Utilization of fly ash and ultrafine GGBS for higher strength foam concrete

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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, lightweight concrete blocks, ground stabilization, void filling etc. Currently, foam concrete is being used for structural applications with a density above 1800kg/m³. This study focuses on evolving mix proportions for foam concrete with a material density in the range of 1200 kg/m³ to 1600 kg/m³, so as to obtain strength ranges that will be sufficient to adopt it as a structural material. Foam concrete is made lighter by 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. In this study efforts are 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. The fresh state and hardened state properties of foam concrete at varying proportions of cement, sand, water and additives are evaluated. The proportion of ultrafine GGBS and fly ash in the foam concrete mix are varied aiming at higher compressive strength. Studies on air void-strength relationship of foam concrete are also included in this paper.

1. 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 heavy foundations are needed. The self-weight of the structure can be brought down by replacing normal weight concrete with a light, durable, environmental friendly and sustainable concrete. A material, which has the ability to fulfil all the above-mentioned requirements, is foam concrete, which is flowing and self-compacting. It is produced by entraining air into cement-filler slurry in the form of bubbles, which is generated by aerating foaming agent. It can be designed to have a density range of 400kg/m³ to 1800kg/m³. A strength of 10 N/mm² can be achieved with normal foam concrete, which can be used for non-structural purposes. Strength of at least 20 N/mm² is needed to use foam concrete for structural purposes. The ability of foam concrete to perform as a structural material has to be investigated.

Foam concrete is produced by incorporating foaming agent into cement mortar. The foam can be produced by two methods; Pre-foaming method, Mixed foaming method. Pre-foaming method comprises of base mix, preformed foam separately, and then thoroughly blended into the base mix. In mixed foaming, the foaming agent is mixed along with the base mix while mixing. The foam must be stable enough to resist the pressure of mortar until the cement takes its initial set. The foam is generated using a foam generator, in which a diluted foaming agent with a known volume of water is poured.
Compressed air at a predetermined quantity is used to agitate the mix and generate foam. 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 is typically between 25 and 80 kg/m³. There are different types of foaming agents available in the market both protein base and synthetic base. The most commonly used foaming agent is of synthetic type. The common types of synthetic foaming agents [1] are Sodium lauryl sulphate, Sodium lauryl ether sulphate, coco diethanolamide etc.

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 and hardened state characteristics of foam concrete of medium density ranges.

2. Background Literature

Studies by Indu Siva Ranjini and Ramamurthy [1] indicate that the properties of the foam depend 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 types of foaming agents used for the study include, protein based foaming agents and synthetic based foaming agents (Sodium lauryl sulphate, Sodium lauryl ether sulphate, Sulfanol, cocodiethanolamide). The stability of foam is generally measured by free drainage test as prescribed in Def Standard 42-40 [2]. 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 [3]. In the studies on characteristics of foam concrete in its fresh state, by Nambiar and Ramamurthy [4], 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. Foam concrete exhibits high drying shrinkage due to the absence of aggregates. The particles tend to get closer with the evaporation of water thereby increasing the shrinkage value of concrete. Hanizam Awang and Muhammad Hafiz [6] concluded from the study that the inclusion of fibres such as polypropylene and glass fibres have been proven to reduce shrinkage. A study [7] on the influence of ultrafine slag addition on the properties of cement grout have shown reduction in shrinkage strain and a reasonable increase in compressive strength. Nambiar and K. Ramamurthy [8] also report an investigation on the properties of foam concrete with fly ash as filler material. Conclusion from the study is that the foam volume and filler type mainly influence the flow behaviour of foam concrete. The study also says that for higher flow values, increased water to solids ratio has to be adopted and finer filler material results in higher strength to density ratio.

