Research Journal of Applied Sciences, Engineering and Technology 5(4): 1317-1322, 2013
DOI:10.19026/rjaset.5.4867
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: July 02, 2012 Accepted: July 31, 2012 Published: February 01, 2013

Research Article

Mechanical Properties of Plastic Concrete Containing Bentonite

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Abstract: Plastic concrete consists of aggregates, cement, water and bentonite, mixed at a high water cement ratio, to produce a ductile material. It is used for creating an impermeable barrier (cut-off wall) for containment of contaminated sites or seepage control in highly permeable dam foundations. The effects of water to binder ratio and clay dosage on mechanical properties of plastic concrete were investigated. The results indicate that the water to binder ratio and clay dosage have great influence on the mechanical properties of plastic concrete. There is a tendency of decrease in the compressive strength, splitting tensile strength, shear strength and elastic modulus of plastic concrete with the increase of water to binder ratio and clay dosage, while, the internal friction angle of the shear specimens is increasing gradually. To improve the resistance to deformation of cut-off walls constructed with plastic concrete, the higher water to binder ratio and clay dosage can be selected to decrease the elastic modulus of plastic concrete in the practical design and applications of plastic concrete on condition that the plastic concrete has enough compressive strength, tensile strength and shear strength.

Keywords: Bentonite, clay dosage, mechanical property, plastic concrete, water to binder ratio

INTRODUCTION

Water tightness and seepage control are important considerations in the design and construction of dams. Plastic concrete consists of aggregates, cement, water and clay and some also contains bentonite, mixed at a high water cement ratio, to produce a ductile concrete material (Liu *et al*., 2011; Xiong *et al*., 2011; Hinchberger *et al*., 2010). Compared with ordinary concrete, the largest difference is that the cement content of plastic concrete is very small and plastic concrete contains clay and bentonite. In dam engineering, cut-off walls constructed by plastic concrete are often used for the construction of the slurry cut-off wall in highly permeable dam foundations (Mahboubi and Ajorloo, 2005; Gao *et al*., 2009a; Li *et al*., 2009). A plastic concrete cut-off wall acts essentially as a barrier to stop or reduce the groundwater flow. An important requirement for the plastic concrete in such applications is a low elastic modulus compatible with the foundation. Values of elastic modulus of up to four times the foundation elastic modulus are generally recommended (Bagheri *et al*., 2008). The other requirements for plastic concretes are adequate strength for the design loads and low enough permeability to meet the water tightness requirements of the dam (Guo and Zhu, 2008). To achieve the low elastic modulus requirement, the water to binder ratio of plastic concrete is generally very high (Bagheri *et al*., 2008; Wang *et al*., 2011; Gao *et al*., 2009b).

Seepage control is critical to the safe operation of earth dams. While remedial seepage control can be achieved with a rigid concrete cut-off wall, deformation of the earth embankment and its foundation can cause the concrete wall to rupture. Therefore, materials selected for construction of cut-off walls must be strong and watertight and have stiffness comparable to the surrounding soil. Satisfying strain-compatibility between the wall and surrounding soil will lessen the likelihood of overstressing the wall and will allow the wall and soil to deform without separating. Plastic concrete consists of the same materials as those of normal concrete with a high water-cement ratio and the only difference is that clay or bentonite is added to the mixture to increase its ductility (Gao *et al*., 2009c). This concrete shows great promise to satisfy the requirements of the strength, stiffness and permeability for remedial cut-off wall construction (Yu *et al*., 1997).

Regarding the plastic concrete which is added with clay and bentonite, its ductility is obtained mainly by clay and bentonite. The water to binder ratio has a significant effect on the mechanical properties of plastic concrete. Although most researches have been carried

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out on the mechanical behavior of plastic concrete (Li *et al*., 2005; Mahboubi and Ajorloo, 2005; Zhang *et al*., 2007; Zhang and Li, 2008; Zhou *et al*., 2009, 2011; Ding *et al*., 2011), the results of effect of water to binder ratio and clay dosage on mechanical properties of plastic concrete containing bentonite are rare and the existent results are not completely appropriate for practical purposes. Here, the water to binder ratio is the ratio of water content to the total content of cement, clay and bentonite. Therefore, the present work investigate the effect of water to binder ratio and clay dosage on mechanical properties of plastic concrete containing bentonite, which has great instruction in the design and applications of plastic concrete containing bentonite.

