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EXPERIMENTAL STUDY ON ARTIFICIAL LIGHTWEIGHT AGGREGATE USING POLYSTYRENE

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Abstract—*Due to excessive usage of natural coarse aggregates, the light weight concrete produced from industrial waste polystyrene is viable source of structural light weight aggregate material. The usage of PLCA (polystyrene lightweight coarse aggregates) concrete reduces considerably the self-weight of structure. The structural member produced from utilising PLCA in concrete production not only solves the problem of polystyrene waste disposal but also helps conserve natural resources.*

This paper presents the results of extensive tests to investigate the mixing proportion, density, mechanical properties (compressive strength, flexural strength and tensile strength) of lightweight concrete made of polystyrene aggregates with the strength level of 7 to 19.1 MPa and the corresponding density of 15.24 kN/m3 to 24.18 kN/m3.

Material variables include the volume and composition of cement, natural sand, polystyrene aggregate content by volume. Particular emphasis has been given to study the effect of concrete density on compressive strength, tensile strengths, flexural and workability. To exploit the potential of using polystyrene concrete as structural element, further study has been carried out on the flexural behaviour of polystyrene concrete beams with limited experimental data.

The concrete strength is targeted at 20 MPa for all the beams. Experimental results showed that the compressive, tensile and flexural strength of polystyrene aggregate concrete decreases as the decrease in density of PLCA concrete. It is also observed that the concrete segregate at lower percentage replacement of natural aggregates with PLCA.

Key words*: Polystyrene, aggregates, lightweight, concrete, waste*

I. INTRODUCTION

Most of normal weight coarse aggregate of normal weight concrete is natural stone such as lime stone and granite. With the amount of concrete used keeps increasing, natural environment and resources are excessively exploited. Synthetic lightweight aggregate produced from industrial waste, expanded polystyrene, is a viable new source of structural lightweight aggregate material. The use of light weight concrete permits greater design flexibility and substantial cost savings, reducing dead load, longer spans, better fire ratings, thinner sections, smaller size structural members, less reinforcing steel and lower foundation cost. Weight of light concrete 25% to 35% but its strength is comparable to normal weight concrete. The structural member produced from utilising PLCA (Polystyrene Light Weight Coarse Aggregate) in concrete production not only solves the problem of polystyrene waste disposal but also helps conserve natural resources.

There are many types lightweight concrete. It has been manufactured by several materials by such as fuel ash, perlite, pumice etc. these materials are lightweight, low density and low compressive strength. Polystyrene beads can be categories as lightweight material. Polystyrene beads can be used to produce lightweight concrete. The PLCA concrete has good thermal and acoustic insulation properties leading mainly to non-structural application including precast roof, precast wall panels and lightweight infill blocks.

The idea of using Polystyrene particle as a substitute of air bubbles (lightweight aggregate) has been introduced, as the density of Polystyrene is nearly negligible (16-27 kg/m3) when compared to that of conventional concrete coarse aggregates (17-20 kN/m3).

1.1 POLYSTYRENE

Polystyrene is a polymer of styrene in the form of a clear plastic or stiff foam, used in moulded objects and as an insulator in refrigerators and air conditioners. Polystyrene foams are good thermal insulators and are therefore often used as building insulation materials, such as in structural insulated panel building systems. They are also used for non-weight-bearing architectural structures (such as ornamental pillars). PS foams exhibit also good damping properties, therefore it is used widely in packaging.

Expanded polystyrene are non-absorbent, since their cells are closed. They are easily compressible and hence their direct contribution to the compressive strength of the concrete is negligible. Their primary function is to act as small, regular void formers in the surrounding mortars. However, the high thermal resistivity of the concrete and some of its other desirable properties result from the presence of the beads.

