

# Experimental Study on Fresh State Characteristics of Foam Concrete with Ultrafine GGBS

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**ABSTRACT:** Foam concrete is a widely accepted construction material which is popular for diverse construction applications such as, thermal insulation in buildings, light weight concrete blocks, ground stabilization, void filling etc. Currently, foam concrete is being used for structural applications with a density above  $1800\text{kg/m}^3$ . This study focuses on evolving foam concrete with a material density in the range of  $1200\text{ kg/m}^3$  to  $1600\text{ kg/m}^3$ , so as to obtain a higher strength material with a good workability. Concurrently efforts are also made to make it a sustainable construction material by incorporating industrial waste products such as ultrafine GGBS as partial replacement of cement and fly ash for replacement of fine aggregate.

Foam concrete is made adding pre-formed foam of a particular density to the mortar mix. The foaming agent used in this study is Sodium Lauryl Sulphate and in order to densify the foam generated, Sodium hydroxide solution at a normality of one is also added.

The fresh state characteristics of foam concrete are tested at varying proportions of cement, sand, water and additives. The proportion of ultrafine GGBS and fly ash in the foam concrete mix are varied.

**KEYWORDS:** Foam concrete; Foam stability; Fresh state properties of Foam concrete

## I. INTRODUCTION

Concrete is a construction material which is unavoidable in the construction industry. For huge structures to be built, a large amount of concrete is required and also massive foundations should be laid. This increases the self-weight of the structure which shall be brought down by replacing normal weight concrete with a light, durable, simple to use, more environmental friendly and sustainable concrete. A material which has the ability to fulfil all the above mentioned requirements is foam concrete. It should be self-flowing and self-compacting. It can be designed to have a fresh density range of  $400\text{kg/m}^3$  to  $1800\text{kg/m}^3$ . A strength of  $10\text{ N/mm}^2$  can be achieved with normal foam concrete which can be used only for non-structural purposes. A strength of at least  $20\text{ N/mm}^2$  has to be obtained in order to use foam concrete for structural purposes with a fair workability.

This paper reports a laboratory based research work on foam concrete. It mainly looks into the use of ultra-fine GGBS (ground granulated blast furnace slag) in foam concrete as partial replacement of Ordinary Portland cement and fly ash as replacement for fine aggregate. The overall aim of the study was to investigate the fresh state characteristics of foam concrete which would give a good degree of workability at different foam concrete densities.

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### II. LITERATURE REVIEW

Foam concrete is a form of lightweight concrete, also known as aerated or cellular concrete which was first developed in Scandinavia. It is obtained by entraining air into concrete in the form of bubbles with the help of foaming agent and compressed air. When the mix hardens, it results in a concrete which is light weight with evenly distributed air bubbles throughout the element.

As per the studies done by Indu Siva Ranjini and Ramamurthy [1], the properties of the foam depends on the type of foaming agent or surfactant that is used. The two important characteristics influenced by the type of surfactant used are (i) the stability of foam and (ii) foam density. It was concluded that the concentration of the foaming agent does not have much effect on the foam density at different foam generation pressures. The different type of foaming agents include, protein based foaming agents and synthetic based foaming agents. There are different foaming agents that come under synthetic foaming agent such as Sodium lauryl sulphate, Sodium lauryl ether sulphate, Sulfanol, cocodiethanolamide etc.

The stability of foam is generally measured by free drainage test as prescribed in Def Standard 42-40 [12]. The optimum concentration of Sodium lauryl sulphate and foam generation pressure were observed as 1.8% and 115KPa respectively from the studies done by Indu Siva Ranjini and Ramamurthy [2]. As per the studies on characteristics of foam concrete in its fresh state, by Nambiar and Ramamurthy [5], it is observed that the consistency of the foam concrete mainly depends on the volume of foam added and the water to solids ratio. The consistency of the mix reduces when the foam is added due to the reduction in self weight of the mix.

