UTILIZATION OF JEHANGIRA BENTONITE AS PARTIAL REPLACEMENT OF CEMENT

By

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(2004 – NUST – MS PhD – STR - 09)

A Thesis submitted in partial fulfillment of

the requirements for the degree of

Master of Science

In

Department of Civil Engineering

National Institute of Transportation

National University of Sciences and Technology

Rawalpindi, Pakistan

(2006)

This is to certify that the

thesis entitled

UTILIZATION OF JEHANGIRA BENTONITE AS PARTIAL REPLACEMENT OF CEMENT

Submitted by

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Has been assented towards the partial fulfillment

of

the requirements

for

Master of Science in Civil Engineering

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2006

DEDICATED

TO

MY PARENTS, TEACHERS

AND

WELL WISHERS

ACKNOWLEDGEMENT

Thanks to The Merciful and Kind All Mighty Allah Who made me able to carry out this research work.

I would like to express my gratitude to everyone who has contributed to this study. Special thanks are extended to :

Dr. Tayyeb Akram, Advisor and Committee Chairman, for his invaluable support and encouragement to me in my research work. I am profoundly thankful to committee members: Lieutenant Colonel Shabbir Ahmad, Lecturer Shaukat Ali Khan and very special thanks to Lecturer Shazim Ali Memon for his valuable suggestions and advice. I am also thankful to Lieutenant Colonel (Retired) Muhammad Ali for providing all possible administrative support.

Finally, I pay my deepest gratitude with deepest sense of respect to my parents, for their eternal support, encouragement, prayers and patience.

ABSTRACT

Jehangira bentonite deposits occur at 33º59'56" latitude and 72º12'47" longitude in the Survey of Pakistan topographic sheet 43 C/1. These deposits are spread over an area of 26 Sq. km and average depth of the bed is almost 3.5m. Chemical analysis shows that Jehangira bentonite contains high amount of silicon, ferric and aluminium oxides as main components, which have the characteristics to react with free lime made available as the by-product of cement hydration. This research study is carried out to evaluate the feasibility of use of Jehangira bentonite, in production of concrete, as partial replacement of cement.

The main variables in this research study are the amount of bentonite and dosage of superplasticizer. The parameters which are kept constant are the amount of cementitious material equal to 460 Kg/m^3 and water to cementitious material ratio equal to 0.55.

Test results revealed that mixes associated with bentonite, showed slightly lower compressive strength than control mix (CM). However, it showed excellent resistance against acid attack. Water absorption was found minimum for mix containing 20 per cent bentonite as partial replacement of cement (20BC). Moreover, reactivity index for 20BC was found to be within the standards laid by ASTM C618.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL DESCRIPTION

At present lot of construction is taking place in earthquake-affected areas and much more is anticipated in backdrop of recently announced construction of hydroelectric projects in the country. Furthermore, reconstruction phase in Afghanistan is also in progress. Demand of construction materials in the region have increased manifold. Cement is the most essential ingredient of the construction industry and directly affects the overall cost of the project. Therefore, economy in the prevailing environment will remain a key feature in all engineering activities.

World's yearly cement production is about 1.6 billion tons, which accounts for about 7 percent of the global emission of carbon dioxide into atmosphere. Portland cement is one of the most energy-intensive construction materials and is also responsible for a large amount of green house gases. Production of one ton Portland cement consumes about 4GJ energy and releases approximately one ton of carbon dioxide into the atmosphere (Mehta 2006).

To cater for the said problems, there is considerable need to develop alternative materials which can be used as pozzolana. Major advantages of these alternatives to cement are that they are usually cheaper to produce, need much lower or even negligible capital inputs to get started, and require far less imported technology and equipment to process. This will reduce the consumption of raw material, thermal and electrical energy, together with the reduction in CO_2 emission. Furthermore, concretes utilizing these pozzolans can be of enhanced properties which include improved workability, lower heat of hydration and thermal shrinkage, improved resistance to sulphate attack, and reduced bleeding (Mehta 2006).