1.2.1 USES OF POLYSTRENE

I. Extruded foam sheet of polystyrene can be thermoformed into such parts as egg cartons or carryout food containers. Foam grade polystyrene is generally high heat crystal polystyrene with a high molecular weight.
II. Another type of polystyrene foam is that produced from expandable polystyrene beads. These beads can be moulded to produce hot drink cups, ice chests, or foam packaging. Also, the expandable beads can be moulded in very large blocks that can then be cut into sheets for thermal insulation. Densities of as low as 1lb/ft3 on foamed products are commercially obtainable.
III. Extruded crystal polystyrene sheet can be bi-axially oriented by mechanically pulling the extruded melt in multiple directions. The stretched sheets is then cooled and allowed to set with the bi-axially orientation frozen into the sheet. This process produces crystal polystyrene sheet of thin gauge with very high strength. Typical applications include envelope windows, cap layers for glossy sheet, or thermoforming into food packaging applications.
IV. Optical property of polystyrene is used in manufacture of unbreakable glasses for gauges, windows and lenses, as well as in countless specialties and novelties and also for edge lighting for the edge lighting of indicators and dials
V. Solid or liquid pigments and dies colour high impact and crystal polystyrenes. This can be accomplished in both extrusion and injection moulding processes. These colorants are added and mixed during the melting stage of both the processes. Also, polystyrene parts are amenable to high quality printing. Labels can be printed directly on the polystyrene part to produce attractive containers.
VI. Polystyrenes are also used in furniture, packaging, appliances, automobiles, construction, radios, televisions, toys, house ware items, and luggage.

1.2.2 ENVIRONMENTAL IMPACT

Discarded polystyrene does not biodegrade for hundreds of years and is resistant to photolysis. Because of this stability, very little of the waste discarded in today's modern, highly engineered landfills biodegrades. Because degradation of materials creates potentially harmful liquid and gaseous by-products that could contaminate groundwater and air, today's landfills are designed to minimize contact with air and water required for degradation, thereby practically eliminating the degradation of waste.

Polystyrene foam is a major component of plastic debris in the ocean, where it becomes toxic to marine life. Foamed polystyrene blows in the wind and floats on water, and is abundant in the outdoor environment. Polystyrene foams are produced using blowing agents that form bubbles and expand the foam. In expanded polystyrene, these are usually hydrocarbons such as pentane, which may pose a flammability hazard in manufacturing or storage of newly manufactured material, but have relatively mild environmental impact. However, extruded polystyrene is usually made with hydrochloro fluorocarbons (HCFC) blowing agents which have effects on ozone depletion and on global warming. Their ozone depletion potential is greatly reduced relative to chlorofluorocarbon (CFC) which were formerly used, but their global warming_potential can be on the order of 1000 or more, meaning it has 1000 times greater effect on global warming than does carbon dioxide.

1.3 SCOPE AND LIMITATIONS

The main focus of the study is to determine the compressive strength of light weight concrete samples and to know the proportion of light weight concrete which has optimum compressive strength. The compressive strength is a very important indicator in order to determine the characteristic of concrete.

In this study, waste polystyrene aggregates will be used as a substitute to coarse aggregate. It is chosen due to its light weight property, with good energy absorbing characteristic and good thermal insulator leading mainly to non- structural application. These materials are very light and can decrease a lot of concrete weight compare with lightweight materials such as fly ash and slag, expended polystyrene aggregates are more economical and easy to get.

Polystyrene will be as a part of natural coarse aggregates in the mix. In this study ordinary Portland cement grade 43 is used. Cylinder moulds will be prepared to make concrete samples with diameter of 100mm and 300 mm height. Water cement ratio is fixed at 050. Density and compressive strength will be applied in samples.

1.4 SIGNIFICANCE OF STUDY

The crisis of economy that hit the country has a significant impact on the construction industry. There were many construction have stop due to rising cost of raw materials and labours. Labour shortages in the construction industry also contributed to this problem. In addition, the cost of services for the operation of construction machinery it seen increase due to prevailing economic instability. This led some parties such as researches and students to do some research to solve this problem.