According to Nambiar and Ramamurthy [9], the moisture movement behaviour of foam concrete becomes more complex as it contains larger volume of air voids. Sorptivity and water absorption are the most useful parameters which can explain the moisture movement behaviour of concrete. It is concluded that the water absorption and sorptivity of foam concrete are lower than the corresponding base mixes and they reduce with increase in foam content.

An investigation on the properties of foam concrete was also done with fly ash as filler material by Nambiar and K. Ramamurthy [11]. Conclusion from the study is that the flow behaviour of foam concrete is mainly influenced by the foam volume and filler type. The study also says that for higher flow values, increased water to solids ratio has to be adopted and also finer filler material results in higher strength to density ratio.

As per the studies by M. R. Jones and McCarthy [6], the use of fine fly ash in foam concrete as a partial replacement of cement and partial replacement of fine aggregate with coarse fly ash improves the strength of foam concrete. According to the studies done by Ameer A Hilal et al. [7], the compressive strength of foam concrete is greatly improved with the use of additives such as silica fume and fly ash.

Considering all the above mentioned salient observations, an attempt has been made in the study for achieving foam concrete of higher strength.

### III. OBJECTIVES

- To obtain the most stable foam of density around  $50 \text{ kg/m}^3$  using the foaming agent, Sodium lauryl sulphate
- To obtain foam concrete which is self-flowing and self-compacting, which has higher strength on hardening, with ultra-fine GGBS as partial replacement of cement

### IV. MATERIALS USED

The following material combinations were used to produce foam concrete specimens.

1. Portland cement: 53 grade of specific gravity 3.15, conforming to IS 12269: 1987

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2. Ultra-fine GGBS (Alcofine 1203): It is a specially processed material based on slag with high glass content of high reactivity obtained through process of controlled granulation.
3. Fly ash: Class F fly ash of specific gravity 2.1 (Brand – Ashtech Flyash Superpozz)
4. Fine sand of size less than 300µm of specific gravity 2.65
5. Surfactant (Foaming agent): Sodium Lauryl Sulphate (SLS) which is a commonly available synthetic foaming agent

## V. EXPERIMENTAL STUDY

Foam concrete is produced by incorporating a measured volume of foam into the mortar mix. The foam is produced by a foam generator in which the foaming agent is poured in a specific ratio with water. The foam generator consists of a static mixer, an air compressor and an outlet gun through which the foam is discharged in the required pressure.

The outlet can be hand held and the foam can be put into the mixer. The density of the foam typically ranges between 25 and 80kg/m<sup>3</sup>. The preformed foam which is generated is directly poured into the base concrete mix and mixed thoroughly to obtain foam concrete.

Referring to the previous studies done on foam concrete, the mix was prepared by directly adding the preformed foam into the mix. It can also be prepared by adding the foaming agent in liquid form into the base mix, and mixing together to obtain foam concrete. The prime design criterion was to maintain the required plastic design densities. It is difficult to maintain the density ratio (plastic density obtained to design density) as one since the control of the foam within the mix is difficult. The difference in the plastic density of foam concrete with its design density may vary between 50 and 100 kg/m<sup>3</sup> and not exceeding 100 kg/m<sup>3</sup>.

Assuming the target plastic density as  $D$  kg/m<sup>3</sup> with water content as  $w$  kg/m<sup>3</sup>, total solids as  $s$  kg/m<sup>3</sup>, cement content as  $c$  kg/m<sup>3</sup>, fine aggregate content as  $f$  kg/m<sup>3</sup>,

$$D = s + w \text{ (for 1 m}^3\text{)}$$

$$s = f + c$$

By keeping the water to solids ratio and design density as constant, the amount of water, cement, fine aggregate and fly ash to be added can be found out. In this study, a mix ratio of 1:1 has been adopted in which one set is with cement and sand, and the other set is with 50% fly ash replacement for sand.

### A. CHARACTERIZATION OF FOAM

Foam stability is an important parameter which gives the retention period of the bubbles in the foam. The stability of the foam is measured as per the Defence standard code 42-40 [12], which helps in the determination of foam expansion and drainage time.

