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Effect of Homogenous Ceramic Waste on Drying Shrinkage of Mortar

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Abstract

Concrete has become important building material in the construction industry due to its mechanical and physical properties. However, large needs of concrete usage lead to the depletion of natural resources. Therefore the use of industrial by-product has been given attention. Ceramic materials are largely used worldwide and consequently, produced large amount of waste from the tile manufacturers and construction industry. These wastes were dumped in landfills and not recyclable. This study investigates the effect of ceramic powder as cement replacement and ceramic fine aggregates as sand replacement on the strength development and drying shrinkage of the mortar. The cement was replaced by 40% ceramic powder by weight of cement. The specimens were cast in 50 x 50 x 50 mm cube for compressive strength test and 25x25x250 mm size for drying shrinkage. The fineness of ceramic powder used is less than 45μm. The developments of compressive strength were studied for all samples. It is found that the increases replacement cause growing strength of samples containing homogenous ceramic waste. The shrinkage value of ceramic mortar was reduced by 16% compared to OPC mortar thus, shows better performance in restraining the shrinkage deformation of the mortar. Furthermore, with replacing cement and natural fine aggregates by ceramic powder and ceramic fine aggregates reduces the usage of natural resources and minimizes the landfills problem.

Keywords: Composite cement; mortar, drying shrinkage, homogenous ceramic waste

1 Introduction

Concrete has become important building material in the construction industry due to its mechanical and physical properties. More than 10 billion tonnes of concrete is produced annually [1]. Furthermore, with the large quantities of concrete being produced, there are consequences that will affect the environment. It has been found that approximately one tonne of carbon dioxide (CO_2) is released with every one tonne of cement produced. Worldwide, around 5% of total CO_2 emission is contributed by the cement industry alone [2]. Due to the implementation of the Kyoto protocol in February 2005, countries all over the world have to reduce their greenhouse gases emissions. Besides, the continuous need of concrete structures for housing development resulting in depletion of natural resources. Therefore, the use of industrial by-products has been given attention in the concrete technology research since the beginning of the twentieth century [3-5]. Nowadays huge amount of ceramic wastes is produced by the ceramic industries which cause environmental impact and landfill problems. Malaysia manufactured 92 million square metres ceramic in 2012 and is increasing by 2.2% each year [6]. It is estimated that 10 to 30% of total ceramic production goes as a waste [7]. Most of these huge ceramic wastes cannot be recycled and produce a disposal issues at later age [8]. The ceramic waste have been researched and approved to have better mechanical properties compared to conventional mortar [9-11]. However, there is a limited study in term of the drying shrinkage incorporating ceramic waste. Therefore, there is necessary to study the effect of ceramic waste on the shrinkage as it is important factor for the structural application.

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2 Materials and Test Methods

2.1 Materials

Ordinary Portland Cement (OPC) satisfying the requirement of ASTM C150-15 for cement Type I was used. OPC was obtained from local cement producer in Malaysia. The ceramic waste was obtained from ceramic factory located in the south of Malaysia. The chemical compositions of the cement and ceramic powder are shown in Table 1. Tap water which is available in the laboratory was used.

Saturated surface dry (SSD) fine aggregates were used with specific gravity of 2.61 and fineness modulus of 2.86. Fine aggregates were modified according to ASTM C33-13. Figure 1 shows the sieve analysis of fine aggregates used in this research. The well graded aggregates usually reduce the demand for water and thereby, improve the packing density, robustness and workability of the mortar.

2.2 Specimens preparation

A mixer with a rotating speed of 80rpm was used for the preparation of the mortar. All specimens and testing procedure were done in accordance to ASTM C109-13. Firstly, binder and fine aggregates were mixed for 2 minutes before adding water into them. Then water was added to the mixture and continued mixing for another 5 minutes. The mortar specimens were placed in cube moulds (50x50x50 mm size) according to ASTM C109-13 and 25x25x250 mm size for drying shrinkage. Specimens were vibrated for (30 second) using a vibrating table to remove the trapped air voids. After (24 hours) of casting, mortar specimens were demoulded and then immersed in water until the day of testing. Mix proportions of mortar are shown in Table 2.