MATERIALS AND EXPERIMENTAL METHODS

Raw materials: Ordinary Portland cement (Class 32.5R) made by Long Gang cement plant was used. The water to be mixed was local tap water. The clay used is silty clay and the clay was dried in the sun, smashed, levigated and sieved with the mesh size of 5 mm before added into the concrete mixture. The results of particle size analysis of the clay is shown in Table 1. The clay was added in the form of mud. The bentonite was made by Xinyang Huashen bentonite Co., Ltd., which belongs to calcium-based bentonite. The properties of calcium-based bentonite are given in Table 2. The coarse aggregate used was composed of continuous gravel with different size of 5-20 mm. The fine aggregate was coarse river sand with the fineness modulus of 3.2. The physical properties of coarse aggregate and fine aggregate are shown in Table 3 and the gradation of the coarse aggregate adopted in this investigation is shown in Table 4. The mixing procedure, which was designed by trial and error, was chosen as follows: the coarse aggregate and fine aggregate were mixed initially for 1 min and the mixture was mixed for another 1 min after the cement and calcium-based bentonite were added into the mixture. Then, the water was added and mixed for 1 min. Finally, the clay was added in the form of mud and the mixture was mixed for 2 min. The mix proportions of plastic concrete are shown in Table 5. After casting, all the specimens were finished with a steel trowel. Immediately after finishing, the specimens were covered with plastic sheets to minimize the moisture loss from them.

Experimental method: Series of cube specimens with the size of 150×150×150 mm were used to determine the compressive strength and splitting tensile strength of plastic concrete. Before testing, the specimens were cured for 28 days at 100% relative humidity and controlled temperature (21±2°C). The tests of compressive strength and splitting tensile strength were carried out by hydraulic pressure universal testing machine according to the Chinese Standard (DL/T 5150, 2001) (National Standard of China, 2001). The loading rate of compressive strength and splitting tensile strength tests was controlled between 0.5 and 1.5 kN/s. The average value of the 6 data was computed as the final result.

Plastic concrete was added large quantities of clay and shear failure may occur in conditions of confining pressure. Therefore, the shear strength indices of cohesion and internal friction angle can be taken to describe the shear performance of plastic concrete. Series of cylinder specimens with the size of 150×Ø150 mm were used to determine the shear strength. Before testing, the specimens were cured for 28 days at 100% relative humidity and controlled temperature (21±2°C) and the specimens was vacuum saturated after 28 days curing according to the Chinese Standard (GB/T 50123, 1999). The tests were carried out applying strain-controlled direct shear apparatus using the method of saturated quickly shearing according to the Chinese Standard (SL 237-021, 1999). The average value of the 6 data was computed as the final result.

Table 1: Results of particle size analysis of the clay

Particle size (mm)	Percentage passing of clay particle (%)
0.0592	92.3
0.0425	88.8
0.0211	66.6
0.0095	40.7
0.0069	32.8
0.0050	25.9
0.0029	18.3
0.0015	9.10

Table 2: Properties of calcium-based bentonite

Composition (%)	Calcium-based bentonite
Chemical compositions	
SiO_2	72.02
Al_2O_3	15.76
Fe_2O_3	1.440
CaO	2.190
MgO	3.270
Na_2O	0.220
K_2O	0.380
TiO_2	0.210
Physical properties	
Green compressive strength (kPa)	37.5
Dry compressive strength (kPa)	320
Water absorption (%)	165
Specific gravity	1.1
Amount of methylene blue absorption (g/100 g)	34

Table 3: Physical properties of coarse aggregate and fine aggregate

Property index	Apparent specific gravity (g/cm^3)	Bulk specific gravity (g/cm^3)	Void ratio (%)	Silt content (%)	Fineness modulus	Needle and sheet percentage (%)	Crushing value (%)
Coarse aggregate	2.72	1.48	44.8	0.4	-	7.3	12.4
Fine aggregate	2.68	1.46	44.2	0.5	3.2	-	-