A glass drainage pan of 1612ml nominal volume is used to determine the foam stability. The centre of the conical base of the drainage pan is rounded by 25mm long polymethyl methacrylate tube which has a 1.6mm bore at its lower end to accept a 12.7mm bore.

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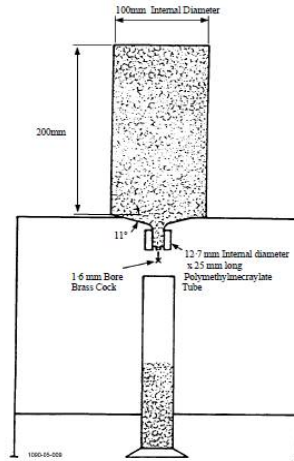


Fig.1. Drainage pan and stand (Source: Def Stan 42-40 [12])

When the correct flow rate has been established and foam is being produced continuously for at least 10 seconds, the drainage pan is kept vertically in the foam stream for collection. The drainage pan is weighed to obtain the initial foam density. The drainage pan is placed on its stand and the graduated jar is placed below the drainage pan for collection of liquid foaming agent. The stopcock is opened carefully to allow the flow of liquid to the measuring cylinder. The liquid collected in the jar is weighed to determine the amount of drainage, at various time intervals.

**B. FRESH STATE CHARACTERISTICS OF FOAM CONCRETE**

The important fresh state characteristics of foam concrete are flowability and self compactability. The measurement of consistency of foam concrete includes spreadability and flowability.

Table 1: Foam density and drainage for SLS foaming agent

Ratio of water to foaming agent	Foam pressure (KPa)	Foam density (kg/m <sup>3</sup> )	Drainage in 300 seconds (gm)	12% drainage volume (gm)
1:50	100	10.54	4	2.04
	160	12.41	5	2.4
	200	9.3	2	1.8
1:55	100	12.41	9	2.4
	150	9.92	3	1.92
1:30	200	11.79	4	2.28
	100	13.02	4	2.52
	150	11.17	1	2.26
	200	12.4	2	2.4
	250	10.55	2	2.04

Table 2: Foam density and drainage for foaming agent with NaOH stabilizer

Trial No:	Foam pressure K Pa	Foam Density kg/m <sup>3</sup>	Drainage (g)		
			In 300s	In 900s	In 1800s
1	110	61.41	0	5	44
2	110	65.34	0	4	37
3	110	58.56	0	5	30
4	110	57.09	0	6	41
5	110	60.2	0	4.5	39
6	130	53.26	0	3	30
7	130	55.8	0	4	26
8	130	52.5	0	4	24
9	130	54.35	0	3.5	29
10	130	49.78	0	4.5	34

Table 3: Composition of various mixes for 1m<sup>3</sup> and the fresh state property results

Sl. no	Design density (kg/m <sup>3</sup> )	Wet density obtained (kg/m <sup>3</sup> )		GGBS (Alcofine)		Cement (kg)	Sand (kg)	Fly ash (kg)	Water (L)	Weight of foam (kg)	Water/solid ratio	Fresh state characteristics	
		%	grams	(sec)	% spread								
1	1200	1276.0	0	0	425	425	-	330	20	0.42	17	102	
2		1256.0	5	21.25	403.75							20	58
3		1294.0	10	42.5	382.5							15	75
4		1140.0	15	63.75	361.25							16	58
5	1200	1156.0	0	0	387	193.5	193.5	426	15	0.55	15	75	
6	(50% fly ash as filler)	1140.0	5	19.35	367.65							14	75
7	1242.0	10	38.7	348.3	18							93	
8	1196.0	15	58.05	328.95	16							84	
9	1400	1376.0	0	0	500	500	-	390	15	0.40	12	111	
10	1380.0	5	25	475	13							84	
11	1448.0	10	50	450	12							111	
12	1368.0	15	75	425	13							93	
13	1400	1476.0	0	0	483	241.5	241.5	424	10	0.45	45	58	
14	(50% fly ash as filler)	1456.0	5	24.15	458.85							50	58
15	1450.0	10	48.3	434.7	52							67	
16	1464.0	15	72.45	410.55	49							58	
17	1600	1592.0	0	0	593	593	-	405	10	0.35	14	75	
18	1684.0	5	29.65	563.35	17							75	
19	1680.0	10	59.3	533.7	15							93	
20	1552.0	15	88.95	504.05	15							84	
21	1600	1692.0	0	0	571	285.5	285.5	457	5	0.4	56	23	
22	(50% fly ash as filler)	1710.0	5	28.55	542.45							54	32
23	1690.0	10	57.1	513.9	43							40	
24	1676.0	15	85.65	485.35	52							32	

