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MECHANICAL AND DURABILITY PROPERTIES OF POLYPROPYLENE CONCRETE CONTAINING BENTONITE AND SILICA FUME

[a] Inzimam Ul Haq*, [b] Ayub Elahi, [c] Syed Aamir Qadeer Shah, [c] Malik Ahmad Ghaffar

a: MSc student, Department of Civil Engineering, University of Engineering and Technology Taxila. inzimamsafi@gmail.com
b: Professor at Department of Civil Engineering, University of Engineering and Technology Taxila. ayub.elahi@uettaxila.edu.pk
c: Dy. Chief Engineer (Civil), OGDCL Islamabad. aamirqadeer@ogdcl.com

Abstract- This paper reports the mechanical and durability properties of bentonite and silica fume (SF) concrete containing fibrillated micro polypropylene fibers (PPF). The fresh property was investigated by slump test and mechanical property was investigated by compressive strength and ultrasonic pulse velocity (UPV) tests. For durability properties, permeability test was performed. This research is based on the previous published research and selected the optimum percentages of supplementary cementing material (SCMs) for bentonite and SF. The concrete mixture consists of total of nine mixes: control mix (CC), two binary mixes (i.e., 10% bentonite (B10SF0P0), 10% SF(B0SF10P0)), ternary mix (B10SF10P0), also known as ternary control mix (TCC) and then additional mixes by adding polypropylene fiber equal to 0%, 0.25%, 0.50%, 0.75%, 1% and 1.25% in TCC. It was concluded that all the binary and ternary mixes showed decrease in the workability. The UPV test indicated good quality of concrete for binary mixes and ternary mixes up to the PPF content equal to 0.75%. It was observed that compressive strength and permeability properties of concrete were improved for both the binary mixes and ternary mixes up to addition of PPF equal to 0.5%. PPF increased the deformability properties and completely changed the failure pattern of concrete as compared to ternary mix without PPF.

Keywords- Workability, supplementary cementing material, bentonite, compressive strength, ultrasonic pulse velocity, permeability.

1. Introduction

In the current era, Pakistan is trying to boost their economic state and provide best standard of life to the inhabitant of the state. To facilitate the public and provide standard of living, different projects are on their track line, like housing, highway, dam and the most important CPEC projects. For all these infrastructure of development projects, concrete is one of the abundantly used construction material. Cement is the important constituent of concrete responsible for binding all other ingredients. All these projects increase the demand of cement [1]. Recently Govt of Pakistan announced to increase the cement manufacturing industries to fulfil the current huge demand required for infrastructure development. Cement industry is responsible for consuming large amount of energy and CO_2 emission that ultimately causes climatic problem [2]. Supplementary cementing material (SCMs) is one of the solutions to minimize the consumption of natural raw material for cement, energy consumption and reduce the negative impacts on the environment. Different researchers used SCMs to investigate fresh properties and hardened properties to study mechanical and durability performance of concrete [3] [4]. The pozzolanic material can also be added during the manufacturing process of cement at different proportion. Uzal et al [5] studied the manufacturing laboratory based blended Portland cement by addition of natural volcanic pozzolanic material. Experimental study was limited to material from two volcanic sources by 55% replacement at different grinding time. The blended cement improved compressive strength and reduced the ability of alkali silica expansion.

Bentonite is a pozzolanic material abundantly available in Pakistan. Different researchers worked on bentonite as a partial replacement of cement [6] [7]. Memon at al., observed that the particle size of bentonite is flaky and elongated, which tends to reduce the workability [8]. SF is being used as partial replacement of cement at a certain proportion to increase certain mechanical and durability properties. From the scanning electron microscopy, it was observed in past research that the use of silica fume in concrete significantly reduced the porosity and provide dense concrete, which ultimately reduced the permeability [9]. In another study, SF increased both mechanical and durability properties of concrete due to the formation calcium silicate hydrate gel (C-S-H) in the result of pozzolanic reaction [10]

The addition of PPF and polyester fibers improved mechanical properties and ductility. In addition, PPF showed greater ductility than polyester fiber [11]. PPF significantly reduced workability, increased air content, improved ductility of mortar. Increase in the proportion of PPF, permeability was increased [12]. The combine effect of SCMs improved the mechanical and durability properties of concrete and different fibers were added to improve the ductility properties [13]. Akbar et al studied the combine effect of Pakistani bentonite and SF on various aspects of high-performance concrete [3].

