Jurnal
Teknologi

Full Paper

PROPERTIES OF MORTAR CONTAINING CERAMIC POWDER WASTE AS CEMENT REPLACEMENT

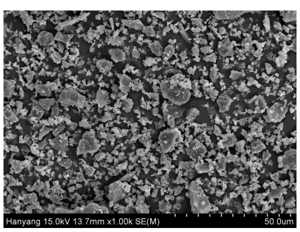
Mostafa Samadi[a], Mohd Warid Hussin[b*], Han Seung Lee[c], Abdul Rahman Mohd Sam[d], Mohamed A. Ismail[e], Nor Hasanah Abdul Shukor Lim[a], Nur Farhayu Ariffin[a], Nur Hafizah A. Khalid[a]

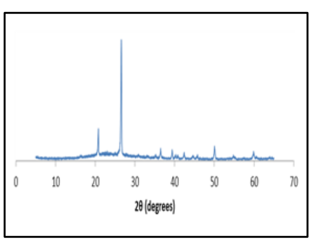
[a]Postgraduate student, Construction Material Research Group (CMRG), Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[b]Professor, Construction Research Centre (UTM CRC), Institute for Smart Infrastructure and Innovative Construction, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[c]Professor, Dept. of Architectural Engineering, Hanyang University Ansan, Republic of Korea
[d]Associate Professor, Department of Structures and Materials, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[e]Research Professor, Dept. of Architectural Engineering, Hanyang University Ansan, Republic of Korea

Article history
Received
15 April 2015
Received in revised form
29 September 2015
Accepted
12 November 2015

*Corresponding author
warid@utm.my

Graphical abstract





Abstract

Ceramic materials are largely used in all over the world and consequently, large quantities of wastes are produced simultaneously by tile manufacturers and construction industry. Nevertheless, part of these wastes and those produced by the construction industry are dumped in landfills. This paper presents the effect of using ceramic waste in mortar as cement replacement. Four mortar mixes were prepared in this study and focuses on the effect of ceramic powder as cement replacement on the strength development and the morphology of the mortar. The microstructural characteristics of the mortar were investigated by scanning field emission electron microscopy (FESEM) and the mineralogical properties was investigated using the X-ray diffraction (XRD). The cement was replaced by ceramic powder from 0% to 60% by weight of cement. The specimens were cast in 50 x 50 x 50 mm cube and water curing regime was used until the age of testing. 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 optimum replacement that gave the highest strength was 40% replacement. It was also found that the use of ceramic powder enhanced the microstructure and strength properties of the mortar.

Keywords: Ceramic powder, cement replacement, FESEM, XRD, ceramic mortar

1.0 INTRODUCTION

Nowadays, pozzolanic materials have been used as construction material, especially for their effect on improving the microstructure and durability of concrete [1, 2]. Recently, concern about environmental pollution due to environmental protection regulations motivates further researches on the possibility of using pozzolanic materials from industrial waste like ceramic wastes, fly ash and silica fume [3].

Partial replacement of cement by waste materials such as fly ash, silica fume or ceramic would assist in solving the landfill problems and lead to improvement of durability, workability and strength of concrete [4].

This research is part of experimental work which focuses on ceramic waste from a Malaysian ceramic manufacturing industry. The chemical, physical, and mineralogical characteristics of the ceramic waste and their effect on the properties of mortar are explained by previous researchers such as [3].

In the hydration process of Pozzolanic materials, reaction of $Ca(OH)_2$ incorporated or released in the hydration of Portland Cement, forming hydrated phases that resemble Portland Cement silicates hydration products ($Ca(OH)_2 + H_4SiO_4 \rightarrow Ca^{2+} + H_2SiO_4^{2-} + 2\ H_2O \rightarrow CaH_2SiO_4 \cdot 2\ H_2O$). Activated clay was used as pozzolanic material since ancient times [1]. Raw clays do not have pozzolanic properties, however by calcination of clay ($CaCO_3 \rightarrow CaO + CO_2(g)$) and grounding it to an appropriate fineness it can be activated and used as pozzolanic material [5].

