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MECHANICAL PERFORMANCE OF CELLULAR LIGHT WEIGHT CONCRETE WITH OR WITHOUT FIBER

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Abstract* — The present work investigates the performance of cellular light weight concrete (CLC) to study the effects, on the workability, compressive strength and shrinkage of foamed concrete by replacing the cement with Fly Ash. Adding different percentage of synthetic fiber in foamed concrete. In this work find out the densities, workability, shrinkage, flexural strength and compressive strength development of foamed concrete. Preformed foam by using local protein based foaming agent and foam generator is used to produce the foamed concrete. Different types of mixtures with varying fly ash content, different percentage of synthetic fiber and foaming agent/water ratio (1:40) is prepared and tested. Then after to gain maximum strength at 28 days with optimum fly ash content with and without synthetic fiber. Workability and drying shrinkage increase as the fly ash replacement of cement increases.

***Keywords*— Foam concrete, Fly ash, Synthetic fiber, Compressive strength, Flexural strength, Flowability and shrinkage.**

I. INTRODUCTION

One of the Cellular light weight concrete (CLC) is produced by mixing of cement, fly-ash, sand, foam and water in required proportions using ready mix plant or ordinary concrete mixer. Cellular light weight concrete is also known as “foam concrete", CLC and light weight concrete.

CLC is a different type of concrete, where natural gravel is replaced by the air, embedded in stable and bio-degradable, organic foam which has no chemical reaction. The foam in the CLC does not involve any gas releasing chemical reaction, and therefore it maintains its density and does not expand. The density range of lightweight concrete is 800-1800 kg/m³ appropriated with its compressive strength.

Foamed concrete may be produce by mixing the above mentioned ingredients in ready mix plant or ordinary concrete mixer. Foamed concrete is self-compacting concrete requires no compaction, and will flow readily from a pump to fill mould, form restricted and irregular cavities. It is very popular in the construction industry because of its good properties such as easy moulding, light in weight, cheap and easy to manufacturing.

The air content in CLC is typically between 45 and 85 percent of the total volume of concrete. The bubbles size vary from around 0.1 to 1.5 mm in diameter but bubbles are quite larger than this, particularly at the top of the surface of concrete. Foamed light weight concrete are moulded in the different shapes according to requirements like bricks, blocks or poured, which is used for thermal insulation over flat roofs or for cold storage walls or as non-load bearing walls in RCC/Steel framed buildings.

Applications of CLC – Blocks, Panels, Ceiling panels, Pre-cast exterior walls, Void filling, Roof insulation, Thermal insulations, Sound insulation, Floors, Road construction, Low cast housing.

The characteristics of CLC such as high strength-to-weight ratio and low density. Using of CLC to reduces dead loads on the structure and foundation, contributes to energy conservation, and lowers the labor cost during construction.

It can also reduce the cost of production and transportation of building components compared to normal concrete and has the potential of being used as a structural material.

In the recent years, more attention has been focused to the development of cellular lightweight concrete due to its advantages of being a relatively ‘green’ building material, energy saving and environmental – friendly. CLC is light in weight and gives high strength in low density which is very useful for the tall structures or heavy structures and bridges where the self-weight of the structure creates problem for the designers.

CLC is also useful in construction of tall buildings to reduce the amount of reinforcement and member cross-sections, and foundation size. CLC has a unique feature, it takes large surface area with low density and gives good strength.

II. MATERIAL AND MIX DESIGN

1. MATERIAL

1. Cement – The cement used in this study was a 53 Grade ordinary Portland cement. Its density is 3150 kg/m3, and its physical properties are shown in Table 1.

Table 1 Physical property of cement

Parameter	53 grade opc
Minimum compressive strength(N/mm²)	
7 days	23
14 days	33
28 days	43
Fineness	
Minimum specific surface (m²/kg)	225
Setting time (minute)	
Initial time	30
Final time	600
Soundness expansion (mm)	10

2. Fly ash – Fly ash was received from the power plant in pithampur, India. Fly ash was used as dry and screened to remove some large particles. Fly ash is sieved with 90 micron for screening of large partial. It is partially replaced to the cement for reduce the cost, and to reduce heat of hydration while contributing towards long term strength (as per IS-3812-2003 part 1). Chemical composition of fly ash as shown in Table2.

Table 2 Chemical composition of fly ash

Chemical composition	Fly ash content
Fe_2O_3+Al_2O_3+SiO_2	50
SiO_2	25
CaO	More than 10%
Relative silica	20
MgO	5.0
Na_2O	3.1
Chloride (Cl)	2.6
SO_3	3.0

3. Sand – The sand is generally preferred from river which is washed and free from dust, organic materials and other impurities. Locally available sand used in our experimental work which is received from Indore, India. Sand is sieved with 600 micron for screening the large particles. Small amount of sand in foam concrete is good for contribution in strength. Specific gravity and water absorption of locally available sand is 2.64 and 0.80% are calculated from the experimental work.