The flowability is determined by Marsh cone test which is a simple method to study the rheological properties of cement and mortar. It consists of a conical brass vessel held on a wooden stand with an orifice of 8mm at its bottom. A stop watch is needed to measure the time taken by 500ml of foam concrete mix to pass through the vessel. The longer the flow time, lower the workability.

The spreadability of foam concrete is determined by flow cone or mini slump test as spread percentage. It is done using a slump cone of top diameter 2mm, height 3.8mm and bottom diameter 5.7mm. The mix is poured in the cone the cone is pulled up. The final spread diameter is measured. The more the percentage, more is the workability.

Based on the previous studies by Nambiar and Ramamurthy [3], it is evident that the consistency is dependent on the volume of foam and water to solids ratio along with other ingredients of the mix. Hence the different proportions of different ingredients in foam concrete such as water to solids ratio, foam volume, fly ash percentage, and ultra-fine GGBS replacement level are studied.

## VI. RESULTS AND DISCUSSION

### 1) FOAM CHARACTERIZATION

Foam stability is an important parameter which reflects the life of each bubble in the foam generated. One of the important requirements of foam stability is to ensure that the texture is uniform throughout the process of hardening of foam concrete. Table 1 shows the results obtained for various mix ratios of foaming agent with water at various pressures.

The foam stability influences the density of foam which is useful to calculate the amount of foam required to be added for achieving a desired density of foam concrete.

The foam drainage is an important parameter in the selection of a foaming agent. The drainage percentage is measured after 5 minutes and 10 minutes. A stable and economical foam will have a drainage of less than 12% in 300s [2]. When SLS was used as foaming agent, as per the results obtained in Table 1, the drainage exceeded 12% in 300s. The foam stability is a factor which influences the foam density which has to be maintained around 50 kg/m<sup>3</sup> for obtaining structural foam concrete [6].

As per the work done by M. Siva et.al [6], foam with maximum stability is obtained when Sodium hydroxide is added along with SLS and water. Referring to this particular result, trials were done with SLS concentration of 2.5% and NaOH concentration of 4% with water at pressures 110 KPa and 130 KPa and the density obtained are shown in table

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2. The drainage obtained in 5, 15 and 30 minutes are also shown in table 2, which indicates that even for longer durations the drainage is much less for foam with NaOH stabilizer when compared to foam without NaOH.

2) FRESH STATE PROPERTIES OF FOAM CONCRETE

Table 3 shows the amount of cement, sand, flyash, ultrafine GGBS and water added in preparing the different foam concrete mixtures. The summary of results obtained from the study done on fresh foam concrete is also shown. The fresh state characteristics of foam concrete were tested at three plastic densities of 1200, 1400 and 1600 kg/m<sup>3</sup>, with and without fly ash at different water/solids ratio and different foam volume content. The required density of foam concrete is attained by adjusting the foam volume. As the foam volume is increased, self weight reduces down and hence density. When the self weight is less, the self flowing ability of foam concrete also decreases which demands for more water.

