The Effects of Steam Curing on Porosity of High Strength Concrete Containing Metakaolin

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Abstract: Steam curing is an important technique for obtaining high early strength in precast concrete production, hence, an experimental investigation was conducted to study the effects of steam curing on porosity of high strength concrete containing metakaolin. Porosity refers to the proportion of total volume of concrete occupied by pores, which usually expressed in percent. Porosity of concrete must be determined because it can negatively affect the durability of the concrete. Four concretes mixes with 0, 5, 10 and 15% metakaolin replacement levels by weight of cement were prepared and exposed to steam curing periods of 0, 4, 8 and 16 hours. Steam curing at 55°C was implemented 3 hours after casting to avoid microcracking and increased porosity due to difference in thermal expansion of the concrete ingredients. Then, the samples were stored in fog room before they were demoulded after 24 hours. Steam curing was found to deteriorate the properties of OPC concrete for all ages. On the other hand, it slightly enhances properties of metakaolin concrete at early age, but present no improvement at later age.
[Papzan A, Taksiah A,M. **The Effects of Steam Curing on Porosity of High Strength Concrete Containing Metakaolin.** *J Am Sci* 2012:8(11):518-522]. (ISSN: 1545-1003). http://www.americanscience.org. 79

Keywords: Steam curing; porosity; HSC; metakaolin

1. Introduction

High strength concrete (HSC) becomes famous nowadays because of its high workability, high durability and high ultimate strength (> 50 MPa), which is useful in construction field, especially for construction of tall buildings. Typical classification of concrete is shown in the Table 1 (Mehta and Monteiro, 1993).

Table 1. Classification of concrete (Her-Yung, 2008)

Concrete	Classification Strength
Normal Strength	20-50 MPa
High strength	50-100 MPa
Ultra high strength	MPa
Especial	>150 MPa

There are many types of Portland cement used all around the world; however, ordinary Portland cement (OPC) is the most common one (Alidoust et.al, 2007). In this project, OPC Type I is used. The specification for this cement is given in BS 12:1978, as well as MS 522.

Concrete quality can be improved by keeping the concrete moist, either by wetting (providing water) or by preventing concrete surface from drying using cover or membrane (Neville, 1995), in order to ensure continuous hydration process. There are few types of curing, which include steam curing, autoclave curing, control curing and so forth (Rattanadecho et.al. 2008). The effectiveness of the curing method depends on how the method can prevent the loss of moisture from the concrete (Soroka, 1979)

Many factors are needed to be considered in determining how long the curing should be applied. These include size of the element, type of concrete, exposure conditions after curing and the requirements of the specification (Newman and Ban, 2003).

Without proper curing, the concrete might lose strength when the water within the concrete freezes in cold weather (Cusson et.al, 2010). Besides, excessive evaporation from the exposed surface will cause plastic shrinkage, even though this phenomenon will not significantly affect the properties of concrete. Extreme temperature difference within a concrete element will lead to thermal cracking. It is unlikely that a poor curing will affect the structural properties of concrete, however, assessment on poor curing give pessimistic results (Newman and Ban, 2003).

Steam curing is one of the curing method, which consists of few stages in its regime, namely delay period, heating period, curing period, cooling period and sometimes will followed by wetting. In many cases, once the casting is finished, steam- curing is applied to the concrete, and both the delay and heating period are eliminated (Soroka, 1979).

Generally, after steam curing, the concrete will have 50% of the 28- day desired compressive strength (Barnett et.al 2006). However, ultimate strength of steam- cured concrete will be adversely affected. According to experiment done by Soroka et al. (1979), they revealed that at age

7- 10 days, the strength of the steam- cured concrete will gradually become lower than the normal- cured concrete. At the age of 90 days, the difference can reach up to 26- 40%. As a result, conclusion can be made that steam curing can increase early strength development; on the other hand, it significantly reduces the ultimate strength of concrete.

2. Material and Methods

2.1. Materials

The purpose of this investigation is to obtain the porosity of High Strength Concrete (HSC) containing metakaolin (0, 5, 10 and 15% by weight of cement) under different steam curing periods (0, 4, 8, and 16h) and comparisons are made with the control concrete samples (under normal curing). For achieving this aim the proper experiment is conducted.

In this experiment, Ordinary Portland Cement Type I (OPC I) is utilized as a common used material in concrete construction. The river sand which is free from silt or clay is used as fine aggregate.

