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SHRINKAGE BEHAVIOR OF FOAM CONCRETE

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Abstract

In the absence of coarse aggregate, the relative influence of factors affecting the shrinkage of foam concrete are likely to be different as compared to normal concrete. This paper presents the shrinkage behaviour of preformed foam concrete for the influences of basic parameters viz., density, moisture content, composition like filler-cement ratio, levels of replacement of sand with fly ash and foam volume. Shrinkage of foam concrete is lower than the corresponding base mix. The shrinkage of foam concrete is a function of foam volume and thus indirectly related to the amount and properties of shrinkable paste. Shrinkage increases greatly in the range of low moisture content. Even though removal of water from comparatively bigger artificial air pores will not contribute to shrinkage, artificial air voids may have, to some extent, an effect on volume stability indirectly by allowing some shrinkage; this effect was more at higher foam volume.

Keywords: Drying shrinkage, Foam concrete, Fly ash, Filler type, Paste ratio, shrinkage ratio, Filler-cement ratio

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Introduction

The volume change resulting from removal of moisture (drying shrinkage) of a cement based material is primarily due to the change in volume of unrestrained hydrated cement paste by removal of adsorbed water from the surface of gel pores (Neville 1995). As far as normal concrete is considered, the major parameters identified are the paste shrinkage and aggregate content (Hansen and Almudaiheem, 1987). Cellular concrete like aerated concrete and foam concrete possess high drying shrinkage due to the absence of aggregates, were up to 10 times greater than those observed on normal weight concrete (Valore, 1954; Jones et. Al, 2003). Significant reduction in shrinkage of aerated concrete obtained by autoclaving suggests that drying shrinkage is predominantly a function of the physical structure of the hydration product (Ramamurthy and Narayanan, 2000). While Tada and Nakano (1983) attribute the higher shrinkage in aerated concrete to its larger volume of finer pores, Ziembicka (1977) and Georgiades and Ftikos (1991) have related shrinkage to the volume and specific surface of micropores. Schubert (1983) related shrinkage to volume of pores affecting shrinkage, to the pore distribution and moisture content. In a comparative study on the shrinkage behaviour with sand and fly ash as filler, mixes with sand exhibited smaller drying shrinkage as the sand particles have higher shrinkage restraining capacity compared to fly ash particles ((Jones et. al, 2003). Nmai et. al. (1997) in a study on new foaming agent for CLSM applications indicated a reduction in shrinkage as density decreases. In addition lightweight aggregate could be used to reduce the shrinkage of foam concrete (Regan and Arasteh, 1990).

Research significance

The method of curing, composition, density, initial and final moisture content, duration and climate of storage and micropore structure and its distribution are reported to affect the drying shrinkage of cellular concrete. Review shows that most of the earlier research on drying shrinkage of cellular concrete has been confined to aerated concrete. Only limited studies with specific parameters and conditions of test are reported on the shrinkage behaviour of foam concrete. Hence, this paper discusses the results of experiments conducted to ascertain the influence of basic components viz., density, moisture content and composition like foam volume, filler-cement ratio and replacement of sand with fly ash, on the drying shrinkage of moist-cured preformed foam concrete.

Materials and methodology

Constituent materials

The constituent materials used to produce foamed concrete are given in Table 1. Different mixes of foam concrete were made by varying i) Filler-cement ratio from 1 to 3 ii) Fly ash replacement for sand (FA) from 0 to 100% by weight, and iii) Foam volume (FV) from 10 to 50 % . The water-solids ratio of these mixes were arrived based on (i) the stability of the foam concrete mix which is defined as the state of condition at which measured density is equal to or nearly equal to design density and (ii) the consistence of mix (for a flow cone spread value of 45 ± 5%) (Nambiar and Ramamurthy, 2006).

Experimental investigations

Tests for drying shrinkage were carried out on prisms of size 40 x 40x 160 mm in accordance with the recommended practice of RILEM-ACC 5.2 and IS 6441-part II - 1972 for aerated concrete. Spherical gauge plugs were attached at both the ends of the specimen to facilitate length change measurements. For each combination of the parameters, three specimens were tested for shrinkage and the mean value is reported.