The use of Bentonite and SF as a partial replacement of cement increased the mechanical, durability properties of concrete along with reducing the emission of global warming gases and reduced the cost of concrete. Further addition of SF in Bentonite concrete increased the mechanical and durability properties of concrete due to the preformation of C-S-H gel. The addition of PPF further increased certain properties of concrete.

However, there is limited and contradictory data available in the literature regarding effect of PPF on binary and ternary mixes of concrete with Bentonite and SF. The proposed study will help the stakeholders of construction industry in using SCMs and PPF without any hesitation for the intended purpose.

2. *Experimental Work*

2.1 Materials used

Ordinary Portland cement (OPC) of type-I was used as the main binding material followed by ASTM C150 [14]. Specific gravity of OPC was 2.99, initial and final setting time was 109min and 285 min respectively. Bentonite and SF was used as a SCMs. Properties of OPC, Bentonite and SF are shown in the Table 1.

Table 1Properties of OPC, Bentonite and SF

Chemicals	**SiO_2**	**TiO_2**	**Al_2O_3**	**Fe_2O_3**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**P_2O_3**	**LOI**
OPC	17.4	-	10.2	3.6	-	1.8	62.3	0.9	1.4		0.9
Bentonite	56.8	1.45	15.45	12.27		3.71	0.55	-	-	-	6.89
Silica fume	92.2										2.7

Tap water was used both for mixing and curing of the concrete samples. The addition of both SCMs caused reduction in the workability. Water- cement ration was kept constants for all mixes. In order to get the required slump, dosage of superplasticizer was adjusted. Fine aggregate (FA) was used from Lawrencepur source in Pakistan. Coarse aggregate (CA) from Margalla hills source was used in concrete. The maximum size of coarse aggregate was 19mm. The properties of FA and CA are shown in the Table 2. PPF of length 19mm was used. Its properties, as reported by manufacturer [15], are shown in the Table 3.

Table 2. Properties of inert materials

	FA	**CA**
Specific gravity	2.7	2.65
Water absorption (%age)	1.3	0.54
Loose density (Kg/m^3)	-	1412
Rodded density (Kg/m^3)	-	1550
Fineness modulus	2.99	-

Table 3. Properties PPF (Matrixx Company).

Tensile Strength at breakage (MPa)	31-41 [16]
Elongation at break (%)	100-600 [16]
Tensile modulus (MPa)	1137-1551 [16]
Specific gravity	0.9-0.91 [17]

2.2 Mix Proportions

Total nine different mix proportion were used to investigate the mechanical and durability properties of concrete. The optimum percentage for partial replacement of Bentonite and SF was selected on the basis of previous research [18] [7].

A total of nine mixes were prepared with a constant water to binder ratio of 0.5. Mixes include CC mix, 10% bentonite(B10SF0P0), 10% SF (B0SF10P0), ternary mix (B10SF10P0). PPF was then added into the ternary mix with varying percentages up to 1.25% with an interval of 0.25%.

2.3 Sample preparation

Yielding of all the batches of ingredients were done by weight. The ingredients were mixed in an electric concrete mixer and revolved at a rate of 30 rev/min. To get desired workability, Visconcrete 3110 superplasticizer (SP) was used in the concrete mixes. Different sample were prepared for different tests. To get the average value of each testing results, three sample were prepared and tested. Cube of 150x150x150mm was used for compressive strength, whereas, 100x100x150mm size samples were prepared and tested for permeability results. Fresh property was observed through slump test. Hardened properties of concrete were investigated by performing mechanical and durability tests. For mechanical properties, compressive strength was investigated by preparing cubes and ultrasonic pulse velocity test was also performed. For durability property, permeability test was conducted. The coefficient of permeability was calculated by the following formula;

$$k = \mathrm{Qxh/AxtxP}$$

Where Q=discharge from sample; P is hydrostatic pressure; A is sample top surface area; h is sample height and t is permeability time.