In past years, natural and artificial pozzolans have been used successfully as cement replacement throughout the world. The natural pozzolans include volcanic ash or pumicite, opaline cherts and shales, tuffs, and some diatomaceous earths (Neville 2000). One of the clay, which essentially consists of smectite mineral is bentonite (Ahmad 1992), which contains silica in reactive form, thereby, characterizing this material of volcanic origin as pozzolana. Therefore, to produce environmental friendly and low cost concrete, it is essential to evaluate whether bentonite clay deposits present in different regions of Pakistan can be used in concrete as partial replacement of cement, and if so, how the variation of this material affect the fresh and hardened concrete properties.

1.2 OBJECTIVES

The main objectives of this research study are;

- To produce low cost concrete utilizing bentonite as partial replacement of cement.
- To study the properties of fresh and hardened concrete with and without addition of bentonite.
- To study the cost effect of concrete with and without addition of bentonite as partial replacement of cement.

1.3 SCOPE AND LIMITATIONS

Variables involved in this research study are;

- Amount of bentonite (5, 10, 15, 20, 25, 30, and 35 per cent by weight of cement).
- Dosage of superplasticizer to maintain required range of slump (25-50 mm).

Following parameters are kept constant;

- Water to cementitious material ratio, i.e., 0.55.
- Amount of cementitious material, i.e., 460 kg/m^3.
- Source and grading of fine and coarse aggregate.

- Dosage of acid solution, 5 per cent, both for hydrochloric (HCl) and sulfuric (H_2SO_4) acids.

CHAPTER 2

LITERATURE REVIEW

2.1 HISTORY

Lime and limestone are among the oldest materials used by mankind for construction purposes. Long before the invention of Portland cement in 1824, mortars and concretes composed of mixtures and fillers and raw or heat-treated lime were used for construction throughout the world. It is reported that the oldest example of hydraulic binder, dating from 5000-4000 B.C., was a mixture of lime and natural pozzolan, a diatomaceous earth from the Persian Gulf. During archaeological excavations in the 1970s at the ancient city of Camiros on the Island of Rhodes, Greece, an ancient water tank built in 600 B.C. was discovered. The concrete blocks and mortars used in that structure were made out of a mixture of lime, Santorin earth, fine sand and siliceous aggregates. These mortars were used as the first hydraulic cements in aqueducts, bridges, sewers, and structures of all kinds by Romans and Greeks. All of these structures provide evidence of the durability of pozzolan-lime mortar under conditions of mild weathering exposure. Roman monuments in many parts of Europe are in use today, standing as a tribute to the performance of lime-pozzolan mortars (ACI 2005).

2. 2 POZZOLAN

According to ACI 116R, "pozzolan is a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but will in finely divided form and in presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties". Pozzolans can be divided into two categories (Neville 2000).

2.2.1 Natural Pozzolan

The natural pozzolans include volcanic ashes, opaline shales and cherts, calcined diatomaceous earth, and burnt clays. According to ASTM C618, these materials are described as Class N type pozzolans (Neville 2000). These materials are processed for producing pozzolan which involves drying, grinding, and calcination (Mehta 2006). Since bentonite is clay, it comes under the category of natural pozzolan.

Bentonite is clay consisting essentially of smectite mineral of the montmorillonite group regardless of origin of occurrence. The term Bentonite was first proposed by Knight in 1898 after the Benton shale, in which the clay was believed at that time to occur. The Benton shale is named after Fort Benton in Montana, USA (Ahmad 1992).

2.2.2 Artificial Pozzolan

These are the by-product of industries producing them. For example, fly ash is the most common pozzolan in use. These materials may or may not require processing before use (Mehta 2006). According to ASTM C618, these pozzolans are termed as Class C or Class F type pozzolans depending upon the silica content.

2.3 MECHANISM OF POZZOLANIC REACTION

When Portland cement is mixed with water, it produces within a few hours a solution supersaturated with calcium hydroxide $Ca(OH)_2$ and containing concentrations of calcium silicate hydrate in a metastable condition (Neville 2000). The reaction between calcium hydroxide and pozzolan is called the pozzolanic reaction. The technical significance of the pozzolanic reaction is threefold. First, the reaction is slow. Second, the reaction is lime consuming instead of lime producing, which has an important bearing on the durability of the hydrated paste to acidic environments. Third, pore size distribution has shown that the reaction products are very efficient in filling up large capillary space, thus improving the strength and impermeability of the system (Mehta 2006).

