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Experimental study to find strength properties of lightweight foam concrete

Abhijit Mangaraj
Department of Civil Engineering
GIFT Autonomous
Gangapada, Bhubaneswar

Rohit Kumar
Department of Civil Engineering
GIFT Autonomous
Gangapada, Bhubaneswar

Ananya Punyotoya Parida
Department of Civil Engineering
GIFT Autonomous
Gangapada, Bhubaneswar

Surajit Pattnaik
Department of Civil Engineering
GIFT Autonomous
Gangapada, Bhubaneswar

***Abstract*— The strength of foam concrete is relatively lower than conventional concrete. High water content, required to enable mixing of foam with slurry. Compaction can also not be done on this concrete. Due to these reasons the concrete made is of low density and strength.The focus of this project is to study strength properties of foam concrete with different mix proportions and different densities.**

Following materials have been used to prepare specimen:

- **Portland Pozzolana Cement (PPC)**
- **Sand**
- **Foaming Agent**

To study the strength properties specimen have been prepared with variations in density and water cement ratio. These specimen have been tested to check the effect of change in these parameters on the compressive strength of specimen.

Keywords: low density, Water Content, Pozzolana.

Introduction: Concrete is the most popular material in construction industry all over the world. It is a mixture of a binding agent, usually cement, coarse and fine aggregates, and water. The mixture produces a brittle material on hardening which may be designed for specific purposes by modifying the proportions or by adding of additives or admixtures. Different types of cements are also industrially produced to cater to specific needs in different types of environments.

While conventional concrete has good compressive strength, it is heavy and significantly increases the dead load of the building. The density of this concrete was then reduced to create a lighter concrete with better insulating properties. This was done by either using lightweight aggregates or by entraining air to create cellular voids. The latter produces a concrete known as foamed concrete.

Conventional concrete which is made with natural aggregate originating from hard rock has a high density lying within the range of 2200 to 2260 kg/m3 and represents a large proportion of the dead load on a structure. According to BS: 8110: Part 2: 1985 classifies lightweight concrete as one with a density of 2000 kg/m3 or less.

Lightweight foamed concrete is a class of aerated concrete. Aerated concrete can be classified according to the methods and agents used to introduce air in the concrete. Aerated concrete can be produced by introducing air entraining agents, gas forming chemicals or directly mixing preformed foam. Concrete which is aerated using foam is known as lightweight foamed concrete. Foaming agents used to create foam can be synthetic based or protein based.

Lightweight foamed concrete was first used as precast bricks in the early 19th century prepared by curing aerated concrete bricks at high temperatures (300°C) in an autoclave (AAC) in both Denmark and Sweden.

Foamed concrete is a material which has many practical aspects owing to it’s a low weight, good acoustical properties and low thermal conductibility. Due to these properties, foamed concrete is widely used for building insulating walls, bricks and as a filling material.

The applications of foamed concrete as building material for load bearing structures is limited due to its low compressive strength.

Lightweight foamed concrete can be prepared with density from 400 kg/rn3 to 1800 kg/m3 on the basis of which classification is done. Properties of foamed concrete depend mainly on its mix design. But a number of general properties such as good freeze/thaw resistance, good acoustical properties, low shrinkage and thermal insulation are common to all mixes.

1.2 Advantages and Applications of Lightweight Concrete

There are many properties and advantages offered by lightweight foam concrete over conventional concrete. Due to its low compressive strength, the use of foamed concrete is prevalent for making of non-load bearing structures. But due to its lower density, using lightweight concrete leads to reduced dead load and hence smaller size of load bearing members, smaller footing and hence reduced cost of construction.

Another advantage offered by foam concrete is its high thermal insulation due to its highly porous structure. High thermal insulation ensures that the interior of the building is insulated against outside temperature. This is widely incorporated in construction of green buildings byindirectly saving the energy used for air-conditioners and heaters.

More advantages offered by lightweight foam concrete over conventional concrete include its good acoustical properties and high degree of workability offered. High workability makes this concrete an optimum choice as filler material fro insulation.

1.3 Objective of Study

The objective of study is:

a. To produce lightweight foamed concrete with different densities.

b. To obtain optimum w/c ratios for various types of lightweight concrete.

c. To determine the compressive strength of lightweight concrete.