The specimens were immersed in water for 72 hours after removal from the moulds. After this period of immersion, the specimens were kept in a controlled environment (humidity chamber) at a temperature of 23 ± 1.7 ^{0}C and relative humidity of 50 ± 4 % (ASTM C 157-1998). First length measurement (l_1) was made immediately after 72 hours of immersion in water. The moisture from the surface of the specimen was wiped off and the moisture on the gauge plugs also carefully removed to nullify chance of faulty readings. The length measurements were made in a length comparator with a least count of 0.002 mm. Length measurements were taken for 28 days. The change in length, ∇l expressed as a % is calculated as $((l_2 - l_1)/L_d)$ x 100 where l_1 is the first reading of length, l_2 is the final reading after 28 days and L_d is the original length of the specimen.

Results and Discussion

Influence of filler-cement ratio and filler type

Fig 1 shows the effect of filler-cement ratio on the shrinkage of foam concrete at the end of 28 days. As expected, both cement-sand and cement-fly ash-sand mixes showed a reduction in shrinkage with an increase in filler-cement ratio, the variation being relatively steeper for the filler-cement ratio range 1 to 2. This is can be attributed to the combined effect of reduction in cement content and restraining effect of increased fine aggregate content. Also, for a given filler-cement ratio, cement-sand mix showed lower shrinkage than typical mix with fly ash replacing sand (40% replacement). This is due to the reduced shrinking ability of the sand particles compared to fly ash (Jones et. al, 2003; Ramamurthy and Narayanan, 2000).

Fig 2 indicates that an increase in the fly ash content of the mix, lead to an increase in shrinkage (i.e. shrinkage of mix with 100% fly ash is 31% higher than that of mix with sand). Similar observations were reported for foam concrete by Jones and McCarthy (2005) and for aerated concrete by Ramamurthy and Narayanan (2000). The variation of percentage shrinkage and 28 day compressive strength with dry density for foam concrete with cement-sand and cement-fly ash-sand mixes are shown in Fig 3. For a given density, mixes with fly ash replacement (say, 40% replacement) showed relatively higher shrinkage (about 20%) than that in cement-sand mix.

Apart from the effect of reduced restraining capacity of fly ash compared to sand, higher water-solids ratio requirement of mixes with fly ash for achieving a stable and workable mix also will contribute to this higher shrinkage. Such an increase in water-solids ratio makes the mix more pervious resulting in higher water absorption during curing. Higher water content leads to thicker layer of adsorbed water (Nmai et. al., 1998). The rate at which this water moves towards the surface of the specimen (drying) is increased as the mix is more pervious, leading to higher shrinkage. Further, mixes with fly ash takes relatively longer time to form a stable structure and till such a time this adsorbed water is allowed to escape from the surface of the unreacted and as well as partially reacted particles. Thus the physical structure of the gel formed with fly ash is also responsible for its increased shrinkage (Ramamurthy and Narayanan, 2000). Adding to this, relatively lower foam volume requirement (for mixes with fly ash to achieve a given density) resulting in higher volume of shrinkable paste, contributes to this increase in shrinkage.

At the same time, for a constant density of foam concrete, mixes with fly ash resulted in relatively higher strength (2 to 3 times) as compared mixes with cement-sand (Fig 3).

This increase in strength is attributed to the reduced foam volume requirement for fly ash mixes over and above the filler and pozzolanic effect (Nambiar and Ramamurthy, 2006). Though inclusion of fly ash in the mix causes a small increase in shrinkage, it significantly contributes in enhancing the strength of foam concrete of comparable density. It can also be seen that irrespective of type of mixes, low density products are stable for drying shrinkage in spite of its low strength.

Influence of foam volume

The variations of shrinkage with time for different mixture compositions in Fig 4 (a) and (b) indicate that the shrinkage reduces with an increase in foam volume (i.e. with a reduction in density).

