International Journal of Civil Engineering and Geo-Environmental

Journal homepage:http://ijceg.ump.edu.my
ISSN:21802742

Behaviour of Metakaolin Concrete in Different Curing Condition

M. N. Muhd Sidek [1*], M. A. Megat Johari [2], M. F. Arshad [3], M. F. Md Jaafar[4]

[1] Faculty of Civil Engineering, Universiti Teknologi MARA, Perlis, Malaysia
[2] School of Civil Engineering, Universiti Sains Malaysia, Transkrian, Nibong Tebal, Pulau Pinang, Malaysia
[3] Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam, Malaysia
[4] Faculty of Civil Engineering & Earth Resources, Universiti Malaysia Pahang, Malaysia

ARTICLE INFO

Keywords:
Metakaolin
Curing condition
Physical properties
Mechanical properties

ABSTRACT

This paper presents the result of an investigation on the effect of curing condition on concrete containing Metakaolin. Concrete grade 40 was used in this research and Metakaolin is replaced from 5%, 10% and 15%. All sample been cured by using three different curing condition which is normal curing ($\pm$20°C), expose curing (28 – 34°C) and high temperature curing ($\pm$55°). The effect of Metakaolin on concrete will be seen by physical and mechanical properties. From physical properties the effect of Metakaolin will be seen by using soundness, setting time and workability and for mechanical properties compression and flexural test will be performed. From physical test shows Metakaolin reduce the workability of concrete and hence increase the water demand in concrete mix but the addition of Metakaolin reduce the ability of cement paste to expand. This happen because the addition of Metakaolin will fill the void around the cement paste. Results from physical test are supported by testing the mechanical part. Results show that concrete containing Metakaolin improved in all curing condition except for high temperature curing. These can be seen from compression test that shows Metakaolin increase strength of concrete except for high temperature curing. The same phenomena can be seen from flexural test. Results show the optimum replacement is at 10% and the best curing effect for Metakaolin is normal curing. Three elements that contribute to the result is the addition of Metakaolin act as a filler, accelerate the cement hydration and pozzolanic reaction that improve the physical and mechanical properties.

1. Introduction

The concrete industry is one of the most important industries in Malaysia. Most of the infrastructure in Malaysia is constructed by using concrete. However the cost to produce concrete especially cement is increasing from time to time and many research and studies have been performed to reduce the cost to produce concrete. One of the researches is by replacing cement partially with other material that have the same effect and chemical composition of cement such as pozzolan.

Metakaolin is one type of pozzolanic materials that been studied which has the potential as partial cement replacement material. Other type of pozzolanic material such as fly ash, silica fume and others have shown that the addition of pozzolanic material have been

*Corresponding author. Tel: 6013-3351286; Fax: 604-9882000
*Email address: norhasri@gmail.com

proved to improve the properties of concrete in terms of mechanical properties and performance. Pozzolanic materials is materials that have a high content of silica or alumina that will gives a better effect on hydration of cement and improve the strength as well as microstructure of concrete. In the presence of moisture, this material will react with calcium hydroxide to form secondary Calcium Silica Hydrate which will improve strength and performance of concrete. Some very fine pozzolanic material also could act as filler in concrete.

The addition of metakaolin in concrete will affect the properties of concrete both in the fresh and hardened states. In fresh state the properties that always been highlight is workability and setting time. Workability is defined as how easy the fresh concrete can be handled, placed, compacted and finished. The setting time is been divided into two (2) which initial and final set that show how fast the metakaolin can be hydrated. For hardened state the properties that always been highlight is compressive strength and flexural strength test because these properties gives a clear picture of the quality of the concrete. For this study also the mechanical properties effect is tested by three (3) different type of curing condition which is normal curing, exposed curing and high temperature curing. For normal curing has been stated in the British Standard as a control temperature around 20^{o} C and proved that the hydration of cement is fully control. For expose condition the sample is been left out to room temperature around 26–28^{o} C and for high temperature curing sample been cured in elevated curing tank and the temperature is control at 55^{o}C. The objective of this study is to investigate the effect of curing conditions on the physical and mechanical properties of concrete containing Metakaolin. It is part of an ongoing research dealing with effect of curing conditions on the properties and performance of concrete containing metakaolin.