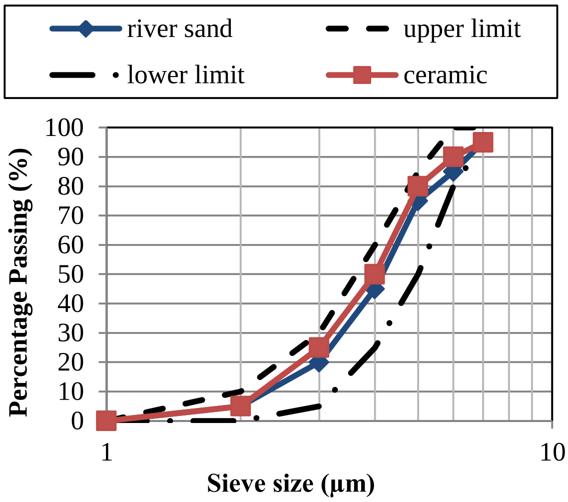


Figure 1: Sieve analysis of fine aggregates according to ASTM C33

Table 1: Chemical compositions 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	2.40
Ceramic powder	74.10	17.80	3.57	1.11	2.69	0.46	0.10

Table 2: Mix design of OPC mortar and ceramic mortar

Mortar mixes	**Cement (kg/m^3)**	**Ceramic powder (kg/m^3)**	**Natural Fine Aggregates (kg/m^3)**	**Ceramic Fine Aggregates (kg/m^3)**	**Water Cement Ratio**
OPC	550	-	1460	-	0.48
Ceramic	330	220	-	1460	0.48

2.3 Testing Procedures

Drying shrinkage is strain associated with the loss of moisture from the mortar or concrete by evaporation of water or hydration of cement. For drying shrinkage test, the size of specimens was 25x25x250 mm as shown in Figure 2. The test was conducted in accordance to ASTM C596-09. After demoulding, the mortar specimens were prepared for the installation of demec discs for shrinkage measurement. The demec disc was glued to both sides at a distance of 75 mm from the centre. After that, demec gauge was used to measure initial readings. Shrinkage readings were recorded by using mechanical extensometer. The drying shrinkage strain of each type of mortar was calculated. The percentage of shrinkage was calculated using Equation 1.

$$\text{Percentage of shrinkage} = \frac{Lo-L}{Lo} \times 100 \qquad \text{Equation 1}$$

where, *Lo* is original length (length of standard bar) (mm) and *L is* length as measured during or after cure excluding studs (mm).

3 Results and Discussion

3.1 Drying Shrinkage

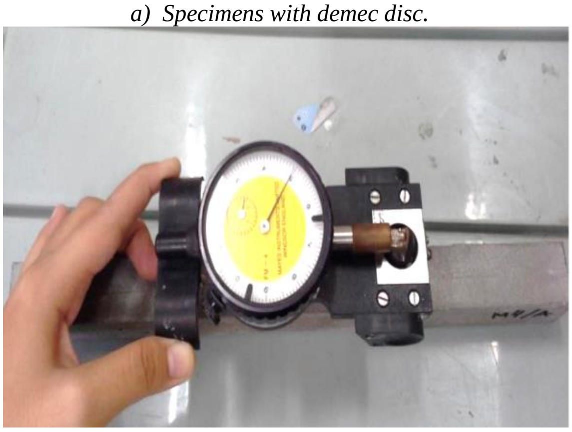
Figure 3 shows the development of the drying shrinkage for OPC and ceramic mortars until the age of 90 days. As can be seen in the figure, the drying shrinkage of OPC mortar is higher than ceramic mortar at all ages. The drying shrinkage values for both mortars are increasing very sharp in the early age. The recorded drying shrinkage of OPC and ceramic mortars at the age of 90 days are 993×10^{-6} mm/mm and 837×10^{-6} mm/mm, respectively. The use of ceramic powder and ceramic fine aggregates significantly reduces the drying shrinkage of the mortar which was mainly related to the reduced free water content in capillary pore. Less free water content will result in less water lost during drying that leads to lower shrinkage.