4. Crushed stone – Locally available crushed stone used in our experimental work which is received from Indore, India. Crushed stone is sieved from 600 micron. Natural sand is rounded in shape but the crushed stone is angular in shape. Crushed stone is highly used in construction work which is good for normal concrete but crushed stone is not good for foam concrete because the sharp edges of crushed stone destroyed the foam bubbles.

5. Foaming agent – Protein based foaming agent was used in experimental work. It is suitable for densities of 1000kg/m³ and above. Foaming agent diluted with water in the ratio of 1:40. It is bio-degradable, organic foam which has no chemical reaction. It has 27.5% concentration of hydrogen peroxide, it reacts with the catalyst manganese dioxide (MnO2) to form oxygen gas during the making process of Foam. The property of protein based foaming agent as shown in Table 3. The reaction equation is

$$2H2O2 \xrightarrow{Mno2} 2H2O + O2$$

Table 3 Property of protein based foaming agent

Parameter	Protein based foaming agent
Appearance	Dark brown liquid
Specific gravity	1.15 – 1.18
PH at 20°C	6.5 – 7.5
Solubility	Good
Mixing ratio	1:40 (foaming agent : water)
Freezing point	0°C

4. Fiber – Fiber used in this study was a polypropylene synthetic fiber, that was received from Jaipur, Rajasthan as shown in Figure 4.6. The fibers are manufactured in a continuous process of extraction of polypropylene granules. Synthetic fibers are often added to concrete for crack control in concrete block. Its properties are shown in Table 4.

Table 4 Property of fiber

	Polypropylene synthetic fiber
Specification	Bi-component fiber
Material	Polypropylene
Form	Structural fiber
Specific gravity	0.91
Length	50 mm
Tensile strength	618 N/mm²
Modulus of elasticity	10 mm
Diameter	0.5 Gpa
Decomposition temperature	360°C

2 Mix design

The base mix comprises the solids (cement, Fly ash, foam, fibers) and water. Its strength depends on its constituent proportions and density. The strength of the base mix defines the maximum strength of the foamed concrete.
Mix proportion - There is at present, no guidance or standard method for proportioning foamed concrete. Because the hardened density of foamed concrete depends on the saturation level in its pores, it is difficult to obtain an accurate measure of its density on site. Mix proportion were design for the density of 1000kg/m³, 1200kg/m³, 1400kg/m³, 1600kg/m³.

Table 5. Best proportion for cement and fly ash ratio

Type	**Number of samples**	**Ratio Cement : fly ash**	**W/C ratio**	**Foam (1:40) In kg/m³**
A1	9	1:1	0.45	<70
B1	9	1:2	0.45	<70
C1	9	2:1	0.45	<70

Table 6. Different % of fiber with best cement/fly ash ratio

Type	**Number of sample**	**Ratio Cement : fly ash**	**W/C ratio**	**Fiber (% of wt. of cement)**	**Foam(1:40) In kg/m³**
A2	9	1:1	0.45	0.3	<70
B2	9	1:1	0.45	0.5	<70
C2	9	1:1	0.45	0.7	<70

Table 7. Different % of sand in best cement/ fly ash ratio

Type	**Number of sample**	**Ratio Cement : fly ash**	**W/C ratio**	**Sand (% of wt. of C+FA)**	**Foam (1:40) In kg/m³**
X1	9	1:1	0.45	5	<70
Y1	9	1:1	0.45	7	<70
Z1	9	1:1	0.45	10	<70

Table 8. Different % of crushed stone in best cement/ fly ash ratio

Type	**Number of sample**	**Ratio Cement : fly ash**	**W/C ratio**	**Crushed stone (% of wt. of C+FA)**	**Foam (1:40) In kg/m³**
X2	9	1:1	0.45	2	<70
Y2	9	1:1	0.45	4	<70
Z2	9	1:1	0.45	6	<70

Table 9. Best cement/fly ash ratio and % of fiber is taken

Type	**Density (kg/m^3)**	**Cement : fly ash (1:1)**		**W/C ratio 0.45 (in liter)**	**Fiber (0.5 % of weight of cement in kg)**	**Foam(1:40) (kg/m^3)**	**Design density (kg/m^3)**
		Cement	**Fly ash**				
A3	1200	480	480	216	2.4	<70	1248
B3	1400	550	550	248	2.75	<70	1420
C3	1600	650	650	292	3.25	<70	1650

III. CASTING AND DEMOULDING

1. Before casting, oil was applied to the moulds to make sure concrete will not stick to it.

2. Prepared foam concrete filled in the mould and the surface was leveled to get smooth finish. The dimensions of cubes are – 70.6 X 70.6 X 70.6 mm3 as shown in Figure 4.13 and 4.14 and the blocks are 500 X 250 X 150 mm. Foam concrete is a self compacting concrete that was not required vibration and tamping.

3. The specimen was left for the hardening for 24 hr. – 48 hr., after the time period, specimen were demoulded with necessary tools.