Malaysia is one of the developing countries where the constructions of infrastructure are still ongoing, hence there is high demand of construction material. Therefore, this work focuses on recycle and reuse of waste product to produce a new construction material. In this research ceramic waste was used as cement replacement. High demand of ordinary Portland cement increases its production, which consequently contributes to pollution by releasing carbon dioxide gasses into the atmosphere [6].

Ceramic wastes are not biodegradable and consume much space in landfill. Finding new way to recycle this waste in construction of infrastructures can be useful to preserve natural resources and our planet. According to the previous research, ceramic waste was found to have pozzolanic properties [7, 8].

abrasion test machine with 8 stainless steel bars of 18 mm diameter and 800 mm long. Only fine ceramic that passes through 40 μm sieve were collected and used in the mixing process [9, 10].

This ceramic powder was used as cement replacement material [11, 12]. The percentage of replacement was varied in order to get an optimum mix proportion. The chemical composition of the ceramic is shown in Table 1.

Crushed river sand is used to prepare the mortar in this study. To ensure the sand does not absorb excess water from the mix during casting and do not have effect on workability of mortar, the sand used was in saturated surface dry (SSD) condition. The size of sand for casting was modified according to ASTM C33-03 Standard Specification for Concrete Aggregates. Figure 1 shows the sieve analysis curve for sand used in this study. The bulk density of sand is 1614 kg/m^3.

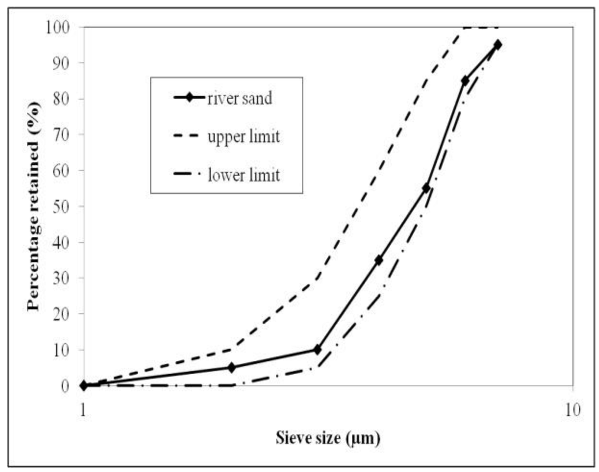


Figure 1 Sieve analysis for sand

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

2.0 EXPERIMENTAL PROGRAM

2.1 Materials

The Ordinary Portland Cement (OPC) used in this experimental work satisfy the requirement of ASTM C150-12 for cement Type I and it was obtained from one of the cement industry of Malaysia. The ceramic wastes were crushed in a jaw crusher and sieved through 1.18 mm size sieve to remove larger particles. Then, it was grounded in the modified Los Angeles

2.2 Preparation of Specimens

Mechanical mortar mixer with a rotating speed of 80 rpm was used in preparing the mortar. All sampling and testing was performed according to ASTM standard C1329/C1329M-12.

Cement, ceramic powder and sand were mixed for around 2 minutes before adding water to the mix. Finally water was added to the mixture and continuous mixing for another 5 minutes. The prepared mortars were placed in a mould of 50 x 50 x 50 mm cubes according ASTM standard C109/C109M-13. To remove 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 are shown in Table 2.

Table 2 Mix proportions of mortar

Materials (kg/m³)	Mortar mix			
	OPC (C0)	**20% (C2)**	**40% (C4)**	**60% (C6)**
OPC	550	440	330	220
Ceramic Powder	-	110	220	330
Sand	1460	1460	1460	1460
w/c ratio	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 the ages of 7, 14 and 28 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 image of ceramic powder is shown in Figure 2. This image proves that the particle size of ceramic powder is less than 50 µm. Many previous researches were carried out on microstructure of cement paste with or without pozzolanic additive [13, 14]. However, only few studies were carried out on the effect of ceramic powder on microstructure of mortar. The present work is therefore focusing on the microstructure and strength properties of mortar using ceramic powder.

