International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:8, No:3, 2014

High Volume Fly Ash Concrete for Paver Blocks

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Abstract**—**Use of concrete paver blocks is becoming increasingly popular. They are used for paving of approaches, paths and parking areas including their application in pre-engineered buildings and pavements. This paper discusses the results of an experimental study conducted on Fly Ash Concrete with the aim to report its suitability for concrete paver blocks. In this study, the effect of varying proportions of fly ash, 20% to 40%, on compressive strength and flexural strength of concrete has been evaluated. The mix designs studied are M-30, M-35, M-40 and M-50. It is observed that all the fly ash based mixes are able to achieve the required compressive and flexural strengths. In comparison to control mixes, the compressive and flexural strengths of the fly ash based mixes are found to be slightly less at 7-days and 28 days and a little more at 90 days.

Keywords**—**Compressive strength, flexural strength, high volume fly ash concrete, paver blocks.

I. Introduction

CONCRETE paver blocks were first introduced in Holland in the fifties as replacement of paver bricks which had become scarce due to the post-war building construction boom. These blocks were rectangular in shape and had more or less the same size as the bricks. During the past five decades, the block shape has steadily evolved from non-interlocking to partially interlocking to fully interlocking shapes. Consequently, the pavements in which non-interlocking blocks are used are designated as ‘Concrete Block Pavement (CBP)’ or non-interlocking CBP, and those in which partially, or fully interlocking blocks are used are designated as ‘Interlocking Concrete Block Pavement (ICBP)’ [1].

CBP/ICBP consists of a surface layer of small-element, solid un-reinforced pre-cast concrete paver blocks laid on a thin, compacted bedding material which is constructed over a properly profiled base course and is bounded by edge restraints/kerb stones. The block joints are filled using suitable fine material. A properly designed and constructed CBP/lCBP gives excellent performance when applied at locations where conventional systems have lower service life due to a number of geological, traffic, environmental and operational constraints. Many number of such applications for light, medium, heavy and very heavy traffic conditions are currently in practice around the world. In India, the recommended usages are given in Table I [1].

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The use of fly ash in concrete paver blocks is aimed at reducing cement content and heat of hydration leading to better economy and durability. It will also help in safe-guarding the environment from ill effects of CO_2 emissions from cement industry and contribute towards the solution for safe disposal of fly ash produced by thermal power plants.

II. Objectives of the Study

The present study aims at evaluating the performance of high volume fly ash concrete for paver blocks for use in pavements and other application areas. As compressive and flexural strengths are the most significant properties for concrete paver blocks [2], the same have been studied for various concrete mixes with varying percentages of fly ash.

III. Materials Used and Their Properties

The materials used in the study are:

(i) Crushed coarse aggregate and fine aggregate (coarse sand) of Yamuna Nagar region.
(ii) Cement: OPC-43 grade.
(iii) Fly ash obtained from Panipat Thermal Power plant.
(iv) Potable water.

Table II gives the grading of 20mm and 10mm size aggregates. The fine aggregates conform to grading zone II having fineness modulus as 3.034. Various relevant test results of the properties of materials used in the mix designs have been given in Tables III and IV.

IV. Mix Designs

A. Design Stipulations

- Characteristic compressive strength required in the field at 28 days is 30, 35, 40 and 50 N/mm^2 for four mix designs of M-30, M-35, M-40 and M-50 respectively.
- Nominal maximum size of aggregates is 12.5mm (crushed) [1].
- Thickness of paver blocks = 80mm
- Degree of workability = Zero slump, suitable for paver blocks
- Degree of quality control: Good
- Design aids: IS: 10262 [4]
- Coarse aggregates grading as per IS: 383 [3].

B. Proportioning of Coarse Aggregates

Their grading of coarse aggregate as given in Table II is found to be such that only 10mm size aggregate can be used in the mix designs as the nominal maximum size of aggregate recommended to be used for paver blocks is 12.5mm [1].