4. The cube was transferred for curing to the curing tank.

IV. CONDUCTED TESTS

1. Consistency Test

The consistency test is used to find the amount of water to be mixed with cement by vicat apparatus. It is necessary to find the consistency because amount of water present in the cement paste may affect the setting time. Consistency of cement should between 5 – 7mm. If the water is less than its quantity couldn't complete reaction. Thus, resulting is reduction of strain and more water would increase water cement ratio and so would reduce its strength.

2. Density test

I. Foam density – Density of foam is depending on the proportion of water and foaming agent to be mixed. Generally the density of foam is about 40-80 kg/m^3. Density of foam is checked by filling of 1 liter of vessel with foam and calculates the weight, after removing foam again calculate the weight of vessel. The difference between empty and filled vessel gives the density of foam.

II. Foam concrete density – The foam concrete slurry test is conducted after the mixing of all material. The density of slurry is check by the filling of foam concrete slurry in 1 liter of glass and check the weight of it that gives us the actual density of foam concrete. The density of foam concrete may be varying about $\pm 50 kg/m^3$.

3 Flowability test – Flowability test were conducted by using of slump cone equipment which is very important test for the concrete to check the flow ability of concrete. The flow test is conducted to calculate the deformability of foam concrete. If the measurement of the two diameters differs by more than (50 mm), the test is invalid and shall be repeated. (ASTM C1611)

The deformability of foam concrete is calculated by the equation and shown in Table 10.

$$\text{Slump flow} = (D1 + D2)/2$$

Where, D1 = 1st diameter of spread concrete
D2 = 2nd diameter of spread concrete

Figure 1. Slump cone test for flowability

Table 10 Slump flow value of concrete

Density (kg/m^3)	D1 (in cm)	D2 (in cm)	Slump flow (in cm)
1200	53	51	52
1400	50	48	49
1600	45	46	45.5

4 Drying shrinkage tests - The difference between the length of specimen which has been immersed in water and then subsequently dried to constant length, all under specified conditions: expressed as a percentage of the dry length of the specimen. Drying shrinkage shall be a maximum of 0.05 percent for the load bearing class of blocks and a maximum of 0.08 percent for the non-load bearing class of blocks as shown in Table 11.

Table 11 Shrinkage value of block

Density (kg/m^3)	Drying shrinkage (%)
1200	0.08
1400	0.07
1600	0.06

5 Water absorption test – Different density blocks completely immersed in the clean water at a room temperature for 24 hr. or 1 day. After the completion of time then the all blocks are removed form the water and allow to drain for 1 minute. Remove surface water with dry cloth and dry block immediately weighed. After weighing all blocks are free for drying at 100 to 1150°C for 24 hr. weighing the dry weighed block as shown in Table 12.
The water absorption calculated as –

$$\text{Absorption percentage} = (A-B)/B*100$$

Where, A = Wet mass of block in kg.
B = Dry mass of block in kg.

Table 12 Water absorption of blocks

Density (kg/m^3)	Dry weight of block (in kg)	Wetted weight of block (in kg)	Weight of absorbed water (in kg)
1200	22.6	25	2.4
1400	26.4	29.16	2.79
1600	30	32.9	2.9

6 Compression test – The compressive test is performed by the compressive testing machine. An axial compressive load with a specified rate of loading is applied to the cube until failure. The cube was taken out from the water tank and places it for dry of minimum 1 day. Before test, the dimension of the cube was measured. The cube is placed at center of the testing machine for test as shown in Figure 2. Constant rate of loading applied to the specimen until the specimen fails. Compressive strength of cube is calculated by the given load and the surface area of the cube.

The compressive strength of cube is calculated as –
Compressive strength = P / A (N/mm²)
Where, P = maximum load in newton (N)
A = cross sectional area of cube in mm².

(a) (b)

Figure 2 (a) compression test of cube (b) failed cube

7 Flexural test – Flexural strength of concrete block is one measure of the tensile strength. It is measure of an concrete block without reinforcement to resist the failure in bending. The flexural strength is expressed as modulus of rupture in MPA and is determined by the three point loading or four point loading (ASTM C 78) as shown in Figure 3.
The flexural strength or modulus of rupture calculated as
Flexural strength = PL / BD²
(When a > 20cm for 15 cm specimen or a > 13cm for 10 cm specimen)
Flexural strength = P a / BD²
(When a < 20cm but > 17 cm for 15 cm specimen or a < 13cm but > 11cm for 10 cm specimen)
Where,
a = distance between fracture and nearest support
P = maximum applied load
B = width of specimen
D = depth of specimen
L = length of specimen

Figure 3 flexural test of block and failure of block

V. RESULTS

The testing of various samples has been done by varying the percentage of fly ash and also varying the percentage of polypropylene synthetic fiber. 50% of fly ash and 0.5 % of fiber of the weight of cement gives the best results. To find out the compressive strength and flexural strength of foam concrete and also find the water absorption and drying shrinkage of the foam concrete.