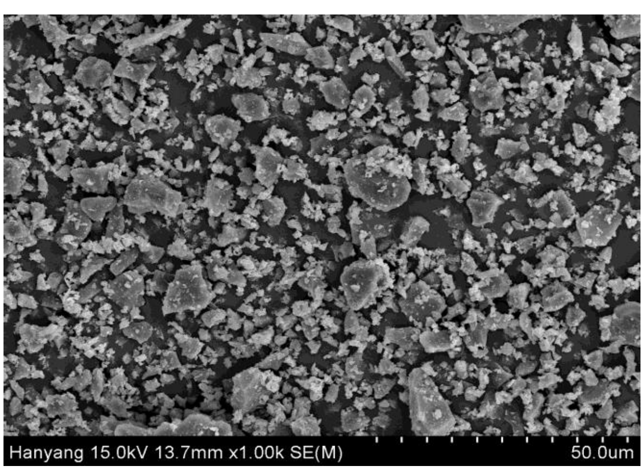


Figure 2 Field Emission Scanning Electron Micrograph of ceramic powder

The microstructure of mortar was studied using Field emission scanning electron micrograph (FESEM) techniques. By increasing the amount of ceramic powder in the samples the total amount of calcium silicate hydrated (C-S-H) crystals increase and consequently reduces the porosity. The best results were obtained at 40% cement replacement by ceramic powder with respect to improvement in the microstructure of the sample. The ability of pozzolanic material to reduce the amount of calcium hydroxide ($Ca(OH)_2$) in the paste has been proven by previous researchers such as [3, 15].

Figure 3 shows Field Emission Scanning Electron Micrograph of sample with 20% Ceramic as cement replacement. In this image crystal of calcium hydroxide ($Ca(OH)_2$) easily can be seen. This crystals look like plate that originates from hydration reaction of cement. The main component of cement is calcium oxide (CaO) which in hydration process gives crystals of calcium hydroxide. This crystal is one of the crystals that give strength to cement paste.

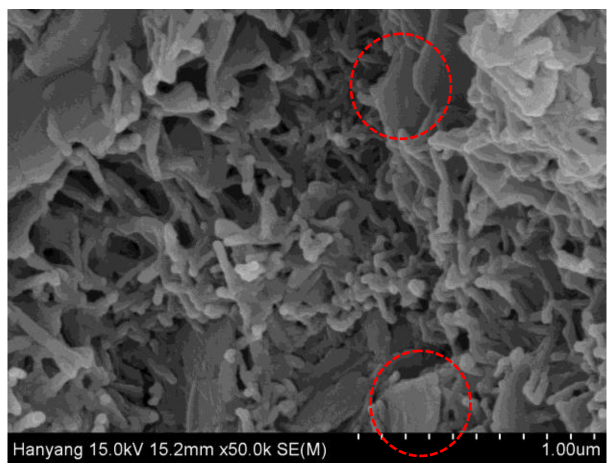


Figure 3 Field emission scanning electron micrograph of sample with 20% ceramic as cement replacement

Figure 4 shows the Field Emission Scanning Electron Micrograph of sample with 40% Ceramic as cement replacement. In this image three different crystals were observed, calcium silicate hydroxide crystal (C-S-H), calcium hydroxide crystal and ettringite crystal. All these crystals strengthen the paste with some of them doing so at early age like calcium hydroxide and others coming from reaction of pozzolanic material at later age like calcium silicate hydroxide crystal.