Before the fine aggregate is added to the batch, they are first dried in the oven at 100°C for 15 minutes to obtain saturated and surface- dry aggregate. The objective of the drying is to avoid the surface moisture affects the strength of the concrete at early stage. Further drying will cause the aggregate over- dried, where they will absorb the mixing water and reduce the workability of the concrete.

Coarse aggregate used in this experiment is granite. Maximum size of the granite is 20mm. These aggregates are kept in a dry place to avoid from the moisture, which will affect the bonding between aggregates and the cement paste.

Metakaolin is prepared by calcining the kaolin clay in a furnace at temperature 700°C for 3 hours. Metakaolin is collected after 24 hours to avoid thermal shock. Then, it is stored in a place away from moisture until the concrete mixing (Megat Johari et al., 2003). The physical properties of kaolin are shown in Table2.

Table 2. Physical properties of kaolin(MS 756)

Properties	Description
Color	Usually white, colorless
Luster	Earthy
Transparency	Crystals are translucent
Cleavage	Perfect in one direction
Fracture	Earthy
Hardness	1.5-2(can leave marks on paper)
Specific gravity	2.6 (average)

In this study, Glenium C380 is used as superplasticizer. Glenium C380 is new generation superplasticizer developed for precast and prestressed concretes, even it is suitable for the use in other type of concrete too. Usually, the dosage of the superplasticizer is high, which falls in the range 5 -15 l/m^3 of concrete. Trial mix is needed to determine the dosage of superplasticizer because usage of matakaolin will highly increase the water demand. Water demand is estimated to reduce about 20 to 30% with the use of superplasticizer. The physical and chemical properties of used plasticizer are shown at Table3.

Table 3. Physical and chemical properties of superplasticizer

Physical state	Liquid
Colour	Brown
Odour	Specific odour
Freezing temperature	-3.0 ^{o} C
Boiling point	>100 ^{o} C
Melting point	n.d
Flash point	n.a.(aqueous)
P1	n.a
EPL (in)	n.a
Vapor pressure	n.a
Vapor Density	n.a
Relative density	Approx.1.08gcm-^{3}@20^{oC}
Solubility	Soluble
pH value	Approx. 7.0
Viscosity	n.a

2.2. Trial mix and mix proportion

Trial mix should be carried out to obtain suitable mix proportion to produce high strength concrete. After determining cement, sand and gravel content, different dosages of superplasticizer are tried and satisfactory dosage is based on the slump of fresh concrete and compressive strength at 7 days after casting.

The content of high strength concrete is shown in the table below with different metakaolin replacement level on mass- for- mass basis. The proportion of cement: sand: aggregate is 1: 1.5: 2.5 and the optimum dosage of superplasticizer is 15 l/m^3. Below this dosage, the mix has zero slump at 15% metakaolin replacement level. For other perspective, average compressive strength of concrete containing 0% metakaolin at 7th day is 51.5 MPa. Therefore, it can be concluded that the mix proportion below is satisfactory to produce high strength concrete (Table4).

Table 4. Mix proportion for different metakaolin replacement level

Concrete mixes	Control mix	MK5	MK10	MK15
Cement (kg/m^3)	450.0	427.5	405.0	382.5
Mineral admixtures (kg/m^3)	-	22.5	45.0	67.5
Sand (kg/m^3)	675.0	675.0	675.0	675.0
Gravel (kg/m^3)	1118.0	1118.0	1118.0	1118.0
Superplasticizer (l/m^3)	15.0	15.0	15.0	15.0
Water/cement ratio	0.32	0.32	0.32	0.32

2.3. Mixing of concrete

Mixing of concrete must be done accordingly so that superplasticizer can be effectively reduces water demand and increases workability. First, cement, sand and aggregate are dry mixed in the mixer for 2 minutes. Then, 50 to 70% of water is added and mixed for another 2 minutes. Lastly, the remaining water and superplasticizer are added and mixed for 2 minutes. According to Neville (1995), mixing time which is less than 1 minute will produce significantly low- strength concrete, whereas, time beyond 2 minutes gives no noticeable improvement to the concrete properties. As a result, 2 minutes is chosen for both dry and wet mixing.