C. Target Mean Strength of Concrete

For a tolerance factor of 1.65 and using a standard deviation 5.0 N/mm2 [4], the target mean strengths for mix designs are adopted as under:

M-30: Comp St. 38.3 N/mm^2, Flexural St: 4.33 N/mm^2
M-35: Comp St. 43.3 N/mm^2, Flexural St: 4.61 N/mm^2
M-40: Comp St. 48.3 N/mm^2, Flexural St: 4.86 N/mm^2
M-50: Comp St. 58.3 N/mm^2, Flexural St: 5.34 N/mm^2

D. Proportions of Concrete Mixes and Test Results

Proportioning of constituents of concrete mixes per m^3 of concrete for saturated surface dry (SSD) aggregates is given in Table V. The results of compressive and flexural strength of various mixes are given in Table VI. Four mix designs of M-30, M-35, M-40 and M-45 have been designed each having four mix designations of 1, 2, 3 and 4 with fly ash proportions as 0, 20, 30 and 40% of cementitious material. The cementitious material consists of cement plus fly ash. The quantity of cementitious material is increased by 10% for fly ash based mixes as compared to the control mix without fly ash as per trial in all the mix designs [4].

V. Analysis and Discussion of Results

A. Water Cementitious Ratio (w/c)

With the addition of fly ash, for same level of workability, the water to cementitious material ratio reduces from 0.4 to 0.376 in M-30 grade, 0.38 to 0.357 in M-35, 0.36 to 0.338 in M-40 and 0.32 to 0.291 in M-50 grade concrete. Water Cementitious Ratio (w/c) for all proportions of fly ash in a given mix type is kept the same as the total weight of the cementitious material remains the same in these mixes. It is observed that a partial substitution of cement by fly ash in concrete mixture reduces the water requirement for obtaining a given consistency. The phenomenon is attributable to three mechanisms [5]. First, fine particles of fly ash get absorbed on the oppositely charged surfaces of cement particles and prevent them from flocculation. The cement particles are thus effectively dispersed and will not trap large amounts of water that means that the system will have a reduced water requirement to achieve a given consistency. Secondly, the spherical shape and the smooth surface of fly ash particles help to reduce the inter-particle friction and thus facilitate mobility. Thirdly, the 'particle packing effect' is also responsible for the reduced water demand in plasticizing the system. It may be noted that both portland cement and fly ash contribute particles that are mostly in the 1 to 45μm size range, and therefore serve as excellent fillers for the void space within the aggregate mixture. In fact, due to its lower density and higher volume per unit mass, fly ash is a more efficient void-filler than portland cement.

B. Compressive and Flexural Strengths

Cube compressive strengths at 7-days and 28 days for all the four mix designs with different proportions of fly ash (20, 30 & 40%) are found to slightly decrease as compared to the control mix with no fly ash. However, 28-day cube compressive strength for all the mixes, except M-50, with all proportions of fly ash upto 40% is found to be more than the target mean strength of the mixes. Cube compressive strength at 90 days for all the four mix designs with different proportions of fly ash (20, 30 & 40%) is found to slightly increase as compared to the control mix with no fly ash (Figs. 1-4). Similar to compressive strength trends, flexural strength (Figs. 5-8) is also found to decrease slightly at 7 and 28 days but it increases at 90 days as compared to control mix for all the four mixes for different proportions of fly ash. The 28-day flexural strength for all mixes is found to be more than the target flexural strength of the mix for all proportions of fly ash used in the study.

Figs. 9 to 16 indicate the decrease / increase in the values of compressive and flexural strength at 7, 28 and 90 days with respect to the control mix values. It is observed that the 90 day strength increases up to the addition of 30% fly ash after which it falls. However, for all mixes with all fly ash proportions, it remains more than the strength of the control mix at 90 days.

The lower compressive and flexural strengths at the initial ages can be due to the reason of reduction of the quantity of cement by replacement with fly ash, resulting in weakening the cohesion of the cement paste. It is known that majority of strength rendering primary mineralogical phases are developed at the ultimate hydration of cement. Due to this reason sufficient cementitious action of fly ash is not activated at the initial stages and thus the non-reactive quantity of fly ash, at this stage, reflect insignificant effect on strengths. At the later ages between 28 days onwards, improvement in the strength is observed due to the reason that the surplus lime released from cement hydration becomes the source for pozzolanic reactions contributing for additional mineralogy [6], [7] for additional strength.