Hydration of silicates (Neville 2000):-

$3C_3S + 6H$ ------------------ $C_3S_2H_3 + 3Ca(OH)_2$

$2C_2S + 4H$ ------------------ $C_3S_2H_3 + Ca(OH)_2$

C_3S --------------------- Tricalcium silicate

C_2S --------------------- Dicalcium silicate

$C_3S_2H_3$ ----------------- Calcium silicate hydrate

Pozzolanic reaction (Mehta 2006):-

Pozzolan + $Ca(OH)_2$ + H --------- $C_3S_2H_3$

2.4 PREVIOUS RESEARCH

The properties and appropriate usage of minerals and clays as replacement of cement are being studied for many years. Uzal and Turanli (2003) studied the characteristics of laboratory-produced blended cements containing volcanic tuff. He observed that blended cements containing 55 per cent volcanic tuff showed excellent ability to reduce the alkali-silica expansion and yielded almost equal strength to Portland cement at the age of 91 days, when grinding time was 120 minutes. For instance, the compressive strength of blended cement containing 55 per cent tuff was only 2 per cent lower than ordinary Portland cement.

Poon et al. (2005) studied the mechanical and durability properties of metakaolin clay and silica fume concretes. It was found that metakaolinite-clay concrete has superior strength development and similar chloride resistance to silica-fume concrete. It was also observed that chloride ion penetration for metakaolin and silica fume concrete was less than that of control concrete.

Al-Akhras (2006) investigated the effect of metakaolin clay replacement of cement on the durability of concrete to sulphate attack. The study showed that metakaoline replacement of cement increased the sulphate resistance of the concrete. The sulphate resistance of metakaoline concrete increased with increasing the metakaolin replacement level. He also observed that sulphate resistance of metakaolin concrete at w/c ratio of 0.5 was more than, at w/c ratio of 0.6.

In Pakistan, research carried out on the use of bentonite clay as replacement of cement is given as under;

Hassan et al. (2003) found out the reactivity index of mortar cubes containing Jehangira bentonite as replacement of cement. He concluded that 40 per cent replacement of bentonite in mortar and 25 per cent replacement in concrete yielded satisfactory results when used AS SUCH (without any heat treatment). Modulus of rupture of bentonite concrete beam was less than control beam and decreased further as the bentonite replacement increased. He also concluded that 11 per cent of the concrete cost can be saved by replacing 25 per cent of bentonite with cement.

Badshah (2003) found out the optimum replacement of Jehangira bentonite as pozzolana on the basis of XRD diffraction analysis and compressive strength results. He also studied the sulfate resistance of concrete utilizing Jehangira bentonite. He concluded that 20 per cent of bentonite replacement in concrete yields satisfactory results but any firther addition reduces strength drastically. Sulfate resistance of concrete increases as the pozzolana replacement increases. At 20 per cent of bentonite replacement, sulphate resistance of mortar in 2 per cent sulphate solution is maximum.

Iqbal (2004) found out the reactivity of Jehangira bentonite when used in AS SUCH form and calcined at 500 ^{o}C and 900 ^{o}C. He concluded that Jehangira bentonite is more reactive when used AS SUCH than calcined at 500 ^{o}C and 900 ^{o}C. He also concluded that soundness of concrete is better in the presence of bentonite and sulphate resistance is maximum at 30 per cent substitution of bentonite. Porosity of concrete was found out to be minimum at 30 per cent substitution of bentonite.

2.5 DEPOSITS OF BENTONITE IN NWFP

2.5.1 Chashma Wali Bentonite

The Chashma Wali Bentonite deposits are situated 2 km due north-northwest of Jabli village, Peshawar division in Survey of Pakistan topographic sheet 38 O/12 (Ahmad 1992).

2.5.2 Karak Bentonite

The Karak Bentonite deposits are situated 112 km due south of Kohat town and about 56 km northeast of Bannu town in Survey of Pakistan topographic sheet 38 O/4. The deposits are spread over an area of 18 Sq. km (Ahmad 1992).

