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Synergistic Effect of Fly Ash and Bentonite as Partial Replacement of Cement in Mass Concrete

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Abstract

This research focuses on the effects of using fly ash and bentonite as partial replacement of ordinary Portland cement (OPC) in mass concrete. Replacement of OPC with supplementary cementing materials such as fly ash or bentonite is one of the promising ways to mitigate thermal cracking due to temperature differentials in mass concrete. In this study, three types of concrete mixes with varying amount of partial replacement of OPC were investigated, 25% bentonite, 25% fly ash, and 12.5% bentonite and 12.5% fly ash. These mixtures were named BM, FM and BF, respectively. A fourth control mixture (CM) with no OPC replacement was also studied for comparison purposes. From each mix, one large specimen (having 600 × 800 × 1000 mm overall dimensions) representing mass concrete, and concrete cylinders of standard size representing normal structural concrete were prepared. Various tests were performed on these specimens at ages of 7, 14, 28, 56 and 91 days. Comparatively, BF was the most effective in controlling temperature rise in mass concrete. Moreover, this mix resulted in the highest values of compressive strength at 91 days and higher early-age strength. Ultrasonic pulse velocity (UPV) tests were conducted on mass concrete samples as well as on cores extracted from concrete blocks. Results of these tests revealed that mass concrete blocks made of BF and FM resulted in more uniform properties, or in other words, suffered least from large concrete placement by reducing the heat of hydration.

Keywords: *Mass concrete, heat of hydration, bentonite, fly ash, Portland cement*

1. Introduction

Concrete gains strength as a result of the hydration of cement with water, which is an exothermic reaction that raises the temperature of concrete. In mass concrete placements, the temperature at the core might become excessively high and negatively affect the concrete properties. Furthermore, the temperature at the core of mass concrete decreases more slowly as compared to the outer surface. This temperature differential may cause thermal stresses, which are a major cause of early-age thermal cracking of concrete (Altoubat and Lange, 2001). Thermal cracking may increase the ingress of external agents, e.g., chloride laden water, and oxygen, which may reach the reinforcing steel and result in corrosion. Negative effects of thermal cracks also include loss of structural integrity and monolithic action, excessive seepage and unpleasant aesthetics, which may reduce the safety and serviceability of structures (ACI, 1995). Increase of temperature in mass concrete can be controlled by using supplementary cementitious material; ice, chilled water or liquid nitrogen for cooling the concrete; surface insulation; preplaced aggregate concrete; cooling pipes; cooling the aggregates by spraying; or by using smaller and successive lifts for placing concrete (Gajda and Alsamsam, 2006).

Using supplementary cementing materials (known also as pozzolanic materials or pozzolana) such as fly ash and ground granulated blast-furnace slag (GGBFS) is one of the effective means of reducing the heat generation in mass concrete. Concretes containing pozzolana replacement of cement gain strength slowly as compared concretes containing ordinary portland cement (OPC) only. However, similar results in terms of compressive strength are usually observed for similar total binder contents. The slower strength gain is due to comparatively slowly occurring hydration reactions in presence of fly ash, slag, bentonite or any other pozzolanic material. The rate of retardation is different for different pozzolana based on their chemical composition, fineness and the dosage in concrete.

As mentioned above, reducing the quantity of OPC decreases the heat of hydration and hence the thermal stresses (ACI, 1992, 1995). In today's practice, most mass concrete applications use 25 to 40% of fly ash or 50 to 75% GGBFS replacement of

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cement (Gajda and Alsamsam, 2006). Shabab *et al.* (2013) reported that the effect of Class C fly ash in terms of lowering the heat of hydration almost ceases when the replacement dosage is increased to 45%. Depending on the curing temperature, GGBFS delays the formation of peak temperature gradients. It was found by Schindler and Folliard (2003) that a dosage of up to 75% GGBFS can be used to liberate the same amount of heat of hydration as liberated by 30% dosage of Class F fly ash. Class C fly ash tests indicated that with an increase in dosage, the hydration of the total cementitious system is retarded and the ultimate degree of hydration is increased. Further, it was reported in the same study that the use of Class F fly ash reduces the amount of heat generated while GGBFS significantly retards the hydration process and reduces the rate of hydration during the acceleration stage. In contrast to fly ash and GGBFS, highly reactive supplementary cementitious materials, such as silica fume and metakaolin accelerate the cement hydration at high water-to-cement (w/c) ratios (Alshamsi, 1997).

Use of bentonite as partial replacement of OPC provides a high amount of siliceous and aluminous compounds after the pozzolanic reactions as compared to a conventional concrete mixture with OPC as the sole binder (Afzal *et al*., 2014). Furthermore, as a supplementary cementing material, bentonite is expected to reduce the heat of hydration and help in mass concrete placements. As briefly reviewed above, although there have been previous studies on effects of fly ash and GGBFS on properties of concrete, the studies on the effects of bentonite has been limited. Therefore, there is a need to investigate the effect of binary and ternary blends of bentonite on the properties of mass concrete, which is also the main motivation of this research. An experimental study on the synergistic effects of bentonite and fly ash in mass concrete was conducted. The temperature variations, compressive strength and homogeneity of mass concrete containing bentonite were assessed and compared to those of fly ash and ordinary concrete. Promising results were obtained for ternary mix of bentonite and fly ash with OPC, which could lead to economical mass concrete mixture designs in regions where bentonite is abundantly available.

