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Ultrasonic Properties of Fly Ash Composites

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***Abstract*— *This paper reports the results of the study conducted to evaluate the influence of fly ash and mine overburden stabilized with lime on the Ultrasonic pulse velocity (UPV). In this investigation a varying percentage of lime 2%, 3%, 6% and 9% were used in preparing the fly ash-overburden composites. Ultrasonic pulse velocity tests were conducted at 7, 14, 28 and 56 days cured samples. P wave velocities were obtained at 7, 14, 28 and 56 days curing ranged from 797 to 1170 m/s, 1012 to 1350 m/s, 1057 to 1553 m/s and 1187 to 1699 m/s respectively. There was a continuous increase in the UPV with time for all the composites. Addition of lime improved the pulse velocity of fly ash composites*.

***Keywords*— *Fly ash, mine overburden, ultrasonic pulse velocity, lime, curing, composites.*

I. Introduction

Fly ash is a major industrial byproduct of coal combustion. Fly ash utilization for soil stabilization, that would be land filled, promotes sustainable construction through reduction of energy use and reduction of greenhouse gases [1]. The enhancement of mechanical strength of fly ash with addition of lime has been reported elsewhere [2]–[8]. Overburden is the waste material which lies above as well as in between the coal seams. With the rising demand for coal, often surface mine operation go deeper and deeper. It creates dump site with huge excavated wastes.

Ultrasonic pulse velocity test is a nondestructive testing technique which is used to determine the dynamic properties of materials. The ultrasonic velocity increased with increase in curing period of the masonry composite material made of limestone powder and fly ash [9]. He reported that the ultrasonic pulse velocity increased from 1150 to 1800 m/s in the composite containing 10% fly ash at 7 days curing. Dimter et al. [10] reported that the increase in fly ash percentage (from 0% to 75%) causes a decrease in ultrasonic velocity. The ultrasonic velocity of the mix containing 25% fly ash was 2.06 km/s and 75% fly ash was 1.36 km/s. She also reported that the ultrasonic velocity increases with increase in density of the material. Ultrasonic pulse velocity technique proved to be an effective method for characterizing the early strength gain properties of different cementitious systems [11]. The present study reports the results of Ultrasonic properties of the fly ash composites.

II. Materials and Methods

A. Materials

The fly ash used in the present study was collected from electrostatic precipitators of a thermal power unit of Rourkela Steel Plant, Odisha, India. The overburden used in this study was collected from Bharatpur opencast coal mine, Talcher, Odisha. The additive selected was commercially available superior grade quick lime. The fly ash and overburden mixes were stabilized with 2%, 3%, 6%, and 9% of lime. Weight fractions of fly ash of 15%, 20%, 25%, 30%, 35%, 40%, 45% and 50% were used to mix with overburden.

B. Methods

The tests for specific gravity, consistency limits, free swell index, pH, and loss on ignition were carried out as per the prescribed Indian Standards. The compaction characteristics of the fly ash, overburden and all the mixes were determined by conducting heavy compaction tests on specimens according to IS: 2720 (Part 8) 1983 with different amounts of lime. Ultrasonic pulse velocity tests were conducted using an Ultrasonic Velocity Measurement System (GCTS, Tempe, AZ, USA). This system includes 10 MHz bandwidth receiver pulse raise time less than 5 nano-seconds, 20MHz acquisition rate with 12bit resolution digitizing board, transducer platens with 200 KHz compression mode and 200KHz shears mode. The GCTS pulse velocity device operates in a through transmission mode of testing, that is, a signal is produced at one end of the specimen and received at the other end. The two, 54-mm diameter test platens are wired to a data acquisition and processing unit. The equipment provides pulse and shear wave velocity to determine elastic constants. The measurement was carried out according to ASTM D 2845-05.

III. Results and Discussion

The physical and engineering properties of fly ash and mine overburden were reported in table I & table II. The specific gravity of fly ash is found to be less than that of mine overburden, due to the presence of cenospheres. Free swell index of fly ash is found to be negative which is negligible due to flocculation. The grain size distribution curves of fly ash and mine overburden are as shown in fig. 1.

TABLE I. Physical properties of fly ash and mine overburden.