Table 4: Gradation of coarse aggregate

Sieve size (mm)	26.5	19	16	9.50	4.75	2.36
Percentage passing of aggregate (%)	100	98.6	87.6	41.5	6.70	0.20

For elastic modulus test, series of cylinder specimens with the size of 300×Ø150 mm were used. Before testing, the specimens were cured for 28 days at 100% relative humidity and controlled temperature (21±2°C). The prism compressive strength of each mixture was measured in advance. Two dial indicators were fixed symmetrically on both sides of the specimen with brackets to measure the deformation of both sides. Before the formal testing, the specimen should be pre-compressed at least 3 times until the difference of the data values of the 2 dial indicators is satisfied with the requirement of allowable error. The tests of elastic modulus were carried out by hydraulic pressure universal testing machine according to the Chinese Standard (DL/T 5150, 2001). The average value of the 6 data was computed as the final result.

RESULTS AND DISCUSSION

Compressive and tensile strength: Compressive and tensile strengths of plastic concrete were determined at 28 days of curing. The test results are given in Fig. 1 to 4. The effect of the water to binder ratio on the compressive strength and splitting tensile strength, respectively of plastic concrete are presented in Fig. 1 and 2. The relationships between the strengths of plastic concrete and water to binder ratio is similar to those of the common concrete. Great decrease both in compressive and tensile strengths as the water to binder ratio increases gradually can be seen from Fig. 1 and 2. Compressive strength decreases from 3.70 to 2.02 MPa and decreases by 45% when the water to binder ratio increases from 0.8 to 1.1. Tensile strength decreases from 0.63 to 0.23 MPa and decreases by 63% when the water to binder ratio increases from 0.8 to 1.1.

Figure 3 and 4 show the varying rules of the compressive strength and splitting tensile strength respectively of plastic concrete as the dosage of clay varies. From the figures, it can be seen that there is a tendency of decrease in the compressive strength and splitting tensile with the increase of clay dosage. For tensile strength, there is the same varying rule. Clay is 1 of the chief constituents of plastic concrete and it is made of clay minerals, among which montmorillonite