2 5.3 Jehangira Bentonite

The Jehangira Bentonite deposits are situated at 33º59'56" latitude and 72º12'47" longitude in Survey of Pakistan topographic sheet 43 C/1. River Kabul truncates these deposits in the south (Badshah 2003). Bentonite used in this research work is taken from Jehangira.

2.5.4 Garhi Chandan Bentonite

These deposits are situated along the Shingle road and about half kilometer south of Garhi Chandan village. The deposits are spread over an area of 12 Sq. km (Badshah 2003).

CHAPTER 3

EXPERIMENTAL PROGRAM

The concrete mixes were prepared under laboratory conditions having slump in the range of 25-50 mm. The slump was maintained by adjusting the dosage of superplasticizer. The overall cementitious materials content of 460 kg/m^3 was kept constant. For each mix, normal consistency and setting time were determined according to ASTM C187-98 and ASTM C197-04. The density of fresh concrete was determined by using compacting factor apparatus as described by Neville (2000) while reactivity index test was carried out according to ASTM specification C109M. Compressive strength test of cylinders at 3, 7, 28, and 56 days was carried out according to ASTM C39. For acid attack test, procedure mentioned by Rawal (2003) was adopted and water absorption test was carried out according to ASTM C642.

3.1 MATERIALS

The materials used in this experimental study and their specifications are summarized as follows.

3.1.1 Cement

Ordinary Portland Cement (OPC) from Askari Cement Factory was used. It conformed to requirements of ASTM C150 Type I cement. The physical properties and chemical composition of cement is tabulated in Table 3.1 (Appendix I).

3.1.2 Pozzolan

Bentonite clay obtained from Jehangira was used as pozzolan. At first, bentonite was dried for 24-hours at a temperature of 105^{o}C and then grinding was carried out in Los Angles abrasion machine. Each batch of 5 kg was given 4500 revolution to maintain uniform fineness. The specimen was sieved through sieve No.100. The resulting sample after sieving was preserved in air-tight polythene bags and later on used for producing different mixes. The physical properties and chemical composition of bentonite clay is tabulated in Table 3.1 (Appendix I).

3.1.3 Fine Aggregate

Sand from Lawrencepur of size ranging between 5mm (No.4) sieve to 150 μm (No.100) sieve was used. Sieve analysis was carried out in accordance with ASTM C136-04. Specific gravity and water absorption was determined as given in ASTM C128-04.

Results of sieve analysis are tabulated in Table 3.2 (Appendix I) and particle size distribution is shown in Figure 3.1 (Appendix I). Physical properties of fine aggregates are given in Table 3.3 (Appendix I).

3.1.4 Coarse Aggregate

Crushed stone from Margalla quarry of size 19mm and down gauge was used. The sieve analysis was carried out in accordance with ASTM C136-04. Specific gravity and water absorption was determined as given in ASTM C128-04.

The physical properties of coarse aggregates are given in Table 3.3 (Appendix I) and results of sieve analysis are tabulated in Table 3.4 (Appendix I). The particle size distribution is shown in Figure 3.2 (Appendix I).

3.1.5 Superplasticizer

The superplasticizer used was “Sikament 163”. Dosage of superplasticizer was varied to get the slump with in range of 25mm to 50mm.

3.1.6 Water

Tap water from Nowshera was used for the entire experimental work.

3.2 MIX PROPORTIONS

Eight mix designs were prepared with ratio of 1:2:4 (one part cementitious material (Cement + Pozzolana): two parts of sand: four parts of coarse aggregate).

Water to cementitious material ratio and cementitious material content was kept constant, i.e., 0.55 and 460 Kg/m^3 respectively for concrete. Dosage of superplasticizer was varied to get the slump within range of 25mm and 50mm. The experimental matrix of mix proportions for concrete is summarized in Table 3.5 (Appendix I). Details of concrete and mortar specimens casted are summarized in Tables 3.6 to 3.8 (Appendix I).

3.3 SPECIMEN DESIGNATION

The various mixes used in this experimental work are abbreviated in two different ways, i.e., CM and XBC. Specimen cast without addition of bentonite are designated as Control mix (CM), while XB represents the amount of cement, in per cent, that has been replaced with bentonite and C represents cement. For instance, the specific designation, 5BC, indicates that 5 per cent cement has been replaced with bentonite in the mix.