1. Compressive Strength Test

1. Compressive strength of foam concrete - (Density - 1000kg/m³)

Table 13. 33% of fly ash replaced with cement, without fiber

Type	Days	Compressive strength (N/mm²)
A1	7	2.08
	14	2.92
	28	3.12

Table 14. 50% of fly ash replaced with cement, without fiber.

Type	Days	Compressive strength (N/mm²)
B1	7	2.65
	14	3.48
	28	3.57

Table 15. 67% of fly ash replaced with cement, without fiber.

Type	Days	Compressive strength (N/mm²)
C1	7	2.11
	14	2.81
	28	3.07

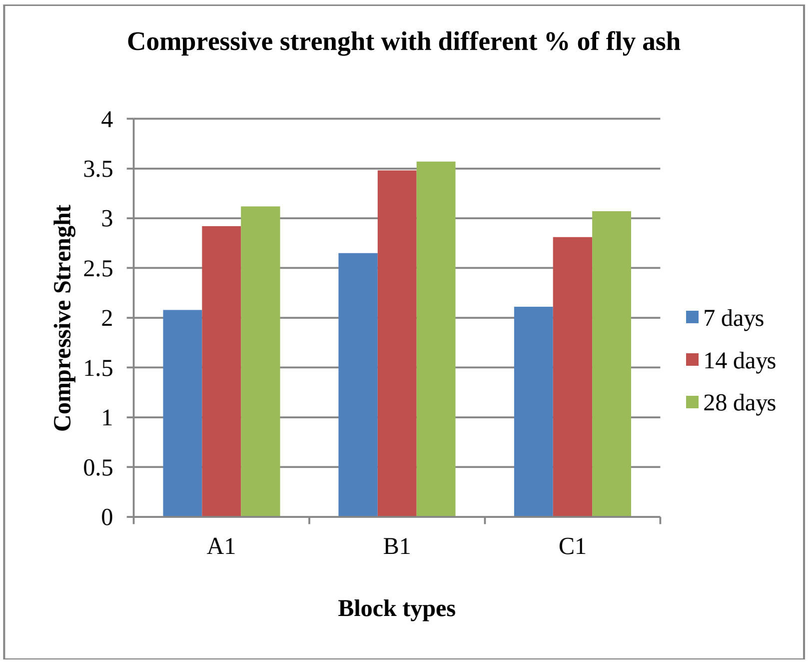

Figure 4. Compressive strength with different % of fly ash

2 .Compressive strength of foam concrete with sand (Density-1000kg/m³)

Table 16. 5% sand of wt. of C+FA in best cement/fly ash ratio

Type	Days	Compressive strength (N/mm²)
X1	7	2.00
	14	2.62
	28	3.01

Table 17. 7% sand of wt. of C+FA in best cement/fly ash ratio

Type	Days	Compressive strength (N/mm²)
Y1	7	2.18
	14	2.89
	28	3.21

Table 18. 10% sand of wt. of C+FA in best cement/fly ash ratio

Type	Days	Compressive strength (N/mm^2)
Z1	7	2.09
	14	2.70
	28	3.10

3. Compressive strength of foam concrete with crushed stone (Density-1000kg/m³)

Table 19. 2% crushed stone of wt. of C+FA in best cement/fly ash ratio

Type	Days	Compressive strength (N/mm^2)
X2	7	1.89
	14	2.45
	28	2.78

Table 20. 4% crushed stone of wt. of C+FA in best cement/fly ash ratio

Type	Days	Compressive strength (N/mm^2)
Y2	7	1.90
	14	2.47
	28	2.80

Table 21. 6% crushed stone of wt. of C+FA in best cement/fly ash ratio

Type	Days	Compressive strength (N/mm^2)
Z2	7	1.87
	14	2.33
	28	2.67

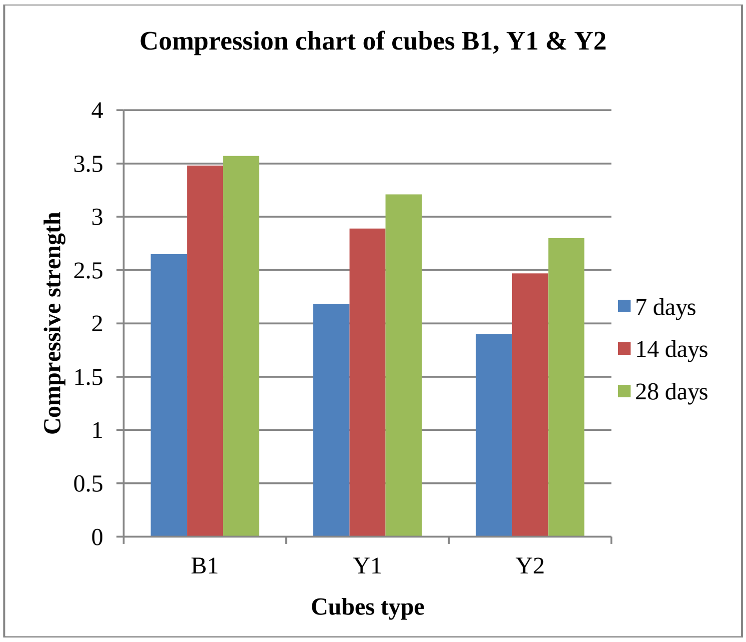

Figure 5 Compression of compressive strength of cubes B1, Y1 & Y2

4. Compressive strength of foam concrete with fiber (Density - 1000kg/m³)

Table 22. 50% of fly ash replaced with cement, add 0.4% fiber.