3.2. Results and discussion

3.1. Fresh properties

3.1.1. Workability

Workability of each mix (with constant water-cement ratio) was determined using slump test according to ASTM C143 [19]. Slump values for varying percentage of Bentonite, SF and PPF were tried to keep constant. Dosage of SP (by %age weight of binder) reflected that workability was reduced by adding Bentonite and SF. It was concluded from the results that the addition of bentonite, SF and PPF significantly reduced the workability. Required dosage of SP for Bentonite binary mix was more as compared to that of SF binary mix, showing comparatively severe effect of Bentonite as compared with that of SF in reducing workability. However, TCC mix, being highest replacement value among unstrengthen mixes used combatively high dosage of SP. For other mixes achieved by adding PPF, there was no improvement, even at maximum permissible dosage of SP. Therefore, Workability results of all the PPF strengthened ternary mix were discarded in the Figure 1. Because of the fine particle size of bentonite and SF compared to cement particle, reduced slump value was experienced. The particle shape of bentonite and SF was flaky and spherical respectively. Due to spherical nature, SF showed better workability than that of Bentonite which is in accordance with other studies [12].

3.2. Mechanical properties

3.2.1. Compressive strength

It is one of the important properties widely used to determine the uniaxial load carrying capacity of concrete. It was determined on cubes according to BS [20]. The results of compressive strength of cubes are shown in the Figure 2. It was concluded that PPF increased the ductility properties of concrete. The addition of Bentonite and SF increased the compressive strength, and PPF showed slightly improvement in the strength up to 0.5% its addition as compared to that of TCC mix, but further increase in the proportion of PPF caused reduction in the compressive strength which is in accordance with previous work [21]. Increase in strength by adding PPF

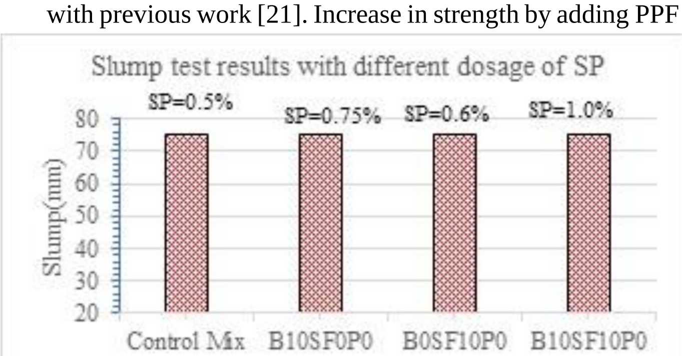


Figure 1. Slump test results

up to 0.5% is due to effective bond of PPF with the cement paste. However, further addition in optimum content of PPF caused decrease in compressive strength. The addition of PPF completely changed the failure pattern of concrete. It was observed with naked eye that there was about half inch deformation without crushing of concrete. However, this deformation was not experienced by control mix, rather crushing was noted. The compressive strength of the TCC mix was improved by about 8% as that of control mix at 90 days. PPF content up to 0.5% addition, showed optimum compressive strength results but further increase in PPF proportion caused decrease in the compressive strength and the mix containing maximum PPF (1,25%) reduced the strength by 44% as compared to the CC mix. It might be due to poor bond between PPF and concrete ingredients. Up to 0.5% addition of PPF, parameter of interlocking was dominate on any adverse effect due to bond between two different materials. When cracks became visible in the sample, there was no reduction in applied load, but the load became constant and only the strain was increased, after a short period of time again the load started increasing due to the bond interlocking capacity of the PPF in concrete.