This study will be aim to know the efficiency and potential of using light weight concrete by using polystyrene in construction industry. Polystyrene had been chosen because of its low density, light weight, inexpensive and easily to produce compared to the normal concrete use of aggregates. The construction of light weight concrete can decreases the number of labours. Otherwise, the use of light weight concrete polystyrene can minimise the cost of the use of heavy machineries. So, this shows the importance of this study in order to improve the construction industry by using light weight concrete.

II. RESEARCH PROGRAM AND EXPERIMENTAL PROCEDURE

2.1 INTRODUCTION

This chapter explains clearly about the study methods for producing lightweight concrete by using polystyrene. The various laboratory tests will be conducted to find properties of polystyrene aggregates like specific gravity, water absorption, crushing value, impact value, abrasion value etc. and mechanical properties of polystyrene concrete such as Compressive strength, Split tensile strength and Flexural strength. All the procedures and methods of test based on Indian standard code. Cubical, cylindrical, and beam samples are used to perform the above test. The materials used for casting concrete samples along with tested results are described.

2.2 TEST RESULTS OF MATERIALS USED IN PRESENT WORK

2.2.1 CEMENT

IS mark 43 grade cement (Brand-ACC cement) was used for all concrete mixes. The cement used was fresh and without any lumps. Testing of cement was done as per IS: 8112-1989. The various tests results conducted on the cement are reported in Table2.1.

Table 2.1 Properties of cement

Sr. No.	Characteristics	Values obtained	Standard value
1	Normal consistency	34%	-
2	Initial setting time (minutes)	48 min.	Not less than 30
3	Final setting time (minutes)	240 min.	Not greater than 600
4	Fineness (%)	3.5 %	<10
5	Specific gravity	3.07	-

2.2.2 COARSE AGGREGATE

Locally available coarse aggregates having the maximum size of 10 mm and 20mm were used in the present work. Testing of coarse aggregates was done as per IS: 383-1970. The 10mm aggregates used were first sieved through 10mm sieve and then through 4.75 mm sieve and 20mm aggregates were firstly sieved through 20mm sieve. They were then washed to remove dust and dirt and were dried to surface dry condition. The results of various tests conducted on coarse aggregate are given in Table 2.2, Table 2.3 & Table 2.4

Table 2.2 Properties of Coarse aggregates

S. No.	Characteristics	Value
1	Type	Crushed

2	Maximum size	20 mm
3	Specific gravity(10 mm)	2.704
4	Specific gravity (20 mm)	2.825
5	Total water absorption (10 mm)	1.6432 %
6	Total water absorption (20 mm)	3.645 %
7	Moisture content (10 mm)	0.806%
8	Moisture content (20 mm)	0.7049 %
9	Fineness modulus (10 mm)	6.46
10	Fineness modulus (20 mm)	7.68

Table 2.3 Sieve analysis of 10mm aggregates

S. No.	Sieve No.	Mass - Retained(kg)	Percentage Retained,%	Percentage Passing,%	Cumulative %age Retained
1	80mm	-	0.00	100	0.00
2	40mm	-	0.00	100	0.00
3	20mm	-	0.00	100	0.00
4	12.5mm	0.555	18.5	81.5	18.5
5	10mm	0.8905	29.68	51.82	48.18
6	4.75mm	0.9565	31.88	19.94	80.06
7	Pan	0.5970	19.90	0.04	99.96
				∑ C =	146.74

Fineness Modulus of Coarse aggregate (10 mm) = ΣC+500/100 = 146.74+500/ 100
= 6.46.

