

POLYURETHANE FOAM CONCRETE INVESTIGATIONAL STUDY FOR USE IN STRUCTURES

¹N.Bhageeradh, ²M. Guru Prakash, ³S.Satyavathi, ⁴A.Pravalika Mala

^{1,2,3}Assistant Professor, ⁴UG Student, ^{1,2,3,4}Department of Civil Engineering, Brilliant Grammar School Educational Society
Group of Institutions Integrated Campus, Hyderabad, India

ABSTRACT

Because to its high fluidity and settling, low self-weight, and low thermal conductivity, foamed concrete is now often utilized in civil construction and building. It does, however, have some significant drawbacks, such as poor strength and increasing shrinking with age. The curing conditions are one of the many factors that affect the strength growth of concrete. By experimenting with different curing techniques, this effort intends to investigate the possible creation of foamed concrete as a sustainable structural material. To do this, sample cubes, cylinders, and prisms were created in order to determine the compressive strength, elastic modulus, and drying shrinkage at various ages. Four different curing regimes were used to cure polyurethane foamed concrete sample pieces (water, moisture, sealing by membrane-forming curing compound and air curing). At the end of the study, poly- urethane foamed concrete used for this study has shown the potential for use in structural applications. Also, the results show that the samples cured by moisture have the highest compressive strength at all ages

Keywords: Polyurethane foamed concrete Curing conditions, Fly ash, and Compressive strength, Static modulus of elasticity drying shrinkage

INTRODUCTION

The kind and length of curing affect the characteristics of foamed concrete. Proper curing will boost strength, volume stability, abrasion resistance, impermeability, and resistance to freezing and thawing, all of which will increase durability. It was discovered that specimens of foamed concrete with 10% air curing acquired a better strength than specimens with 10% water curing. Compared to regular weight concrete, which has a density in the range of (2240–2400 kg /m³), structural lightweight concrete, has an in-place density (unit weight) of about (1440–1840 kg/m³). According to ACI 213R, the concrete strength should be more than (18 MPa) for structural purposes. A form of lightweight aerated concrete known as foamed concrete is primarily composed of a cement paste or mortar that contains at least 20% air by volume. Foamed concrete is produced by two methods: the first is the pre-foaming method and the second is the mixed foaming method. The pre-foaming method involves the isolated production of the base mix cement slurry (cement paste or mortar) and production of a stable foam (foam agent with water) and then mixing this foam into the base mix. In the mixed foaming method, the foaming agent is added to the pre-prepared base mixture and during the mixing foam is produced resulting in a cellular structure in the concrete.

Foamed concrete can have a wide range of dry densities (400–1600) kg/m³ and compressive strengths (1–25) MPa. The increase in compressive strength of foamed concrete formed of fly ash, micro silica, and SiO₂ powder is in the range of (20–25) MPa, this increment in strength shows that this foamed concrete is satisfactory to be used for structural applications or load bearing purposes. The strength of foamed concrete is little affected by the percent cement replaced by fly ash and even when replacing a high amount of cement with fly ash it does not much affect the later compressive strength of properly cured foamed concrete. The best-pulverized fly ash content for greatest strength of foamed concrete is around 20% to 30%.

Benefit of the Work

The goals of this works are to:

1. Find the Applicability to produce foamed concrete using polyutherene asa foaming agent and its applicability as a construction building material.
2. Test the effect of different curing conditions on some mechanical properties of polyutherene foamed concrete.
3. Find some mechanical properties of polyurethane foamed concrete withand without fly ash.

Experimental work Materials

Combinations of the following constituent materials were used to produce foamedconcrete in this study:

1. Ordinary Portland Cement type (I): The chemical and physical properties of thiscement conformed to BSEN 196-1; 2005
2. Class F fly ash supplied by a local supplier and conformed to ASTM C618.
3. Natural sand supplied locally and conformed to the requirements of BS 812- 103.1:1985 [7] for verifying distribution and particle size. The specific gravity of the sand was 2.6.
4. High range water reducing agent (HRWRA) Glenium 51; the normal dosage for Glenium 51 is (0.5–0.8) 1/100 kg of cement.
5. Tap water was used for both miXing and curing.
6. Liquid membrane-forming curing compounds: Setseal 22 is a water based curing compound formulated from selected emulsified
7. paraffin to form a low viscosity wax emulsion. The color is a white liquid, which creates a white film when applied to concrete surfaces and reflects (60–80)% of the sunlight.
8. Foam: The foaming agent of density 45 kg/m³ used in this study was polyurethane (PU) foam.