It is reported that the shrinkage of cellular concrete is a function of volume and specific surface of micropores of radii between 75 and 625^0A (Ziembicka, 1977). Georgiades and Ftikos (1991) reported that the pore radii range is between 20 and 200^0A. Hence the removal of water from comparatively bigger pores will not contribute to shrinkage. According to Cebeci (1981) entrained large air voids do not alter the characteristics of fine pore structure of hardened cement paste appreciably. Hence for a given base mix, the micropores which affect shrinkage can be proportionately related to the paste content in foam concrete. Thus lower shrinkage value at higher foam volume is caused by lower paste content in the mix.

In an attempt to characterize the air voids present in foam concrete at different foam volume, images of polished and prepared cut surfaces of specimen were captured by an optical microscope and analysed using an image processing software, after suitable morphological operations and shown in Fig 5 for mixes with 10 and 50% foam volume.

These images were analysed for pore wall thickness (median value of minimum distances between two air-voids measured through the paste phase) and its variation with foam volume plotted in Fig 6 shows that the pore wall thickness reduces as the air-void volume (foam volume) increases. This corroborates the observation of Tada and Nakano (1983) who attribute the lower shrinkage at higher foam volume to thinner pore wall and relatively reduced volume of microcapillary pores which is distributed in this wall.

Table 2 show that the shrinkage % of foam concrete is lower than the corresponding base mix (which is basically a normal mortar). As the foam volume increases the difference between the shrinkage values increases and this confirms the effect of paste content and thus the amount of pores which affects shrinkage in the mix. The reduction in shrinkage of foam concrete compared to base mix may also be attributed the reduction in surface tension of pore water in the presence of foaming agents which are basically surfactants. Similar concept is being used in shrinkage reducing admixtures which when added in concrete interfere with the surface chemistry of the air/water interface within the capillary pore, reducing surface tension and so reducing shrinkage as water evaporates (Concrete Society Technical Report 18, 2002).

Similar observation of reduction in shrinkage with reduction in density (increase in foam volume) was reported by Nmai et al. (1997) for foam concrete and Schubert (1983) for aerated concrete. But in a study by Giannakou and Jones (2002) on shrinkage of foam concrete at different densities reported a slight increase in shrinkage at lower plastic densities. Such a behaviour is attributed to mixture design procedure adopted by Giannakou and Jones (2002), wherein the cement content and water-cement ratio were kept constant at all densities and the density was varied by replacing fine aggregate with air. Hence the sand content becomes less for lower densities, resulting in higher shrinkage. In the study by Nmai et al. (1997) and present study, the mixture design was done keeping the filler-cement ratio (FC) as constant at all foam volume dosage and so the reduction in volume of paste with increase in foam volume cause lower shrinkage at lower densities.

In order to investigate further the effect of paste content on the shrinkage of foam concrete the variation of paste ratio with shrinkage ratio was plotted for both the mixes (Fig 7 (a) and (b)). Shrinkage ratio (SR) is defined as the ratio of shrinkage of foam concrete to corresponding base mix (without foam) and paste ratio (PR) is the ratio of the total paste content in foam concrete to base mix.

It is seen from the plot that shrinkage ratio reduces with paste content. Dotted line is marked in the plots to check whether the variation is linearly proportional to the paste content. But at any given paste content, the shrinkage was higher than the proportionality line and the difference is higher at high foam volume. A possible explanation for this is that the artificial air voids influences the volume stability by allowing some shrinkage and this effect was relatively more at higher foam volume. The following relations for shrinkage of foam concrete fit well with R^2 values of 0.974 and 0.966 for cement sand mix and cement-sand-fly ash mix respectively.

For cement sand mix : $s_{fc} = 0.9814 s_c (PR)^{0.693}$

For Cement-fly ash-sand mix : $s_{fc} = 0.9993 s_c (PR)^{0.7721}$

where s_{fc} and s_c are the shrinkage of foam concrete and base mix respectively.