Table 2.4 Sieve analysis of 20 mm aggregates

S. No.	Sieve No.	Mass Retained(kg)	Percentage Retained,%	Percentage Passing,%	Cumulative %age Retained
1	80	-	0.00	100	0.00
2	40	-	0.00	100	0.00
3	20	0.00	0.00	100	0.00
4	12.5	2.1865	72.883	27.117	72.883
5	10	0.6745	22.483	4.634	95.366
6	4.75	0.1390	4.633	0.01	99.999
7	Pan	0.0	0.00	-	-
				∑ C =	268.244

Fineness Modulus of Coarse aggregate (20mm) = ΣC+500/100 = 268.244+500/ 100
= 7.68

2.2.3 FINE AGGREGATE

The sand used for the experimental programme was locally procured and conformed to grading zone III as per IS: 383-1970. The sand was first sieved through 4.75 mm sieve to remove any particles greater than 4.75 mm and then was washed to remove the dust. Properties of the fine aggregate used in the experimental work are tabulated in Table 2.5 and Table 2.6.

Table 2.5 Properties of fine aggregates

S. No.	Characteristics	Value
1	Type	Uncrushed
2	Specific gravity	2.68
3	Total water absorption	1.02 %
4	Moisture content	0.16 %
5	Net water absorption	0.86 %
6	Fineness Modulus	2.507
7	Grading Zone	III

Table 2.6 Sieve analysis of fine aggregate

S. No.	Sieve No.	Mass Retained(kg)	Percentage Retained,%	Percentage Passing,%	Cumulative %age Retained
1	4.75mm	95.0	9.5	90.5	9.5
2	2.36mm	42.5	4.25	86.25	13.75
3	1.18mm	110.5	11.05	75.2	24.8
4	600μm	128.5	12.85	62.35	37.65
5	300 μm	308.0	30.8	31.55	68.45
6	150 μm	281.0	28.1	3.45	96.45
7	Pan	34.5	3.45	-	
				∑ F =	250.7

Fineness Modulus of fine aggregate = ΣF/100 = 250.7/100 = 2.507

2.2.4 PREPARATION OF POLYSTYRENE AGGREGATE

Common waste polystyrene foam had to be cut into the dimension of approximate 10 mm to 20 mm; this dimension is designed to pass the sieve 20 mm. These aggregates are easily compressed at less compressive force, to increase its compressive strength and stiffness it is coated with cement and acrylic solution. After drying these PLCA aggregates are ready to use in concrete to make concrete lightweight

Table 2.7 Physical Properties of Polystyrene

Property	Results
Specific Gravity	1.3
Bulk Relative Density	17.92
Water Absorption, %	0.03 TO 0.04 %
Moisture content, %	0%

Densities of expanded polystyrene are between 10 and 30 kg/m3. It is durable against heat up to 100 °C for a short period, it is durable and can be used up to 75-85 °C according to its density for a long period.

Figure 2.1 Coated PLCA

2.2.5 WATER

Potable tap water was used for the concrete preparation and for the curing of specimens.

2.2.6 SUPERPLASTICIZER

Conplast – SP 430, a concrete super-plasticizer based on sulphonated naphthalene polymer was used as a water-reducing admixture and to improve the workability of concrete containing polystyrene aggregate. Conplast - SP 430 has been specially formulated to give high water reductions up to 25% without loss of workability or to produce high quality concrete of reduced permeability. Conplast - SP 430 is non-toxic. Super-plasticizer complies with IS: 9103: 1999, ASTM C – 494 Type F, BS 5057 part III. The dosage of super-plasticizer varied from 0.5% to 2% by weight of cement in plain concrete, concrete incorporating foundry sand. Technical data of Super-plasticizer are listed in Table 2.8

Table 2.8 Technical data of Super-plasticizer

Sr. No.	Characteristics	Value
1	Colour	Dark Brown liquid
2	Specific Gravity @ 30c	1.220 to 1.225

2.3 PREPARATION OF TEST SAMPLES

Cubical mould of size 150mm x 150mm x 150mm were used to prepare the concrete specimens for the determination of compressive strength of PLCA concrete at various replacement levels. Care was taken during casting and vibrator was used for proper compaction. Cylindrical mould of size 150 mm diameter x 300 mm were used to prepare the concrete specimens for the determinations of split tensile strength of polystyrene light weight concrete. All the specimens were prepared in accordance with Indian Standard Specifications IS: 516-1959.All the moulds were cleaned and oiled properly. These were securely tightened to correct dimensions before casting. Care was taken that there is no gaps left from where there is any possibility of leakage out of slurry.