Property	Fly ash	Overburden
Specific gravity	2.16	2.6
Particle size analysis (%)		
Gravel (>4.75 mm)	----	9.71
Sand (4.75mm–0.075 mm)	22.17	32.91
Silt (0.075mm– 0.002 mm)	75.04	43.73
Clay (<0.002 mm)	2.79	13.65
Specific Surface Area (m^2/kg)	458	943
Consistency limits		
Liquid limit (%)	30.75	25.7
Plastic limit (%)	Non-plastic	15.04
Shrinkage limit (%)	----	13.44
Plasticity index (%)	----	10.66
Free swell index (%)	Negligible	20

Compaction characteristics

The compaction characteristics of untreated mixes varied between 1965 kg/m^3 to 1686 kg/m^3 (Fig. 2). As the fly ash percentage was increased the values for OMC also increased.

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As the aim of the investigation was to develop an engineering material with mine overburden and fly ash stabilized with lime. Accordingly samples were prepared. The maximum dry density values of all developed materials decreased and optimum moisture content increased with increase in lime content.

TABLE II. Engineering properties of overburden and fly ash.

Property	Overburden	Fly ash
1. Compaction characteristics		
(a) Maximum dry density (kg/m^3)	2040	1396
(b) Optimum moisture content (%)	8.15	20.06
2. Permeability (cm/sec)	3.06E-06	1.01E-05
3. Shear strength parameters		
(a) Cohesion (kPa)	58.09	39.35
(b) Angle of internal friction	36.23^0	28.45^0
4. Angle of repose	33.77^0	12^0
5. Unconfined compressive strength (kPa)	313.91	142.76
6. CBR value (%)		
(a) Unsoaked condition	23.65	22.42
(b) Soaked condition	2.95	0.72

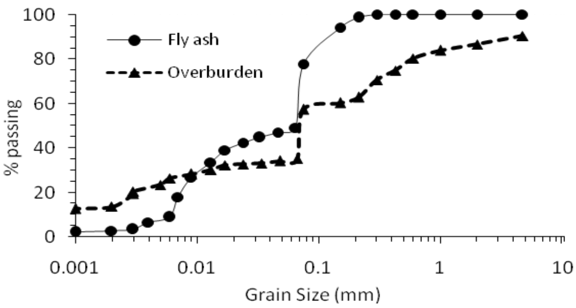

FIg. 1. Grain size distribution curves.

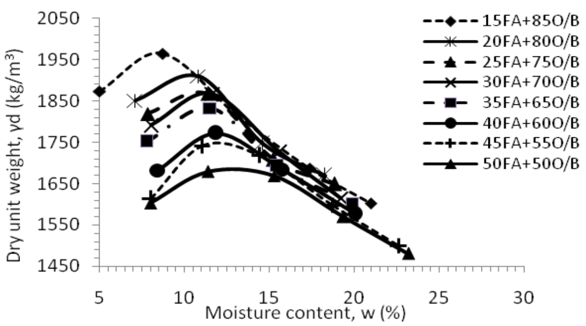

Fig. 2. Compaction curves of untreated mixes.

Ultrasonic pulse velocity

The velocity of Ultrasonic P (pulse) wave is measured over a distance and it depends on the quality of transmission, cohesiveness of constituent materials, dampness, presence of weaknesses as crack, voids, etc. Its accuracy also depends on the homogeneity of the sample. The P wave tests conducted in all the samples confirm it. The P wave velocities of untreated fly ash, overburden and composites were not conducted as those did not exhibit any significant strength values.

The P wave values of treated samples are reported here and analyzed. The ultrasonic pulse velocities varied in the range of 797 m/s to 1699 m/s for varying curing periods. The increase in P wave velocity was steep between 2 to 3% lime content at 7 days, 14 days, 28 days and 56 days curing period (Fig. 3, 4, 5 & 6). The maximum P wave velocity values were obtained for mixture with 30% fly ash+70% overburden and 9% lime which is similar to the results obtained for UCS and CBR tests. P wave velocities obtained at 7, 14, 28 and 56 days curing ranged from 797 to 1170 m/s, 1012 to 1350 m/s, 1057 to 1553 m/s and 1187 to 1699 m/s respectively. There was a continuous increase in the UPV with time for all the composites. Addition of lime improved the pulse velocity of fly ash composites. The P wave velocity signal plot of fly ash mixture is shown in Fig. 7.

The Poisson's ratio is a measure of the behaviour of material under loading. The ultrasonic tests produced the Poisson's ratio between 0.30 and 0.41 (Table III) except a few composites with 0.24 to 0.29. The Poisson's ratio values of each composite did not change significantly either with higher lime content or longer curing periods which are the typical characteristics of any material.