2. Problem Statement

Malaysia is one country that produces kaolin because Malaysia have a surplus of kaolin that has a potential as a pozzolanic material. However in Malaysia kaolin is normally used as in ceramic, paper and paint industries, not as a cement replacement material. Earlier research has shown metakaolin produced from locally available kaolin has the potential to improve the properties and performance of concrete. However, more research works are required to prove that this material could really improve the properties and performance of concrete. In addition, not much information is available on the effect of curing conditions on concrete containing metakaolin.

3. Objectives

1. To investigate the effect of curing condition of concrete based on normal, exposed and high temperature curing
2. To investigate the mechanical properties of concrete containing metakaolin based on compressive and flexural strength test
3. To investigate the physical properties of the metakolin cement paste based on workability, setting time and soundness test
4. To investigate the optimum replacement for metakaolin in concrete from 5%, 10% and 15%.

4. Methodolgy

4.1 Calcination Process

Before metakaolin can be used in concrete mix, the raw kaolin must be subjected to thermal activation to obtain the pozzolanic property. This process is called calcination process. Based on previous studies, kaolin must be calcined at temperature of around 600–800^{o} C with the duration from 2–3 hours. However different calcination temperatures will have different effect on the pozzolanic reactivity of the metakaolin. In this study the raw kaolin was heat treated at 700^{o} C for a period of 3 hours.

4.2 Materials and Mix Proportions

The cementitious materials used were Ordinary Portland Cement (OPC) and metakaolin. The chemical composition of metakaolin and physical properties of metakaolin are given in Table 1. The coarse aggregates used were crushed aggregates with maximum size of 10mm. The control mix was prepared using OPC while the other mixes were prepared by replacing part of the cement with metakaolin at 5%, 10% and 15% replacement levels. A constant water/binder ratio of 0.47 was used for every concrete mix and 0.75% of superplasticizers was added to every concrete mix. The superplasticizer used in this research was Rheobuild 1000 provided by MBT (M) Sdn. Bhd.

Table 1: Chemical Composition Of Metakaolin

Chemical	OPC	Metakaolin
SiO_2	20.40	55.00
Al_2O_3	4.90	39.00
Fe_2O_3	3.10	1.30
CaO	63.10	0.041
MgO	3.10	0.30
K_2O	1.05	1.2
SO_3	2.30	0.025
TiO_2	0.25	0.56
NiO	-	0.016

4.3 Test Procedures

The workability of the concrete mix was measured by using slump test in accordance to BS 1881: Part 102. The soundness test also was determined in accordance with BS 1881. For standard consistency the sample was tested by using the vicat apparatus in accordance to BS 1881. To minimize the effect of environmental exposure on setting and hardening the specimens were kept in controlled temperature range from 20±2°C and another specimens where kept and expose to room temperature from 27–28°C. For high temperature curing the specimens where kept in elevated curing tank and the temperature is controlled at 55°C. Specimens for mechanical properties were subjected to normal water curing, exposed curing and high temperature curing. Compressive strength was determined by using 100 mm cube in accordance to BS 1881:Part 116. Flexural strength was determined by using 100 mm x 100 mm x 500 mm prism. For compressive strength test specimens will be tested at 1, 3, 7, 28, 90 and 180 days and for flexural test specimens will be tested at 28 and 180 days only.

5.0 Result and Discussion

5.1 Effects on Workability

The workability of the concrete mix as measured by the slump test is shown in Figure 1. From the observation, it is clear that metakaolin will reduce the workability of concrete with greater reduction at higher replacement levels. At the higher the replacement level the workability will be reduced from normal to low slump. This shows that metakaolin has a greater water requirement, more water is needed to maintain consistency and workability of concrete mix. The results on workability are in agreement with standard consistency tests performed on cement pastes. Figure 2 shows that OPC–metakaolin pastes need more water in order to maintain similar consistency. Due to the greater water demand of metakaolin, a superplasticizer was added to all concrete mixes to obtain a target slump of 60–180 mm. The higher water demand of concrete containing metakaolin could be attributed to the high surface area of metakaolin. The same behavior was observed by Megat Johari (2002) on the workability of concrete mix. However, in term of compaction, all concrete mixes could be compacted successfully without any problem. The same scenario was observed by Sabir et al. (2001).