Chapter 4

TEST RESULTS AND DISCUSSIONS

4.1 SETTING TIME

The setting time results are tabulated in Table 4.1 (Appendix II) and graphically shown in Figure 4.1 (Appendix II). From the results, it is clear that initial setting time and final setting time was lowest for the CM. As anticipated, the initial and final setting time increased as the amount of bentonite was increased. This may be because of substantial amount of non-reactive crystalline minerals present in bentonite. The maximum initial and final setting time was observed for the mix 35 BC, i.e., 3 hours 15 minutes and 9 hours respectively.

Results of consistencies of cement pastes having different bentonite content are tabulated in Table 4.1 (Appendix II) and graphically shown in Figure 4.2 (Appendix II). From the results, it is clear that water requirement to make the paste of standard consistency increased with the increase in bentonite replacement. CM required 28 per cent and 35BC required 32 per cent water to make the paste of standard consistency. This is because of the fact that bentonite clay has finer particle and more specific surface, so the water requirement to make the paste of standard consistency increases.

4.2 FRESH DENSITY OF CONCRETE

The results of fresh density of different mixes are tabulated in Table 4.1 (Appendix II) and graphically shown in Figure 4.3 (Appendix II). It can be observed that density of control mix (CM) in fresh state is maximum, i.e., 2292 Kg/m^3 and lowest for 35BC, i.e., 2141 Kg/m^3. This is because of the fact that the specific gravity of cement is more than bentonite and density being function of specific gravity, density of control mix (CM) is maximum.

4.3 REACTIVITY INDEX

Results of reactivity index of 50mm mortar cubes at 7 and 28 days are tabulated in Table 4.2 (Appendix II) and graphically shown in Figure 4.4 (Appendix II). From the results, it is clear that 28 day reactivity index is more as compared to 7 day reactivity index for all the mixes. This is because of the fact that for pozzolanic activity free calcium hydroxide $Ca(OH)_2$ is required which is by-product of hydration reaction. At the age of 7 day, less calcium hydroxide is available for pozzolanic activity; hence 7 day reactivity index is less than 28 day reactivity index. Furthermore, it can be seen from Table 4.3 (Appendix II) that 20 per cent replacement of cement with bentonite, meet the requirements laid by ASTM C618 for reactivity index.

4.4 COMPRESSIVE STRENGTH

The compressive strengths of the mixes for 3, 7, 28, and 56 days are tabulated in Table 4.4 (Appendix III) and graphically shown in Figure 4.5 to Figure 4.7 (Appendix III). The results show that the compressive strength of the CM is maximum at all stages of testing than the mixes with bentonite.

The comparative compressive strength of different mixes is shown in Figure 4.8 to Figure 4.11 (Appendix III). The comparative compressive strength analysis of Figure 4.8 indicate that at 3 days of testing, the difference in compressive strength between CM and the mixes containing bentonite (5BC, 10BC, 15BC, 20BC, 25BC, 30BC, and 35BC) is found to be 6.16, 14.45, 19.85, 29.52, 37.06, 38.19, and 44.22 per cent respectively. At 56 days of testing, the difference in the compressive strengths between CM and mixes containing bentonite is found to be 1.80, 3.35, 5.39, 11.18, 11.18, 14.85, 18.07, and 20.59 per cent respectively as shown in Figure 4.11 (Appendix III).

When the compressive strength of the mix containing bentonite is evaluated at later ages, it can be seen that there is substantial increase in the strength. The main reason for this being the pozzolanic reaction that takes place at slower rate than the hydration of cement, coupled with the micro filler effect caused by the bentonite.

When the mix 5BC is compared with the mix 35BC, 5BC showed higher strength at every stage of testing, which means that the amount of cement also plays an important role. As 5BC is richer in cement content than 35BC, thus when the hydration of Portland cement commences, the principal silicates namely tricalcium silicate, dicalcium silicate and tricalcium aluminate which are crystalline in nature decomposes rapidly in water to provide the desired silicate and aluminate ions for the formation of the cementitious hydrates. Therefore, for the mix containing higher amount of cement, higher compressive strength can be expected.