Young's modulus (E) values were also obtained from nondestructive testing. Its values ranged between 776 to 3107 MPa (Table IV). These values are very high compared to that obtained from static tests. Nondestructive tests do not cause either generation or extension of flaws unlike static tests. The Young's modulus (E) values increased with lime content as well as curing periods confirming to enhance pozzolanic activities resulting in higher stiffness of the composites. The velocity of propagation increases with increased stiffness of the material.

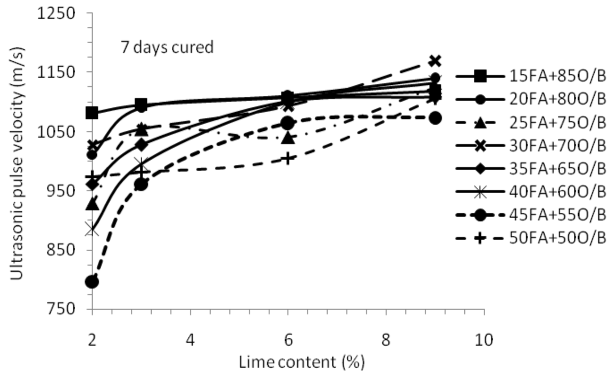

Fig. 3. Effect of lime on pulse wave velocity of fly ash composites at 7 days curing.

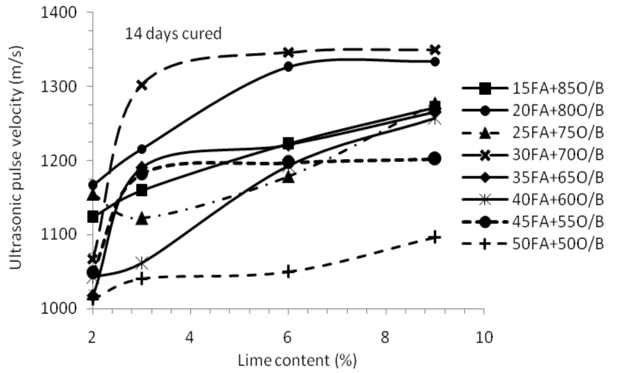

Fig. 4. Effect of lime on pulse wave velocity of fly ash composites at 14 days curing.

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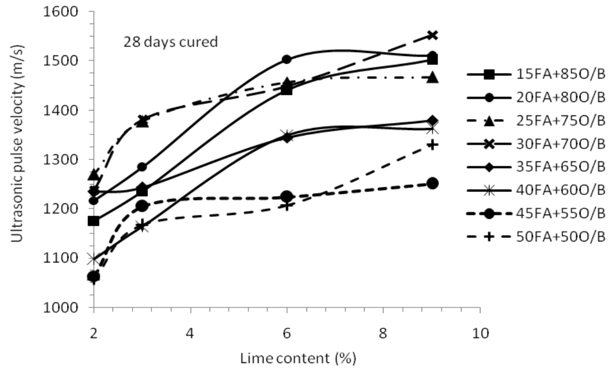

Fig. 5. Effect of lime on pulse wave velocity of fly ash composites at 28 days curing.

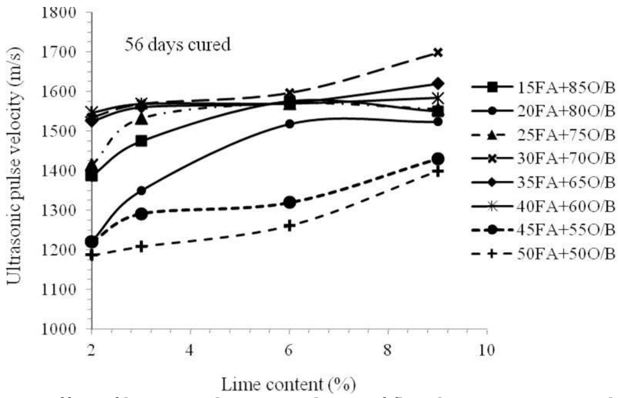

Fig. 6. Effect of lime on pulse wave velocity of fly ash composites at 56 days curing.