Effect of drying

Fig 8(a) and (b) shows the variation of shrinkage with moisture content in foam concrete with different foam volume. Moisture content was expressed as % by volume as expressing as % by weight will give misleading results due to significant variations in foam concrete density (Nambiar and Ramamurthy, 2006). The initial moisture content (after storage in water for 72 h) is higher for foam concrete with lower foam volume. As the artificial air-voids are not inter-connected as well as air being trapped in these air-voids, they are not taking part in water absorption. Hence the contribution to water absorption is only by pores other than artificial air-voids present in the sorbing paste. Thus the above observed increase in water absorption of foam concrete containing lower foam volume (artificial air-voids) is caused by the higher volume of sorbing paste (Nambiar and Ramamurthy, 2006).It can be seen that mixes with higher foam volume dried faster as it contain less absorbed water.

Both cement-sand and cement-sand-fly ash mixes showed similar behaviour with marginally higher shrinkage values for fly ash mixes at all foam volume contents. At any moisture content, the shrinkage reduces with an increase in foam volume which, as mentioned earlier, is due to the lower content of micropores affecting shrinkage in foam concrete with higher foam volume. In the range of higher moisture content, a relatively small shrinkage occurs with loss of moisture as this loss of moisture is from relatively larger pores and loss of free water from such pores do not cause significant shrinkage. As drying continues the shrinkage rate is increased due to the removal of water from very small pores and adsorbed water from gel surface. At very low moisture content (about 3% or less) all mixes exhibited a steep increase in shrinkage without any appreciable change in moisture content. Similar relationship of shrinkage with moisture content for aerated concrete was reported by Schubert (1983). Shrinkage in a conservative system, when no moisture movement to or from the paste is permitted, is known as autogenous shrinkage (Neville 1995) and thus at lower moisture content range autogenous shrinkage may also contributed to this total shrinkage. Further experimental studies are necessary to explain the above behavior.

Conclusions

- As the filler-cement ratio increases, shrinkage reduces due to the restraining effect of increased aggregate content.
- Shrinkage of foam concrete is lower than the corresponding base mix. Shrinkage decreases with an increase in foam content. The lower shrinkage value at higher foam volume content is caused by lower content of paste in the mix and thus the lower content of pores affecting shrinkage.
- Higher the fly ash content in the foam concrete mix replacing sand, higher the shrinkage. This is attributed to (i) Low shrinkage resisting capacity of fine fly ash than sand (ii) Greater volume water-solids ratio requirement with fly ash for a stable and workable mix (iii) Greater volume of shrinkable paste with fly ash replacement due to reduced foam volume requirement at a given density.
- Even though addition of fly ash causes a small increase in shrinkage it has got a major contribution towards increasing the strength of foam concrete of comparable density. It can also be seen that irrespective of type of mixes low density products are stable for drying shrinkage in spite of its low strength.
- Artificial air voids may have an effect on volume stability by allowing some shrinkage; this effect increases with increase in foam volume.

Notations

FC – Filler-cement ratio
PR- Paste ratio
SR- Shrinkage ratio
∇l - Change in length expressed as a %
l_1 - length measured after 72 hours immersion in water
l_2 - Final reading after 28 days
L_d - original length of the specimen
s_{fc} - Shrinkage of foam concrete
s_c - Shrinkage base mix

References

ASTM (1989). “Standard specification for fly ash and raw or calcined natural pozzolana for use as a mineral admixture in Portland cement concrete”, ASTM C 618, Philadelphia, 1989.

ASTM (1998). “Standard test method for length change of hardened hydraulic-cement mortar and concrete”. ASTM C 157, Philadelphia, 1998.

Bureau of Indian Standards (1972). “Methods of tests for autoclaved cellular concrete-Determination of drying shrinkage”. IS 6441-part II, New Delhi.

Bureau of Indian Standards (1987). “Specifications for 53 grade ordinary Portland cement”. I S 12269, New Delhi.

Cebeci OZ (1981). “Pore structure of air-entrained hardened cement paste”. *Cement and Concrete Research*, 11, 257-265.

Concrete Society Technical Report 18 (2002), “A guide to the selection of admixtures for concrete”, *The concrete Society*, Berkshire, UK.