3.2.2. Ultrasonic Pulse Velocity (UPV) Test

The quality of concrete was determined by a non-destructive UPV test by using direct method. A direct pulse transit time was calculated between the two opposite transducers emitter and receiver by passing sound pulse from one transducer to receive by other. The propagation of signal was directly noted and velocity was determined by putting the distance between the transducers. The pulse time taken depends on the uniformity, porosity and cracks availability [22]. From the pulse transit time, velocities were calculated by dividing the pulse distance by transit time. It was performed for cubes in all the three planes of the cube to get the average value of the stable pulse time. From this test quality of concrete was investigated from the velocity of waves. The results of UPV are shown in the Figure 3. From the results it was observed that the addition of bentonite and SF increased the velocity of signals and PPF reduced its value due to porous nature. All the mixes up to 0.75% PPF showed good quality of concrete because its UPV value lies in the range 3660-4575m/s [23]. Greater the addition of PPF fiber, greater was the time to pass the waves in concrete body. It was because of the greater absorption of pulse wave by PPF and voids developed due to PPF and ultimately it reduced the quality of concrete as compared to CC.

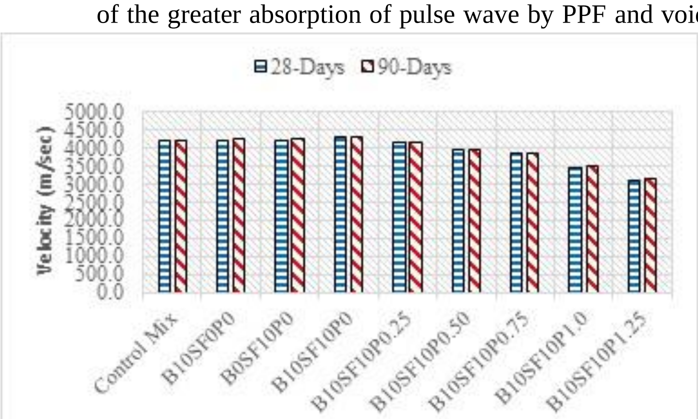


Figure 3. UPV test results

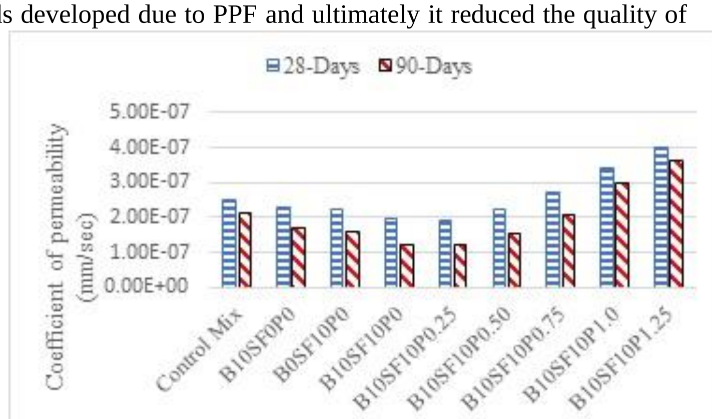


Figure 4. Permeability coefficient of concrete

3.3. Durability properties

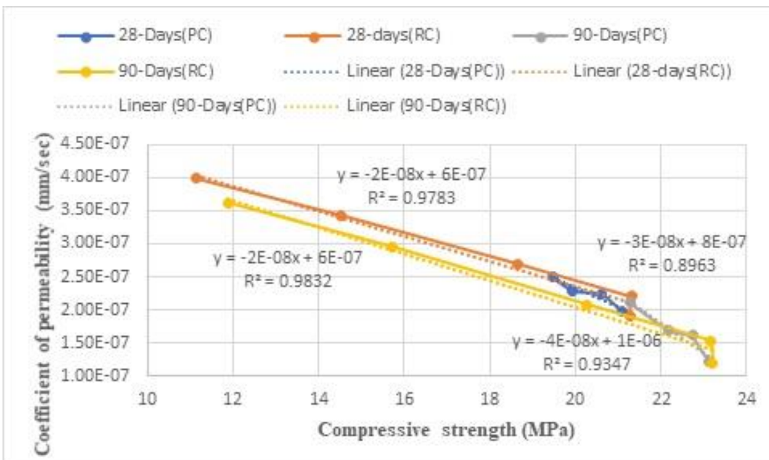
3.3.1. Permeability

It was observed by an apparatus specially design for permeability test was performed according to Indian Standard [24]. Samples with sizes of 100x100x150 were prepared and cured in water for 24 hours and then cured in room temperature in hessian cloth till 72 hours before the age of testing at 28 days and 90 days. The samples were then oven dried by placing it in oven for a period of 48 hours before performing test on it. The oven dried samples were placed in open air to bring its temperature to atmospheric level and after that they were painted from all the four sides to retain the penetration of water from the sides and water was made to flow from the top and bottom side only. Samples were fitted in the machine and open spaces were closed by silicon abrasive to maintain constant pressure of water and hindering the water to flow out from the sides. After complete dry of silicon, machine was fixed for performing the test [25]. The results of each mix are shown in the Figure 4. From the results it was observed that the TCC mix reduced the penetration of water by 42% compared to CC. It was due to dense structure of concrete and the fine particle of pozzolana. The addition of PPF up to 0.5% contributed in the reduction of permeability and further addition of PPF in concrete increased the permeability due increased in porosity of concrete [12]. The mix containing maximum PPF (B10SF10P1.25) increased permeability by 41.5% as compared to CC mix at 90 days curing.