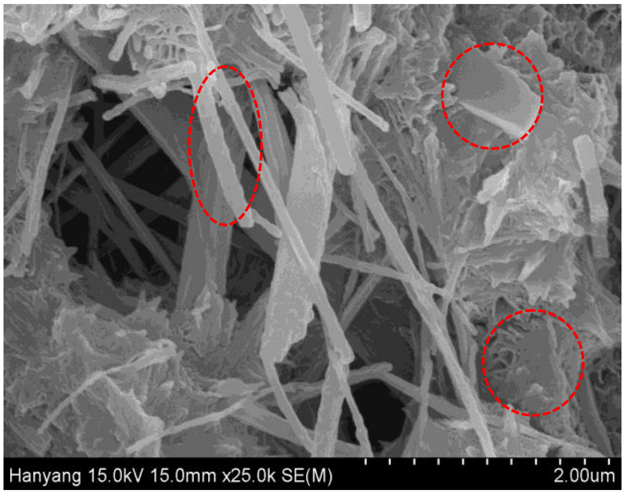


Figure 4 Field emission scanning electron micrograph of sample with 40% ceramic as cement replacement

Figure 5 shows the Field Emission Scanning Electron Micrograph of sample with 60% Ceramic as cement replacement. In this image needle of ettringite can obviously be observed. In concrete chemistry ettringite is a hexacalcium aluminate trisulfate hydrate, of general formula is $(CaO)_6(Al_2O_3)(SO_3)_3 \cdot 32H_2O$ or $(CaO)_3(Al_2O_3)(CaSO_4)_3 \cdot 32H_2O$.$(CaO)_3Al_2O_3+3CaSO_4 \rightarrow (CaO)_3(Al_2O_3)(CaSO_4)_3 \cdot 32H_2O$ (ettringite).

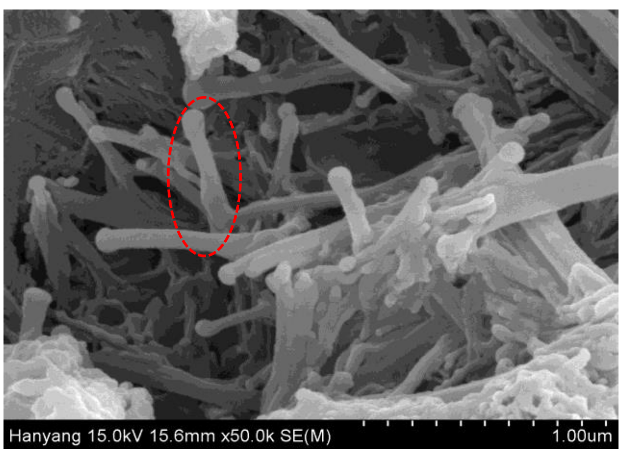


Figure 5 Field emission scanning electron micrograph of sample with 60% ceramic as cement replacement

3.2 Compressive Strength

The compressive strength of the mortar with different percentage of ceramic as cement replacement is shown in Figure 6. The 20% and 40% ceramic replacement showed higher compressive strength compared to the normal mortar at 28 days. This may be due to the pozzolanic reaction that happened between silicon oxide (SiO_2) and calcium hydroxide $Ca(OH)_2$ from hydration process [16]. Ceramic mortar shows increment of compressive strength at later age compared to the normal mortar.

