CHEMICAL ENGINEERING TRANSACTIONS

VOL. 59, 2017

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Zhuo Yang, Junjie Ba, Jing Pan

ISBN 978-88-95608- 49-5; **ISSN** 2283-9216

DOI: 10.3303/CET1759069

Study on Mechanics and Chemical Properties of Low Volume Alkaline Kaolin Modified Concrete

Junyan Liao

Jinhua Polytechnic, Jinhua 321007, China
junyanjinhua@126.com

The test basis is provided for the development of high performance concrete of metakaolin through studying the performance of metakaolin in high performance concrete, which is to meet the demand of high performance concrete in modern industry. The experiment shows that the incorporation of metakaolin has a great influence on the strength of concrete. The compressive strength of concrete increases with the increase of the content of metakaolin. And the strength increases slowly as the content is more than fifteen percent. From the overall test data, the strength of 3 days is not very stable. But the strength of 7 days and 28 days can be increased about 20%, and the effect is significant. It can be sure that the optimum content of metakaolin in the concrete is 15% of the cementitious material. The durability of concrete mixed with kaolinite is better than that of non-adobe kaolin concrete. The metakaolin has abilities to improve the strength and compactness of concrete, to improve the frost resistance of concrete and impermeability and the resistance to chloride ion permeability. According to the advantages of metakaolin concrete in durability, the application of it to roads, bridges and water conservancy projects in the South - to - North Water Diversion Project is generalized to provide a broad prospect for the utilization of metakaolin. And it is also imperative to bring considerable social and economic benefits.

1. Introduction

Since it was invented from the nineteenth century, cement concrete materials have become the most important building materials because of its unique low price, easy preparation, relative durability and fire resistance, low maintenance costs and other unparalleled advantages. So that the demand is that the concrete material is constantly high performance (Premkumar and Thangamani, 2017). With the continuous progress of the society, people’s requirements on the performance of the concrete materials rise. The design and construction of some lightweight, high-rise, large-span, heavy-duty building structures come up with a higher demand on the various properties of concrete (Mah et al., 2017; Khankhaje et al., 2017; Rafieizonooz et al., 2017; Sarkar, et al., 2016. Zhang, 2015; Geng et al., 2016).
Compared with the traditional ordinary concrete, the high strength, especially the ultrahigh strength concrete has the advantages of high strength, large load capacity, low energy consumption and energy consumption, and good durability. It represents direction of the concrete material of large construction and large span (Koper, et al., 2017). In the preparation of high-strength concrete, the application of silica fume is more extensive. And the metakaolin is gradually applied to the preparation of high-strength concrete due to its unique advantages (Tafraoui, et al., 2016).
The active components of Al_2O_3 and SiO_2 in metakaolin can react with $Ca(OH)_2$ produced by hydration of cement to produce hydration products, which contain hydrated calcium silicate and hydrated calcium aluminate. Thereby the alkali content of concrete is reduced and the alkali-aggregate reaction is decreased or eliminated, and the strength of concrete is improved (Cheng, et al., 2016). The kaolinite particles are very fine (less than 10 μm), and the filling performance is good, which can improve the compactness, anti-carbonization ability and acid and alkali resistance of concrete and other properties (Lenka and Panda, 2017). It has achieved very good results as it is applied to high-performance concrete. It can avoid insufficiency of the early strength in concrete caused by the traditional mineral admixture (Williams Et al., 2016). Therefore, the use of

Please cite this article as: Junyan Liao, 2017, Study on mechanics and chemical properties of low volume alkaline kaolin modified concrete, Chemical Engineering Transactions, 59, 409-414 DOI:10.3303/CET1759069

metakaolin for high-strength concrete preparation and performance research to study has great significances, both for high-strength concrete energy-saving preparation technology development and the promotion and application of kaolin minerals. (El-Din, et al., 2017).

2. Experimental parts

2.1 Experimental materials

Experimental use of cement was the Huaxin cement, the chemical composition was shown in Table 1.
The chemical composition of Guangdong Maoming kaolin that was used in the experiment was shown in Table 2. The fine aggregate that was used in the preparation of concrete was Dongting Lake sand, and the fineness modulus of sand was 2.6. The coarse aggregate was the limestone gravel, which was divided into two grades of 5 ~ 16 mm and 16 ~ 26.5 mm. The superplasticizer that was used in the experiment was polyhydroxy acid superplasticizer.