2. Literature Review

The historical development of lightweight foam concrete can be traced back to the second century, with the Romans utilizing pumice in structures like 'The Pantheon'. Since then, its use has spread globally, with significant advancements in countries such as the USA, UK, Sweden, and India. In the UK, the adoption of lightweight foam concrete has surged rapidly over the past decade. Defined as a type of concrete with an expanding agent to increase volume while maintaining stability and reducing weight, lightweight foam concrete is 23% to 87% lighter than traditional concrete, with densities ranging from 300 kg/m³ to 1840 kg/m³. Its primary advantages include reduced dead load, faster construction rates, and lower transportation costs. Researchers have enhanced its properties by adding materials like silica fume, fly ash, and polypropylene fibers, resulting in improved compressive strength and durability. These developments have positioned lightweight foam concrete as a versatile and sustainable building material.

3.1.1 Preparation of Materials:

3.1.2 Foaming Agent

A foaming agent is used to create foam for mixing in foam concrete. The foaming agents when added into the water and mixed, produce discrete bubbles cavities which become incorporated in the cement paste. The quality of the foam is critical in governing the properties of foamed concrete. Foam agent can be classified according to types of foaming agent:

i) Synthetic based for densities of 1000kg/m3 and above.

ii) Protein based for densities from 400kg/m3 to 1600 kg/m3.

Foams derived from protein-based agents have a unit weight of around 80 g/l. Protein- based foaming agents come from processing animal proteins made out of horn, blood, bones of cows, pigs and other remainders of animal carcasses. This leads not only to occasional inconsistencies in quality, due to the differing raw materials used in different batches, but also to a repulsive odour of such foaming agents. Synthetic foams have a density of about 40g /l.

Synthetic foaming agents are purely chemical products. They are very stable at concrete densities above 1000 kg/m3 and give good strength. Synthetic foam has finer bubble size as compared to protein but they generally give lower strength of foamed concrete especially at densities below 1000kg/m3.

Foaming agent used for our tests was Profo-1000, which is a protein based foaming agent. Protein based foaming agent (PROFO) is a foam-forming agent based on highly-active, foam- forming proteins. The specially developed manufacturing process for foam stabilization guarantees optimum foam-forming characteristics and foam stability.

It is manufactured by MARUTI PROTECH INDIA. Hariyana : Samples were procured from their store.

3.1.3 Cement:

Cement used was Jaypee Cement . The cement was PPC (fly ash based) conforming to Part 1 of IS 1489:1991.

3.1.4 Fine aggregates

Locally available sand was used as fine aggregate.

3.2. Testing of Materials for Mix Design

3.2.1 Cement Testing

Jaypee Portland Pozzalana Cement provided by university was tested to find its Specific Gravity, Initial Setting Time(IST) and Final Setting Time(FST).

- Specific Gravity

Specific Gravity of cement was found out by using a 50 ml Specific Gravity Bottle. Specific Gravity is the ratio of density of a given substance to the density of water. Since cement reacts with water, kerosene was used to find the relative density of cement to kerosene and then compared with water to get Specific Gravity of cement.

Specific Gravity of Cement (SGC) was found to be 3.07.

- Initial Setting Time(IST) and Final Setting Time(FST)

Initial setting time is defined as the time taken for a cement mix in a Vicat's mould to gain enough stiffness to prevent the penetration of Vicat needle within the range of 5 mm to 7 mm from the bottom of the mould. It is time period when water is first mixed in the dry mix and it just starts losing its plasticity.

Final setting time is that time period between the time water is added to cement and the time at which 1 mm needle makes an impression on the paste in the mould but 5 mm attachment does not make any impression. This test is done to gauge the time taken for cement mix to completely lose its plasticity. The test was performed in accordance to IS:4031(Part 5):1988.

- Initial Setting Time of Cement = 55 minutes
- Final Setting Time of Cement = 6 Hours 35 minutes

3.2.2 Fine Aggregate Testing

Specific Gravity

Specific Gravity of cement was found out by using a 50 ml Specific Gravity Bottle, similar tofinding specific gravity of cement. Water is used as sand is insoluble in water.

Specific Gravity of FA was found out to be 2.48.

3.3. Mix Design

The mix proportion is designed as per the guidelines given in ASTM C796, similar to one used by Nambiar and Ramamurthy (2006). As the standard deals with only cement slurry, the procedure was modified to include cement–sand components.

3.3.1 Foam Preparation

In ASTM C796 foam volume being generated from the foam generator is measured with time, and an appropriate quantity of foam is added to the mix. The foam generator fills foam in a container with known volume in excess. The excess part is struck off and an estimate of foam generated with time is made. The container is further used to find the density of the foam being created.

Fig 3.3.1. Hand held Foam generator for generating foam.