Marsh cone test

The water/solids ratio along with foam volume largely influences the workability of the mix. As the density increases, a lower water/solids ratio is provided for mixes without fly ash, as 0.42, 0.40 and 0.35 for densities of 1200, 1400 and 1600kg/m<sup>3</sup> respectively. For mixes with fly ash, the water to solid ratio was provided as 0.55, 0.45 and 0.4 for densities of 1200, 1400 and 1600kg/m<sup>3</sup> respectively. These water/solids ratios corresponding to each densities are fixed after trials, based on the consistency at which the mix is flowable and self compacting. As a whole, all the mixes were found to be workable referring to the studies done by Nambiar and Ramamurthy [5]. As indicated in figure 2, the addition of ultrafine GGBS to the mix does not alter much the workability of both the mixes. For the mixes with flyash as 50% filler material, the flow time is more due to higher fineness of flyash.

Mini slump test

The influence of various ingredients of foam concrete on the spreadability of foam concrete is studied in terms of percentage spread using mini slump test. All the foam concrete mixes are showing almost same consistency at 0 and 10% ultra-fine GGBS (Alcofine 1203) as in Figure 3

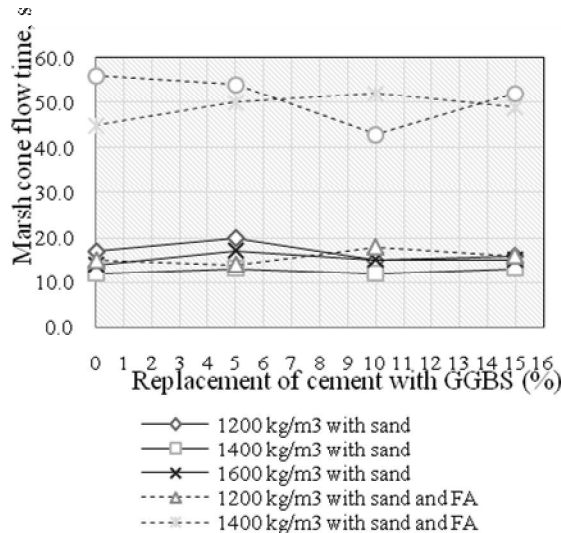


Fig. 2. Flow time for varying percentages of ultrafine GGBS

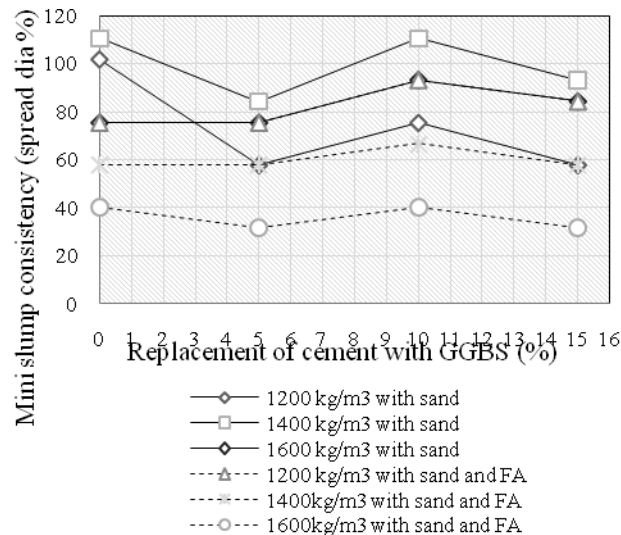


Fig. 3. Percentage spread of foam concrete for various mixes

For same density of foam concrete mixes, the mix which has fly ash shows a lesser flowability compared to the mix without fly ash due to more specific surface area of flyash. This is due to higher fineness of the filler materials in the mix. It is observed that there is reduction in workability when 5% cement is replaced with ultra-fine GGBS. Also, the workability of the mix is reduced at higher percentages of GGBS which may be due to higher fines content.

## VII. CONCLUSION

Within the range of materials and test parameters investigated, following conclusions are drawn:

- A stable foam was obtained in the density range of 50-55kg/m<sup>3</sup>, by using 2.5% SLS and 4% NaOH in water.
- The main factor that influence the workability of foam concrete is the foam volume and the type of filler material used.
- The addition of ultrafine GGBS as partial replacement of cement does not significantly alter the workability of the mixes.
- The use of fly ash as partial replacement of sand increases the water demand to obtain workable mixes.

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