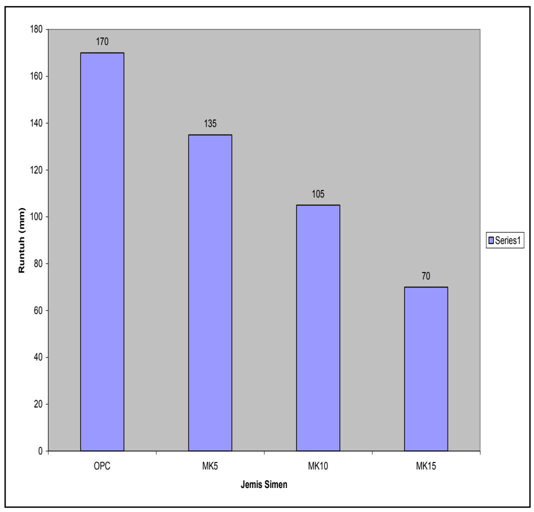


Figure 1: Workability of concrete due to slump test

5.2 Effects on Soundness

The soundness of the cement paste containing metakaolin was measured by using the Le Chatelier apparatus and the results can be seen in Table 2. From the graph shown, it is clear that the addition of metakaolin tends to reduce the expansion of cement pastes. The code of practice (BS 1881) puts a limit on the potential expansion of neat cement paste. This is to reduce any potential expansive reaction in concrete at later ages which could disrupt and damage the concrete. Hence, the use of metakaolin could reduce the potential future expansive reaction in concrete.

Table 2: Soundness Test

	Before boil		After Boil (3 Hours)		Different	
	A	B	A	B	A	B
OPC	7.0	6.5	8.5	8.5	1.5	2.0
MK5	7.0	6.5	8.0	7.5	1.0	1.0
MK10	6.0	7.0	7.0	8.0	1.0	1.0
MK15	6.0	6.5	7.0	7.5	1.0	1.0

5.3 Effects on Setting Time

Apparatus used to determine the setting time is vicat apparatus. However, before running the setting time test, sample must be tested by using standard consistency in order to know the quantity of water to mix cement paste. The result of standard consistency can be seen in Figure 2. From the graph, it is clearly shown that the addition of metakaolin in cement paste increase water demand. The higher the replacement level of metakaolin water content will be increased. These happen because metakaolin absorb more water and the particle size is smaller compare to OPC. The same result was obtained by Bai et al. (1999) which is reported the addition of metakaolin will increase the water demand in cement paste.

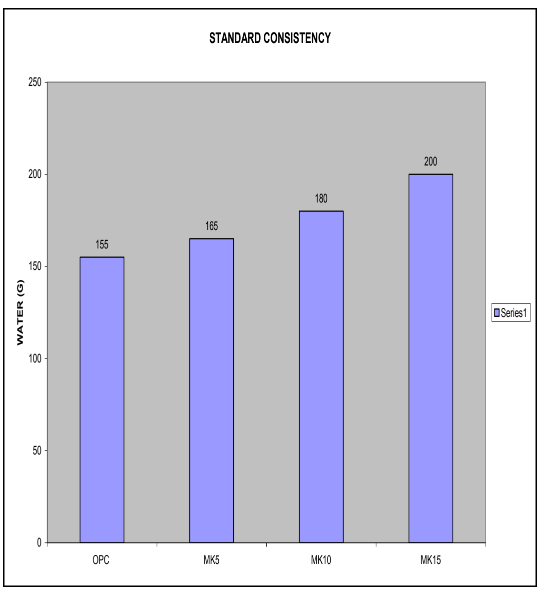


Figure 2: Standard consistency

For setting time the test is divided into two which is initial and final set. The result for setting time can be seen in Figure 3. It is clearly shown the addition of metakaolin will reduce the time for cement paste to set. The higher the replacement level the time of cement paste to set will be reduce. This happen because the addition of pozzolanic material in cement paste will break the bond between the cement paste and resulting the cement paste become lumpy and hard Neville and Brooks (1993). However the effect is depend on type of pozzolanic materials used in cement paste.