2.4 MIX DESIGNATION

Concrete mix has been designed based on Indian Standard Recommended Guidelines IS: 10262-2009. The proportions for the concrete, as determined were 1:1.45:2.2:1.103 with a water cement ratio of 0.5 by weight. The mix designation and quantities of various materials for each designed concrete mix have been tabulated in Table 2.9 and 2.10 for cubes and cylinders.

Concrete specimens with various percentage of polystyrene were prepared. The details of various mix proportions for different replacement levels of cement by polystyrene (0, 20, 40, 60, 80 and 100%) are shown in Table below.

Table 2.9 Proportion of M-20 Grade Concrete

Sample no.	Cement Kg/m3	Fine Aggregate kg/m3	Course Aggregate (10mm) Kg/m3	Course Aggregate (20mm) Kg/m3	Percentage replacement of PLCA(%)	Water (Lts/m3)	Plasticizer (Lts/m3)
M-1	372	538.45	410.4	818.85	0	186	0.288
M-2	372	538.45	328.4	655.08	20	186	0.288
M-3	372	538.45	246.4	491.31	40	186	0.288
M-4	372	538.45	164.4	327.54	60	186	0.288
M-5	372	538.45	82.4	163.77	80	186	0.288
M-6	372	538.45	0.0	0.0	100	186	0.288

Table 2.10 Slump at different PLCA % replacement

Grade of concrete	Concrete type	designation	Percentage binder ratio		Slump test (mm)
			Natural Coarse Aggregate (%)	Polystyrene Coarse Aggregate (%)	Results
M20	Control mix	M-1	100	0	80
	Waste Polystyrene Concrete	M-2	80	20	75
		M-3	60	40	77
		M-4	40	60	80
		M-5	20	80	84
		M-6	0	100	85

2.5 BATCHING, MIXING AND CASTING OF SPECIMENS

A careful procedure was adopted in the batching, mixing and casting operations. The coarse mixture was prepared by hand mixing on a watertight platform. PPC having 43 grades were used in casting. Three proportions of fine aggregates are replaced with light weight polystyrene aggregate and thoroughly mixed. After that coarse aggregates are added to it. Super-plasticizer as per requirement was added to required quantity of water separately in different containers. Then water was added carefully so that no water was lost during mixing. Six clean and oiled moulds for each category were then placed on the vibrating table respectively for the cubical samples for compression strength tests and twelve cylindrical moulds for split tensile and modulus of elasticity testing were filled in three layers. Vibrations were stopped as soon as the cement slurry appeared on the top surface of the mould. The specimens were allowed to remain in the steel mould for the first 24 hours at ambient condition. After that these were de-moulded with care so that no edges were broken and were placed in the curing tank at the ambient temperature for curing. The ambient temperature for curing was 27 ± 20.

III. RESULT AND DISCUSSION

3.1 INTRODUCTION

Various properties of concrete incorporating PLCA at various replacement levels with coarse aggregate were studied, results were compared and checked for compressive strength, split tensile strength and flexural strength.

3.2 TESTS ON PLCA CONCRETE AND CONVENTIONAL CONCRETE

3.2.1 SLUMP TEST ON PLCA CONCRETE CUBE

In slump test, workability of PLCA concrete is determined at different replacement of coarse aggregate by PLCA.