2.4. Casting and curing

After mixing, slump test carried out on the freshly mixed concrete. Then, the concrete was cast into two types of moulds: cube (100mm x 100mm x 100mm) and prism (100mm x 100mm x 500mm). Concretes with cube shape were used for compressive strength and Ultrasonic Pulse Velocity (UPV) test whereas, cylinder- shaped concretes cored from prisms are used to test the porosity.

There are four stages included in a steam curing cycle, namely delay period, controlled heating, steam treatment and controlled cooling. Delay period is important before steam curing because sufficient delay will offset the adverse effects on the strength due to rapid heating. Recommended delay for 38, 54, 74, and 85°C are 2, 3, 5, and 6 hours. For heating period, steep temperature gradient should be avoided and maximum temperature achieved should be limited because 5% reduction of strength at age 28 days is observed (Neville, 1995).

Delay period at room temperature (30°C) is needed before the samples are steam- cured to avoid microcracking due to differences in the thermal expansion coefficient of the concrete ingredients. Three hours is chosen as the delay period because this period is almost equal to the setting time of typical concrete. Therefore, development of microcracking can be minimized.

After 3 hours, the specimens are moved to steam curing tank and the temperature is increased to 55°C. After observing the time profile of the curing tank, it is found out that the tank takes 30 minutes to reach the mentioned curing temperature. Then, the samples are heat- cured at 4, 8 and 16 hours respectively in the tank.

Following the steam treatment, the samples are taken out from the tank and left to be cooled down to room temperature again. Before the samples are tested at 24 hours after casting, they are put into the fog room with high humidity (more than 90% RH) to avoid loss of water from the concrete, which will cause cracking on the concrete surface. After that, tests are carried out at 1, 3, 7, 28 and 56 days to observe the desired characteristics of the concrete.

2.5. Porosity test

Porosity refers to the proportion of total volume of concrete occupied by pores, which usually expressed in percent which must be determined because it can negatively affect the durability of the concrete.

Before carrying out the test, samples with dimension 50 mm diameters x 40mm thick cylinders must be cored from the concrete prism. Then, they are dried in a ventilated oven at 105°C for 24 hours. After that, the weight of the dry specimens (W4) is recorded. The samples are put into the vacuum saturation apparatus and a pressure of one bar is applied for 3 hours. Water is introduced until 2cm above the surface of specimens while they are still under vacuum. The water used in the apparatus must be boiled water that has been cool down. Then, vacuum is maintained for another 3 hours after the introduction of water.

After 3 hours, the samples are kept for another one hour for full saturation when the vacuum is released. The surfaces are wiped with a dry cloth after the samples are taken out from the water to remove the unnecessary moisture and its weight in both air (W2) and in water (W3) are recorded.

Water absorption and porosity are calculated as shown below:

i. Water absorption (A)

$$A (\%) = (W2 - W4) / W4 \times 100$$

ii. Porosity (P)

$$P (\%) = (W2 - W4) / (W2 - W3) \times 100$$

3. Results and discussions

Two parameters of concrete, water

absorption and porosity are related to each other, as ability to absorb water mainly depends on the porosity that exists in the concrete. From the results, we can see that porosity present higher values than water absorption. This is understandable since porosity includes total volumes of pore that exist in the concrete, whereas water absorption related to the pores that have interconnectivity with each other. Not all the pores assist in water absorption, as ability to absorb water will be limited if interconnectivity of the pores is low. This phenomenon is understandable since continuous hydration process will produce concrete with lower porosity. As hydration products fill the pores between cement particles and aggregates to reduce the average pore diameter, the concrete ability to absorb water reduces.

When observation is done on effect of MK, different trends are shown under normal and steam curing condition, even though inclusion of MK will reduce porosity under both curing conditions (Figures1, 2, 3, 4, 5).

When normal curing is implemented, inclusion of 5 and 10% MK in the concrete presents lower water absorption/ porosity, where increment in MK replacement level will further reduce the water absorption ability and porosity. However, when replacement level of MK goes beyond optimum dosage (10%), water absorption/ porosity increases with increased MK inclusion. Since absorption related to the total pore volume (Khatib and Clay,2003), and total pore volume was found to increase with increase in MK content (Sabir et al., 2001). As a result, 15% replacement of cement with MK will produce concrete with higher total pore volume, which will finally lead to increase in water absorption and porosity.