Table 1: P. I 52.5 Chemical composition of cement（% ）

Composition	SiO_2	Al_2O_3	CaO	Fe_2O_3	SO_3	MgO	Na_2O	K_2O	LOI
Content	19.37	3.92	68.30	3.69	0.81	1.61	0.13	0.59	1.09

Table 2: Chemical composition of kaolin（% ）

Composition	Al_2O_3	SiO_2	Fe_2O_3	CaO	K_2O	TiO_2	SO3	P2O5	ZrO2	Na2O	MgO
Content	50.27	34.46	0.75	0.29	0.69	0.42	0.21	0.06	0.01	-	-

2.2 Preparation of materials

2.2.1 Preparation of metakaolin
In this stage, the experimental instrument was the kxx12-12 box resistance furnace, and the voltage was 380V, the power was 12kW. And another instrument was the 101-4 type electric heating oven, the voltage was 380V and the power was 9000 W. And there was SYM Φ5OOx500 cement test mill. The specific experimental steps were to break the caking kaolin raw materials, to dry, to grind by the ball mill for 20 minutes, and to carry out the forging experiment by the use of resistance furnace. And the calcination temperature was 700 ℃, the insulation remained for 2 hours, and it was made through the hot and cold after the ball about 30 minutes.

2.2.2 Preparation of kaolinite doped concrete
This experiment referred to the ratio design scheme of the high-performance concrete. The ratio was as the following. Cementing material: sand: stone was 1: 1.40: 2.30, and the amount of cement was 500kg/m3. The water-cement ratio was 0.33. And the superplasticizer was 2 percent of the amount of gel material. The initial slump was 19 ± 2cm or so, each group of samples of kaolin were equivalent to replace the amount of cement. The amount was as follows, employing 5%, 10%, 15%, 20%, 25%. Totally, the process of the specimen production was in accordance with (GB/T 50081-2002) the standard concrete specimen production process of the ordinary concrete mechanical properties test method.

2.2.3 Testing and analysis
The compressive strength of the concrete cubes used cube test block of 100*100*100mm, the flexural strength was 100*100*400mm test block in accordance with the requirements of "ordinary concrete mechanical properties test method standards" (GB/T 50081-2002), and it was carried out in the SKZY-2000 type pressure testing machine. The concrete anti-chloride ion test used the test block of 100*100*50mm, and the anti-penetration test used the test block of 100*100*100mm in accordance with the "ordinary concrete long-term performance and durability test method standard" GB/T 50082-2009). And they were carried out on HS40 type impermeable apparatus and NEL chloride ion detection system respectively. The concrete frost resistance test was carried out on KDR-V rapid freezing and freezing test machine.

3. Results and discussion

3.1 Effect of different metakaolin content on compressive strength of concrete

From the data in Table 3 and the curve in Figure 1, it showed that the different content of metakaolin (mixed) on the concrete strength had different effects. The overall increased with the increase of the amount of metakaolin, and the strength also increased. The strength of 3 days was not very stable, and the intensity of 7 days and 28 days improved significantly, which the strength promoted mostly when the content referred to 15 percent. 3 days, 7 days and 28 days increased about 25% comparing with the baseline. When the content was more than 20%, the intensity of 28 days increased slowly, even it occurred downward trend. Taking the economic and technical indicators into consideration, 15% was the best dosing amount. When the kaolinite replaced concrete according to 15% of the amount of concrete, the strength of 28 days increased 16.5 MPa comparing with the baseline, and the increase was 25%.