3.3.2 Water Cement Ratio

ASTM C796 specifies w/c ratio of 0.58 for Type I cement and w/c ratio of 0.64 for Type III cement. However, if a particular cement or foaming agent used with these values of w/c does not produce a satisfactory mix, a trial mix or mixes may be made using the cement and foaming agent to achieve a satisfactory mix with required design density.

In the first part of the project, all mix designs were made using a fixed w/c. ratio of 0.64.

- Step 1: Selection of design density

Design density of 600 kg/m3 was selected. Dd =600 kg/m3

- Step 2: Selection of w/c ratio and FA proportion

For PPC, using a w/c ratio of 0.64 And using Cement: Foaming Agent ratio as 1:1.5

- Step 3: Finding volume of foam required

Using trial batch with

1. weight of cement , Wc = 400 kg

Therefore,

2. weight of fine aggregate, WFA = 600 kg
3. Weight of water required , Ww = 256 kg
4. Weight of foam = Volume of foam x Density of Foam
5. Volume of foam required Vf =1.58 m3

Hence using Equation 4,

Hence, Weight of foam required Wf =1.58 x 43.6 = 68.8 kg.

Step 4: Mix Proportions for 1 m3 of concrete

Therefore, for 1 m3

Weight of Cement(Wc) = 181.16 kg

Weight of Sand(WFA) = 271.74 kg

Weight of Water(Ww) = 115.94 kg

Weight of Foam(Wf) = 31.16 kg

Volume of Foam(Vf)= 0.714 m3

Similarly mix proportions for obtaining design density of 600 kg/m3, 800 kg/m3, 1000 kg/m3 and 1200kg/m3 were designed and are tabulated below.

	Mix Type					
Designation	M1	M2	M3	M4	**M5**	**M6**
Design Density (**Kg/m³**)	600	800	1000	1200	1400	1600
w/c ratio	0.64	0.64	0.64	0.64	0.64	0.64
Cement (kg)	181.16	245.70	310.56	376.65	441.50	506.97
Sand (kg)	271.74	368.55	465.84	564.97	662.25	760.45
Water (kg)	115.94	157.25	198.76	241.05	282.56	324.46
Weight of Foam (kg)	31.16	26.78	22.34	17.82	12.12	7.03
Volume of Foam (m^3)	0.714	0.614	0.512	0.409	0.306	0.204

Table 3.1: Mix proportions for different design density (Trial Mix set -1)

RESULTS AND DISCUSSIONS

4.1 Specific Gravity Tests

4.1.1. Specific Gravity of Cement

Weight of empty bottle (W1) = 24.25 g

Weight of bottle filled with kerosene (W2) = 43.85 g

Weight of bottle with cement (W3) = 31.50 g

Weight of bottle filled with cement and kerosene (W4) = 49.00 g

Weight of bottle filled with water (W5) = 49.35 g

Specific gravity of Cement = (W3 –W1) × W2

(W2−W1)−(W4− W3) W5

Hence Specific Gravity of Cement (SGC) was found to be 3.07

4.1.2. Specific Gravity of Fine Aggregates

Weight of empty bottle (W1) = 30.40 g

Weight of bottle filled with water (W2) = 79.40 g

Weight of bottle with FA (W3) = 80.40 g

Weight of bottle filled with sand and water (W4) = 109.6 g

$$\text{Specific gravity of FA} = \frac{(W3 - W1)}{(W2 - W1) - (W4 - W3)}$$

Hence Specific Gravity of FA was found out to be 2.48.

4.2 Foam Density

The foam was filled in a borosil beaker of known volume and weighed to find density of foam generated.

Readings:

Volume of beaker: 1300 ml

Weight of empty beaker: 300 g

Sample 1

Weight of beaker with foam: 360g

Density of foam: 46.2 g/l

Sample 2

Weight of beaker with foam: 355g

Density of foam: 42.3 g/l

Sample 3

Weight of beaker with foam: 355g

Density of foam: 42.3 g/l

Hence foam with average density of 43.6 g/l (kg/m3) was obtained.

4.3 Compressive Strength Tests –

4.3.1. For (Trial Mix set -1)

Three cubes each of specimen M1, M2, M3, M4, M5, and M6 were casted and cured. The compressive strength was then checked for each specimen after 7, 14, 28 days. From above results it is evident that compressive strength varies linearly with density. Compressive strength is higher for concrete with higher densities

Cube Size: 10cm X 10cm X 10 cm.