Table 3.1 Slump observed at different % replacement of coarse aggregate by PLCA

Sample No.	Replacement of Coarse aggregate by PLCA (%)	w/c	Slump (mm)
M-1	0	0.5	75
M-2	20	0.5	60
M-3	40	0.5	70
M-4	60	0.5	78
M-5	80	0.5	85
M-6	100	0.5	90

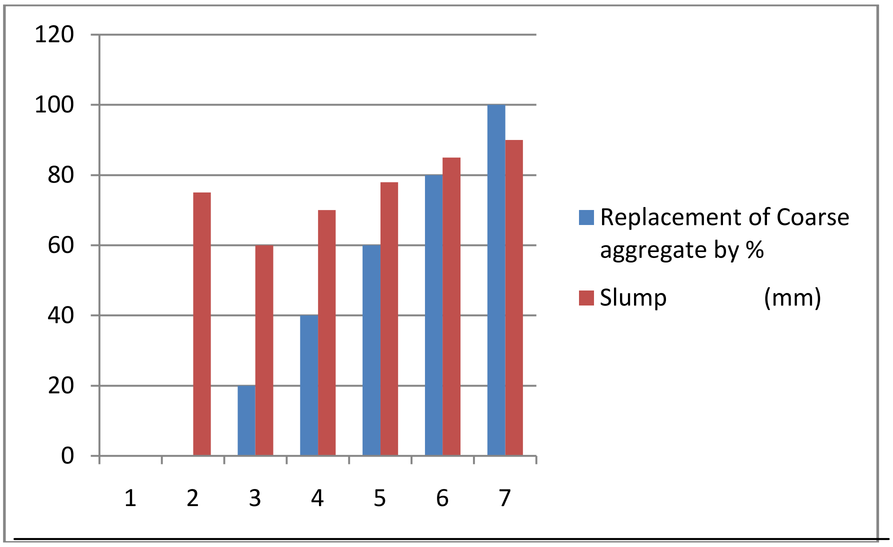

Figure 3.1 Slump observed at different % replacement of coarse aggregate by PLCA

3.2.2 COMPRESSION TEST ON PLCA CONCRETE CUBE

In this research the values of compressive strength for different replacement levels of coarse aggregate contents (0%, 20%, 40%,60%,80% and 100%) at the end of different curing periods (3 days,7 days,28 days) are given in Table 3.2. These values are plotted in figs. 3.1, which show the variation of compressive strength with percentage coarse aggregate replacements.

It is evident from Fig. 3.2 that compressive strength of concrete mixtures with 20%, 40%, 60%, 80% and 100 % of PLCA as coarse aggregate replacement was higher than the control mixture (M-1) at all ages and that the strength of all mixtures continued to increase with the age. Fig. 3.2 shows that compressive strength decreases with the increase in PLCA content.

Table 3.2: Compressive Strength (MPa) of Concrete after curing

Sample No.	Replacement of Coarse aggregate by %	Average compressive strength after curing for		
		3 days	7days	28 days
M-1	0	12.02	16.77	21
M-2	20	8.34	14.5	19.11
M-3	40	5.78	11.56	16.8
M-4	60	4.24	8.56	13.8
M-5	80	3.43	6.25	11.98
M-6	100	3.03	5.83	7.67