3.4. Correlation between compressive strength and coefficient permeability

The compressive strength and coefficient of permeability of concrete are inter-related and are dependent on each other. As Bentonite and SF were added into concrete, both compressive strength and coefficient of permeability of concrete were improved, while the addition PPF contributed further improvement in the properties up to the content of PPF equal to 0.5%. There is a linear relationship between compressive strength and coefficient of permeability of concrete at both the ages (28 days as well as 90 days) and these results are in agreement with previous study [7] as shown in the

Figure 5. The results at 90-days for PC as well as RC mixes showed better performance as compared to those obtained at 28-days. It was due to the consumption of free calcium hydroxides produced during the hydration reaction, which make



C-S-H gel. This C-S-H gel formation contributed in the strength, durability improvement and made concrete denser.

Figure 5. correlation between compressive strength and Coefficient of permeability

4. Conclusion

This study investigated the partial replacement of cement by bentonite and silica fume on PPF concrete. the effect of SCMs and PPF on various parameter of concrete properties such as compressive strength, UPV, permeability was studied. From the experimental results it was concluded that,

1. Compressive strength was increased by addition of SCMs, both Bentonite as well as SF mixes. The ternary mix (B10SF10P0) increased the strength by 8% as compared to CC mix at the age of 90 days.
2. Coefficient of permeability of concrete of both binary and ternary mixes were decreased as compared to CC mix. Coefficient of permeability of ternary mix was reduced by 42% as compared with CC mix at 90 days.
3. PPF strengthened ternary mixes, containing PPF up to 0.5%, showed reduction in the coefficient permeability PPF content as compared to CC mix. Further addition of PPF increased the coefficient of permeability and ternary mix by 42% as compared with CC mix.
4. The addition of PPF increased the ductility and completely change the failure pattern of concrete during compression test.
5. There was a linear relationship between compressive strength and permeability as the dosages of PPF increased both at 28 days and 90 days curing.

5. References

[1] P. K. Mehta, "Greening of the concrete industry for sustainable development," *Concrete International,* 2002.

[2] T. R. W.-J. Da-YoungOh, "CO2 emission reduction by reuse of building material waste in the Japanese cement industry," *Renewable and Sustainable Energy Reviews 38,* vol. 38, p. 796–810, 2014.