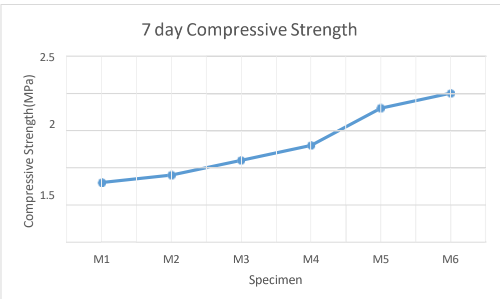

Figure 4.1: 7 day compressive strength of specimen (Trial mix set -1)

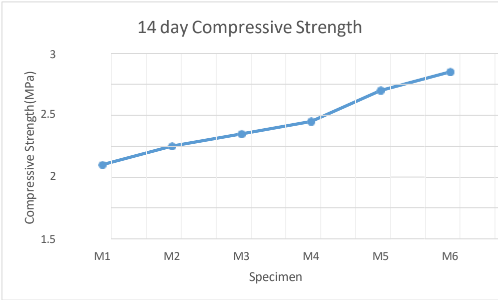

Figure 4.2: 14 day compressive strength of specimen (Trial mix set -1)

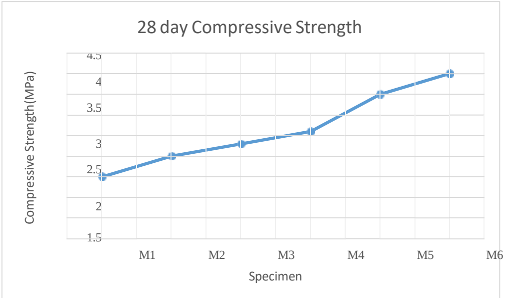

Figure 4.3: 28 day compressive strength of specimen (Trial mix set -1)

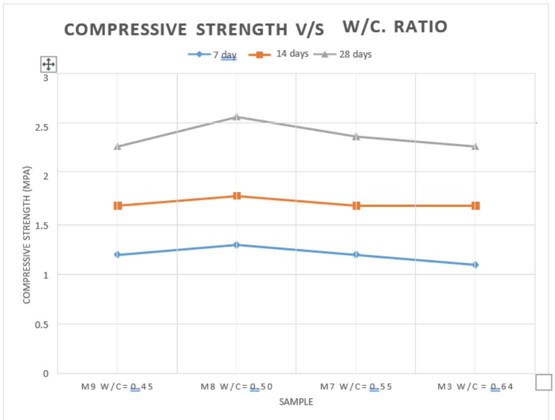

Figure 4.5: Comparison of Compressive Strength of samples with density 800 kg/m^3 but different water cement ratio.

5.1. Conclusions:

1. Compressive strength of foamed concrete varies linearly with density. Higher density results in higher compressive strength values.

2. Water-cement ratio influences the size, shape, distribution, and connectivity of pores in foam concrete. The effect of w/c ratio on the strength of foam concrete is shown in Figure 4.3. With the increase in w/c ratio, the compressive strength of foam concrete increased first and then decreased.

3. This result was achieved because, on one hand,when the w/c ratio was smaller than the optimal ratio, a smaller

w/c ratio generated higher proportions of smal thin-walled, connected, and irregular pores.On the other hand ,the w/c ratio that exceeded the optimal level resultedin a weaker bubble maintaining capability of the paste.

4. Moreover, the bubbles in the paste get easily combined during stirring and result in reduced pores, increased pore diameter, and uneven pore distribution.

5. This occurrence would cause stress concentration on the walls and redundant free water would form capillary channels after the hydration reaction of cementing materials orevap oration ,negating the compactness of the pore walls and consequently reducing the strength of the foam concrete.

6. Optimum water-cement ratio for maximum compressive strength is 0.5 for specimen with densities 800kg/m3 and 1000 kg/m3.

7. Samples with number M6 in trial set 1 shows maximum compressive strength of 4 MPa at 28 days of curing.

8. Samples with number M8 in trial set 1 shows maximum compressive strength of 2.8 MPa at 28 days of curing.

9. Hence Samples with number M6 shows maximum compression strength values among other samples.

5.2. Future Work :

- Fine-Tuning Composition: Further research can focus on optimizing the mix design to improve the mechanical properties, thermal insulation, and durability of foam concrete. Experimenting with different proportions of cement, sand, water, and the foaming agent can yield a more robust and efficient mixture.

- Additive Incorporation: Integrating supplementary cementitious materials (SCMs) such as fly ash, silica fume, or slag can enhance the properties of foam concrete. Additionally, incorporating fibers (e.g., polypropylene, steel) could improve its tensile strength and crack resistance.

- Expanding the applications of foam concrete beyond traditional construction to include uses in prefabricated

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