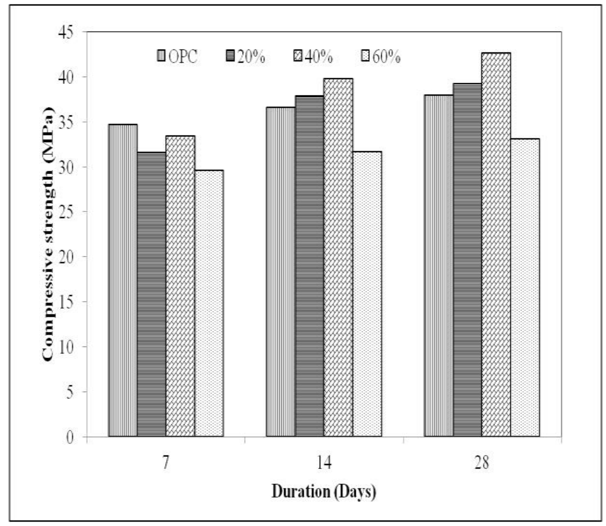


Figure 6 Effect of ceramic waste in compressive strength of mortar

3.3 X-ray Diffraction (XRD) Analysis

Figure 7 illustrates the X-ray diffraction of ceramic powder in which there are some peaks on the graph. These are referring to the characteristic of material which shows that it contained crystal or amorphous or in other word some parts of ceramic powder is crystalline [17]. That part which is highlighted in the graph is referred to amorphous part of ceramic powder. According to the XRD result this ceramic powder is semi-crystalline.

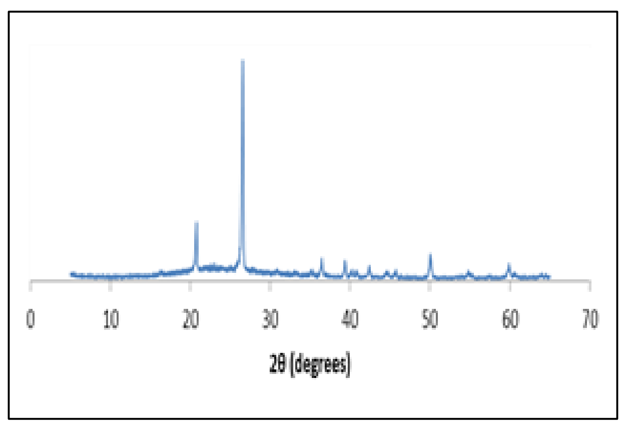


Figure 7 X-ray diffraction of ceramic powder

3.4 Activity Index

Figure 8 shows the activity index result of ceramic powder. The activity index test method is a way of finding out whether the material used as cement replacement has pozzolanic activity or not [17]. This test is performed according to the Standard Test

Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete C311-07. Ceramic powder satisfied the requirement of ASTM C 311 as pozzolanic material. It means after 7 days the compressive strength of sample reaches 75% of the control samples using OPC without any additive.

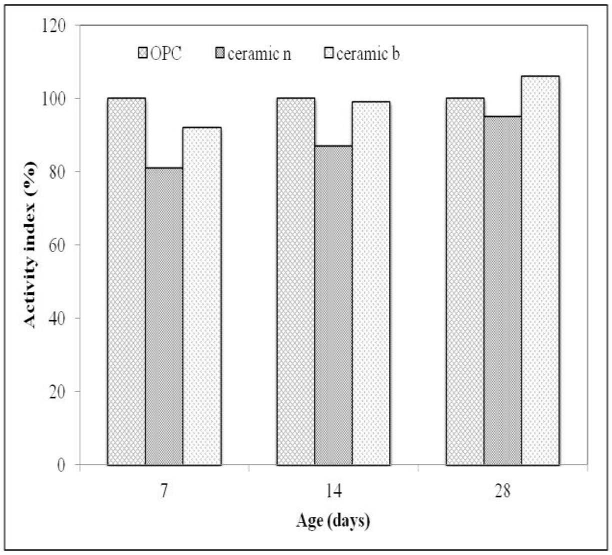


Figure 8 Activity index result

4.0 CONCLUSIONS

FESEM images proved that the experimental results which showed the interface microstructure is improve by adding ceramic powder. This is due to the act of ceramic powder as filler as well as generating pozzolanic reaction. FESEM image shows that the amount of calcium hydroxide which come from the hydration process of cement reduce when ceramic powder is used in the mix. By replacing cement with ceramic powder up to 40% the total amount of calcium silicate hydroxide crystal increase or in other word the rate of pozzolanic reaction increase. The test results indicated that the use of ceramic powder as cement replacement materials enhanced the properties of mortar.