TABLE I
RECOMMENDED USAGE OF PAVER BLOCKS [1]

S. No.	Grade of Paver Blocks	Traffic Category	Design traffic (million standard axles)	Minimum Thickness of Paver Blocks (mm)	Application Examples
1	M-30	Non-traffic	No vehicular traffic	50	Building premises, landscapes, public gardens / parks, domestic drives, paths, embankment slopes, sand stabilization area, etc
2	M-35	Light traffic	up to 0.5	60	Pedestrian plazas, shopping complexes ramps, car parks, office driveways, housing colonies, office complexes, rural roads with low volume traffic, beach sites, tourist resorts local authority footways, residential roads, etc
3	M-40	Medium traffic	0.5-2.0	80	City streets, small and medium market roads, low volume roads, utility cuts on arterial roads, etc
4	M-50	Heavy traffic	2.0 to 5.0	100	Bus terminals, industrial complexes, roads on expansive soils, factory floor, industrial pavements, etc

TABLE II
GRADING OF COARSE AGGREGATE

Sieve size (mm)	Percent by weight of coarse aggregates passing the sieve				
	Nominal Size of Aggregates		Specified Grading for 12.5mm nominal size aggregates[3]		Proportion (%) A:B:: 0:100
	20 mm	10 mm	Range	Mean	
20	100	100	100	100	100
12.5	54.8	91.3	90-100	97.5	100
10	0.5	68.6	40-85	62.5	68.6
4.75	0.2	7.6	0-10	5	7.6

TABLE III
TEST RESULTS OF MATERIALS USED

S. No.	Property	Test Result
(i)	Compressive strength of OPC 43 grade cement after 7-days	340 kgf/cm^2
(ii)	Specific gravity	
	Coarse aggregate	2.66
	Fine aggregate	2.69
	Cement	3.15
	Fly ash (class-F)	2.25
(iii)	Water absorption	
	Coarse aggregate	0.8 %
	Fine aggregate	1.0 %
(iv)	Free (surface) moisture	
	Coarse aggregate (including absorbed moisture)	Nil
	Fine aggregate	Nil
(v)	Lime Reactivity of Fly Ash, N/mm^2	6.0

TABLE IV
GRADING OF FINE AGGREGATE

Sieve Size	Percent by weight of sand passing the sieve	Remarks
10	100	Conforms to grading zone II [3] Fineness Modulus = 3.034
4.75	90.1	
2.36	76.9	
1.18	62.2	
0.6	45.2	
0.3	16.2	
0.15	6.0	

TABLE V
PROPORTIONING OF CONSTITUENTS FOR MIX DESIGNS (PER M^3 OF CONCRETE)

Mix Designation	Fly Ash (% of cementitious material)	water / cementitious ratio	Water (lit)	Cement (kg)	Fly Ash (kg)	Fine Agg (kg)	Coarse Agg (kg)
M-30-1	-	0.4	150	375	-	707.9	1244.4
M-30-2	20	0.376	155	330	82.5	671.1	1205.7
M-30-3	30	-do-	155	288.7	123.8	665.7	1196
M-30-4	40	-do-	155	247.5	165	660.3	1186.3
M-35-1	-	0.38	150	395	-	693.9	1241.3
M-35-2	20	0.357	155	347.6	86.9	656.4	1200.1
M-35-3	30	-do-	155	304.1	130.4	650.7	1189.8
M-35-4	40	-do-	155	260.7	173.8	645.1	1179.5
M-40-1	-	0.36	150	417	-	679.5	1236.9
M-40-2	20	0.338	150	367.0	91.7	642.9	1191.1
M-40-3	30	-do-	150	321.1	137.6	637.0	1180.2
M-40-4	40	-do-	150	275.2	183.5	631.2	1169.3
M-50-1	-	0.32	142	443	-	662.3	1243.8
M-50-2	20	0.291	142	389.8	97.5	626.5	1205.1
M-50-3	30	-do-	142	341.1	146.2	621.6	1186.8
M-50-4	40	-do-	142	292.4	194.9	615.3	1179.6