2. Materials

All the experiments were performed at the Department of Civil Engineering, University of Engineering and Technology, Peshawar, Pakistan. Locally available Type I OPC, that satisfies the requirements of ASTM C150 (2012a) was used. The physical and chemical properties of the OPC used are provided in Table 1.

Table 1. Properties of Ordinary Portland Cement (OPC)

Property	ASTM C150 Limit	Value
Fineness	-	7
Soundness, mm	-	2
Loss on Ignition, %	3 (max)	2.0
Sulfur Trioxide (SO_3), %	3.5 (max)	2.8
Insoluble Residue, %	0.75 (max)	0.3
Magnesium Oxide (MgO) %	6 (max)	1.4

Table 2. Physical Properties of Fine and Coarse Aggregate

Property	Fine Aggregate	Coarse Aggregate	Standards Followed
Bulk Specific Gravity	2.64	2.71	ASTM C128 and C127
Moisture Absorption, %	1.09	1.39	
Moisture Content, %	1.13	0.64	ASTM C566
Fineness Modulus	2.90	-	ASTM C136
Rodded Unit Weight, kg/m^3	-	1552.1	ASTM C29
Nominal Maximum Size, mm	-	25.4	-

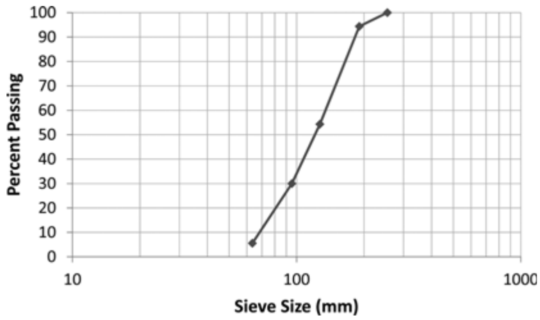

Fig. 1. Gradation Curve for Coarse Aggregate

Table 3. Physical Properties of Fly Ash

Property	Value
Lime Reactivity, N/mm^2	6
Retention on 45 Micron Sieve, %	< 34
Drying Shrinkage, %	0.06
Soundness by Autoclave Expansion, %	0.05
Compressive Strength (as percent of strength of corresponding plain cement mortar cubes), %	80

Fine and coarse aggregates were obtained from a local quarry. The physical properties of the fine and coarse aggregates according to ASTM C127 (2012b) and ASTM C136 (2006) are given in Table 2. The gradation curve for coarse aggregates is shown in Fig. 1.

Locally available (from Islamabad, Pakistan) Class F fly ash was used. The physical properties of fly ash, as provided by the manufacturer, are provided in Table 3. The chemical composition of fly ash obtained from X-Ray Diffraction (XRD) test are given in Table 4. The bentonite used in this research was obtained from the deposits at Karak district, 500 meters North-West of Bahadurkhel tunnel in Khyber Pakhtunkhwa Province of Pakistan. The chemical composition was determined by performing energy-dispersive X-ray florescence (ED-XRF), the results of which are provided in Table 4. Both XRD and ED-XRF are used to determine the chemical composition of a sample. Techniques used in XRD and ED-XRF are different but both provide the percentage of chemical compounds present in the sample. One method is not necessarily better than the other, they are simply complementary techniques to find the chemical composition. Results from two

Table 4. Chemical Composition/Properties of Fly Ash and Bentonite (all values are in percent)

Property/Compound	Fly Ash	Bentonite
Loss on Ignition	1	8.61
Silica (SiO_2)	57.6	52.1
Alumina (Al_2O_3)	4.26	13.4
Iron Oxide (Fe_2O_3)	26.9	7.50
Calcium Oxide (CaO)	2.32	12.0
Magnesium Oxide (MgO)	1.51	2.46
Sodium Oxide (Na_2O)	0.110	Negligible
Potassium Oxide (K_2O)	1.48	2.64

different techniques are reported here because the chemical composition of the fly ash was obtained from the manufacturer and the manufacturer used XRD to obtain this information. On the other hand, ED-XRF was used by the authors to obtain the chemical composition of bentonite. The loss on ignition shown in Table 4 is the quantity of volatile material present in the sample when the sample is heated to approximately 1100°C. The mass before and after the ignition is used to calculate the loss on ignition.

3. Experimental Program

The values obtained from various tests on OPC, fly ash and bentonite, have been presented above. Using these results and ACI 211.1-91 (1991) "Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete," the proportions for a design strength of 27.6 MPa was obtained for the control mixture as shown in Table 5.

Four types of concrete mixes were prepared with varying amounts of partial replacement of OPC by weight as shown in Table 6. Based on the presence of supplementary cementing materials, the mixtures were named as bentonite mix (BM), fly ash mix (FM), and bentonite-fly ash (BF) mix. The control mixture having no pozzolanic materials was named as CM.

