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Research Article

Pulse Velocity Measurements in Fly Ash Blended Cementitious Systems Containing 43 Grade Cement

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Investigations on the different supplementary cementitious materials based on the hardening properties and the optimized dosage in cementitious systems find the right choice of pozzolanic material. It is essential to combine various additive/admixtures in concrete in proper proportions to maximize the benefits resulting in cost savings in construction. In the recent years, production technology and composition of hydraulic cements affect the setting and early age behavior of cementitious material. The addition of fly ash in cement is one viable technology to derive maximum benefits in terms of the economy and improved pozzolanic reaction. Ultrasonic pulse velocity testing is a feasible method for evaluating the hardening properties of cementitious materials. In this study, an attempt was made to derive the engineering basis for understanding the development of hardness during hydration of fly ash (FA) based cementitious systems. The tests conducted using pulse velocity technique proved to be an effective method for characterizing the early strength gain properties of different cementitious systems.

1. Introduction

During recent years many variations have been made in the production technology, and its performance exceeded expectations. In addition, mineral admixtures like fly ash have been combined with Portland cement content improve the demonstrated excellent performance, both in mechanical as well as in durability aspects [1, 2]. The addition of pozzolanic admixtures converts the leachable calcium hydroxide into insoluble nonleachable calcium hydroxide in the cementitious products [3]. One such effect relates to the setting and early strength gain of concrete. Such delays are not desirable on site as tasks cannot be completed as per schedule. It is well known that chemical reactions between cement and water react with cement pastes, mortars, and concrete from fluids to rigid bodies [4]. The term setting has been used to describe the onset of rigidity in fresh cement pastes, mortar, and concrete. The setting phenomena are altered some factors, such as water/binder (w/b) ratio, curing regime temperature, and admixtures [5–8]. Thermodynamically, the initial set is marked by a rapid temperature rise, which corresponds roughly to the beginning of the main factor of chemical reactions that temperature rise will reach a maximum rate around the final set [9]. Chemical admixture becomes inevitably an important component to make a high early strength of hardened concrete [10]. The objective of this study is to establish the scientific and engineering bases for understanding to improve the hardness during the hydration of cement-based materials by using the Vicat apparatus for determining the normal consistency and setting time for cement and measuring the pulse velocity through concrete using ultrasonic equipment. The detailed cement compositions of different percentage with different mixture proportions were studied.

2. Preparation of Specimens

Ordinary Portland cement 43 grade available in the local market was used in investigations. The cement used has been tested for various properties as per IS 4031-1988. The consistency of cement was 30% both ordinary Portland

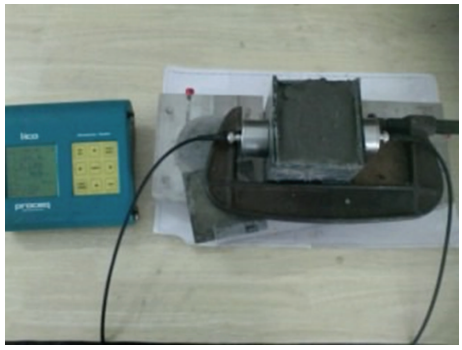

Figure 1: Test setup for Plexiglass ultrasonic pulse velocity for monitoring the various fresh cement paste.

cement and Portland pozzolana cement and normal river sand passing through 2.36 mm IS sieve and conforming (IS 383-1978) to zone III and fineness modulus of 2.89 was used as fine aggregate and normal potable water was used. Mineral admixture like fly ash class F were used for pozzolanic material was greatly increased the workability at different level of replacement was 10%, 20%, 30%, 40%, and 50% by weight of cement and consistency of fly ash was 48%. Cement mortar mixture proportions were 1 : 3 (one part cement which is equally divided into number of percentage by replacement of cement and used as fly ash) and dosage of accelerator 1%, 2%, and 3% by weight of binder material and size of specimens as per standard 70.6 × 70.6 × 70.6 mm were prepared by using a special steel mould designed and cement mortar was made by mixing of water, cement with or without fly ash and also accelerator, an each mix three cubes were cast and tested. The glass plate mould fabricated the size of the mould 100 × 100 × 100 mm. The fluidity of cement paste after finishing the top surface was measured using the ultrasonic pulse velocity (m/sec) by the direct transmission method and the arragement was securred to ensure uniform contact with the transducer and the surface of the plexiglass mould.