Mix proportions

The mix proportion guideline of ASTM C796 was followed in the laboratory mixing. The mix proportions of foamed concrete. The final mix proportions were established by laboratory trials to achieve a target density of 1600 kg/m³.

Specimens preparation

For this investigation, a pre-foaming method was adopted to provide polyurethane foamed concrete. The mixing procedure started with the cleaning of the laboratory mixer and emptying the excess water, one-third of the calculated mixing water was added, then the fine aggregate followed by the cement. The materials were allowed to mix for three minutes, then the fly ash and the remaining water was added. This was allowed to blend together till appreciable slurry was achieved. The ready-made foam was added to the base mix through the nozzle of the foam can according to the calculated amount by trial and error. The density of the foamed concrete produced was then checked against the target density, 1600 kg/m³.

Table 1

Chemical and physical properties of cement, fly ash and fine aggregate.

Oxides composition	Cement Fly Ash	Oxides Content %	Oxides Content % ASTM C618(Class F)
CaO	62.8	5.0	<10
SiO ₂	22.3	54.2	70 (Min)
Al ₂ O ₃	4.5	31.6 70 (min)	
Fe ₂ O ₃	1.9	3.8	
Na ₂ O	0.1	0.7	
K ₂ O	0.7	0.6	
MgO	4.4	1.3	5 (max)
SO ₃	2.0	0.1	
CO ₂	2.5		
Free CaO	1.2		
Loss on Ignition	0.8		
Blain Surface Area m ² /kg	250	350	
Relative Density	3.15	2.2	

Table 2

Grading of fine aggregate

Sieve size (mm)	Passing by weight%	ASTM C33-03
2.36	100	85–100
1.18	85.7	75–100
0.60	71.2	60–79
0.30	29.6	12–40
0.15	3.5	0–10

Table 4

Mix Proportions for Polyurethane Foamed Concrete.

Mix details	Target Density	Cement kg	sand kg	fly ash kg	water kg	w/C+FA	HRWRA L	foam kg
Mixed with fly ash	1600	440	960	160	300	50	3.6	60
Mixed without ash	1600	600	960	0	300	50	2.64	60

The specimens remained in the same condition till 24 h later when the specimens were demolded and the fresh density of concrete measured. Each sample was marked before being separated and transferred to the place where they cured using four different curing conditions, which were: water curing; moist curing; membrane compound curing and air curing. All the specimens remained under same curing condition till the date of testing except the water and moisture cured samples that were removed and placed in an oven for 24 h before testing. The density was checked before placing in an oven and after placing in an oven.

The curing regime adopted was as below:

- Air curing: in laboratory air entire time with the constant range $(25 \pm 2)^\circ\text{C}$ and an average relative humidity of 60%.
- Water curing: in air under laboratory conditions after seven days of water curing with the constant range of temperature $(25 \pm 5)^\circ\text{C}$.
- Moisture curing: covered with wet burlap for seven days.
- Liquid membrane-forming curing compounds: Setseal 22 was applied after 24 h from casting, except for the top face of the casting mold where the liquid compound was applied after 1 h from casting.

Most of these adopted curing conditions in this study chosen were completely compatible with the curing conditions which are performed in the field.

Testing methods

Fresh state properties

The fresh properties of polyurethane foamed concrete consist of flow and fresh density. A flow table test was performed to find the consistency of the freshly mixed mortar as described in ASTM C 1437. The fresh polyurethane foamed concrete produced was first poured into an inverted slump flow cone without any compaction and vibration in accordance with ASTM C 1611. The fresh density was established according to ASTM C 138

Hardened properties

a) Compressive Strength

The compressive strength tests were performed according to (BS. 1881: Part 116: 1983). A total number of 72 cubes of (100×100) mm were tested by using a hydraulic compression machine of 1800 kn, at a loading rate of 18 MPa per minute. The average of three cubes was taken for each test and the test was conducted at ages of (7, 28, and 56) days.

b) Shrinkage

Shrinkage was measured by apparatus with dial gauge of 0.002mm accuracy. Prisms of $(100 \times 100 \times 400)$ mm were used for this test. Measurements of the shrinkage strain were made according to (ASTM C157-2008) [2]. After removing the samples from the mold at an age of 24 h, shrinkage nails were installed on the surface of prisms after being demolded. The readings were taken at ages (3, 7, 14, 21, 28, 56) days for different curing conditions. Two specimens were prepared for each test condition.

c) Static Modulus of Elasticity

The static modulus of elasticity was measured according to (ASTM C 469). A total number of 48 cylinders of (150×300) mm were tested at ages of (7, 14, and 28) days. The average of two cylinders was taken for each test.