Many physical properties of foam concrete depend on its density in hardened state. According to K. Ramamurthy et al. [3] the greater the proportion of aggregate, higher will be the density. It was also observed that replacement of sand with fly ash helps in reducing the density with an increased strength as per Durack J M and Weiqing L. [5]. Compared to a product based on sand and cement, it is observed that replacement of sand with fly ash help in reducing the density with an increased strength. The compressive strength of foam concrete decreases exponentially with a reduction in density. The factors which influence the result are, size and shape of specimen, method of pore formation, direction of loading, age, water content, characteristics of ingredients used and the method of curing. It has been reported that small changes in water-cement ratio does not affect the strength of foam concrete and also an increase in strength had been observed with an increase in water-cement ratio. Conventional foam concrete is typically proportion to achieve only low compressive strength, between 1 and 10N/mm². This concrete is suitable only for void filling and trench reinstatement. As per the studies by M. R. Jones and McCarthy [9], 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. [10], the compressive strength of foam concrete is greatly improved with the use of additives such as silica fume and fly ash.

The pore structure of foam concrete is a very important characteristic that influence the properties of material such as strength and durability. E. K. Kunhanandan Nambiar and K. Ramamurthy [13] have done investigations to characterize the air – void structure of foam concrete by identifying few parameters such as, volume, size and spacing of voids and study the influence of these parameters on density and strength. The conclusions were; at higher foam volume merging of bubbles take place which result in larger voids and lower strength. The pore system in cement-based material which is conventionally classified as gel pores, capillary pores, macropores can be measured by the test methods viz., nitrogen gas absorption–desorption, mercury porosimetry, optical microscopy with image processing and X-ray computed tomography with image processing respectively as per H. Uchikawa, S. Uchida and S. Hanehara [15].

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

3. Objectives

- To identify the optimum concentration foaming agent and aerating pressure for attaining dense and stable foam.
- To study the fresh state characteristics (spreadability and flowability) of foam concrete with varying proportions of different mineral admixtures.
- To study the influence of mineral admixtures and different design densities on the compressive strength of foam concrete.
- To find the relationship between air-void distribution and strength of foam concrete.

4. Materials used

The combinations of the following materials were used to produce foam concrete specimens.

(a) Portland cement: 53 grade of specific gravity 3.15, confirming to IS 12269: 1987
(b) Ultra-fine GGBS (Alccofine 1203): It is a specially processed material based on slag with high glass content of high reactivity obtained through process of controlled granulation.
(c) Fly ash: Class F fly ash of specific gravity 2.1 (Brand – Ashtech Flyash Superpozz)
(d) Fine sand of size less than 300µm of specific gravity 2.65
(e) Surfactant (Foaming agent): Sodium Lauryl Sulphate (SLS) which is a commonly available synthetic foaming agent

5. Experimental study

Foam concrete is produced by incorporating a measured volume of foam into the mortar mix. The density of the foam typically ranges between 25 and 80kg/m³. The preformed foam that is generated is directly poured into the base concrete mix and mixed thoroughly 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/m³ and not exceeding 100 kg/m³. Assuming the target plastic density as \( D \) kg/m³ with water content as \( w \) kg/m³, total solids as \( s \) kg/m³, cement content as \( c \) kg/m³, fine aggregate content as \( f \) kg/m³,

\[
D = s + w \quad \text{for 1 m}^3; \quad s = f + c
\]

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 is 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.
5.1 Foam generation and its properties
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 [2], which helps in the determination of foam expansion and drainage time. One of the important requirements of foam stability is to ensure that the texture is uniform throughout the process of hardening of foam concrete. The foam stability is a factor which influences the foam density which has to be maintained around 50 kg/m$^3$ for obtaining structural foam concrete [9]. A stable and economical foam will have a drainage of less than 12% in 300s [3]. When SLS was used as foaming agent, as per the results obtained in Table 1, the drainage exceeded 12% in 300s. As per the work done by M. Siva et.al [11], foam with maximum stability is obtained when Sodium hydroxide is added along with SLS and water. Trials were done with SLS concentration of 2.5% and NaOH concentration of 4% with water at pressures 110 KPa and 130 KPa. A maximum average density of 55kg/m$^3$ was obtained for the same concentration of SLS and NaOH at a pressure of 130KPa. The drainage obtained even for longer durations were much lesser for foam with NaOH stabilizer when compared to foam without NaOH.

5.2 Fresh state properties 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. The flowability is determined by Marsh cone test [18], which is a simple method to study the rheological properties of cement and mortar. The test has been conducted as per ASTM C 939-94a (1994) [18]. It consists of a conical brass vessel held on a wooden stand with an orifice of 8mm at its bottom. The time taken by 500ml of foam concrete mix to flow through the nozzle is measured. 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 [4], 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. Table 1 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$^3$, 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.