Table 1: Average compressive strength (MPa) of cement mortar (1 : 3) for different mix proportions.

Mix ID	Constituents	7th day	14th day	28th day
A1	0PC + 1% acl	21	24	27.62
A2	0PC + 2% acl	14.45	16	23.92
A3	0PC + 3% acl	13.2	19	22.43
B1	0PC + 20% fly ash + 1% acl	17.1	20	22.47
B2	0PC + 20% fly ash + 2% acl	15	21	24.72
B3	0PC + 20% fly ash + 3% acl	16	18	22.2
C1	0PC + 30% fly ash + 1% acl	16	21	22.59
C2	0PC + 30% fly ash + 2% acl	15	16.5	25.28
C3	0PC + 30% fly ash + 3% acl	10.8	14.1	17.39
D1	0PC + 40% fly ash + 1% acl	11.8	13.5	17.86
D2	0PC + 40% fly ash + 2% acl	12.35	13.98	16.75
D3	0PC + 40% fly ash + 3% acl	13	17.5	18.32

Table 2: Ultrasonic pulse velocity (m/sec) for different mix proportion of cement mortar specimens.

Mix ID	7th day	14th day	28th day
A1	4020	3750	3880
A2	3590	3440	3670
A3	3740	3480	3730
B1	3580	3550	3800
B2	3740	3660	4000
B3	3660	3910	3810
C1	3640	4200	3810
C2	3310	4135	3900
C3	3140	3485	3520
D1	3180	3300	3640
D2	3580	3330	3630
D3	3880	3700	3720

3. Results and Discussions

3.1. Measurement of Ultrasonic Pulse Velocity Test in Cement Mortar. The cement mortar specimens were tested for 1, 3, 7, 14, and 28 days after sufficient curing in water tank, tested on the smooth surface of the both sides, fixed the length of specimen that was 0.076 m in UPV machine, recoded the values by using the ultrasonic pulse velocity techniques, and after that tested for the same specimen by using a universal testing machine for determining the compressive strength for each specimen with respect to day wise as shown in Table 1. It can be also observed that various mixture proportions of cement mortar cubes were recorded that the ultrasonic pulse velocity values with different curing days for all values are presented in Table 2.

3.2. Fresh Cement Pastes Monitoring by UPV Test. The experimental results obtained from the fresh cement paste studies using ultrasonic pulse velocity are shown in Figure 1. To observe the stiffens of early age properties of different cementitious materials by using Plexiglass, the size of the Plexiglass mould was 100 × 100 × 100 mm. The fresh cement paste was gently poured into the glass mould with three layer, for each layer compacted gently after finishing the top surface and measured the Ultrasonic pulse velocity in terms of m/sec and for each different mixtures were carried out immediately after finishing the top surface of the cement past by attaching the transmitter and the reading was taken at every 5 minute intervals for all mixture proportion investigated. A different mixture proportion of fresh cement paste was monitored, and all the values are tabulated in Tables 3, 4, 5, 6, 7, and 8 and plotted graphically in Figures 2, 3, 4, 5, 6, 7, 8, and 9. In general the fly ash-based mortar mixtures with different percentage of fly ash contents showed a decrease in UPV corresponding to setting times. This indicates that the degree of hydration at the same duration is reduced in the case of fly

Table 3: Ultrasonic pulse velocity for different mix proportions of fresh cement paste.

Time (min)	Velocity (meter/second)	
	0PC	PPC
0	1480	950
5	1430	1110
10	1810	1320
15	1350	1260
20	1500	1260
25	1270	1400
30	1500	1040
35	1570	1320
40	1660	1270
45	1590	1290
50	1300	1430
55	1120	1280
60	1250	1170
65	1360	1220
70	1000	1190
75	1100	1260
80	14 60	1310
85	1410	1220
90	920	1360
95	1620	1300
100	1240	1210
105	1610	1220
110	1630	1090
115	2140	1300
120	1200	1200
125	1630	1450
130	1440	1590
135	1910	1290
140	1600	1210
145	1980	1280
150	2240	1320
155	1730	1380
160	2240	1380
165	2180	1410
170	2220	1420

Table 4: Ultrasonic pulse velocity for different mix proportions of fresh cement paste.