Table 5. Mixture Proportions for the Control Mixture

Material	Quantity
OPC[1] (kg/m^3)	434.1
Coarse Aggregate (kg/m^3)	1038
Fine Aggregate (kg/m^3)	746.9
Water (kg/m^3)	201.2

[1]OPC: Ordinary Portland Cement

Table 6. Percentage Replacements of Ordinary Portland Cement (OPC) by Weight

Mix Name	OPC (%)	Bentonite (%)	Fly ash (%)
CM[1]	100	0	0
BM[2]	75	25	0
FM[3]	75	0	25
BF[4]	75	12.5	12.5

[1]Control Mix, [2]Bentonite Mix, [3]Fly Ash Mix, [4]Bentonite-Fly Ash Mix

Fifteen cylinder specimens of standard size (152.4 × 304.8 mm) and one mass concrete specimen (600 × 800 × 1000 mm) were prepared from each mix. The size of the mass concrete block was based on the previous research where it was reported that such size specimens need to be carefully evaluated for heat of hydration at the core (Hassan *et al.*, 2002). For mass concrete specimens, the concrete was poured into the formwork in subsequent layers. Each layer was compacted using vibrator in order to prevent the formation of voids. The mass concrete specimens were then covered with wet blankets for curing in room temperature for 91 days until all the testing is completed.

The temperature rise was measured in the mass concrete specimens with the help of T-type thermocouples. Two thermocouples were installed in each test specimen, one at the center of the specimen and one at the surface (at 10 mm distance from the outer surface) as shown in Fig. 2. The temperature readings were taken soon after the casting of concrete and until the temperature at center and the surface became equal. Ultrasonic Pulse Velocity (UPV) tests were conducted on both the mass concrete and cylinders at ages of 7, 14, 28, 56 and 91 days. Compressive strength tests were performed on the cylinders at the same ages after the UPV measurements were completed. Cylinder cores (91.4 × 182.9 mm) were extracted from the mass concrete specimens at 91 days of casting and both UPV and compressive strength tests were performed on the same day. The dimensions of the cylinder cores were chosen and procedures for extracting and testing were done according to ASTM C42/C42M (2013). Fig. 3

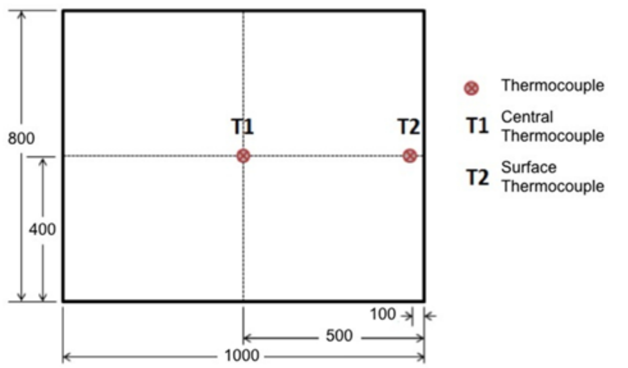

Fig. 2. Locations of Thermocouples (note: all dimensions are in mm)

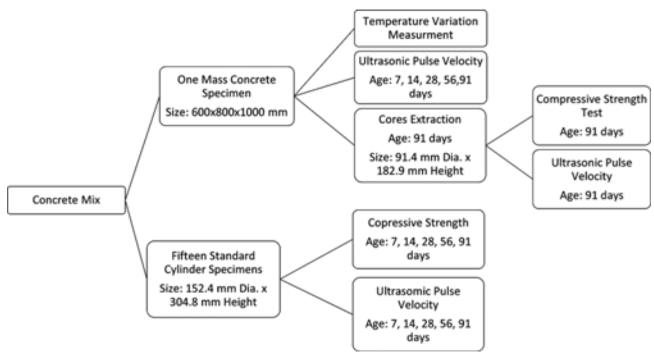

Fig. 3. Flowchart of Tests

Fig. 4. Preparation of Mass Concrete Specimens

shows the flowchart of tests performed on all the specimens. The preparation of mass concrete specimens is shown in Fig. 4.

4. Results and Discussions

4.1 Temperature Variations in Mass Concrete

The temperature variation at the center of each mass concrete specimen with respect to time is plotted in Fig. 5. Since the surface thermocouples were installed at only 10 mm from the outer surface of each specimen, the variation in the surface temperature was almost the same for all the mixes. As a result, the values of surface temperature were overlapping for all the specimens and shown with a single line in Fig. 5. It is noted here that the surface temperature was slightly lower than typical room temperature. This was because the specimens were cast in January and the due to very low outside temperatures at that time of the year in Peshawar, Pakistan, the room temperature where the specimens were cast and stored was lower than typical.