5.2.1 Observations on fresh state properties
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$^3$ 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$^3$ 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 [4]. As indicated in figure 1, 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.
Table 1: Composition of various mixes for 1m³ foam concrete

| Sl. no | Design density (kg/m³) | Wet density obtained (kg/m³) | GGBS (alccofine) % grams | Cement (kg) | Sand (kg) | Fly ash (kg) | Water (L) | Weight of foam (kg) | w/s ratio |
|--------|------------------------|-------------------------------|--------------------------|-------------|-----------|-------------|-----------|---------------------|-----------|
| 1      | 1200                   | 1276.0                        | 0                        | 425         | -         | -           | 330       | 20                  | 0.42      |
| 2      | 1200 (50% fly ash as filler) | 1256.0                     | 5                        | 21.25       | 403.75    | 425         | -         | 330                | 0.45      |
| 3      | 1200                   | 1294.0                        | 10                       | 42.5        | 382.5     | -           | 330       | 20                  | 0.42      |
| 4      | 1200                   | 1140.0                        | 15                       | 63.75       | 361.25    | -           | 330       | 20                  | 0.42      |
| 5      | 1200 (50% fly ash as filler) | 1156.0                     | 0                        | 387         | -         | -           | 330       | 20                  | 0.42      |
| 6      | 1200                   | 1140.0                        | 5                        | 19.35       | 367.65    | 193.5       | 193.5    | 426                | 15        | 0.55    |
| 7      | 1200                   | 1242.0                        | 10                       | 38.7        | 348.3     | 425         | -         | 330                | 20        | 0.42    |
| 8      | 1200                   | 1196.0                        | 15                       | 58.05       | 328.95    | -           | 330       | 20                  | 0.42      |
| 9      | 1400                   | 1376.0                        | 0                        | 500         | -         | -           | 330       | 20                  | 0.42      |
| 10     | 1400                   | 1380.0                        | 5                        | 25          | 475       | -           | 390       | 15                  | 0.40      |
| 11     | 1400                   | 1448.0                        | 10                       | 50          | 450       | -           | 390       | 15                  | 0.40      |
| 12     | 1400                   | 1368.0                        | 15                       | 75          | 425       | -           | 390       | 15                  | 0.40      |
| 13     | 1400 (50% fly ash as filler) | 1476.0                     | 0                        | 483         | -         | -           | 330       | 20                  | 0.42      |
| 14     | 1400 (50% fly ash as filler) | 1456.0                     | 5                        | 24.15       | 458.85    | 241.5       | 241.5   | 424                | 10        | 0.45    |
| 15     | 1400                   | 1450.0                        | 10                       | 48.3        | 434.7     | 425         | -         | 330                | 20        | 0.42    |
| 16     | 1400                   | 1464.0                        | 15                       | 72.45       | 410.55    | -           | 330       | 20                  | 0.42      |
| 17     | 1600                   | 1592.0                        | 0                        | 593         | -         | -           | 330       | 20                  | 0.42      |
| 18     | 1600                   | 1684.0                        | 5                        | 29.65       | 563.35    | 593         | -         | 405                | 10        | 0.35    |
| 19     | 1600                   | 1680.0                        | 10                       | 59.3        | 533.7     | 593         | -         | 405                | 10        | 0.35    |
| 20     | 1600                   | 1552.0                        | 15                       | 88.95       | 504.05    | -           | 405       | 10                  | 0.35      |
| 21     | 1600 (50% fly ash as filler) | 1692.0                     | 0                        | 571         | -         | -           | 330       | 20                  | 0.42      |
| 22     | 1600 (50% fly ash as filler) | 1710.0                     | 5                        | 28.55       | 542.45    | 285.5       | 285.5   | 457                | 5         | 0.4     |
| 23     | 1600                   | 1690.0                        | 10                       | 57.1        | 513.9     | 285.5       | 285.5   | 457                | 5         | 0.4     |
| 24     | 1600                   | 1676.0                        | 15                       | 85.65       | 485.35    | 285.5       | 285.5   | 457                | 5         | 0.4     |
5.2.2 Discussion on 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% ultrafine GGBS as shown in figure 2. 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 ultrafine GGBS. In addition, the workability of the mix is reduced at higher percentages of GGBS, which may be due to higher fines content.