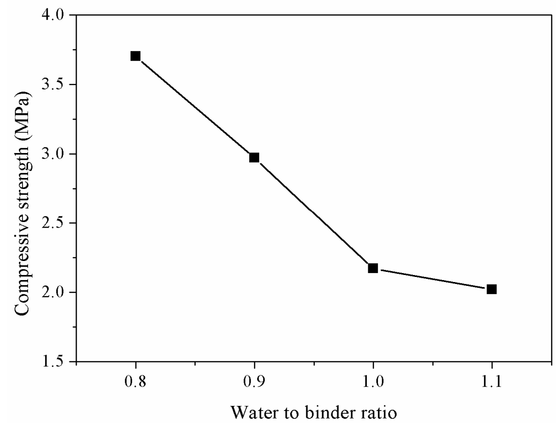

Fig. 1: Compressive strength versus water to binder ratio

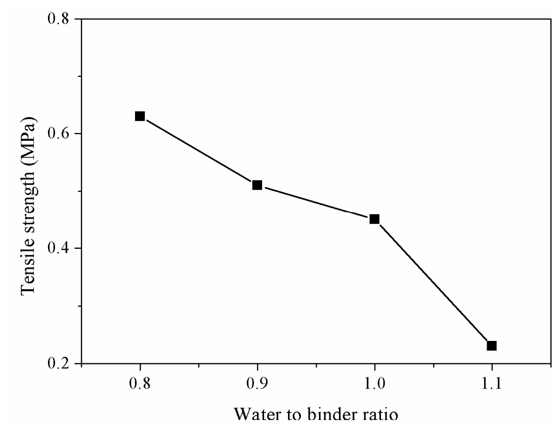

Fig. 2: Tensile strength versus water to binder ratio

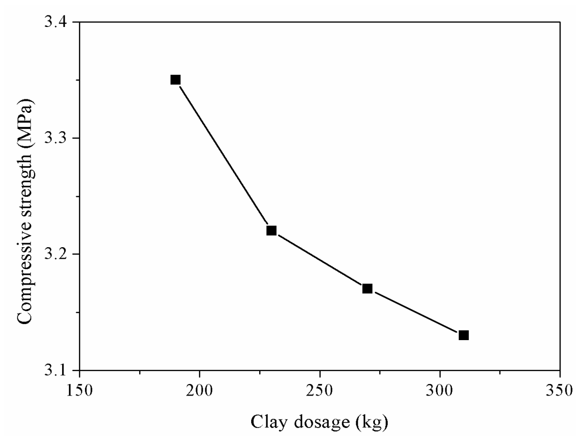

Fig. 3: Compressive strength versus clay dosage

Table 5: Mix proportions of plastic concrete

Cement (kg/m^3)	Clay (kg/m^3)	Bentonite (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)
160	380	20	560	630	450
140	340	20	580	670	450
130	300	20	610	690	450
120	270	20	630	710	450
120	310	50	620	700	400
120	270	50	640	720	400
120	230	50	660	740	400
120	190	50	680	760	400

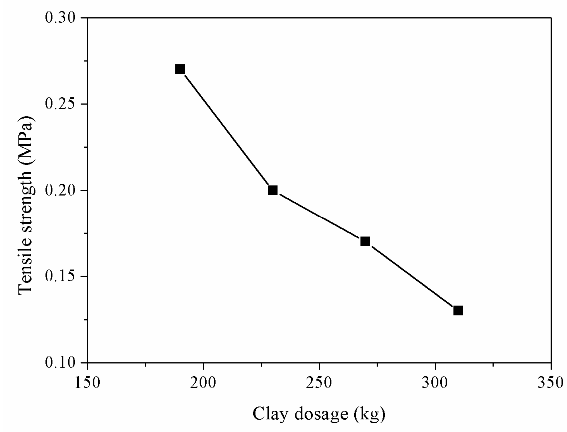

Fig. 4: Tensile strength versus clay dosage

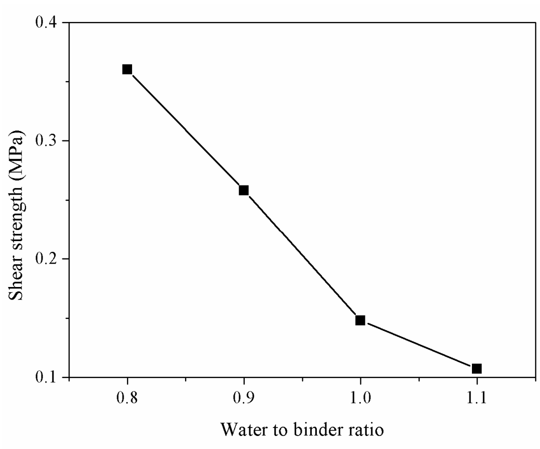

Fig. 5: Shear strength versus water to binder ratio

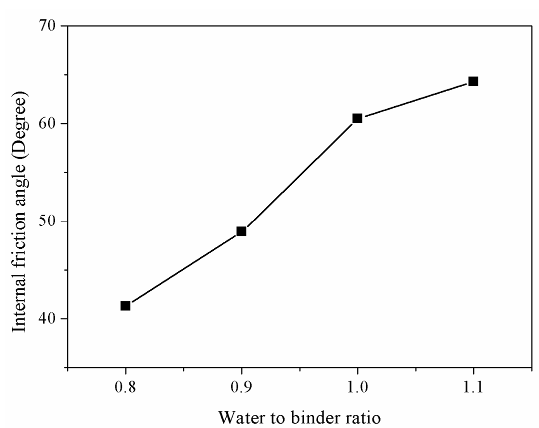

Fig. 6: Internal friction angle versus water to binder ratio

and kaolinite have the most significant effect on the strength of plastic concrete. The volume of these clay minerals with strong water absorbability will expand when they are encountering water and this volume expanding can lead to strength decreasing of plastic concrete, which is so called plasticity effect. Besides, as