Neville, (2011) reported that drying shrinkage of cement paste is affected by the porosity and the size of the capillary system in the hydrated cement paste [12]. Furthermore, ceramic powder exhibited a good pozzolanic reaction and a high packing effect thus lower the drying shrinkage compared to OPC mortar and assisting in transforming large pores into fine pores. This pore refinement reduces the loss of water, and therefore reduces the drying shrinkage of mortars containing ceramic waste. Therefore, the results show that ceramic mortar has better performance in terms of the drying shrinkage of mortar.

3.2 Compressive strength

Figure 4 shows the comparison of compressive strength of OPC and ceramic mortars. As the age of water curing increases, the compressive strength of OPC and ceramic mortars also increases. This was mainly due to the continuous hydration process and pozzolanic reaction occurred in the mortars.

a) Specimens with demec disc.



b) Measuring shrinkage using mechanical extensometer.

Figure 2: Sample preparation for drying shrinkage test

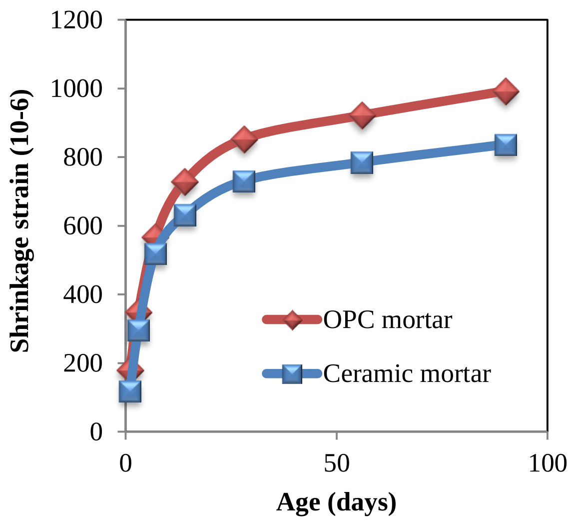


Figure 3: Drying shrinkage of OPC and ceramic mortars

At the age of 28 days, the compressive strength of ceramic mortar was found to increase by 6% as compared to OPC mortar. This was due to the increase in the production of C-S-H gel from pozzolanic reaction. After 90 days of curing, the OPC and ceramic mortars show compressive strength of 55.2 MPa and 58.7 MPa, respectively. The compressive strength of ceramic mortar after 90 days has increased by 6% from its 28 days strength. Despite the stronger bond produced and filler packing effect, the angular shape and rough surface texture of ceramic fine aggregates increase the bond between binder and fine aggregates resulting in an increase in the compressive strength.

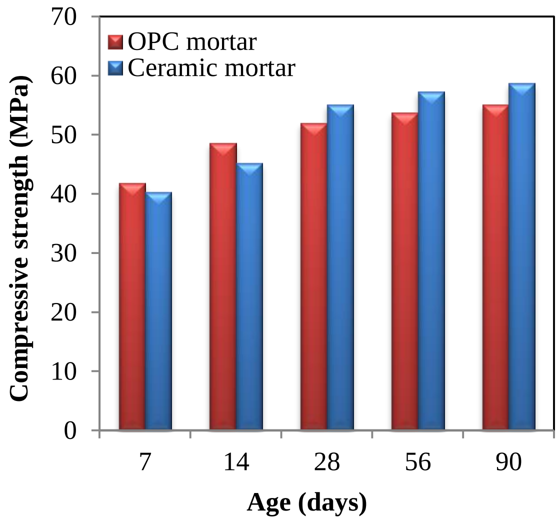


Figure 4: Compressive strength of OPC and ceramic mortars

4 Conclusions

Based on the experimental result of this research the following conclusion can be drawn:

i) Homogenous ceramic waste can be used as cement replacement of up to 40% and 100% as fine aggregates replacement to improve strength compared with OPC mortar.

ii) The drying shrinkage of the OPC and ceramic mortars at the age of 90 days are 993x10^{-6} mm/mm and 837x10^{-6} mm/mm, respectively. The shrinkage value of ceramic mortar was reduced by 16% compared to OPC mortar thus, shows better performance in restraining the shrinkage deformation of the mortar.

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