5.3 Hardened state properties of foam concrete
The hardened state property includes compressive strength and air void characterization for design densities of foam concrete, 1200, 1400 and 1600 kg/m$^3$ which is tested for cubes of size, 50mm x 50mm x 50mm on 28th day as per Appendix A of IS 2250: 1981. The tests were done for foam concrete with ultrafine GGBS at different percentages as 5, 10 and 15% as partial replacement of cement and also 50% fly ash replacement of sand.

5.4 Results and Discussion
5.4.1. Compressive strength
Foam concrete, which generally give compressive strength less than 10 N/mm$^2$, are not, suited for structural applications. The mixture details aimed at higher strength (for various design densities) are shown in Table 2. In this study, compressive strength was measured with the help of cubes, of size 50mm with different proportions of cement, GGBS, fly ash and water.

The compressive strength results obtained are given in Table 2. The compressive strength mainly depends on water to solids ratio, foam volume, cement content, sand and proportion of fillers. The maximum average compressive strength is obtained for a foam concrete density of 1600kg/m$^3$ (with 50% Fly ash filler) after 28 days of curing as 23.04 N/mm$^2$ which is satisfactory for structural applications. It is observed that for some mixes, there is no appreciable increase in strength due to the effect of ultrafine GGBS (Alccofine 1203) in the mix. From table 2, it is observed that the increase in strength is at 10% cement replacement with ultrafine GGBS.
A substantial increase in strength was observed in mixes where sand is replaced with fly ash, compared to mixes with no fly ash. This is due to the effect of fineness of fly ash compared to sand. Also a lesser foam volume is provided for mixes with fly ash to compensate for the lower specific gravity of fly ash.

| Sl.no: | Design density | Wet density obtained (kg/m³) | Dry density obtained (kg/m³) | Volume of foam (%) | w/s ratio | Compressive strength on 28th day (N/mm²) |
|-------|----------------|-------------------------------|-----------------------------|-------------------|----------|---------------------------------------|
| 1     | 1200           | 1276                          | 1222                        |                   |          | 5.5                                   |
| 2     | 1294           | 1256                          | 1338                        | 40                | 0.42     | 6.5                                   |
| 3     | 1140           | 1194                          | 1195                        |                   |          | 5                                     |
| 4     | 1200 (50% fly ash as filler) | 1140                       | 1160                         | 30                | 0.55     | 6.33                                 |
| 5     | 1200           | 1156                          | 1142                        |                   |          | 5.87                                  |
| 6     | 1448           | 1242                          | 1176                        |                   |          | 6.9                                   |
| 7     | 1196           | 1192                          |                             |                   |          | 5.8                                   |
| 8     | 1376           | 1435                          |                             |                   |          | 6.5                                   |
| 9     | 1476           | 1413                          |                             |                   |          | 7.1                                   |
| 10    | 1400           | 1380                          | 1388                        |                   |          | 6.2                                   |
| 11    | 1448           | 1475                          |                             | 30                | 0.4      | 6.3                                   |
| 12    | 1368           | 1355                          |                             |                   |          | 6.3                                   |
| 13    | 1456           | 1395                          |                             | 20                | 0.45     | 14.67                                 |
| 14    | 1450           | 1426                          |                             |                   |          | 15.6                                  |
| 15    | 1464           | 1408                          |                             |                   |          | 10.8                                  |
| 16    | 1592           | 1680                          |                             |                   |          | 10.1                                  |
| 17    | 1684           | 1680                          |                             |                   |          | 8.9                                   |
| 18    | 1680           | 1688                          |                             | 20                | 0.35     | 11.3                                  |
| 19    | 1552           | 1661                          |                             |                   |          | 10.5                                  |
| 20    | 1692           | 1634                          |                             |                   |          | 23.04                                 |
| 21    | 1710           | 1642                          |                             | 10                | 0.4      | 17.63                                 |
| 22    | 1690           | 1672                          |                             |                   |          | 21.76                                 |
| 23    | 1676           | 1614                          |                             |                   |          | 16.24                                 |

A substantial increase in strength was observed in mixes where sand is replaced with fly ash, compared to mixes with no fly ash. This is due to the effect of fineness of fly ash compared to sand. Also a lesser foam volume is provided for mixes with fly ash to compensate for the lower specific gravity of fly ash.
compared to sand. When a lesser volume of foam is provided the pore volume in the foam concrete reduces thereby increasing the strength; however further study is needed in order to correlate the strength with pore structure.