Results and discussions

Fresh properties

Flowability and Fluidity

For this study, the flowability of polyurethane foamed concrete mixes was measured by the diameter of the slump. It was found that the flowability for a mix without fly ash had a lower diameter of a slump than the mix with fly ash. The average slump flow values obtained for fly ash mix and mix without fly ash were 230mm and 200 mm, respectively. This phenomenon is due to the lubrication effect of the spherical shape of most fly ash particles which led to greater workability. The fluidity of polyurethane foamed concrete mixes measured by the diameter of four different angles of the slump. The inverted slump cone spread values are given in Table 5 clearly indicated that the fluidity of the polyurethane foamed concrete was dependent on the fly ash in the mixes. Slump cone spread values obtained for the fly ash mix and the mix without fly ash were 478mm and 452 mm, respectively. This may be ascribable to the higher fineness of fly ash compared to that of the mix without fly ash.

Consistency and Stability

The consistency of the fresh polyurethane foamed concrete represented by a measured fresh density to designated density ratio was kept to nearly unity, without segregation and bleeding. Stability can be represented by a measured fresh density to measured

Table 5

Properties of the fresh polyurethane foamed concrete.

Sample	Consistency	Stability	Inverted slump cone spread value (mm)	Slump value(mm)
Mix with fly ash	1.04	1.015	478	230
Mix without fly ash	1.05	1.018	452	200

hardened density Lim et al. [21]. The measured hardened density of the foamed concrete produced was (1640 and 1650) kg/m³ for the fly ash mix and the mix without fly ash respectively. The fresh density of polyurethane foamed concrete is measured in a container of known volume in order to determine density (unit weight). The use of fly ash resulted in a slight decrease in the fresh density of polyurethane foamed concrete samples. The average fresh density values obtained for the fly ash mix and the mix without fly ash were 1665 kg/m³ and 1680 kg/m³, respectively. However, such results are attributed to the low specific gravity of the fly ash. Portland cement has a higher specific gravity than that of fly ash so they increase the overall density of the polyurethane foamed concrete to a greater extent.

Hardened properties

a) Compressive Strength

The average of the tests results for polyurethane foamed concrete mixes with and without fly ash for different curing conditions. The compressive strength results for mixes without fly ash range between (7.8–20.1) MPa, (10.3–24.2) MPa and (11.1–26.2) MPa at (7, 28 and 56) days while the results for the mixes with fly ash range between (8.1–22.5) MPa, (11.1–29.2) MPa and (12.1–32.1) MPa at (7, 28 and 56) days. It can be seen that the results of mixes without fly ash give lower results of compressive strength when compared with mixes with fly ash under different curing conditions at all ages with percent (9.2, 29.1 and 40.4) for water curing, (11.6, 20.6 and 22.6) for moisture curing, (3.4, 8.7 and 9.4) for air curing and (8.7, 23.7 and 32.2) for the membrane forming curing compound at (7, 28 and 56) days respectively.

This behavior is explained by the densified effect of fly ash with a decrease in the porosity at early ages, while at later ages, in addition to the densified effect of fly ash, a pozzolanic reaction occurs with calcium hydroxide released from cement hydration reacting with the fly ash resulting in a filling effect in the voids among the cement and other powder particles, it can be seen that moisture cured specimens improve compressive strength more than membrane curing compound, water and air cured specimens respectively by (14.9, 44.9 and 177.3)% at 7 days, (5.0, 18.0 and 162.3)% at 28 days, (6.3, 10.0 and 165.5)% at 56 days.