Time (min)	Ultrasonic pulse velocity (meter/second)				
	0PC	0PC + 20% FA	0PC + 20% FA + 1% acl	0PC + 20% FA + 2% acl	0PC + 20% FA + 3% acl
0	1480	1370	1040	490	730
5	1430	1830	1130	570	1210
10	1810	1770	1080	490	1360
15	1350	1420	810	610	1320
20	1500	1970	1160	470	1200
25	1270	1790	910	630	1120
30	1500	1790	1090	700	1370
35	1570	1710	1280	550	1320
40	1660	1740	970	550	1200
45	1590	1620	800	570	1170
50	1300	1620	710	630	1130
55	1120	1700	940	630	1240
60	1250	1440	900	680	1200
65	1360	1380	1000	750	1060
70	1000	1340	810	570	1110
75	1100	1340	740	540	1140
80	1460	1360	900	660	1160
85	1410	1650	810	690	1130
90	920	1720	1020	700	1100
95	1620	1600	920	710	1150
100	1240	1710	960	710	1130
105	1610	1700	910	705	1200
110	1630	1720	890	700	1130
115	2140	1740	900	710	1160
120	1200	1690	910	720	1100
125	1630	1720	900	730	1030
130	1440	1730	920	720	1180
135	1910	1710	940	740	1110
140	1600	1730	960	760	1180
145	1980	1690	960	720	1030
150	2240	1800	980	750	1180
155	1730	1790	960	760	1360
160	2240	1780	920	780	1150
165	2180	1810	980	790	1160
170	2220	1820	1000	800	1130

ash-based mixtures due to the prolonged dormant period and delay during the acceleration period of hydration. Some of the mixes showed different behavior. The fly ash-based mixes also showed normal changes in the ultrasonic pulse velocity with decrease in water to binder ratio. The mixtures incorporating fly ash as a binder at 10%, 20%, 30%, 40%, and 50% with a suitable selection of the water to binder ratio showed better improvement in the rate of hardening with the addition of accelerator. Also the grade of cement used plays a major role in the early setting reaction and faster reactivity due to

Table 5: Ultrasonic pulse velocity for different mix proportions of fresh cement paste.

Time (min)	Ultrasonic pulse velocity (meter/second)			
	0PC + 30% FA	0PC + 30% FA + 1% acl	0PC + 30% FA + 2% acl	0PC + 30% FA + 3% acl
0	1290	660	750	1150
5	1150	310	800	1240
10	1150	550	750	1080
15	1060	340	780	1110
20	1070	660	740	1120
25	1200	650	770	1080
30	1100	510	700	1170
35	1120	530	760	1140
40	1180	420	440	1250
45	1220	430	710	1090
50	1290	400	720	1090
55	1290	350	730	1090
60	1360	620	740	1090
65	1120	390	690	1150
70	1090	510	700	1080
75	1270	420	550	1070
80	1270	340	720	1180
85	1290	420	680	1070
90	1130	340	550	1140
95	1220	410	690	1050
100	1240	410	740	1110
105	1300	500	660	1100
110	1220	490	660	1060
115	1260	390	700	1090
120	1110	430	680	1250
125	1240	270	700	1160
130	1140	700	700	1110
135	1130	730	640	1110
140	1270	690	760	1170
145	1140	950	730	1140
150	1170	710	650	1070
155	1240	940	710	1130
160	1240	960	600	1180
165	1290	740	710	1050
170	1220	960	550	1080

the fineness of cement particles. However, an optimal addition of fly ash in cement shows a gradual increase in the early reaction with the cement hydration products and helps in improved microstructural formation.

Table 6: Ultrasonic pulse velocity for different mix proportions of fresh cement paste.