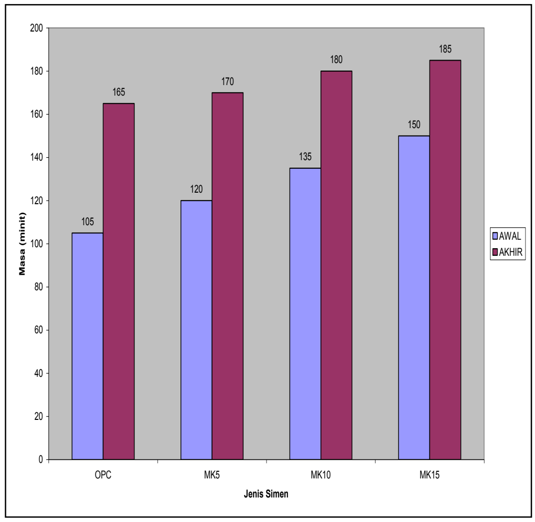


Figure 3: Setting time

5.4 Effects on Compressive Strength

The general effect of metakaolin is to improve the strength of the concrete. Figures 4 and 5 shows that metakaolin will enhance early strength of concrete and the strength increases from 3 days up to 180 days for normal and expose curing. However the strength development also depends on levels of replacement. After three days of curing, at 5% replacement shows a very marginal increasing in strength when compared to the control, but at 10% and 15% replacement levels, strength of concrete starting to increase rapidly. This happen because the addition of metakaolin at early stage acts as a filler effect and then accelerate the hydration of cement and finally as a pozzolanic reaction. Based on previous study done by Sabir et al. (2001) the addition of metakaolin in concrete will increase strength at early ages and the result from this research also gives same findings. Additional of metakaolin from 5% to 15% replacement levels, the strength increase at early age because the filler effect, acceleration on cement hydration and pozzolanic reaction is develop at this level of replacement.

The strength keeps on increasing at 7 and 28 days of curing. The optimum 28 days strength is obtained at 10% replacement level for both curing conditions. The effect of curing conditions is that samples that have been kept in normal curing shows greater enhancement in strength as compared to those cured under exposed condition. These happen because at normal curing the temperature is control at 20^o C at the hydration process is maintained and developed continuously in comparison to the exposed condition. For the exposed condition, the higher temperature and the lost of water due to evaporation could disrupt the hydration and pozzolanic reaction. However from this research also shows that metakaolin in concrete does not improve strength enhancement when cured by using high temperature. Results for high temperature curing can be seen from Figure 6. The higher the replacement level at all age of testing will reduce the strength of concrete. This happen because when cured by using high temperature curing the hydration process will not develop uniformly when compare to normal and expose curing. Hydration process only happen outside cement paste and bonding of cement paste will be decreasing and particle of cement and metakolin will not combine and hydrate uniformly (Mohd Yusof, 1995). The optimum replacements levels are achieve at 10% replacement and the suitable curing method is by using normal curing.