TABLE VI
COMPRESSIVE AND FLEXURAL STRENGTHS OF MIX DESIGNS

Mix Designation	Compressive Strength (N/mm^2)			Flexural Strength (N/mm^2)		
	7-days	28-days	90-days	7-days	28-days	90-days
M-30-1	28.7	40.4	41.2	4.07	4.83	4.88
M-30-2	27.9	39.8	41.5	4.01	4.79	4.89
M-30-3	27.1	39.3	41.8	3.96	4.76	4.91
M-30-4	26.3	38.7	41.6	3.90	4.73	4.90
M-35-1	32.4	45.7	46.6	4.33	5.14	5.19
M-35-2	31.4	44.9	46.8	4.26	5.09	5.20
M-35-3	30.6	44.3	47.1	4.20	5.06	5.22
M-35-4	29.6	43.6	46.9	4.14	5.02	5.20
M-40-1	35.4	49.9	50.9	4.52	5.37	5.42
M-40-2	34.7	49.5	51.6	4.47	5.35	5.46
M-40-3	33.9	49.1	52.2	4.42	5.33	5.49
M-40-4	33.0	48.6	52.3	4.37	5.30	5.48
M-50-1	46.4	58.8	60.2	5.12	5.98	6.10
M-50-2	45.2	58.1	60.6	5.07	5.95	6.15
M-50-3	43.8	57.6	61.4	4.96	5.93	6.18
M-50-4	42.1	57.0	60.8	4.88	5.89	6.14

Note: M-30-1 is control mix with no fly ash. M-30-2, 3 and 4 are mix designs with 20, 30 and 40% fly ash.