On the other hand, if the concrete samples are steam cured, different behaviors were observed. Though 5 and 10% inclusion of MK will reduce water absorption/ porosity, when higher percentage of cement is replaced by MK (15%), further decrease in water absorption/ porosity is viewed. According to Rojas and Rojas (2005), blended pastes containing MK that being cured at 60°C will exhibit a refinement of pore size. Besides, they also showed that increase in MK inclusion will reduce average pore diameter. As a result, 15% replacement with MK gives the lowest water absorption/ porosity. Since steam curing able to reduce the volume of permeable voids under steam curing for concrete containing silica fume (Toutanji and Baysi, 1999), similar effect is expected to be occurred in MK concrete as both of these mineral admixtures possess similar physical properties.

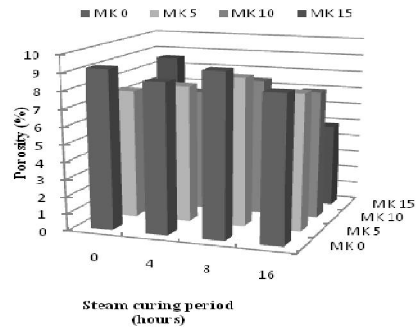

Figure 1. Porosity at different metakaolin replacement levels and steam curing period at 1Day

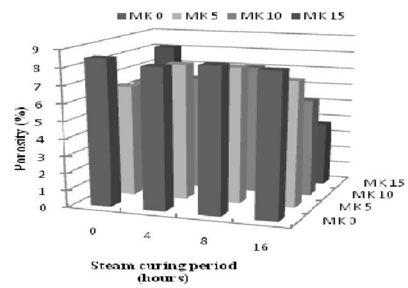

Figure 2. Porosity at different metakaolin replacement levels and steam curing period at 3Days

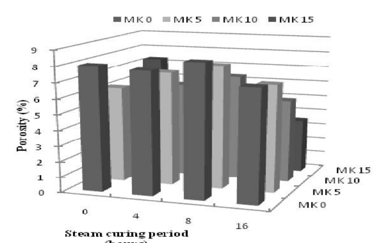

Figure 3. Porosity at different metakaolin replacement levels and steam curing period at 7Days

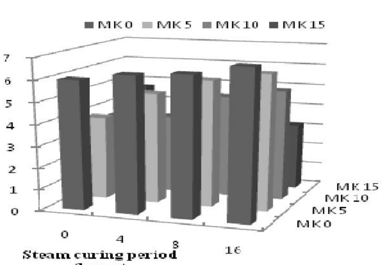

Figure 4. Porosity at different metakaolin replacement levels and steam curing period at 28Day

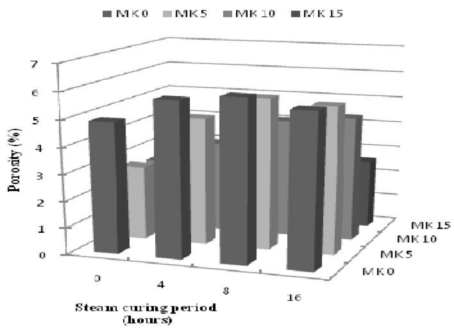

Figure 5. Porosity at different metakaolin replacement levels and steam curing period at 56Day

If discussion is made based on steam curing period, steam curing tends to increase the water absorption and porosity of OPC concrete. For concrete containing 5 and 10% of MK, any steam curing period will significantly increase both water absorption and porosity. However, concretes with 15% inclusion of MK act extraordinarily when subjected to steam curing. The lowest water absorption/ porosity occur when subjected to 16 hours steam curing, follow by 4 and 8 hours. On the other hand, 15% MK concretes under normal curing absorb highest amount of water and possess highest porosity. This shows that steam curing has positive effect on porosity and water absorption of concrete with high content of MK. Rojas and Rojas (2005) support this statement after their analysis, i.e. under 60°C curing, higher content of MK will reveal lower average pore diameter, which will reduce water absorption and porosity of the concrete.

4. Conlusion

Based on the results, water absorption and porosity of concrete decreased with age due to continuous hydration process. In addition, types of curing do affect the optimum dosage of MK. Under normal curing, optimum MK dosage is 10%, on the other hand, 15% is the optimum MK replacement level when concrete samples are exposed to steam curing. As a result, 15% replacement of cement with MK will produce concrete with higher total pore volume, which will finally lead to increase in water absorption and porosity.

10/14/2012

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