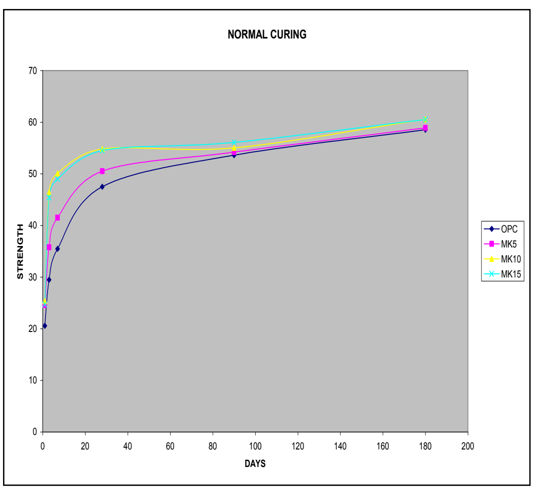


Figure 4: Compressive strength of concrete for normal curing

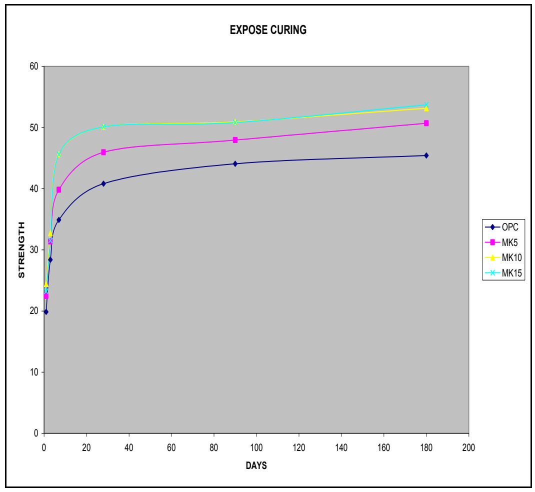


Figure 5: Compressive strength of concrete for expose curing

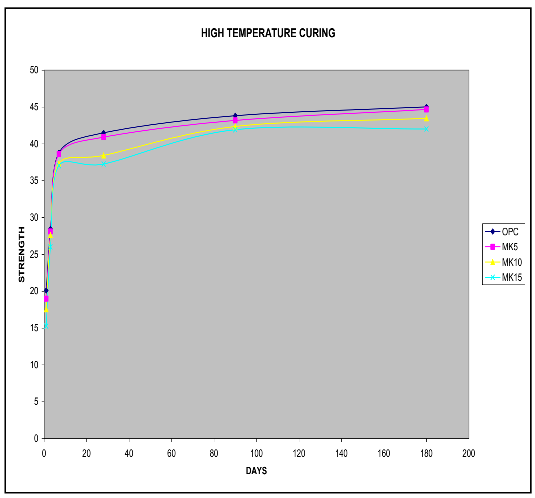
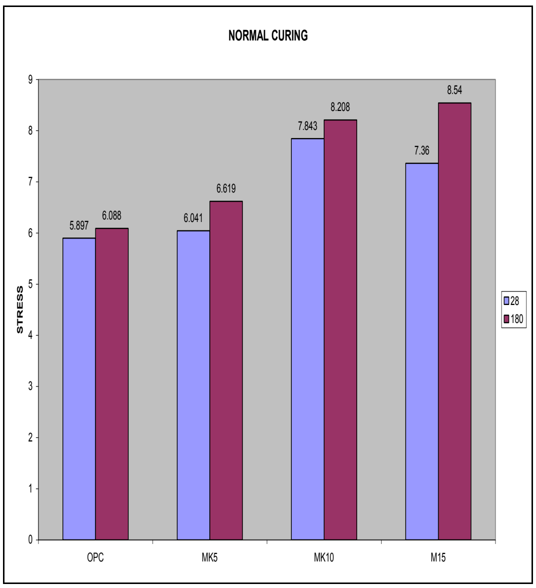


Figure 6: Compressive strength of concrete for high temperature

5.5 Effects on Flexural Strength

From the observations, the addition of metakaolin improved the flexural strength of concrete as in the case of compressive strength. The variations due to replacement levels can be seen in Figures 7 and 8 for normal curing and expose curing respectively. In this study, the flexural strength test was performed after 28 and 180 days of curing. The results show that greater flexural strength was obtained at higher replacement levels and when been expose to normal and expose curing. This happen because the addition of metakaolin in concrete will produce filler effect, accelerates hydration and pozzolanic reaction. However, for high temperature curing the addition of metakaolin will not improve flexural strength of concrete. Results for high temperature curing can be seen in Figure 9. For flexural the optimum flexural strength is obtained at 10% replacement level and normal curing shows the best curing method for metakaolin.