Table 3: Compressive strength of concrete with different kaolin content

Number	Compressive strength of 3 days (MPa)	Improvement (%)	Compressive strength of 7 days (MPa)	Improvement (%)	Compressive strength of 28 days (MPa)	Improvement (%)
MKO	42 . 7	/	52.1	/	62.4	/
MK5	40.6	-5%	55.7	7%	64.2	3%
MK10	44.1	3%	59.5	14%	68.3	9%
MK15	48.9	15%	65.3	25%	78.9	26%
MK20	44	3%	57.6	11%	79.0	27%
MK25	44.2	4%	58.2	12%	75.2	21%

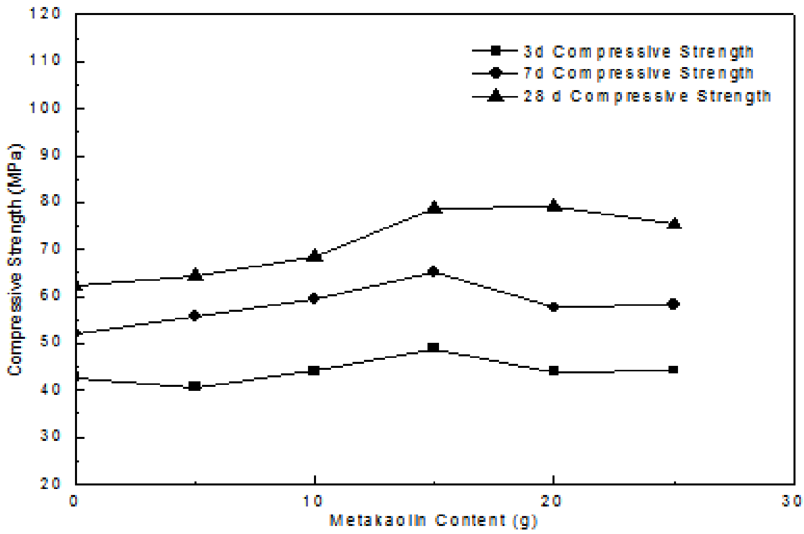

Figure 1: Effect of different metakaolin content on compressive strength of concrete

3.2 Study on the effect of metakaolin on the durability of concrete

Durability of cement concrete referred to the abilities to resist climate, chemical corrosion, wear, or any other damage process. Durable concrete should maintain its morphology, quality and use when it was exposed to the environment. So far, the main types that affected the durability of concrete were as the following. First of all were the freezing and thawing. The second was the erosion of aggressive chemical media. The third was the corrosion of steel bars. The fourth was the chemical reactions of aggregates. The fifth was abrasion. And the final was human factor and so on. The internal factors that affected the durability of the concrete included concrete design factors, material selection, construction quality and other factors. As long as the attention was gotten to these factors and appropriate measures were taken, the impact on the durability could be reduced to the minimum. There was no doubt that the performance of the material itself was the inherent factor of impacting the durability of the concrete. This test mainly studied the effect of metakaolin on the durability of concrete, and the sample ratio was shown in Table 4.

Table 4: The mix ratio of high strength and high performance concrete of the kaolinite

Number	Kaolinite (Kg/m3)	Ceent (Kg/m3)	Mix ratio	Water-binder ratio	Water reducer
E-1	0	500	1：1.40：2.30	0.30	2.6%
E-2	75	425	1：1.40：2.30	0.30	2.6%

Concrete durability test was according to the implementation of the GBJ82-85 "ordinary concrete long-term and durability test method".

3.2.1 Experimental study on impermeability of metakaolin concrete

The impermeability of concrete was the most basic factor in determining the durability of concrete. If the impermeability of concrete was not good, not only the liquid material such as water was permeated into the inside, but also it was damaged by freezing or erosion when concrete was contained in negative temperature or environmental water. The corrosion of the internal reinforcement could be caused in the reinforced concrete. And the cracking and peeling of the surface concrete protective layer also could be caused. Therefore, it was necessary to require concrete employ certain impermeability. Concrete was a kind of heterogeneous heterogeneous material. From the microscopic point of view, it was the porous structure, and the water permeated through these pores in the concrete. It was generally believed that the permeability of concrete was lower, the water and corrosive media infiltration was less, and the durability was better. So that the permeability test of the concrete was made. And the test results were as shown in Table 5.

Table 5: Concrete impermeability test results

Samples of concrete	The pressure (MPa)	The time of the pressure (hour)	The average seepage depth
E-1	4.0	8	34
E-2	4.0	8	28

Test results in Table 5 showed that the metakaolin samples of addition or no addition had excellent resistance to permeability. And the impermeability levels were all above S40, because the ordinary C70, C80 concrete were also added high-quality water-reducing agent of high-performance concrete. The internal structure was dense, and the ability to resist the pressure of water penetration was relatively high. But on this basis, the impermeability of kaolin concrete that was added 15 percent of the kaolinite was significantly improved. And the average penetration depth decreased 6mm, the depth of water decreased 17.7%. So that the effects were significant.