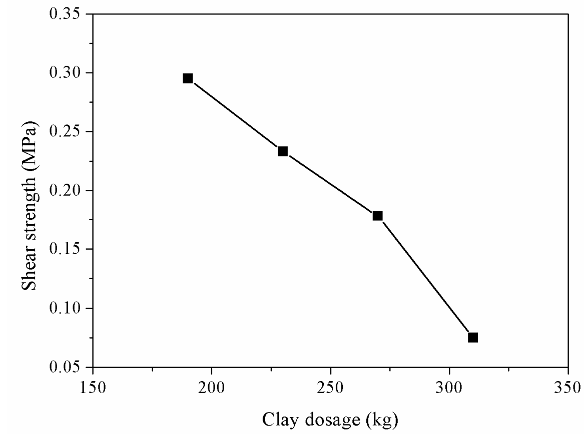

Fig. 7: Shear strength versus clay dosage

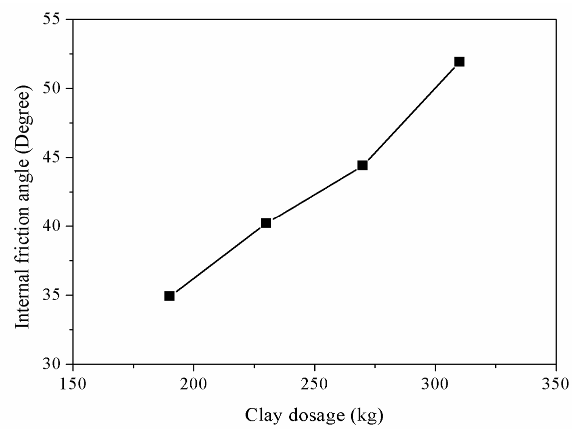

Fig. 8: Internal friction angle versus clay dosage

the content of clay is increasing, the number of clay particles in unit binding mortar increases. In other words, some a diverse impurities are added into the cement paste, which decrease the strength of hardened binding mortar. The failure of plastic concrete often occurs on aggregate interface or inside the binding mortar. As a result, the strength of plastic concrete will decrease with the increase of clay dosage.

Shear strength: The effect of the water to binder ratio on the shear strength and internal friction angle respectively of plastic concrete can be obtained from Fig. 5 and 6. As can be seen, the shear strength was decreasing gradually with the increase of water to binder ratio, while the internal friction was increasing gradually. The shear strength decreases from 0.360 to 0.107 MPa and decreases by 70% when the water to binder ratio increases from 0.8 to 1.1. The internal friction angle increases from 41.3 to 64.3°C and increases by 56% when the water to binder ratio increases from 0.8 to 1.1.

The variations of the shear strength and internal friction angle of shear specimens of plastic concrete versus the dosage of clay are illustrated in Fig. 7 and 8,