Acknowledgement

The authors are grateful to the Ministry of Higher Education, Malaysia (MOHE) and Research Management Centre (RMC), Universiti Teknologi Malaysia (UTM) for the financial support under grant GUP Q.J.130000.2509.06H56 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.

References

[1] Mehta, K. 1998. Role of Pozzolanic and Cementitious Material in Sustainable Development of the Concrete Industry. *Sixth CANMET/ACI Conference International on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, ACI SP 178*. Edited by V. M. Malhotra. American Concrete Institute (ACI), Bangkok, Thailand. 1: 1-20.

[2] Taylor, H. F. W. 1997. *Cement Chemistry*. 2nd edition. Thomas Telford, London.

[3] Frías, M., O. Rodríguez, I. Vegas and R. Vigil. 2008. Properties of Calcined Clay Waste and its Influence on Blended Cement Behavior. *Journal of the American Ceramic Society*. 91(4): 1226-1230.

[4] Naceri, A. and M. C. Hamina. 2009. Use of Waste Brick as a Partial Replacement of Cement in Mortar. *Waste Management*. New York, N.Y. 29(8): 2378-2384.

[5] Lavat, A. E., M. A. Trezza and M. Poggi. 2009. Characterization of Ceramic Roof Tile Wastes as Pozzolanic Admixture. *Waste Management*. New York, N. Y. 29(5): 1666-1674.

[6] Wimpenny, D. 2009. Low Carbon Concrete–Options for the Next Generation of Infrastructure. *Concrete Solutions*. 1-10.

[7] Baronio, G. and L. Binda. 1997. Study of the Pozzolanicity of Some Bricks and Clays. *Constr Build Mater*. 11: 41-46.

[8] Sanchez de Rojas, M. I., F. Marın, J. Rivera, and M. Frıas. 2006. 'Morphology and Properties in Blended with Ceramic Wastes as a Pozzolanic Material. *J. Am. Ceram. Soc*. 89(12): 3701–5.

[9] Eva, V., K. Martin, R. Pavla, O. Michal, K. Zbyne and C. Robert. 2012. Properties of High Performance Concrete Containing Fine-ground Ceramics as Supplementary Cementitious Material. *Cement & Concrete Composites*. 34: 55-56.

[10] Baoshan, H., D. Qiao and G. Edwin, 2009. Burdette Dept. Laboratory Evaluation of Incorporating Waste Ceramic Materials into Portland Cement and Asphaltic Concrete. *Construction and Building Materials*. 23(2009): 3451-3456.

[11] Fatima, E., J. Ankit and K. Rakesh. 2013. Ceramic Dust as Construction Material in Rigid Pavement. *American Journal of Civil Engineering and Architecture*. 1(5): 112-116.

[12] Nuran, A. and U. Mevlut. 2000. The Use of Waste Ceramic Tile in Cement Production. *Cement and Concrete Research*. 30: 497-499.

[13] Tu, T. Y, Y. Y. Chen and C. L. Hwang. 2006. Properties of HPC with Recycled Aggregates. *Cement and Concrete Research*. 36l: 943-50.

[14] Esin, T. and N. Cosgun. 2007. A Study Conducted to Reduce Construction Waste Generation in Turkey. *Building and Environment*. 42: 1667-74.

[15] Marianne, T. J., M. Dorthe, M. P. Christian and B. Dirch, 2001. Durability of Resource Saving ''Green'' Type of Concrete. In: *Proceedings of FIB– Symposium on Concrete and Environment, Berlin, October.*

[16] Sabri, B. B., S. Wild, J. Bai. 2001. Metakaolin and Calcined Clays as Pozzolans for Concrete: A Review. *Cement and Concrete Composites*. 23: 441-454.

[17] Lim, N. H. A. S., M. A. Ismail, H. S., Lee, M. W., Hussin, A. R. M., Sam, & M. Samadi. 2015. The Effects of High Volume Nano Palm Oil Fuel Ash on Microstructure Properties and Hydration Temperature of Mortar. *Construction and Building Materials*. 93: 29-34.