There were two main principles for the reduction of concrete permeability. First, the fineness of the metakaolin was 10 μm, which was finer than the fineness of the cement (80 μm). The concrete had good filling effects, which made the pores refine further to block the capillary channel. Second, there was a certain amount of $Ca(OH)_2$ in the hydration product of cement, which can form seepage channel after dissolving. And metakaolin can react with $Ca(OH)_2$ to produce cement stone, including hydrated calcium silicate and hydrated calcium aluminate Minerals. It reduced the erosion channel and improved the impermeability capacity.

3.2.2 Permeability test of alkaline concrete chloride ion

Chloride ion permeability test was carried out by using NEL-PD type concrete permeability testing system. The NEL method was the fastest experimental method of chloride ion permeation and diffusion, which had been developed so far. The experimental results were satisfactory, and it was a promising method for chloride ion permeability. The standard test results that was referred to the NEL method to evaluate was shown in Table 6. It can be seen from the table that the permeability of the kaolinite concrete and the comparative chloride ion were very low (according to the NEL method). But the effect of the kaolinite concrete against permeation of the chloride ion was better and the diffusion coefficient of the chloride ion reduced by 10.8 DNEL (10-10 m^2/s), and the reduction rate was 34%. The chloride ion that penetrated into the concrete existed in three forms. First, low-soluble calcium monochlorophosphate $3CaOAl_2O_3 \cdot CaCl_2 .10H_2O$ was produced, because the chloride ion reacted with the hydration of calcium aluminate in cement and its derivatives, that was Friede1 salt and called chemical combination of the chloride ion. Second, the chloride ion was adsorbed into the cement hydration products or unhydrated mineral components, and that was called the physical adsorption of chloride ion; Third, the chloride ion existed in the concrete pore solution with the free form. Cl^- bonded by the concrete component material did not substantially harm the reinforcement, and only the free Cl^- remaining in the pore fluid of the concrete caused damage to the reinforcement. Therefore, the binding capacity of concrete to chloride ion was particularly important.

Table 6: Results of chloride ion permeation test for concrete

Number of samples	Strength of 28 days	Diffusion coefficient of chlordion $D_{NEL}(10^{-10}$ $m^2/s)$	Penetration level of the concrete	Evaluation of the permeability of the concrete
E-1	71.5	31.5	V	lower
E-2	83.5	20.7	V	lower

3.2.3 Experimental study on frost resistance of metakaolin concrete

In this experiment, the frost resistance test of the blank concrete mixed with metakaolin and the unfilled metakaolin concrete was tested by the quick-freezing method (SD105-82) hydraulic concrete test. The test results were shown in Table 7 below.

Table 7: Results of concrete frost resistance test

Number	Strength of 27 days	After 300 times of the cycle of freezing and thawing		
		The loss of strength (%)	Relative elastic modulus (%)	Weight loss rate(%)
E-1	71.5	20.6%	85.3	0.84
E-2	83.5	14.7%	90.2	0,.37

From the test results, compared with the comparative samples, the frost resistance of kaolinite concrete was significantly enhanced. The loss of strength was reduced by 5.9%, and the reduction rate was 28.6%. The relative elastic modulus increased by 4.9%, and the improvement rate was 5.5%. The weight loss was reduced by 0.47%, and the reduction rate was 56%. It showed excellent frost resistance of metakaolin concrete. This was mainly on account of high strength and high performance of metakaolin that was added, which was characterized by the water consumption, low water-binder ratio, compact structure, and the content of the water that could be frozen was less in the internal pores and pores as it was in the cycle of freezing and thawing. And the freezing point of water in the pores was reduced by the reason of the refinement of the pore structure. So that the frost resistance was excellent.