Type	Days	Compressive strength (N/mm^2)
A2	7	2.21
	14	3.01
	28	3.23

Table 23. 50% of fly ash replaced with cement, add 0.5% fiber.

Type	Days	Compressive strength (N/mm²)
B2	7	2.76
	14	3.54
	28	3.69

Table 24. 50% of fly ash replaced with cement, add 0.6% fiber.

Type	Days	Compressive strength (N/mm²)
C2	7	2.12
	14	2.79
	28	2.86

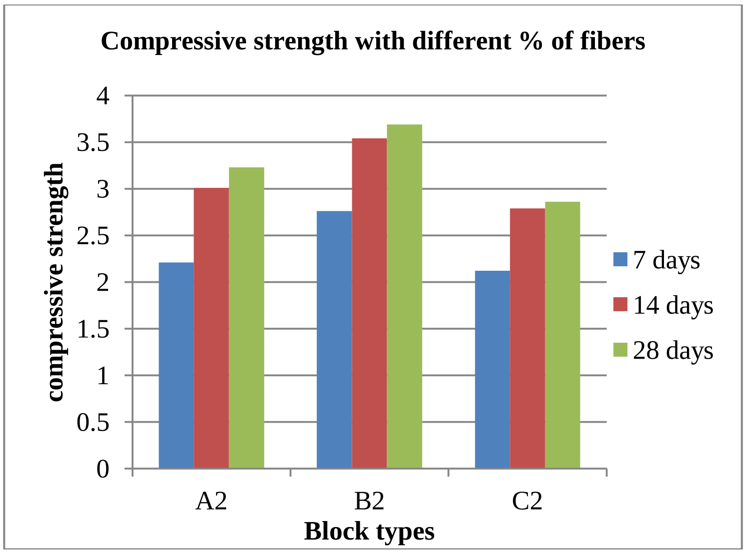

Figure 6 compressive strength of foam concrete with different % of fibers

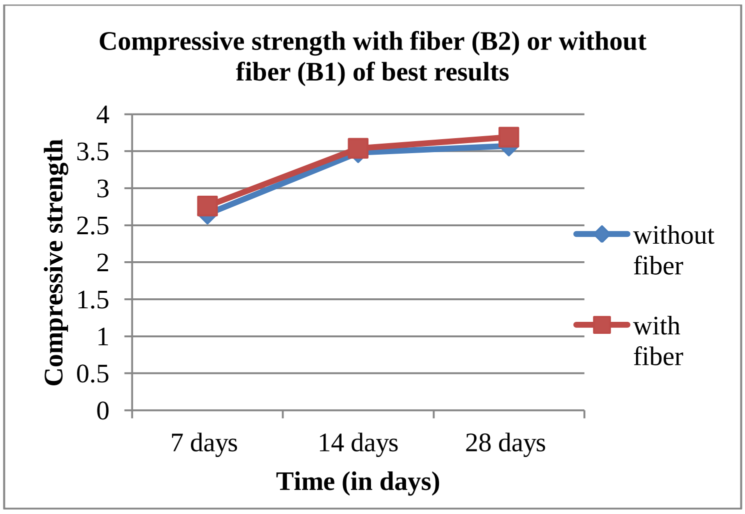

Figure 7 compressive strength of foam concrete with and without fiber

Table 25. Percentage of compressive strength increased of block B2 from without fiber to with fiber in 7 days.

Fiber contain (in %)	Compressive strength (7 days)	Variation (in %)
0 %	2.65	-
0.3 %	2.21	-16.6%
0.5 %	2.76	4.15%
0.7 %	2.12	-20%

Table 26. Percentage of compressive strength increased of block B2 from without fiber to with fiber in 14 days.

Fiber contain	Compressive strength (14 days)	Variation (in %)
0%	3.48	-
0.3%	2.76	-20.67%
0.5%	3.54	1.75%
0.7%	2.79	-19.83%

Table 27. Percentage of compressive strength increased of block B2 from without fiber to with fiber in 28 days.