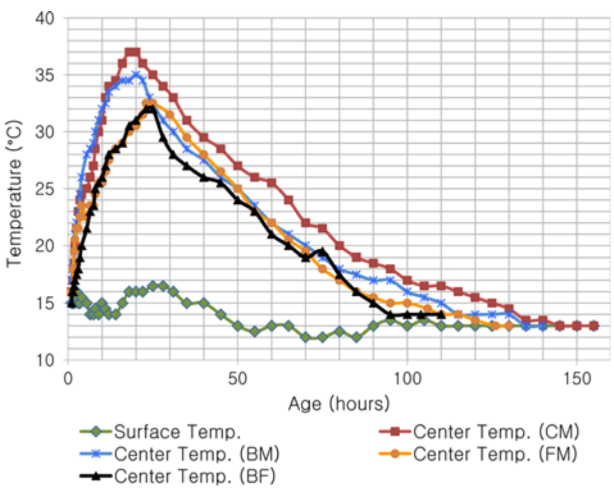

Fig. 5. Temperature Variation versus Time in Mass Concrete Blocks

CM exhibited the highest temperature among all mixes, reaching to a maximum of 37ºC. The addition of fly ash or bentonite, or both caused a reduction in the heat generation. BM, FM and BF resulted in reductions of 2ºC (5.4%), 4.5ºC (12.2%) and 5.5ºC (14.9%), respectively, in the maximum temperature as compared to CM. Additionally, it was observed that the surface and center temperatures balanced relatively rapidly in BF and FM (in about 100 hours following casting) compared to CM and BM, for which the same value was approximately 140 hours (40% higher). An addition of 25% bentonite alone did not provided significant decrease in the temperature differentials. Mirza *et al.* (2009) found that concrete containing 20% bentonite shows compressive strength values comparable to normal concrete at 28 days, however, the compressive strength of concrete containing more than 20% bentonite decreases rapidly as level of cement replacement increases. Although replacing OPC with bentonite in larger quantities, i.e., more than 25% may be effective in decreasing the temperature rise, since this might adversely affect the compressive strength at early ages, higher replacement percentages were not investigated here. Consequently, using bentonite alone was found to be not sufficient to reduce the heat generation.

4.2 Ultrasonic Pulse Velocity (UPV) in Mass Concrete and Cylinder Specimens

The UPV data can be used as a non-destructive means of investigating the strength development in concrete specimens

Table 7. Pulse Velocity versus Concrete Quality as per IS: 13311-Part1 (1992)

Pulse Velocity (m/sec)	Concrete Quality (Grading)
Above 4500	Excellent
3500 to 4500	Good
3000 to 3500	Medium
Below 3000	Doubtful

(Sato *et al*., 1999). Table 7 shows a relationship between the UPV value and the concrete quality based on IS: 13311-Part 1 (1992). It is worth noting here that IS: 13311-Part I (1992) does not differentiate between different concretes. In other words, the presence of other binders such as fly ash or slag in concrete has not been explicitly addressed in IS: 13311-Part I (1992). It is known that the pulse velocity depends primarily upon the soundness (quality) of the concrete (e.g., presence of micro-cracks, voids, etc. will reduce the measured UPV, while higher compactness and absence of defects will increase the same). As such, although the information presented in Table 7 is not specifically calibrated for concretes with pozzolana, since the quality of concrete is effected in a similar way with binder content regardless of the binder type (cement, fly ash or bentonite), the provided guidance is deemed applicable for concretes considered in this research.

A grid was drawn on the surface of each mass concrete block as shown in Fig. 6. The spacing between grid lines was kept equal to 50 mm horizontally and vertically as shown in Fig. 7. There were a total 285 intersection points called nodes on each mass concrete specimen. Three readings of UPV were taken at

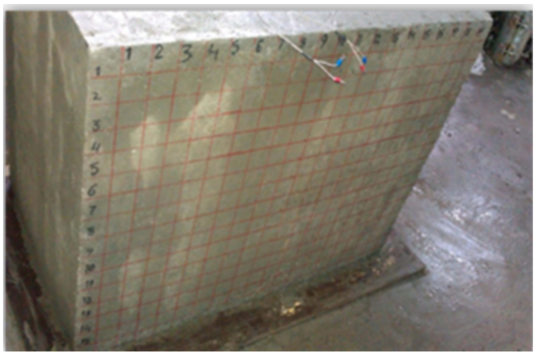

Fig. 6. Grid on Mass Concrete Blocks for UPV Readings

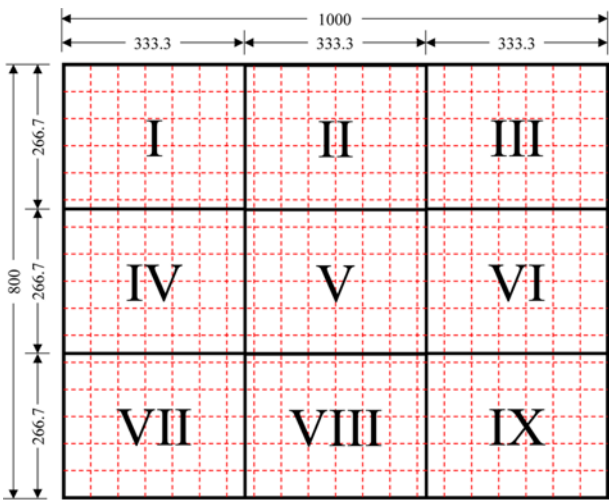

Fig. 7. Division of Mass Concrete Block in Nine Regions (each small square is 50 × 50 mm, all units in are in mm)