4. Conclusion

The metakaolin replaces the concrete about 5 percent to 25 percent at the same amount. The strength of concrete increases, the strength of concrete of 3 days increases unstably and the strength of 7 days and 28 days increases stably. The strength of metakaolin is not increased with the increase of the content of the metakaolin. The strength of concrete is the maximum as the content is added to 5 percent, which the strength of 28 days increases about 25% comparing with the reference. The increase of the intensity is not obvious as the content of the metakaolin increases to 20 percent or 25 percent. And there is a downward trend, so the optimum content can be sure that the metakaolin in concrete is 15% of the cementitious material. The test results also show that the durability of metakaolin concrete is significantly better than the reference. Under the standard conditions of curing for 28 days, the impermeability of metakaolin concrete is better than the blank. The permeability of the coefficient chloride ion is lower than the blank, and the frost resistance is better than the blank obviously. Therefore, metakaolin is a kind of effective auxiliary cementitious material in the preparation of high-performance concrete. And the concrete that is mixed with metakaolin has good durability. It can be used in water conservancy projects, roads, bridges, and some waterproofing works, which has advantages to extend the use of life, to reduce the maintenance costs and the waste of water resources.

Reference

Cheng S., Shui Z., Li Q., Sun T., Yang R., 2016, Properties, microstructure and hydration products of lightweight aggregate concrete with metakaolin and slag addition, Construction and Building Materials, 127, 59-67, DOI: 10.1016/j.conbuildmat.2016.09.135

El-Din H.K.S., Eisa A.S., Aziz B.H.A., Ibrahim A., 2017, Mechanical performance of high strength concrete made from high volume of Metakaolin and hybrid fibers, Construction and Building Materials, 140, 203-209, DOI: 10.1016/j.conbuildmat.2017.02.118

Geng B.Y., Ni W., Wu H., Huang X.Y., Cui X.W., Shuang Wang S., Zhang S.Q., 2016, On high-strength low-shrinkage ITOs-based concrete, International Journal of Heat and Technology, 34(4), 677-686, DOI: 10.18280/ijht.340418

Khankhaje E., Salim M.R., Mirza J., Hussin M.W., Ho C.S., Rafieizonooz M., 2017, Sustainable pervious concrete incorporating palm oil fuel ash as cement replacement, Chemical Engineering Transactions, 56, 445-450, DOI: 10.3303/CET1756075

Koper A., Koper W., Koper M., 2017, Influence of Raw Concrete Material Quality on Selected Properties of Recycled Concrete Aggregates, Procedia Engineering, 172, 536-543, DOI: org/10.1016/j.proeng.2017.02.063

Lenka S., Panda K.C., 2017, Effect of metakaolin on the properties of conventional and self-compacting concrete, Advances In Concrete Construction, 5, 1, 31-48.

Mah C.M., Fujiwara T., Ho C.S., 2017, Concrete waste management decision analysis based on life cycle assessment, Chemical Engineering Transactions, 56, 25-30, DOI: 10.3303/CET1756005

Premkumar S., Thangamani K., 2017, Study of woven and non-woven fabric on water retention property for effective curing of concrete, The Journal of The Textile Institute, 108, 6, 962-970, DOI: org/10.1080/00405000.2016.1204975

Rafieizonooz M., Salim M.R., Hussin M.H., Mirza J., Yunus S.M., Khankhaje E., 2017, Workability, compressive strength and leachability of coal ash concrete, Chemical Engineering Transactions, 56, 439-444, DOI: 10.3303/CET1756074

Sarkar A., Sahani A.K., Roy D.K.S., Samanta A.K., 2016, Compressive Strength of Sustainable Concrete Combining Blast Furnace Slag and Fly Ash, IUP Journal of Structural Engineering, 9, 1, 17-26.

Tafraoui A., Escadeillas G., Vidal T., 2016, Durability of the Ultra High Performances Concrete containing metakaolin, Construction and Building Materials, 112, 980-987, DOI: .org/10.1016/j.conbuildmat.2016.02.169

Williams A., Markandeya A., Stetsko Y., Riding K., Zayed A., 2016, Cracking potential and temperature sensitivity of metakaolin concrete, Construction and Building Materials, 120, 172-180, DOI: 10.1016/j.conbuildmat.2016.05.087

Zhang H.Y., 2015, Thermodynamic property of concrete and temperature field analysis of the base plate of intake tower during construction period, International Journal of Heat and Technology, 33(1), 145-154, DOI: 10.18280/ijht.330120