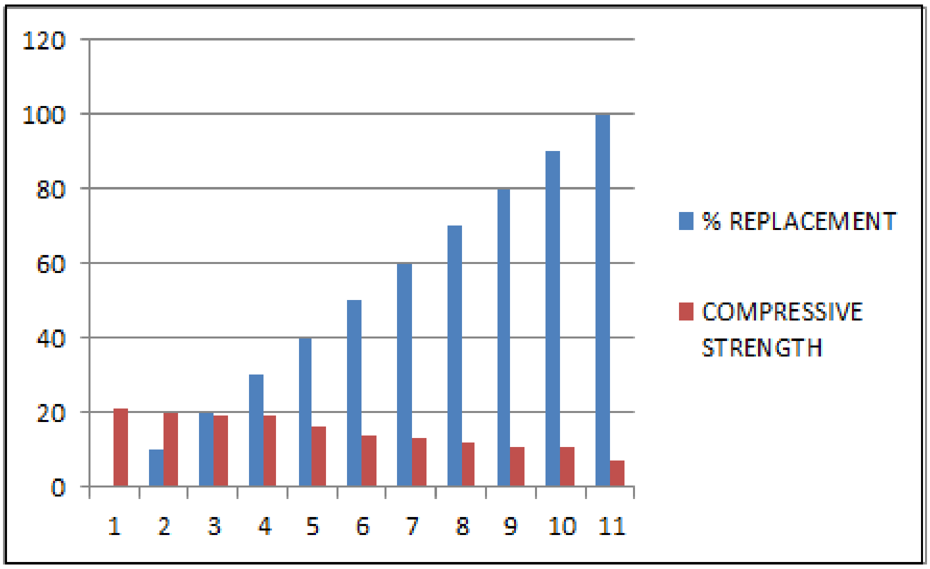

Figure 3.2 Comparison of Compressive strength and percentage replacement

3.2.3 SPLIT TENSILE TEST ON PLCA CONCRETE CUBE

By conducting splitting tensile strength on cylinder following results were obtained which is given in table 3.3

The cylinder split tensile strength is calculated by following formula equation

$T = 2P / \pi L D$

Where,

T = Split tensile strength in N/mm^2

P = Compressive force at failure on cylinder in N

L = Length of cylinder in mm

D = Diameter of cylinder in mm

Figure 3.3 Cylinder split tensile strength test.

Table 3.3 Average tensile strength after 28 days curing

Sample No.	**Replacement of Coarse aggregate by PLCA (%)**	**Average tensile strength after 28 days curing (N/mm^2)**
M-1	0	2.15
M-2	20	1.64
M-3	40	1.1
M-4	60	0.4
M-5	80	0.2
M-6	100	0

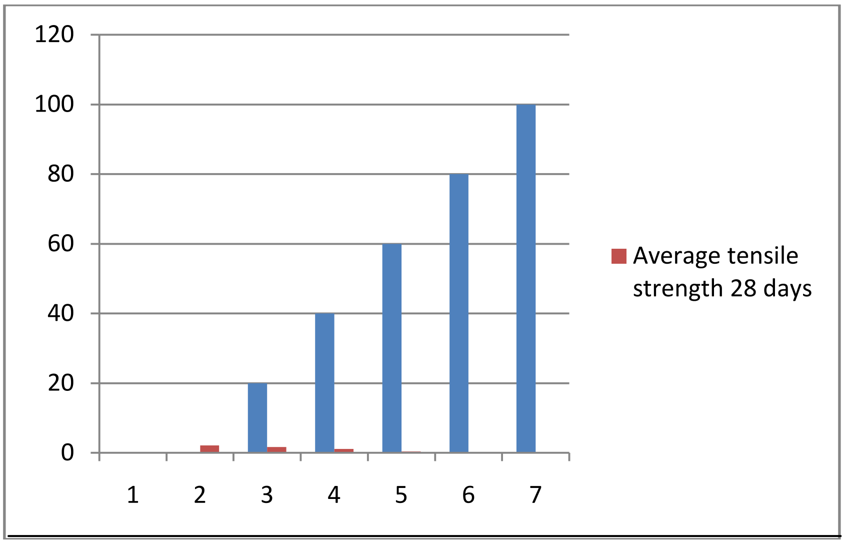

Figure 3.4 Average tensile strength 28 days

From the table 3.3, it can be seen that the concrete containing PLCA shows a lower resistance to splitting as compared to conventional for replacement of PLCA. It is observed that the tensile strength shows significant decrease in value for higher percentage of PLCA.

3.2.4 Flexural strength test on Beam

For finding flexural strength of concrete beam, load is applied uniformly on beam. The load was increased until the specimen fails, and maximum load applied to the specimen during the test, was recorded. Table 3.4 shows results of flexural strength test.

The flexural strength of specimen is calculated by following equation

$$F = M/Z = 6\ P\ L/\ 4BD^2$$

Where:

F = Flexural strength in N/mm^2

M = Moment of resistance in N mm,

Z = bd2/6 = Modulus of section in mm3,

B = Width in mm,

D = Depth in mm,

L = Supported span in mm.