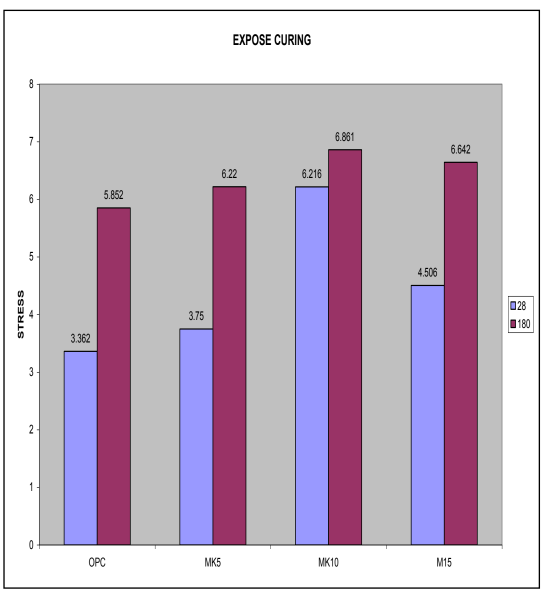


Figure 7: Flexural strength of concrete for normal curing

Figure 8: Flexural strength of concrete for expose curing

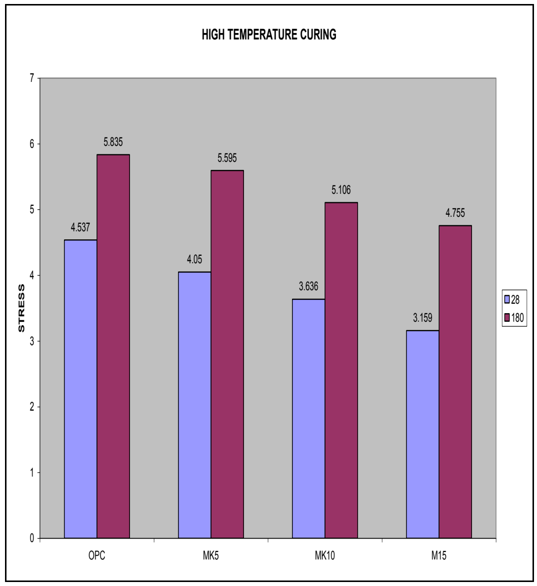


Figure 9: Flexural strength of concrete for high temperature

6.0 Conclusions

Metakaolin have a great effect on the workability of concrete. The addition of concrete containing metakaolin will reduce the workability of concrete depend on level of replacement. The higher the replacement level the workability will be reducing. Therefore, the superplasticizers must be used to obtained adequate workability and consistency in concrete mix.

The addition of metakaolin influences the compressive strength of all concrete mix. At early stage the addition of metakaolin will enhance strength of concrete for every replacement . Strength of concrete at 7 and 28 days curing increases at every replacement level but the optimum strength achieve at 28 days for 10% replacement. For flexural strength test, the addition of Metakaolin in concrete mix also increase the flexural strength for every level of replacement. The optimum flexural strength obtained is similar like the compressive strength which is 10% replacement. In terms of curing conditions, normal curing gives better results compare to expose condition and high temperature in terms of hydration process.

References

M. A. Megat Johari. (2002). 'Effect of silica fume and metakaolin on the workability, setting times and compressive strength of high performance concrete'.World Conference on Concrete Materials and Structure, pp. 319–328.

B. B. Sabir. (2001). 'Metakaolin and calcined clays as pozzolan for concrete: a review'. Cement and Concrete Composites, pp. 441–454.

J. Bai, S.Wild, B.B. Sabir and J.M. Kinuthia. (1999). 'Workability of concrete incorporating PFA and Metakaolin'. Megazine of Concrete Research, 51, No. 3, June, pp.207–216.

A.M. Neville and J.J. Brooks. (1993). 'Concrete Technology'. Longman, pp.43–45, 177, 182.

K. Mohd Yusof (1995), Pengenalan Kekuatan & Ketahanlasakan Konkrit, Dewan Bahasa & Pustaka