That can be ascribed to the gel tiffening by drying for moisture curing, however, it is due to relaxation in the gel of filler type due to the presence of water by water curing. An important observation is drawn here, which reflects the same previous trends for mixes with fly ash and for all type of curing conditions at a different age. The results also yielded that curing by membrane forming curing compound was effective in improving the compressive strength of foamed concrete mixes with and without fly ash more than water and air curing. Like other types of concrete, the compressive strength for polyurethane foamed concrete specimens with air curing is lower than that of the other types of curing. However, the extent of strength reduction for air cured specimens up to an age of 56 days was due to the insufficient curing.

b) Shrinkage

The average results of two prisms are plotted in Figs. 3 and 4 for mixes with and without fly ash under different curing conditions. The results clarify that the values of drying shrinkage are higher for mixes without fly ash than those for fly ash mixes. The values range from (160–610) microstrain for the mixes without fly ash and these values decrease to (150–550) microstrain when fly ash is added at the age from 3 days to 56 days. The drying shrinkage for all mixes extends with time till the age of 56 days. Indicating to the earlier Figures there is a small decrement in drying shrinkage for water cured specimens. Moreover, moisture cured samples showed slightly lower values than those for compound cured samples. An important observation is drawn here, which reflects the same previous trends for mixes with and without fly ash and for all type of curing conditions at a different ages.

It indicates that the internalization of fly ash as a partial replacement of cement leads to a slightly decrease in shrinkage of mixes during the time of drying as compared with mixes without fly ash. This phenomenon is ascribed to the reaction of fly ash consuming more free water in the system, leaving less water evaporation during shrinkage. This promotes the

deduction that fly ash mix has a lower porosity and finer pore structure, which encourages loss of water by self-desiccation and not by diffusion to the surrounding environment.

c) Static Modulus of Elasticity

The secant moduli for all the mixes was experimentally determined for each testing age (7, 14 and 28) days as the average of two cylinders for different curing conditions. The results of static moduli are plotted.

The modulus of elasticity results for mixes without fly ash range between (4.0–9.1) MPa, (4.8–11.5) MPa and (6.0–16.3) MPa at (7, 14 and 28) days while the results for the mixes with fly ash range between (4.5–9.8) MPa, (5.1–12.4) MPa and (6.1–16.5) MPa at (7, 14 and 28) days. This behavior may be attributed to the incorporation of fly ash as a partial replacement of cement in the mixes that increases the densification of concrete and leads to lower strain under compression at transition zone, thus leads to higher static modulus of elasticity of those mixes. From Fig. 5, it can be seen that moisture cured specimens improve modulus of elasticity more than the membrane curing compound, water and air cured specimens respectively by (10.4, 12.2 and 55.6)% at 7 days, (5.2, 11.6 and 58.3)% at 14 days, (8.1, 9.0 and 63.3)% at 28 days. An important observation is drawn here, which reflects approximately the same previous trends for mixes with fly ash and for all type of curing conditions at different ages. d) Oven-dry density The oven-dry density of hardened polyurethane foamed concrete was measured according to ASTM C 642 [21]. For polyurethane foamed concrete, the oven-dry density increased slightly by adding fly ash. The average density values obtained for fly ash mix and mix without fly ash were 1590 kg/m³ and 1600 kg/m³, respectively.

Conclusions

Based on the tests results of the present study on influence of curing methods and fly ash on progressive compressive strength, the following conclusions are drawn:

1. The flowability and fluidity are increased by the presence of fly ash in comparison to mixtures without fly ash of the polyurethane foamed concrete.
2. The compressive strength of samples cured under moisture and membrane forming curing compound produce higher compressive strength range (20–32) MPa. This revealed that polyurethane foamed concrete is satisfactory to be used for structural applications.
3. The samples cured under moisture curing achieve higher strength at all ages than all others curing conditions considered. This revealed that moisture curing affects the compressive strength of foamed concrete more than those cured by a membrane forming curing compound, water, and air curing.
4. Curing by a membrane forming compound was effective in developing the compressive strength of foamed concrete mixes with and without fly ash more than water and air curing.
5. The fly ash utilized improves workability and diminishes the drying shrinkage of foamed concrete.
6. At all ages, the compressive strength of polyurethane foamed concrete without fly ash is lower than that of the polyurethane foamed concrete with fly ash for all curing conditions.

REFERENCES

1. ASTM C157, Standard Test Method for Length Change of Hardened Hydraulic Cement Mortar and Concrete, ASTM International C, 2008 (157, M).
2. ASTM C618, Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, American Society for Testing and Materials, 2002.
3. ASTM C796-97, Standard Test Method for Foaming Agents for Use in Producing Cellular Concrete Using Preformed Foam, ASTM International, West Conshohocken, PA, 1989, <http://dx.doi.org/10.1520/C0033-03> www.astm.org.
4. ASTM, C1611 Standard Test Method for Slump Flow of Self-Consolidating Concrete, ASTM, US, 2014.