Time (min)	Ultrasonic pulse velocity (meter/second)			
	0PC + 40% FA	0PC + 40% FA + 1% acl	0PC + 40% FA + 2% acl	0PC + 40% FA + 3% acl
0	1140	870	970	1000
5	1110	900	910	980
10	1110	890	560	900
15	1130	730	710	940
20	1060	890	920	960
25	1060	860	700	940
30	1150	950	710	880
35	1270	980	800	860
40	1190	920	710	640
45	1090	790	710	840
50	1060	1010	670	620
55	1090	950	680	900
60	1030	870	680	910
65	1110	900	560	990
70	1250	890	550	800
75	990	890	560	1060
80	1150	880	660	1030
85	1100	870	670	730
90	1130	870	670	930
95	1130	890	680	690
100	1160	870	650	990
105	1000	860	620	1010
110	1000	880	680	960
115	720	900	670	650
120	1140	910	690	920
125	820	920	700	950
130	1040	940	710	1040
135	1210	900	710	890
140	1150	890	690	650
145	1210	890	720	860
150	1220	910	710	910
155	1160	920	720	920
160	1240	930	690	930
165	1390	910	710	940
170	1320	950	700	960

4. Summary

The important conclusions arrived based on these investigations are as follows.

The UPV values show a varied pattern, which is very much affected by setting time, which in turn is affected by water-binder ratio and chemical admixture dosage. There is a

Table 7: Ultrasonic pulse velocity for different mix proportions of fresh cement paste.

Time (min)	Ultrasonic pulse velocity (meter/second)			
	0PC + 50% FA	0PC + 50% FA + 1% acl	0PC + 50% FA + 2% acl	0PC + 50% FA + 3% acl
0	1110	640	1100	1070
5	1100	690	1090	1080
10	1240	660	1010	1000
15	1130	690	1060	1050
20	1120	640	970	1100
25	1090	680	1010	1130
30	1120	630	950	1070
35	1110	520	1080	1080
40	1100	520	1090	1240
45	1020	650	1090	1180
50	1120	520	1110	1260
55	1080	540	1110	1210
60	1080	540	1090	1240
65	1030	620	1120	1260
70	950	530	1130	1290
75	1100	520	1110	1200
80	1130	620	1060	1240
85	1060	610	1070	1210
90	1030	540	1160	1240
95	1130	560	1120	1190
100	1270	600	1190	1010
105	1130	560	1030	1010
110	1130	570	1090	1130
115	1210	590	1080	1310
120	1190	600	1100	1150
125	1200	610	1090	1060
130	1130	620	1130	1170
135	1150	620	1160	1160
140	1220	630	1120	1000
145	1130	640	1060	1210
150	1150	650	1140	1030
155	1220	660	1170	1270
160	1380	680	1180	1290
165	1210	700	1080	1270
170	1240	710	1240	1280

Table 8: Ultrasonic pulse velocity for different mix proportions of cement paste.

Time (min)	0PC	0PC + 1% acl	0PC + 2% acl
0	950	800	480
5	1110	1090	380
10	1320	1050	860
15	1260	1070	870
20	1260	1100	860
25	1400	1210	510
30	1040	1050	860
35	1320	1100	880
40	1270	1130	490
45	1290	1070	550
50	1430	1240	910
55	1280	1450	1020
60	1170	1390	920
65	1220	1230	950
70	1190	1210	900
75	1260	1140	920
80	1310	1350	960
85	1220	1310	930
90	1360	1390	900
95	1300	1150	1030
100	1210	1180	890
105	1220	1040	920
110	1090	1040	960
115	1300	1060	870
120	1200	1080	970
125	1450	1080	860
130	1590	1210	1100
135	1290	1220	1020
140	1210	1210	1040
145	1280	1220	1030
150	1320	1230	1020
155	1380	1220	1060
160	1380	1240	1060
165	1410	1230	940
170	1420	1210	1020

need for development of a technique based on more reliable methods for prediction of setting times. The ultrasonic pulse velocity techniques the test result values observed a different pattern, which is very much affected by setting time, which in turn is affected by water-binder ratio and chemical admixture dosage. The pulse velocity measurements showed an increased rate of hardening in cementitious systems and thereby proves to be a worthy method of assessment of cement hydration. It was observed from the test results of