5.4.2 Air void characterization
The air void distribution in foam concrete is an important parameter which influences the strength and durability of the structure. In this study, the air void distribution was studied with the help of a metallurgical microscope. A total of six specimens were tested, three for each design density with 0% and 50% sand replacement with fly ash.

![Figure 3. Cumulative frequency distribution of air void size for 1600 kg/m³ foam](image1)
![Figure 4. Cumulative frequency distribution of air void size for 1400 kg/m³ foam concrete](image2)
![Figure 5. Cumulative frequency distribution of air void size for 1200 kg/m³ foam concrete](image3)
![Figure 6. Strength v/s air void distribution for D90](image4)
Before placing the specimen in the microscope the surface of specimen was finished to obtain a good contrast between the air voids and the matrix. After smoothening the cut surfaces with emery paper, they are wiped with dark coloured glue and talcum powder. From each specimen four trials were done on the finished surface, each of size, 2.6 x 2mm (area=5.2 mm$^2$). Hence, a total area of 20.8 mm$^2$ were covered in each specimen. Each specimen was placed in the microscope and the image was captured on to the image analysis software in the computer. The number of air voids and also the diameter of each air void were noted down. The mixes with sand show highly irregular and continuous air voids. The merged air bubbles were of bigger sizes, leading to discontinuity in load distribution, and hence reduce the strength. The distribution of air voids also depends on self-weight of other ingredients of the mix and foam volume. As the foam volume is more, merging of bubbles occur and produce larger voids.

In order to evaluate the influence of air void distribution of different mixes, on strength of foam concrete, a graph is plotted between the equivalent air void diameter and strength using the parameter D90. Referring to the studies done by Nambiar and Ramamurthy [13], the equivalent air void diameter is obtained from the frequency distribution curves for three different densities as shown in figures 3, 4 and 5. The air void diameter corresponding to 90% (D90) cumulative frequency is taken from the graph for all the mixes. These air void diameters are then plotted against compressive strength of corresponding mixes and the D90 curve is obtained.

The D90 is defined as the median of size in microns where 90% of the distribution lies below D90 and 10% lies above D90. The graph shown in figure 6 represent strength as a function of air void size parameters for foam concrete with cement-sand and cement-fly ash mixes. An increase in the equivalent diameter, of air voids leads to reduction in strength. The higher strength ranges are obtained for a lesser air void diameter, which is due to lesser foam volume and fine filler. The plot between strength and equivalent air void diameter in figure 6 shows a steeper curve, which indicates that the voids are more uniform than cement-sand mixes. For the mixes with sand, a flat curve is obtained which indicates that the mix contains air voids of a wide range. The foam volume is also less for cement-fly ash mixes compared to cement-sand mixes which helps in attaining more uniformly distribution of voids.

6. Conclusion

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

- Sodium Lauryl Sulphate along with Sodium hydroxide used as foaming agent gives a stable foam with a density greater than 50 kg/m$^3$ at an SLS concentration of 2.5% and NaOH concentration of 4% with a pressure of 130 KPa.
- The addition of ultrafine GGBS as partial replacement of cement does not significantly alter the workability of the mixes, whereas a marginal increase in strength is obtained.
- The use of fly ash as partial replacement of sand increases the water demand to obtain workable mixes.
- Addition of fly ash as 50% replacement of sand filler shows an increase in the compressive strength of foam concrete up to 23 N/mm$^2$ for a design density of 1600 kg/m$^3$.
- Higher strength values are obtained for mixes with lower diameter and uniformly sized air voids. The distribution of air bubbles are uniform and even for mixes utilizing fly ash as filler.
- The distribution of air voids depend on self weight of ingredients of the mix and foam volume. As the foam volume is more, merging of bubbles occur and produce larger voids.

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