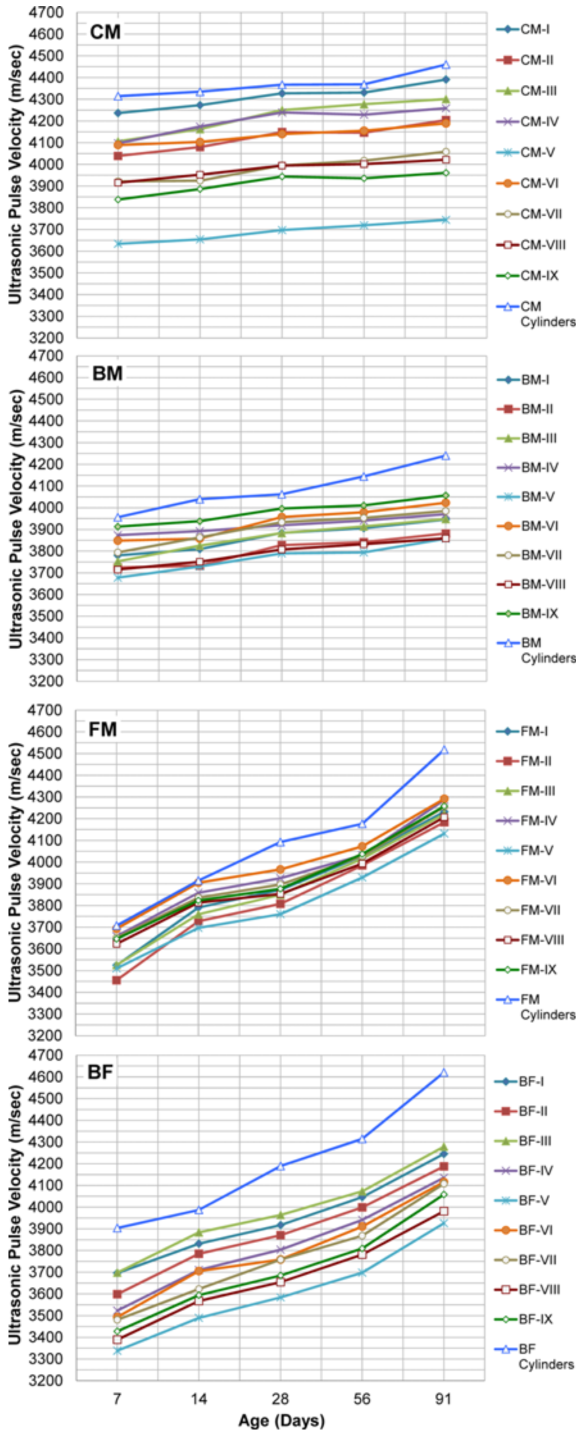

Fig. 8. UPV Values as a Function of Time in Mass Concrete and Cylinder Specimens

each node on each mass concrete specimen at ages of 7, 14, 28, 56 and 91 days. Average of three UPV readings was considered as the UPV value for a particular node at a particular age. Afterwards, the block was divided into nine rectangular regions as shown in Fig. 7, to investigate the variation in the UPV values at different locations along the two in-plane directions of the concrete block on the surface. The regions are designated using the numbering scheme shown in Fig. 7 and the two-letter acronym for each mix (e.g., CM-III represents region III of the control mix). After the division, regions II, V, VIII enclosed 35 nodes each while regions I, III, IV, VI, VII, IX enclosed 30 nodes each. For each region, the average of the UPV measurement values at nodes enclosed by that region was calculated and plotted in Fig. 8.

The lowest values of UPV were observed in the central regions of the test specimens, i.e., region "V" (see Fig. 8). Moreover, among the nine regions of each mass concrete block, the highest values of UPV were observed in one of the outer regions. In the outer regions, the concrete remains exposed to the outer environment and concrete in these regions gains the compressive strength relatively rapidly. As seen in Fig. 8, the difference between the surface and central UPV values was larger for CM and lower for the remaining mixes. Table 8 shows the standard deviation of UPV values (as obtained from the data consisting of one measurement per region) of mass concrete blocks for each mix at each age. The results indicate that the addition of fly ash or bentonite, or both increased the uniformity of mass concrete. FM was the most homogenous among all. It was also observed that the addition of fly ash and bentonite together reduced the uniformity for BF as compared to FM and BM. FM and BF showed a considerable increase in the UPV values until 91 days and there was a tendency of further increase in the UPV values with age. It was concluded that even after 91 days, strength development and improvement in the quality of concrete are expected in the mixes containing fly ash. Fig. 8 and Table 8 also show that the UPV values tend to become more uniform for FM and BF as the specimens age. These results clearly indicate an increase in the homogeneity of mass concrete with the addition of fly ash and bentonite, or fly ash alone.

Figure 8 also shows the comparison of UPV results for cylinder specimens with those of the mass concrete specimens. Three cylinder specimens for each mix were tested for UPV at ages of 7, 14, 28, 56 and 91 days before the compressive strength tests were conducted. The average value of three cylinders was taken. For concrete cylinders, the values of UPV were observed to be higher than those of the mass concrete specimens of the same mix. Given that the UPV results are representative of the concrete quality (see Table 7), the quality of mass concrete of the same mix was lower than that of the concrete cylinders. Additionally, the result of UPV tests for the cylinder specimens are compared in Fig. 9. It is seen that there is not a significant increase in the UPV values of CM specimens with time. The reason is the faster rate of hydration in normal concrete and slower rate of hydration in concrete containing pozzolanic materials. FM and BF showed a very large increase in the UPV values with time. At 91 days, FM and BF acquired UPV values greater than those of CM specimens. BF developed the highest value, although at early ages BF showed the second lowest values of UPV. At early ages, FM specimens showed the least value of UPV among all the mixes because of slower rate of hydration. It is seen that the UPV values for BF and FM specimens have a tendency to increase further at a comparatively higher rate after 91 days. Hence, it is evident that the addition of fly ash alone and ternary blend of fly ash and bentonite have a beneficial role in terms of improving the quality of concrete.