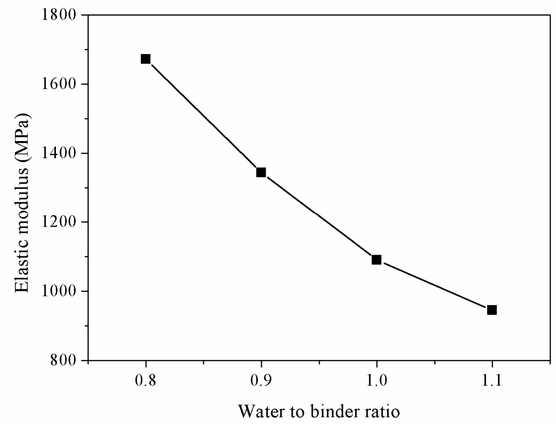

Fig. 9: Elastic modulus versus water to binder ratio

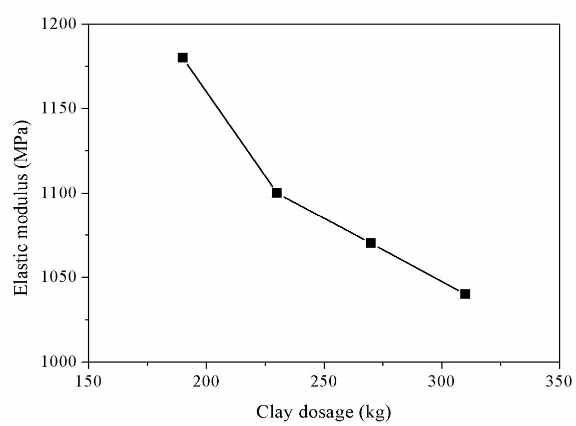

Fig. 10: Elastic modulus versus clay dosage

respectively. From Fig. 7, it can be seen that the varying rule of shear strength is the same as that of the compressive strength and splitting tensile strength, i.e. the shear strength is decreasing gradually with the increase of clay dosage. From Fig. 8, it can be seen that the internal friction angle is increasing gradually with the increase of clay dosage. The shear strength of the shear specimen will increase with the increase of compressive strength. Therefore, the shear strength is decreasing gradually with the increase of clay dosage. The internal friction angle of plastic concrete mainly depends on the ductility and the higher ductility, the bigger internal friction angle. With the clay dosage increase, the ductility is increasing gradually, so the internal friction angle is increasing gradually.

Elastic modulus: The variations of the elastic modulus of plastic concrete versus water binder ratio are given in Fig. 9. From the figure, it can be seen that the water binder ratio has great effect on the elastic modulus of plastic concrete and the elastic modulus decreases gradually with the increase of water to binder ratio. The elastic modulus decreases from 1671 to 945 MPa and decreases by 43% when the water to binder ratio increases from 0.8 to 1.1. The increase of water to binder ratio can decrease the elastic modulus of plastic concrete, which would be beneficial to improving the resistance to deformation of cut-off walls constructed with plastic concrete. However, from the discussion before-mentioned, it is known that the higher water to binder ratio has adverse effect on the strengths of plastic concrete. Therefore, in the mix proportion design of plastic concrete, the higher water to binder ratio can be applied to decrease the elastic modulus of plastic concrete on condition that the strengths of plastic concrete can meet the requirements.

Figure 10 shows the varying rules of the elastic modulus of plastic concrete as the dosage of clay varies. From Fig. 10, it can be seen that there is a tendency of decrease in the elastic modulus with the increase of clay dosage. After the clay is added into plastic concrete, the ductility of the concrete is improved, which can ensure than the concrete can bear larger deformation before failure. The increase of clay dosage has both advantages and disadvantages. On the one hand, the increase of clay dosage can save the cement dosage and decrease the elastic modulus of plastic concrete to improve the resistance to deformation of cut-off walls constructed with plastic concrete, however, on the other hand, the increase of clay dosage also decreases the strengths of plastic concrete. Therefore, the higher clay dosage can be selected to decrease the elastic modulus of plastic concrete in the practical design and applications of plastic concrete; however, the plastic concrete must has enough compressive strength, tensile strength and shear strength.

CONCLUSION

This study reported experimental results of compressive strength, splitting tensile strength, shear strength and elastic modulus of plastic concrete containing bentonite. The following conclusions can be draw from the results presented in this study:

- Water to binder ratio has great influence on the mechanical properties of plastic concrete. There is a tendency of decrease in the compressive strength, splitting tensile strength, shear strength and elastic modulus of plastic concrete with the increase of water to binder ratio. However, the internal friction angle of the shear specimens is increasing gradually with the increase of water to binder ratio.
- Clay dosage has great influence on the mechanical properties of plastic concrete. With the increase of clay dosage, the compressive strength, splitting tensile strength, shear strength and elastic modulus of plastic concrete are decreasing gradually. However, the internal friction angle of the shear specimens is increasing gradually with the increase of clay dosage.

- The higher water to binder ratio and clay dosage seems to be beneficial to improving the resistance to deformation of cut-off walls constructed with plastic concrete. However, at the same time, the higher water to binder ratio and clay dosage has adverse effect on the strengths of plastic concrete. Therefore, the higher water to binder ratio and clay dosage can be selected to decrease the elastic modulus of plastic concrete in the practical design and applications on condition that the plastic concrete has enough compressive strength, tensile strength and shear strength.

ACKNOWLEDGMENT

The authors are thankful to Long Gang cement plant and Xinyang Huashen bentonite Co., Ltd., for providing the Ordinary Portland cement and bentonite.

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