[3] B. A. M. A. Junaid Akbar, "Combined effect of Bentonite and Silica Fume properties of High Performance Concrete," *International Journal of Advanced Structures and Geotechnical Engineering,* vol. 02, 2013.

[4] A. E. Muhammad Hamza Irshad, "Effect of rice hush ash on properties of Self compacting concrete containing marble powder," in *International Civil Engineering Conference (ICEC 2020)*, Karachi, 2020.

[5] L. T. B. Uzal, "Studies on blended cements containing a high volume of natural pozzolans," *Cement and Concrete Research 33,* p. 1777–1781, 2003.

[6] I. J. a. H. U. Shams ul khaliq, "Evaluating permeability and mechanical properties of waste marble dust mix concrete and bentonite mix concrete," *ISEC,* 2018.

[7] M. Y. Safi Ur Rehman, "The Influence of Thermo-Mechanical Activation of Bentonite on the Mechanical and Durability Performance of Concrete," *Applied Science,* 2019.

[8] R. A. S. K. T. Y. L. Shazim Ali Memona, "Utilization of Pakistani bentonite as partial replacement of cement in concrete," *Construction and Building Materials,* p. 237–242, 2011.

[9] K. B. M. Rostami, "The effect of silica fume on durability of alkali activated slag concrete," *Construction and Building Materials,* p. 262–268, 2016.

[10] S. D. ,. a. C. I. Ali Hamza, "The effects of silica fume and hydrated lime on the strength development and durability characteristics of concrete under hot water curing condition," in *ASCMCES-17*, 2017.

[11] M. Z. M. K. S. M. M. A. Rohallah Rostami, "The effect of concrete alkalinity on behavior of reinforcing polyester and polypropylene fibers with similar properties," *Cement and Concrete Composites,* 2018.

[12] K. S. M. T. N. Bilal Zaman Afridi, "Mechanical properties of polypropylene fibers mixed cement-sand mortar," *Journal of Applied Engineering Science*, 2019.

[13] B. A. b. A. A. Liaqat Ali Qureshi, "Combined effects of supplementary cementitious materials (silica fume,GGBS, fly ash and rice husk ash) and steel fiber on the hardened properties of recycled aggregate concrete," *Construction and Building Materials,* p. 120636, 2020.

[14] "ASTM C150 / C150M-20, Standard Specification for Portland Cement, ASTM International, West Conshohocken, PA, 2020".

[15] M. Company, "http://matrixxco.net/downloads/duracrete/DURACRETE%20BROCHURE.pdf," 2021.

[16] "ASTM D638 Standard Test Method for Tensile Properties of Plastics".

[17] "ASTM D792 Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement".

[18] A. J. a. U. M. Liaqat A. Qureshi, "Effect of Cement Replacement by Silica Fume on Compressive Strength of Glass Fiber Reinforced Concrete," *International Journal of Structural and Civil Engineering Research,* vol. 7 No 3, 2018.

[19] "ASTM C-143 Standard Test Method for Slump of Hydraulic-Cement Concrete".

[20] "BS EN 12390-3:2019 Testing hardened concrete, Compressive strength of test specimens," 2019.

[21] A. A. M. A. R. S. Z. Tuqa Waleed Ahmed, "Properties of high strength polypropylene fiber concrete containing recycled aggregate," *Construction and Building Materials,* p. 118010, 2020.

[22] "ASTM C597-16 Standard Test Method for Pulse Velocity Through Concrete," 2016.

[23] V. M. Malhotra, Testing Hardened Concrete: Nondestructive Methods, 1976.

[24] "Indian Standard 3085 (1965): Method of test for permeability of cement mortar and concrete," 2002.

[25] A. A. Ayub Elahi, "Experimental investigation of fibre reinforced self-compacting concrete containing marble powder," *ned university journal of research - structural mechanics,* vol. XIV, 2017.

[26] A. E. Bilal Masood, "Mechanical and durability performance of recycled aggregate concrete incorporating low calcium bentonite," *Construction & building material,* pp. 1-8, 28 November 2019.