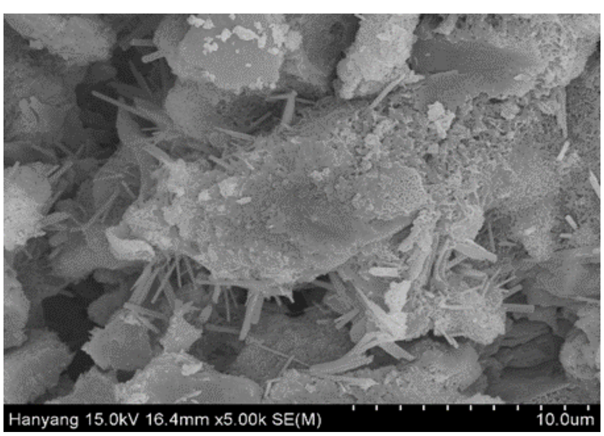


Figure 3 Field emission scanning electron micrograph of sample with ceramic aggregate as sand replacement

3.2 Compressive Strength

The compressive strength of mortar with different percentage of ceramic aggregate as river sand replacement is shown in Figure 4. For each batch three samples tested and get the average as result. 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 values of all the samples is not too significant. This may be due to the size distribution and physical characteristic of ceramic aggregate which 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 compressive strength of control sample and 100% ceramic aggregate as sand replacement in 7days are 41.9 MPa and 40.9 MPa, respectively. The results indicate that the ceramic aggregates can be used to replace sand in mortar mix.

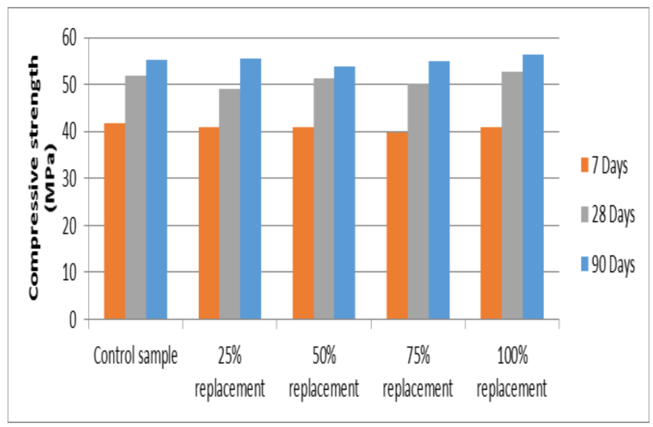


Figure 4 Effect of ceramic waste in compressive strength of mortar

3.3 Splitting Tensile Strength

The result of the splitting tensile strength of samples are shown in Figure 5. The strength was determined at 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. By increasing the age of samples the splitting tensile strength also increases, similar to compressive strength. This was due to the strength generation as a results of continuous cement hydration process. The splitting tensile strength results at 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.

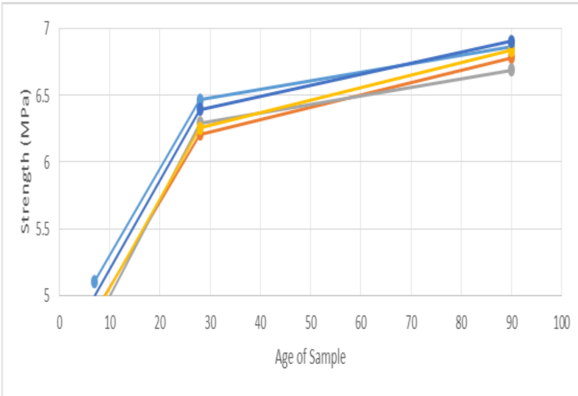


Figure 5 Splitting tensile strength of mortar samples

3.4 Thermo-Gravimetric Analysis (TGA)

Figure 6 shows the Thermo-Gravimetric Analysis of samples containing different percentages of ceramic aggregate as river sand replacement. This figure shows that the TGA results of all the samples are the same and hump and bump in graph almost similar. Similar behaviour of the different samples indicate that the aggregates did not react with the binder. In other words, 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 reacted in the mix.

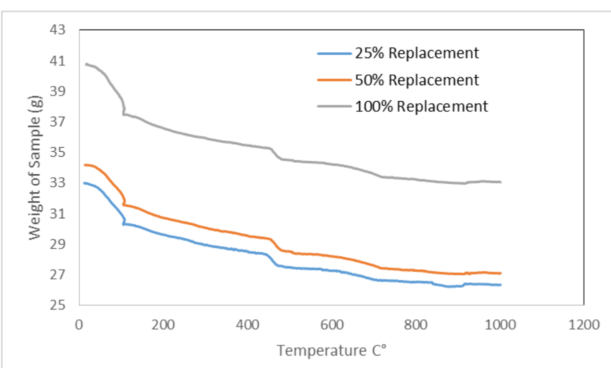


Figure 6 TGA of samples containing 25%, 50% and 100% ceramic aggregate

The evaporation of moisture causes first weight lost which happened at the temperature of 100 to 110 ºC. At this temperature the weight of samples was sharply decreased because the physical water (H_2O (L)) inside the samples vaporized. After that reduction in the weight is slight until the point where dehydration happened [20, 21].

The dehydration of $Ca(OH)_2$ happened at temperature of 400 to 600 °C. In the temperature between 400-600 °C Calcium hydroxide ($Ca(OH)_2$) will be dehydrated. Calcium oxide (CaO) and water (H_2O) are the results of dehydration of calcium hydroxide in which water is in gas phase and evaporated [22].

The decarbonation of samples occurred at temperatures ranging from 600 to 800 C°. At these temperatures, the calcium carbonate ($Ca(CO_3)$) decomposed to calcium oxide (CaO) and carbon dioxide (CO_2).

4.0 CONCLUSIONS

The use of ceramic aggregate as replacement for river sand has positive effect on the harden properties of specimens. 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 there existed a strong bond between ceramic aggregate and binder. This is due to the shape, surface texture and microstructural characteristic of the ceramic aggregate. The TGA result of samples show even after 28 days that there is no chemical reaction between ceramic aggregate and cement. By replacing river sand with ceramic aggregate up to 100% can preserve the natural resources and reduce impact on the environment.

Acknowledgement

The authors are grateful to the Ministry of Higher Education, Malaysia (MOHE) and Research Management Centre (RMC), Universiti Teknologi Malaysia (UTM) for financial support under grant GUP Q.J130000.2509.06H56 and grant GUP Q.J130000.2517.07H32. The authors are also thankful to the staff of Structures & Materials Laboratory, Faculty of Civil Engineering for the support throughout the study.

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