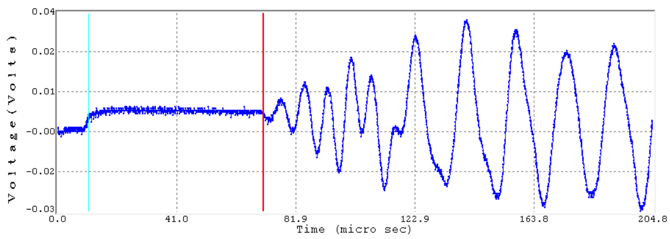

Fig. 7. A typical P wave velocity signal plot of fly ash mix.

TABLE III. Poisson's ratios of the composites for 7, 14, 28 and 56 days.

Sample		Curing	Lime content (% weight)			
Fly ash (% wt)	Overburden (% wt)	period (days)	2	3	6	9
			Poisson's ratios			
15	85	7	0.35	0.33	0.34	0.33
		14	0.35	0.32	0.35	0.35
		28	0.34	0.34	0.36	0.35
		56	0.31	0.39	0.35	0.29
20	80	7	0.33	0.33	0.29	0.27
		14	0.37	0.37	0.36	0.36
		28	0.37	0.35	0.37	0.39
		56	0.37	0.38	0.38	0.33
25	75	7	0.35	0.34	0.24	0.3
		14	0.36	0.29	0.41	0.38
		28	0.37	0.36	0.36	0.35
		56	0.39	0.35	0.38	0.35
30	70	7	0.33	0.36	0.37	0.28
		14	0.31	0.36	0.36	0.26
		28	0.34	0.37	0.37	0.35
		56	0.39	0.3	0.35	0.35
35	65	7	0.35	0.34	0.32	0.34
		14	0.37	0.3	0.37	0.33
		28	0.34	0.29	0.36	0.32
		56	0.31	0.4	0.34	0.36
40	60	7	0.3	0.33	0.32	0.32
		14	0.3	0.32	0.35	0.35
		28	0.29	0.32	0.34	0.36
		56	0.4	0.36	0.38	0.34
45	55	7	0.31	0.37	0.37	0.37
		14	0.35	0.38	0.36	0.34
		28	0.31	0.35	0.34	0.33
		56	0.32	0.31	0.3	0.3
50	50	7	0.36	0.36	0.35	0.37
		14	0.31	0.32	0.39	0.36
		28	0.33	0.33	0.38	0.33
		56	0.31	0.27	0.31	0.34

TABLE IV. Young's (dynamic) modulus values of the composites at 7, 14, 28 and 56 days.

Sample		Curing	Lime content (% weight)			
Fly ash (% wt)	Overburden (% wt)	period (days)	2	3	6	9
			Young's moduli (MPa)			
15	85	7	1501	1644	1740	1679
		14	1528	1855	1794	1893
		28	1755	1866	2291	2536
		56	1904	2358	3190	2992
20	80	7	1353	1512	1786	1893
		14	1240	1435	1908	1931
		28	1605	1909	2298	2111
		56	1617	1810	2354	2727
25	75	7	1212	1328	1691	1676
		14	1098	1793	1501	1574
		28	1740	2081	2306	2395
		56	1784	2354	2927	2455
30	70	7	1066	1230	1215	1732
		14	1539	1857	2085	2633
		28	1803	1879	2102	2822
		56	1921	2974	2645	3107
35	65	7	1084	1287	1532	1440
		14	1108	1755	1427	1686
		28	1759	2075	1895	2200
		56	2713	2146	2454	2573
40	60	7	1092	1173	1413	1512
		14	1426	1438	1514	1766
		28	1528	1634	1999	1876
		56	2036	2733	2331	2829
45	55	7	776.6	915.1	1111	1061
		14	1187	1300	1436	1693
		28	1296	1439	1532	1731
		56	1628	1987	2116	2781
50	50	7	954.8	974.3	1037	1114
		14	1257	1354	1020	1302
		28	1532	1507	1237	1985
		56	1550	1801	1910	2269

IV. CONCLUSIONS

The results obtained were encouraging. The ultrasonic pulse velocities varied in the range of 797 m/s to 1699 m/s for varying curing periods. The composite containing 30% fly ash and 70% overburden treated with 9% lime produced highest ultrasonic velocities as compared to that of other composites at 7, 14, 28 and 56 days of curing respectively. The ultrasonic tests produced the Poisson's ratio between 0.30 and 0.41. Its values ranged between 776 to 3107 MPa. The velocity of propagation increases with increased stiffness of the material. The pulse wave velocity increased with an increase in lime content though the rate of increase varies.

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