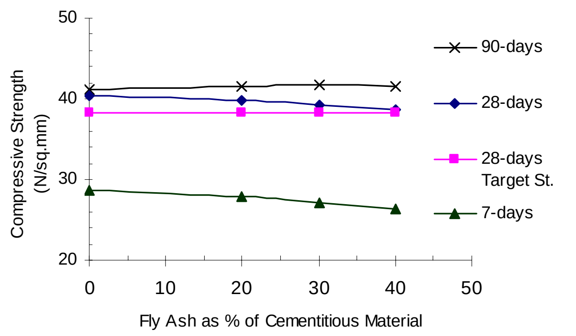

Fig. 1 Compressive Strength of M-30 Mixes

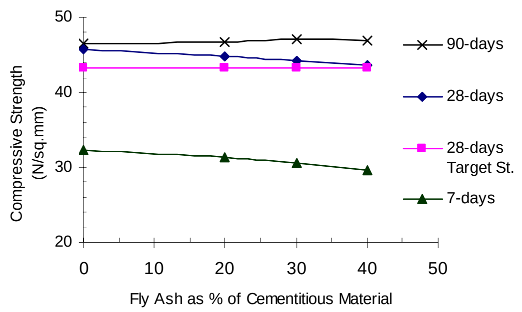

Fig. 2 Compressive Strength of M-35 Mixes

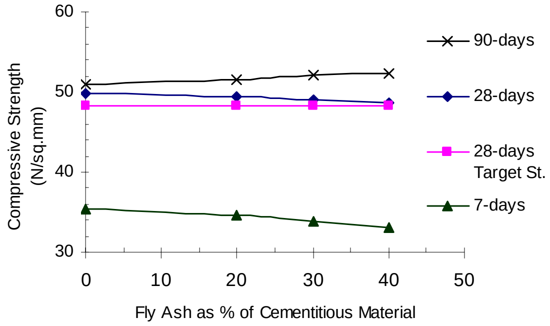

Fig. 3 Compressive Strength of M-40 Mixes

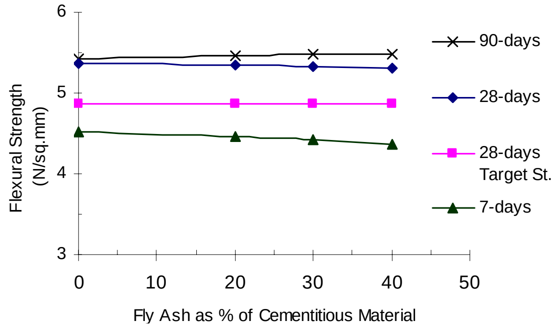

Fig. 7 Flexural Strength of M-40 Mixes

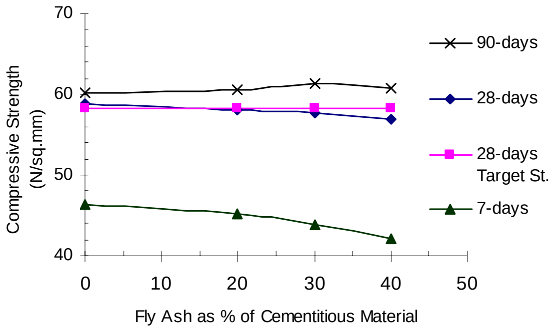

Fig. 4 Compressive Strength of M-50 Mixes

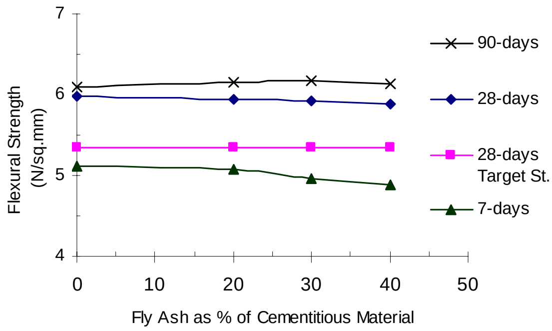

Fig. 8 Flexural Strength of M-50 Mixes

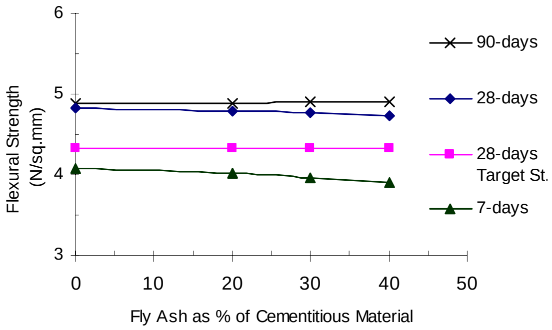

Fig. 5 Flexural Strength of M-30 Mixes

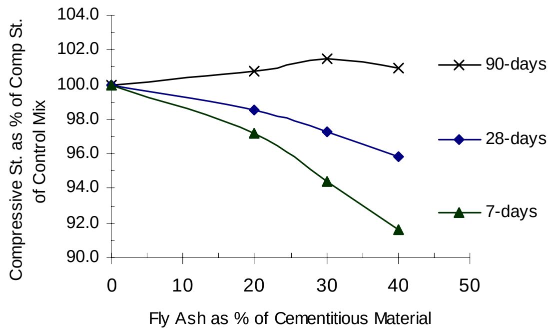

Fig. 9 Change in Compressive Strength of M-30 Mixes

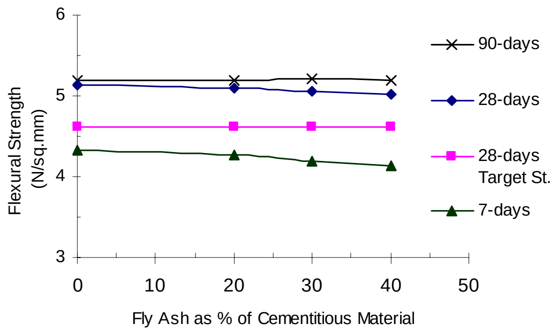

Fig. 6 Flexural Strength of M-35 Mixes

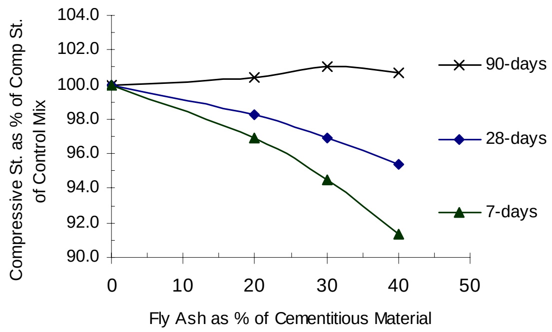

Fig. 10 Change in Compressive Strength of M-35 Mixes

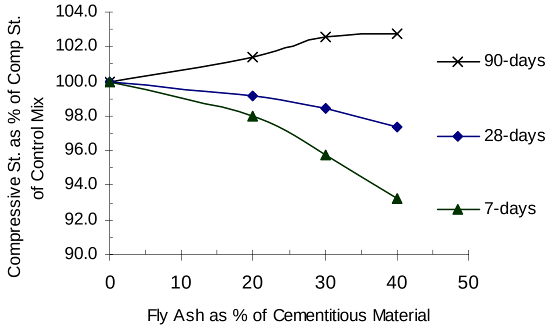

Fig. 11 Change in Compressive Strength of M-40 Mixes

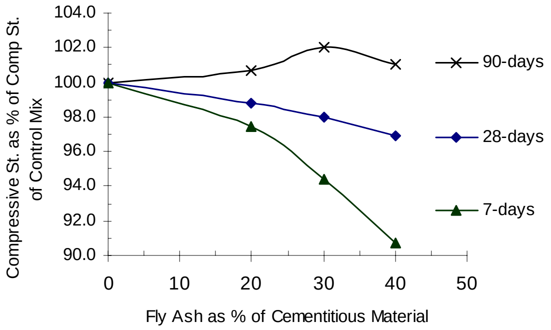

Fig. 12 Change in Compressive Strength of M-50 Mixes

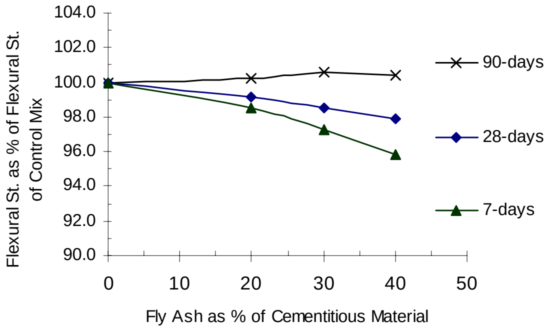

Fig. 13 Change in Flexural Strength of M-30 Mixes

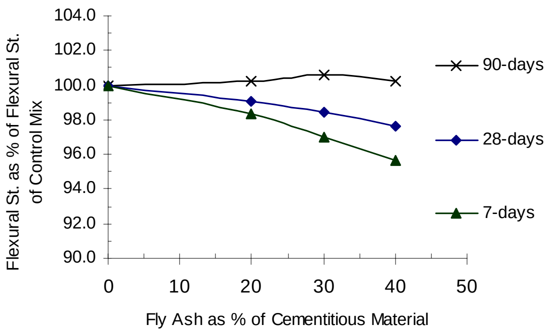

Fig. 14 Change in Flexural Strength of M-35 Mixes

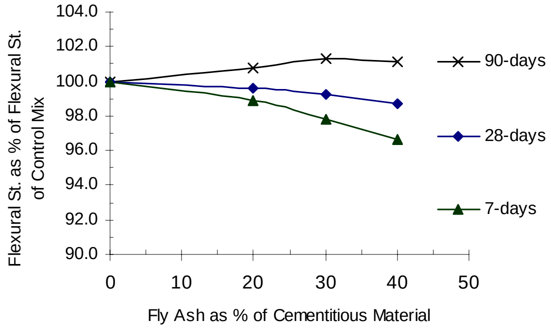

Fig. 15 Change in Flexural Strength of M-40 Mixes

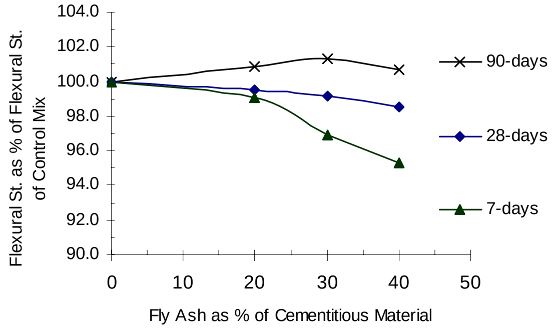

Fig. 16 Change in Flexural Strength of M-50 Mixes

VI. Conclusions

The main conclusions drawn from the study are:

(i) With the addition of fly ash, the water to cementitious material ratio reduces for all mixes for same level of workability.

(ii) Cube compressive strengths at 7-days and 28 days for all the four mix designs with different proportions of fly ash are found to slightly decrease as compared to the control mix with no fly ash.

(iii) 28-day cube compressive strength for all the mixes, except M-50, with all proportions of fly ash is found to be more than the target mean strength of the mixes.

(iv) Cube compressive strength at 90 days for all the four mixes with different proportions of fly ash is found to slightly increase as compared to the control mix with no fly ash.

(v) Flexural strength exhibits similar trends as that of compressive strength.

(vi) 90-day cube compressive strength and flexural strength increase up to addition of 30% fly ash after which their values fall. However, for all mixes with all fly ash proportions, their values remain more than the strength of the control mix at 90 days.

(vii) The given mix designs and their results show that the fly ash in high proportion can be easily used in a cost-effective and ecological manner in the manufacturing of paver blocks for use in pavements and other similar areas of application.

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