Fiber contain	Compressive strength (28 days)	Variation (in %)
0%	3.57	-
0.3%	3.23	-9.52%
0.5%	3.79	6.16%
0.7%	2.86	-19.88%

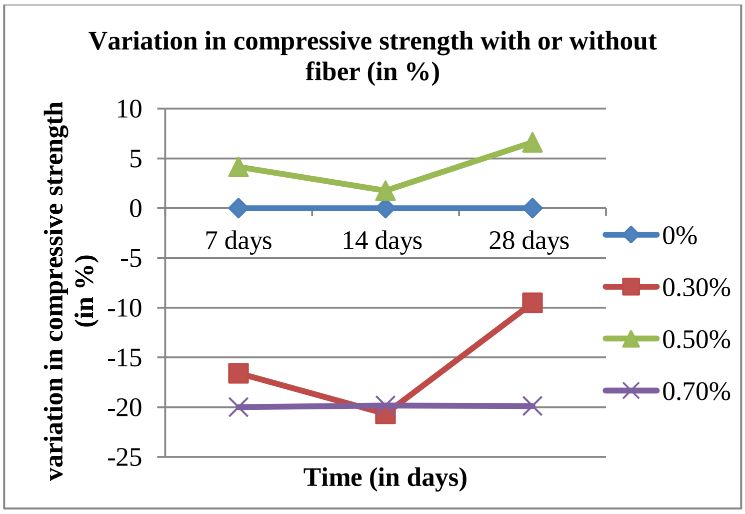

Figure 8 Variation in compressive strength with and without fiber of B2.

2. Flexural strength of blocks

Table 28. Flexural strength of foam concrete without fiber of density 1200 kg/m³

Type	Days	Flexural strength (in N/mm²)
P1	7	0.426
	14	0.663
	28	0.717

Table 29. Flexural strength of foam concrete with fiber of density 1200 kg/m³

Type	Days	Flexural strength (in N/mm²)
Q1	7	0.461
	14	0.766
	28	0.790

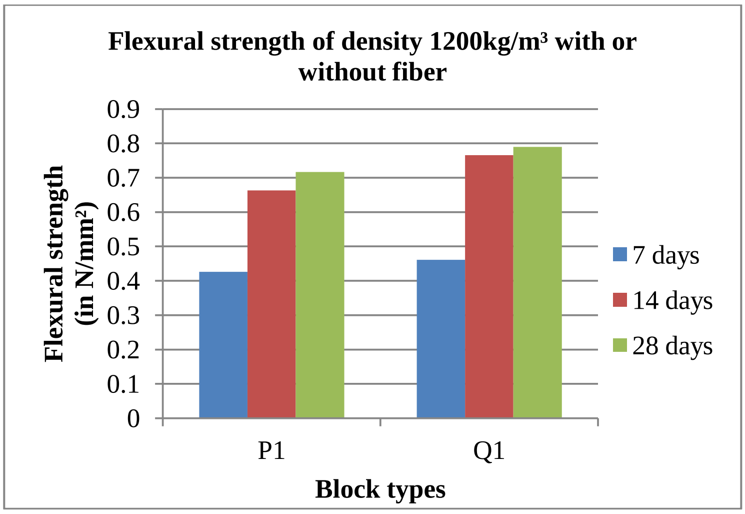

Figure 9 Flexural strength of density 1200kg/m³ block with and without fiber.

Table 30. Flexural strength of foam concrete without fiber of density 1400 kg/m³

Type	**Days**	**Flexural strength (in N/mm²)**
P2	7	0.600
	14	0.804
	28	0.843

Table 31. Flexural strength of foam concrete with fiber of density 1400 kg/m³

Type	**Days**	**Flexural strength (in N/mm²)**
Q2	7	0.663
	14	0.837
	28	0.849

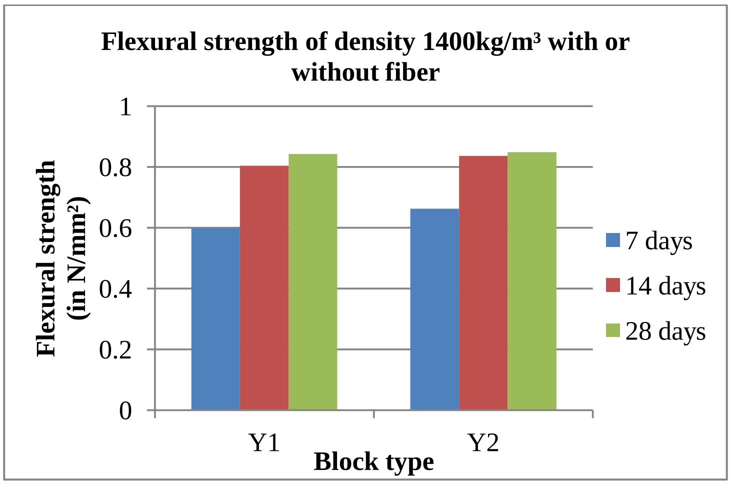

Figure 10 Flexural strength of density 1400kg/m³ block with and without fiber.