Table 8. Standard Deviation of UPV Values for Mass Concrete

Mix Type	Standard Deviation (m/sec)				
	7 Days	14 Days	28 Days	56 Days	91 Days
CM	179.5	188.4	194.7	191.8	199.1
BM	78.49	73.38	69.98	72.55	70.72
FM	83.88	65.25	61.00	40.51	50.98
BF	127.35	130.6	125.3	125.9	115.3

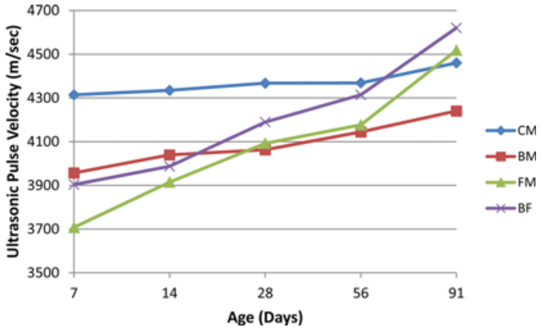

Fig. 9. UPV Measurements for Concrete Cylinders

Comparing the UPV values with those provided in Table 7, FM and BF specimens represent excellent quality of concrete at the age of 91 days. All the other specimens at all the ages considered in this research fall into the category of good concrete. The addition of bentonite alone results in UPV values lower than that of CM at all the ages considered.

It is important to note here that only ages from 7 to 91 days were studied in this paper. Since the degree of hydration is expected to change more drastically between different mixes within the first 7 days, the UPV measurements are expected to follow this trend. However, it is uncommon to measure hardened concrete properties prior to 7 days because the strength gain is usually not as important during this period as the concrete is not expected to carry any significant loading. This was the main motivation for focusing on properties past 7 days. However, in certain applications such as prestressing and others, early strength becomes important and information prior to 7 days might be relevant. Similarly, as discussed above, results indicated that strength development continues past 91 days, especially for mixes containing pozzolanic materials. Therefore, further experiments are needed to quantify properties at ages past 91 days.

4.3 Compressive Strength Test for Cylinder Specimens

BF, which is ternary blend of bentonite and fly ash, resulted in higher values of compressive strength at all ages compared to FM and BF. As shown in Fig. 10, at 7 days, BF attained 81.4% of the compressive strength of CM and even closer values at later ages. It is known that the addition of pozzolanic materials reduces the early-age strength (Schindler and Folliard, 2003). Adding fly ash and bentonite together was observed to mitigate this problem, resulting in higher values of compressive strength at earlier ages. At 28 days, BF had attained 95% of the strength of CM, while this number was equal to 72% and 80% for BM and FM, respectively. At 91 days, BF yielded a compressive strength of 102.7% of CM. Fig. 10 also shows that all mixes had a tendency to attain further strength after 91 days. FM attained only 56% of the compressive strength of CM at 7 days but then it reached to 93.3% at 91 days. Similarly, BM attained only 58% of compressive strength of CM at 7 days and reached to 85.3% at 91 days. From these results it was concluded that the addition of bentonite alone decreases the compressive strength of concrete at all ages considered here, i.e., 7, 14, 28, 56 and 91 days. At all these ages BM showed lower compressive strength than CM as shown in Fig. 10. However, since the addition of pozzolanic materials retards the rate of hydration and hence the rate of strength development, at ages past 91 days, the compressive strength of BM and FM might exceed that of CM, whose strength development is mostly completed by that age.

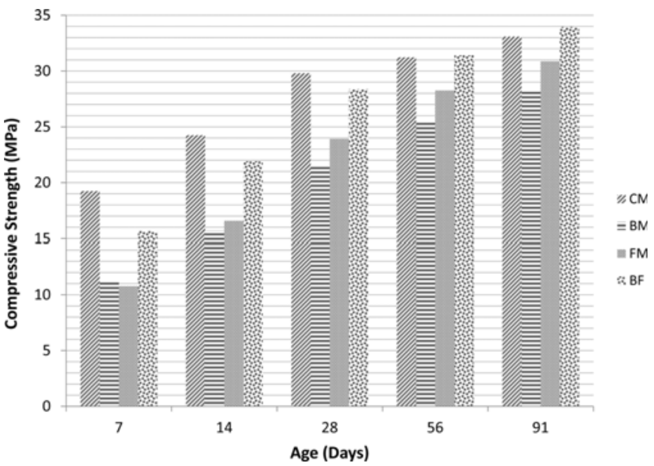

Fig. 10. Compressive Strength of Concrete Cylinders

It is important to note here that the data presented in Fig. 10 pertains to concrete cylinders and not to mass concrete. Therefore, the effect of heat of hydration is not captured. On the other hand, the effect of heat of hydration on the compressive strength was studied by measuring UPV values at various locations of the mass concrete blocks (as presented above), and through compressive strength testing and UPV measurements of cylinders extracted from various locations of the mass concrete blocks (as presented in what follows).