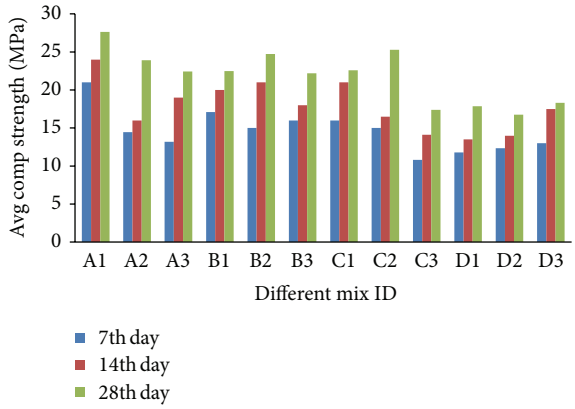

Figure 2: Cement mortar test results for different mix proportions.

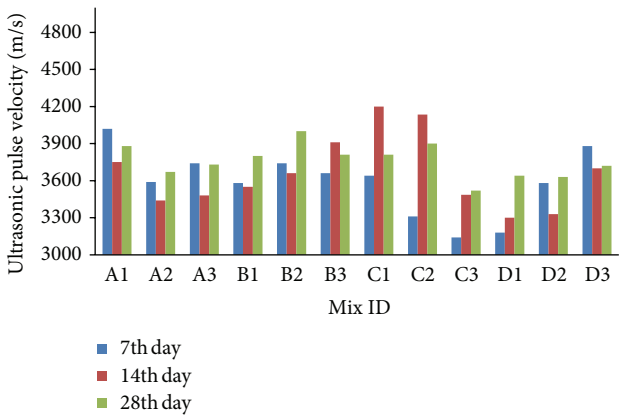

Figure 3: Ultrasonic pulse velocity for various fresh cmentitous systems.

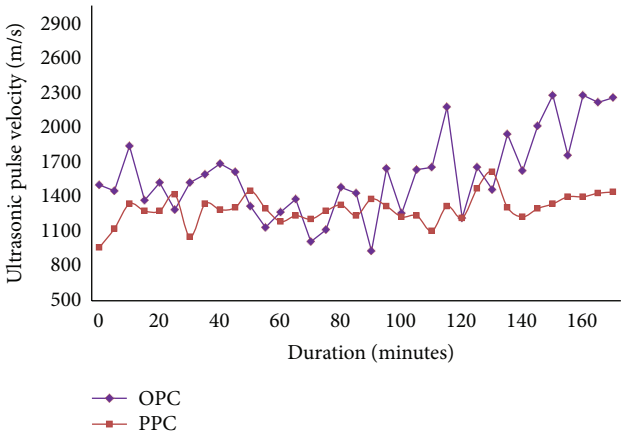

Figure 4: Ultrasonic pulse velocity of fresh 0PC and 0PC systems.

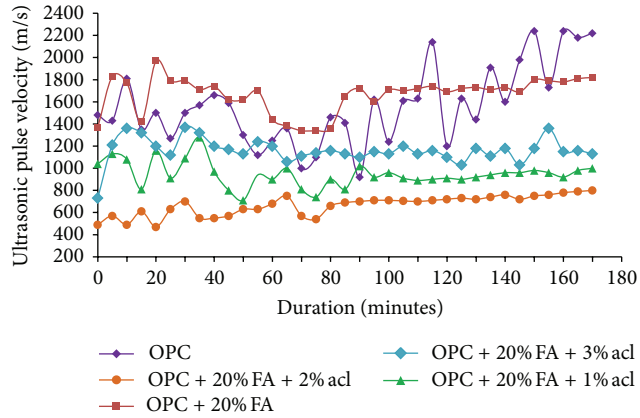

Figure 5: Ultrasonic pulse velocity for 20% fly ash replaced with cement with various percentages of the accelerator.

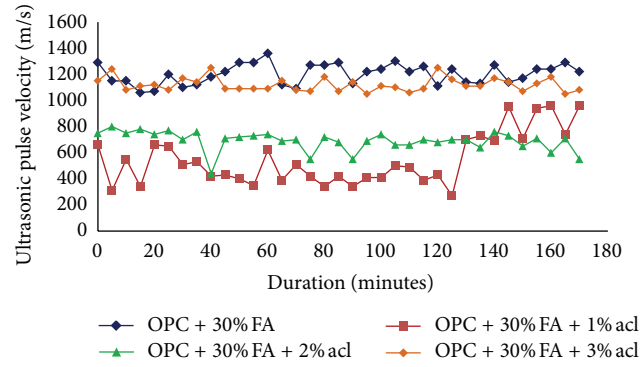

Figure 6: Ultrasonic pulse velocity for 30% fly ash replaced with cement with various percentages of the accelerator.