Table 32. Flexural strength of foam concrete without fiber of density 1600 kg/m³

Type	**Days**	**Flexural strength (in N/mm²)**
P3	7	0.693
	14	0.919
	28	0.935

Table 33. Flexural strength of foam concrete with fiber of density 1600 kg/m³

Type	**Days**	**Flexural strength (in N/mm²)**
Q3	7	0.695
	14	0.974
	28	1.060

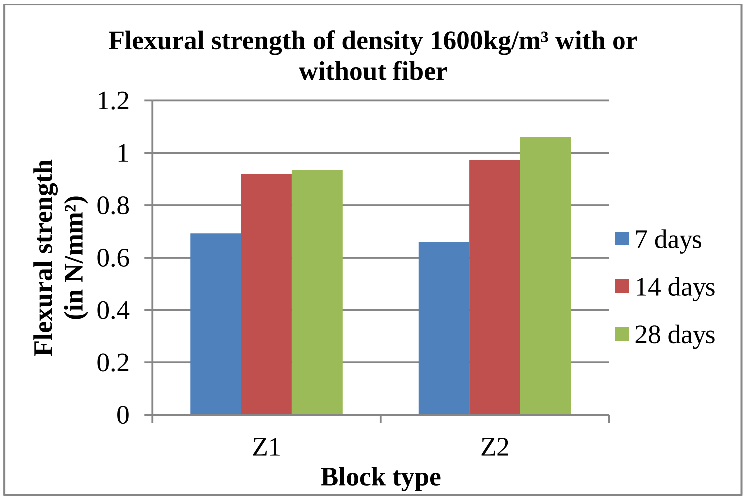

Figure 11. Flexural strength of density 1600kg/m³ block with and without fiber.

3. Water absorption test

Table 34. Percentage of water absorbed

Density (kg/m³)	% of water absorbed
1200	10.62
1400	10.45
1600	9.67

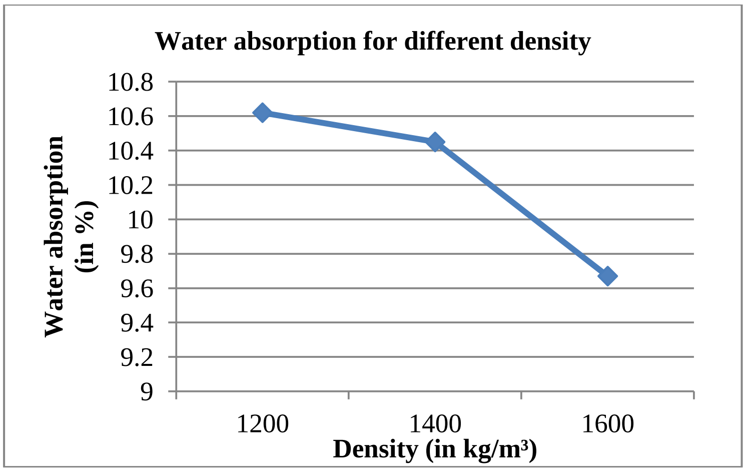

Figure 12 Water absorption chart for different density.

4. Drying shrinkage of blocks

Table 35 Percentage of drying shrinkage of blocks –

Density (kg/m³)	Drying shrinkage
1200	0.08%
1400	0.07%
1600	0.06%

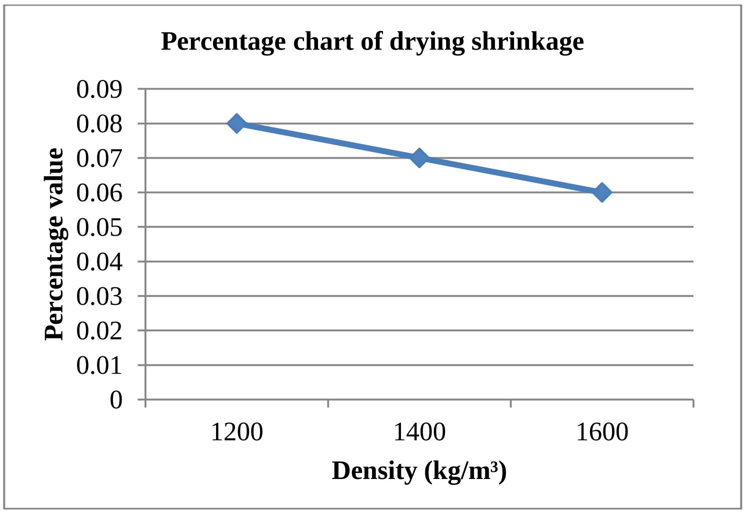

Figure 13 Percentage of drying shrinkage of different density blocks.