Figure 3.5 Experimental setup for Flexural Strength Test

Table 3.4 Average tensile strength after 28 days curing

Sample No.	Replacement of Coarse aggregate by %	Average Flexural strength 28 days (N/mm^2)
M-1	0	6.4
M-2	20	4.2
M-3	40	2.3
M-4	60	1.76
M-5	80	0.8
M-6	100	0.3

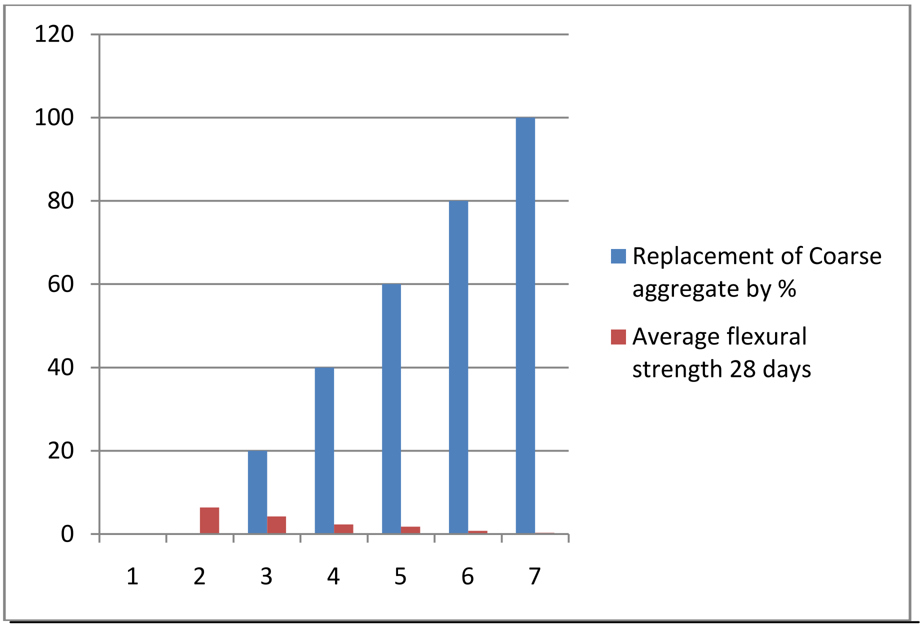

Figure 3. 6 Average tensile strength after 28 days curing

From the table 3.4 and figure 3.6 above, it can be seen that the concrete containing PLCA shows a lower resistance to flexure as compared to conventional for replacement of PLCA. It is observed that the flexural strength shows significant value for lower percentage of PLCA and for further increase; strength will decreases.

IV. CONLUSION

After the entire study been done to determine the strength development of polystyrene concrete, the following conclusion can be drawn from the investigation,

1. It is observed that the compressive strength, tensile strength and flexural strength of PLCA concrete decreases with the increase in percentage replacement of Polystyrene Coarse aggregates.
2. It is also observed that the polystyrene coarse aggregates affect workability of concrete. At lower percentage replacement of natural coarse aggregate by PLCA, the workability is less as compared to conventional concrete but it increases with increase in percentage replacement of PLCA.
3. It is suggested that to use PLCA concrete in construction of non structural members and the members which are subjected to less structural loads.

4. PLCA concrete is very useful for manufacturing bricks as it gives the good compressive strength at higher percentage replacement (100%) of PLCA as compare to conventional bricks.
5. This paper provides a study on the behavior of PLCA concrete under uniaxial compression splitting and flexural tensile strength.
6. The strength of PLCA aggregate is the primary factor controlling the strength of light weight concrete with PLCA. Compressive strength level of 7 to 19.1 MPa with the corresponding air dry density of 12 to 21.00 kN per cu m is observed.
7. The flexural and splitting tensile strength vary from 2.15 to 0.0 Mpa and from 6.4 to 0.3 MPa respectively.

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