4.5 WATER ABSORPTION

Results of water absorption test are tabulated in Table 4.5 (Appendix IV) and shown graphically in Figure 4.12 (Appendix IV). From the results, it can be observed that water absorption reduces as bentonite replacement increases up to 20 per cent. This is because of the reason that with bentonite, the reaction is lime consuming instead of lime producing, which has an important bearing on the durability of the hydrated paste; secondly, pore size distribution has shown that the reaction products are very efficient in filling up large capillary space, thus improving the strength and impermeability of the system (Mehta1986).

Furthermore, it can be observed that water absorption increases for 25BC, 30BC, and 35BC. The reason for the increase in water absorption in this case may be due to the reason that there is un-reacted bentonite present in concrete system which is in excess of pozzolanic activity requirement. Bentonite (montmorillonite) is composed of two silica sheets and one alumina sheet; the bonding between these layers is very weak, so large quantity of water can easily enter and separate them (Coduto2002), so water absorption of concrete increases.

4.6 ACID ATTACK

Results of acid attack test are tabulated in Table 4.6 to Table 4.8 (Appendix V) and graphically shown in Figure 4.13 (Appendix V). It can be seen that, the amount of weight loss for CM was maximum in both the acid solutions, sulfuric and hydrochloric acids. The poor performance of CM against acid attack is due to the fact that it contains 60 to 65 per cent lime which upon hydration releases a considerable portion of free calcium hydroxide which reacts with the acid and a soft and mushy mass is left behind. In the case of mix containing bentonite, the calcium hydroxide reacts with the silica in bentonite mix to form silica gel, this results in negligible amount of calcium hydroxide, thus making bentonite mix more resistant to acid attack.

Furthermore, the weight loss in sulfuric acid was more pronounced than hydrochloric acid. It is due to the fact that in case of sulfuric acid, a product called calcium sulfoaluminate (Ettringite) is formed, which expands and hence causes disruption of the set cement paste; whereas, no such product is formed in case of hydrochloric acid.

4.7 COST ANALYSIS

Cost analysis of the materials used in the research work was carried out on the basis of market prices till March 2006. Comparison is drawn between CM and 20BC, which is optimized for its reasonable strength and durability properties. The detailed calculations are summarized in Table 4.9 (Appendix VI). Based on the cost analysis, cost of mix design of 20BC is less by 7.7 per cent than CM.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Following conclusions are drawn on the basis experimental results:

- The properties of bentonite as pozzolana meets the requirement of ASTM class N Pozzolans, as described in ASTM C618-03.
- Low cost concrete can be produced by substituting bentonite as partial replacement of cement along with the main ingredients of concrete and superplasticizer for compensating loss of workability, without compromising much on strength parameters.
- The optimum substitution of bentonite that fulfills the requirements of reactivity index laid by ASTM C618-03, is 20 per cent.
- Concrete that incorporates 20 per cent of bentonite substitution, yielded 85 per cent 28-day compressive strength and 86 per cent 56-day compressive strength as compared to CM, which is quiet reasonable.
- Concrete utilizing bentonite as pozzolana is effective in resisting acid attack. However, the effect of sulfuric acid on concrete is slightly on higher side than hydrochloric acid.
- Water absorption decreases with the increase in bentonite replacement up to 20 per cent and increases for higher percentage substitution. From durability point of view, bentonite replacement should not exceed 20 per cent.
- The use of bentonite as pozzolana is a cost effective option. 7.7 per cent of the amount can be saved by substituting 20 per cent of bentonite as cement replacement, in concrete.
- The use of bentonite as pozzolana is an environmental friendly option. Technically and financially, bentonite has lots of potential to be used as pozzolan in concrete construction industry.

5.2 RECOMMENDATIONS

- Long term strength development of concrete utilizing bentonite as partial replacement of cement beyond 56 days should be studied.
- Long term durability tests should be conducted on concrete utilizing bentonite as partial replacement of cement.
- Bentonite from sources other then Jehangira should be evaluated for possible use as pozzolana.

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