5. Flowability test

Table 36 Flowability of fresh concrete for different densities –

Density (kg/m³)	Deformation, r (in mm)
1200	26.03
1400	23
1600	19.7

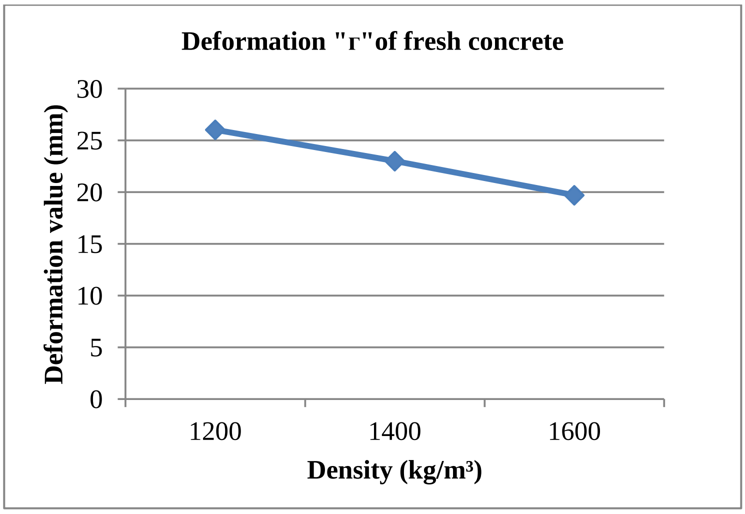

Figure 14 Deformation of fresh concrete of different density

VI DISCUSSION

1. The Influence of the Mixing Amount of Fly Ash on the Compressive Strength

The strength of foam concrete is depends upon the proportion of material mixing. Compressive strength of foam concrete with 50% of fly ash gives the best strength but when the mixing amount changed from 50% to 33%, the strength decreased, when the mixing amount changed from 50% to 66%, the strength decreased as shown in figure 5.1. Therefor the mixing amount of fly ash should be near to 50% for the good compressive strength.

2. The Influence of the Mixing Amount of fiber on the Compressive Strength

The strength of foam concrete is increase with the mixing of fiber in foam concrete. The compressive strength of foam concrete with 0.5% of fiber gives the best strength but when the mixing amount changed from 0.5% to 0.3%, the strength decreased, when the mixing amount changed from 0.5% to 0.7%, the strength decreased as shown in figure 5.3. Therefor the mixing amount of fly ash should be near to 0.5% for the good compressive strength.

3. The Influence of the Mixing Amount of fiber on the flexural Strength

The flexural strength of foam concrete is increase with the mixing of fiber in foam concrete. With the addition of fiber, good amount of strength had increased. The flexural strength of foam concrete with 0.5% of fiber gives the best strength but when the mixing amount changed from 0.5% to 0.3%, the strength decreased, when the mixing amount changed from 0.5% to 0.7%, the strength decreased. Therefor the mixing amount of fly ash should be near to 0.5% for the good compressive strength.

4. The Influence of W/C Ratio on the Compressive Strength and flexural strength

The WC ratio is important factor that can influence the performance of foam concrete. In the preparation of foam concrete, the foaming speed and thickness of the slurry should match. If the w/c ratio decrease from 0.45 than the slurry consistency decreases and the initial setting time of concrete decreases. When the WC ratio increases from 0.45, the denseness of the slurry is too low, thus the gas rush out of the surface of the sample and leave cracks, which decreases the strength of the sample. In the experiment, the optimal WC ratio is 0.45, which gives relatively high compressive strength and flexural strength.

5. Water absorption of different density blocks

The water absorption of foam concrete for different densities such as 1200 kg/m^3, 1400 kg/m^3, 1600 kg/m^3 are 10.62%, 10.65% , 9.67% respectively as shown in table 5.4.1. The percentage of water absorb in decrease when the density of foam concrete increases. If the density of foam concrete decrease than the percentage of water absorption also decreases. So the high density block is much durable as compare to low density block.

6. Drying shrinkage of foam concrete blocks

Drying shrinkage also the important factor for the foam concrete. In the experimental program, observed that the very less shrinkage value is obtained shown in table 5.5.1. The drying shrinkage value for density 1200kg/m^3, 1400kg/m^3 and 1600kg/m^3 are 0.08%, 0.07% and 0.06% respectively.

VII. CONCLUSION

The influences of various mixing amounts of fly ash, fly ash activator, WC ratio, and FA on the compressive strength of FC were experimentally studied and can be summarized as follows.

1). When the fly ash content is smaller than 50%, the product strength decreases, whereas when the fly ash content is larger than 50%, the product strength rapidly decreases. The appropriate mixing amount of fly ash should not exceed 50%.

2). Similarly when the fiber content is smaller than 0.5%, the product strength decreases, whereas when the fiber content is larger than 0.5%, the product strength rapidly decreases. The appropriate mixing amount of fiber should not exceed 0.5%.

3). In the experiment, the optimized proportion of WC is a ratio of 0.45. The foam concrete that was produced with this proportion has a relatively high compressive strength.

4.) Flexural strength of the foam concrete with 0.5% of fiber is increases but the low amount of fiber or high amount of fiber gives low strength. Similarly 50% fly ash contains gives best strength as compare to low or high amount of replacement of fly ash.

5.) The percentage of water absorption is depends on the density of the foam concrete. If density increases, water absorption is decreases. Similarly density decreases, water absorption is increases.

6.) Fibers are very effective in improving the flexural strength of foam concrete but very less amount of compressive strength of foam concrete is increased.

7.) Zero percent shrinkage value achieved in the foam concrete with 50% of fly ash replacement, which improves durability of concrete.

8.) Chances of cracking in the foam concrete are decreased with the zero shrinkage value and low water absorption.

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