4.4 Compressive Strength and UPV for Extracted Core Specimens

In order to assess the mechanical properties of mass concrete, cores 101.6 mm in diameter were extracted from the mass concrete specimens at 91 days after casting. Fig. 11 shows the extraction and cutting of the cores. The locations of the extracted cores are shown in Fig. 12. The cores were extracted from both faces across the 600 mm dimension of the mass concrete block as shown in Fig. 12. The cores obtained from the regions near the

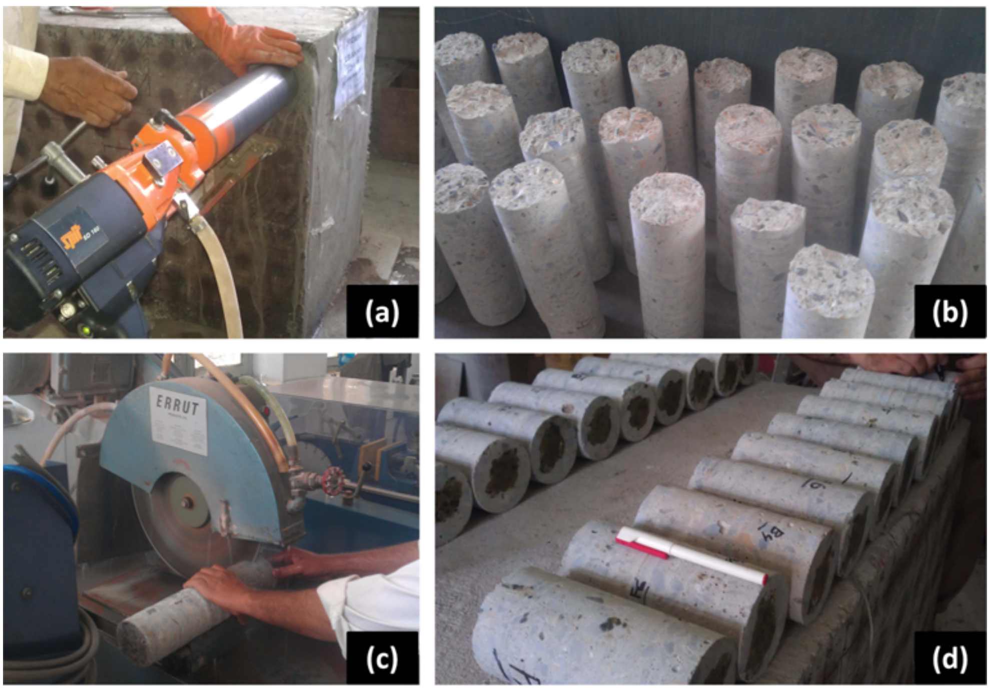

Fig. 11. Concrete Core Specimens

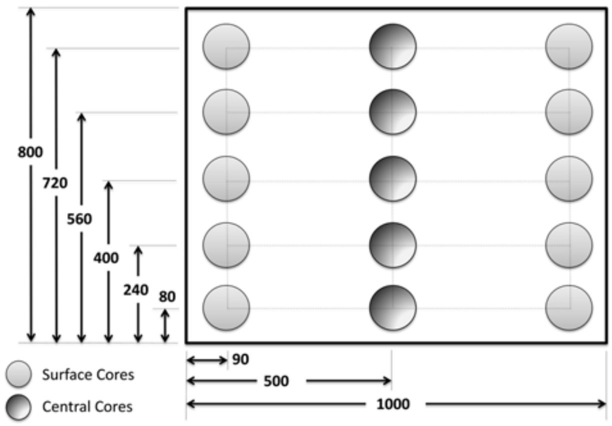

Fig. 12. Location of Cores Extracted (both front face and opposite face, all dimension are in mm, diameter of cores is 101.6 mm)

surface of mass concrete were named as surface cores and those obtained from the central regions were named central cores. A total of thirty cores were extracted from each massive concrete specimen; including 20 surface cores and 10 central cores. These cores were cut to a length to diameter ratio (L/D) of 2.0 according to ASTM C42/C42M (2013), which is the same as for concrete cylinders of standard size. UPV and compressive strength tests were performed for each core specimen. The average values obtained from testing two core specimens were taken as the UPV and compressive strength for each region.

A comparison of the compressive strength values for surface and central cores along with normal concrete cylinder specimens prepared at the same time with the mass concrete specimens is shown in Fig. 13. The results for core samples have been plotted with respect to the location of the cores. At each height, the average of two cylinders is plotted. Fig. 13 also shows the same correlation for UPV values. Past research indicates that the core strengths are generally 85% of the corresponding standard-cured cylinder strengths (ASTM, 2013). If the ratio of length to diameter (L/D) of the core specimens is 1.75 or less, the correct the compressive strength is obtained by multiplying with a correction factor (ASTM, 2013). As stated earlier, the length to diameter ratio (L/D) for the cores here was 2.0, hence no correction was required.