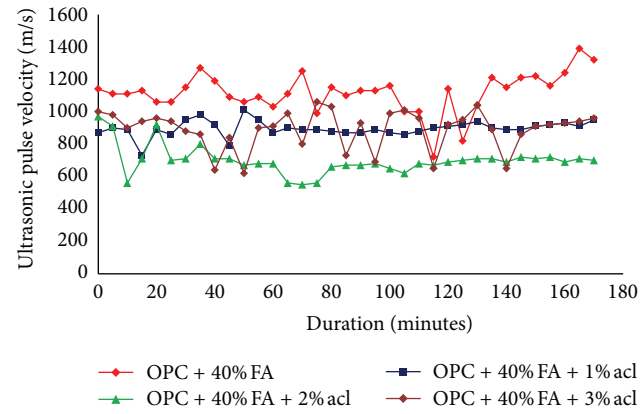

Figure 7: Ultrasonic pulse velocity for 40% fly ash replaced with cement with various percentages of the accelerator.

UPV that the influence of accelerator provided a constant increase in strength gain at the early ages. It may be observed from the graphs that the hydration process occurs in 3 stages. In the 1st stage, the hydration occurs very rapidly in the first few minutes. In the 2nd stage, the hydration process ceases or remains constant for another few minutes. This period is known as "dormant period." After this stage, the rate of hydration starts to increase again. At the end of the dormant period, the C_2S and C_3S in the cement start to react, with the formation of calcium silicate hydrate (C–S–H) and calcium hydroxide $Ca(OH)_2$. It observed that the test result value for 0PC with 20 percentage of fly ash showed an increase in UPV

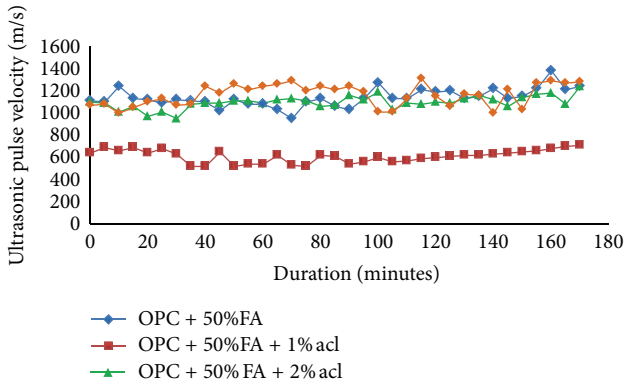

Figure 8: Ultrasonic pulse velocity for 50% fly ash replaced with cement with various percentages of the accelerator.

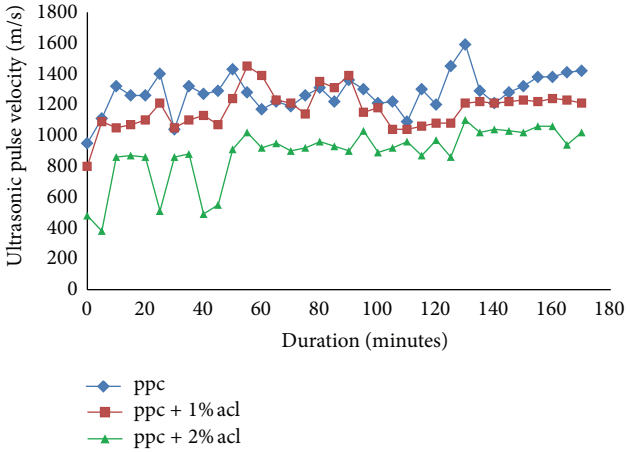

Figure 9: Ultrasonic pulse velocity for 0PC with various percentages of accelerator.

values up to 60 minutes, after that 60 to 90 minutes had a dormant period; that is, the heat of hydration was decreased, after further increasing the setting time will develop the stiffness of the cement paste.

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