Figure 13 shows that the cores extracted from the center of the each mass concrete specimen resulted in the lowest values of compressive strength and UPV. Moreover, the cores extracted from regions exposed to outer environment give closer results to the standard cylinder specimens. These findings are in line with observations presented earlier that the core had higher temperature as compared to the outer surface, which increased the rate of hydration reactions; however, the heat was trapped inside the core resulting in excessive temperatures and caused concrete to crack, lowering the strength. This can be observed from the UPV results presented in Fig. 8 as well as from actual testing of cylinders extracted from various regions of the mass concrete blocks (see Fig. 13). The results indicate that the higher rate of

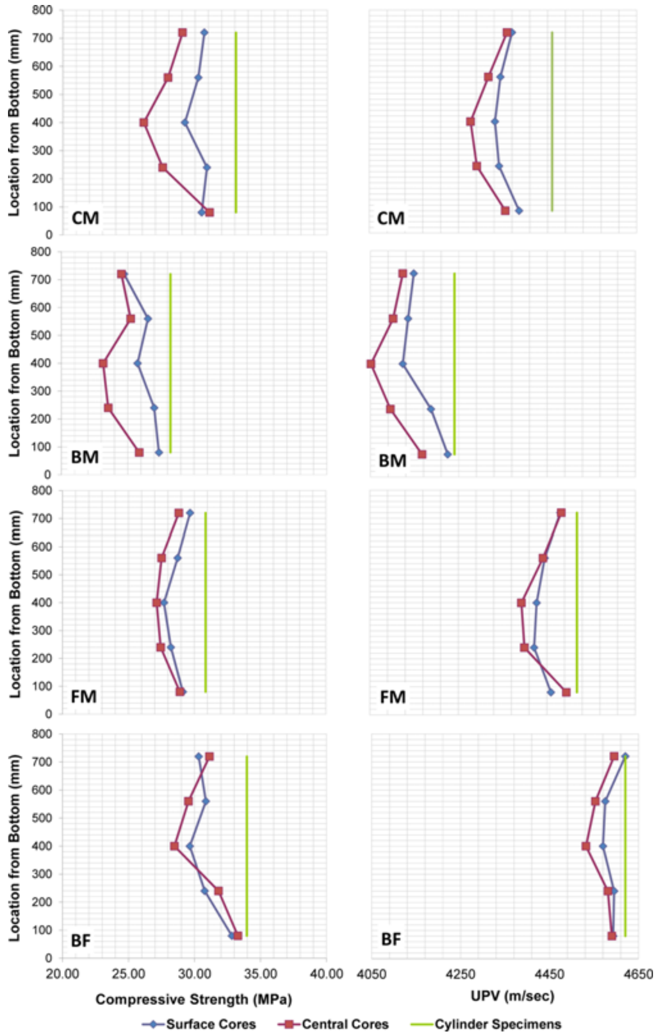

Fig. 13. Comparison of Compressive Strength and UPV of Cores with those of Cylinders

strength gain due to higher temperatures was overcome by the defects developing due to excessive temperatures.

Figure 13 shows that FM and BF core specimens have less variation in compressive strength between the surface and core regions. Hence, the addition of fly ash and ternary blend of fly ash and bentonite improves the homogeneity of mass concrete. The same observations were noted from the results of UPV tests conducted on the surface of mass concrete blocks. A comparison of the compressive strength of top cores to bottom cores reveals that the compressive strength is higher for the latter. The reason for this increase is that the coarser particles in the concrete mix have a tendency to settle in the bottom layer and increase the compressive strength in that region. Moreover, at all ages studied here, the values of compressive strength and UPV for concrete cylinders specimens was more than those of the extracted cores. These results confirm that for the same concrete mix, the compressive strength of mass concrete should not be directly based on the results of cylinder specimens. In fact, the values of compressive strength of cylinder specimens should be modified in order to obtain the compressive strength of mass concrete.

5. Conclusions

In this research the effect of binary and ternary mixes of bentonite and fly ash on mass concrete has been analyzed and compared with a control mix (CM). Three types of mixes with partial replacement of ordinary Portland cement (OPC) were considered: 25% bentonite (BM), 25% fly ash (FM), and 12.5% bentonite and 12.5% fly ash (BF).

From each mix, samples of mass concrete and standard sized cylinders were prepared for testing. Ternary mix of fly ash and bentonite (i.e., BF) was the most effective in reducing the heat of hydration. BF mix reduced the maximum temperature by 14.9% as compared to CM. FM and BM mixes resulted in 12.2% and 5.4% reduction in the maximum temperature, respectively. In mass concrete specimens, more homogenous values of UPV were obtained for mixes containing fly ash. Moreover, the homogeneity increased at higher ages.

High volume replacement of fly ash reduces the early-age strength; using ternary mix of bentonite and fly ash was found to mitigate this problem. BF provided 28 days compressive strength equal to 95% of CM. Moreover, in this mix the UPV values were comparatively higher and significantly increased with age. Cores extracted from FM and BF blocks resulted in higher and more uniform values of compressive strength compared to BM. The surface cores resulted in higher values of compressive strength and UPV as compared to the central cores. The correlation of core specimens and cylinder specimens in terms of compressive strength showed that at the same age, the mass concrete resulted in lower strength as compared to the standard sized concrete cylinders.

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