Georgiades A and Ch.Ftikos (1991). “Effect of micropore structure on autoclaved aerated concrete shrinkage”. *Cement and Concrete Research*, 21, 655-662.

Giannakou A and Jones MR (2002). “Potentials of foamed concrete to enhance the thermal performance of low rise dwellings”, *Proceedings Innovations and Development in Concrete Materials and Construction*, Dhir RK., Hewelett PC and Csetenyi LJ, eds, Thomas Telford, U.K, 533-544

Hansen W and Almudaiheem JA (1987). “Ultimate drying shrinkage of concrete-Influence of major parameters”. *ACI Material Journal*, 84, 217-223.

Jones MR and McCarthy A (2005). “Preliminary views on the potential of foamed concrete as a structural material”. *Magazine of Concrete Research*, 57, 21-31.

Jones MR, McCarthy MJ and McCarthy A (2003). “Moving fly ash utilization in concrete forward: a U K perspective”. *Proceedings of the 2003 International Ash Utilisation Symposium*, Centre for Applied Energy Research, University of Kentucky, 20-22.

Nambiar E.KK and Ramamurthy K (2006a). “Influence of filler type on the properties of foam concrete”. *Cement and Concrete Composite*, 28, 475-480.

Nambiar EKK and Ramamurthy K (2006b). “Fresh state characteristics of foam concrete”. *ASCE Journal of Materials in Civil Engineering*, (Accepted).

Nambiar EKK and Ramamurthy K (2006c). Sorption characteristics of foam concrete, *Cement and Concrete Research*, (Accepted).

Neville AM (1995). *Properties of Concrete*. Longman, London.

Nmai CK, McNeal F and Martin D (1997). “New foaming agent for CLSM applications”. *Concrete International*, 4, 44-47.

Nmai CK, Tomita R, Hondo F and Buffenbarger J (1998). “Shrinkage-reducing admixtures”, *Concrete International*, 4, 31-37.

Ramamurthy K and Narayanan N (2000). “Influence of composition and curing on the drying shrinkage of Aerated concrete”. *Materials and Structures*; 33, 243-250.

Regan PE and Arasteh AR (1990). “Lightweight aggregate foamed concrete”. *Structural Engineer*; 68(9),167-173.

RILEM. (1992) “Determination of drying shrinkage of AAC”. RILEM-AAC 5.2 Technical Recommendations for the Testing and Use of Construction Materials, E&FN Spon. London.

Schubert P (1983). “Shrinkage behaviour of aerated concrete”, *Proceedings Autoclaved Aerated Concrete, Moisture and Properties*, Wittmann FH, ed., Elsevier; Amsterdam, 207-217.

Tada S and Nakano S (1983). “Microstructural approach to properties of moist cellular concrete”. *Proceedings Autoclaved Aerated Concrete, Moisture and Properties*, Wittmann FH, ed,. Elsevier, Amsterdam, 71-88.

Valore RC (1954). “Cellular concrete Part 2. Physical properties”. *ACI Journal*; 50, 817-836.

Ziembicka H (1977). “Effect of micropore structure on cellular concrete shrinkage”. *Cement and Concrete Research*, 7, 323-332.

Table 1 Constituent materials used to produce foam concrete

Materials	Remarks
Cement	Ordinary Portland cement 53 grade conforming to IS 12269- 1987
Sand	Pulverized and finer than 300 microns, Specific gravity = 2.52
Fly ash	Class F Type conforming to ASTM C 618-1989, Specific gravity = 2.09
Foam	Preformed foam by aerating an organic based foaming agent (dilution ratio 1:5 by weight) using an indigenously fabricated foam generator Foam density - 40 kg/m^3

Table 2 Comparison of shrinkage of base mix with foam concrete mix (1:2)

	Foam concrete		Base mix corresponding to each foam volume	
Foam Volume (FV)%	Cement-sand	Cement-sand-fly ash (FA – 40%)	Cement-sand	Cement-sand-fly ash (FA – 40%)
10	0.0989	0.1117	0.1078	0.1190
30	0.0879	0.0946	0.1163	0.1240
50	0.0696	0.0817	0.1128	0.1310

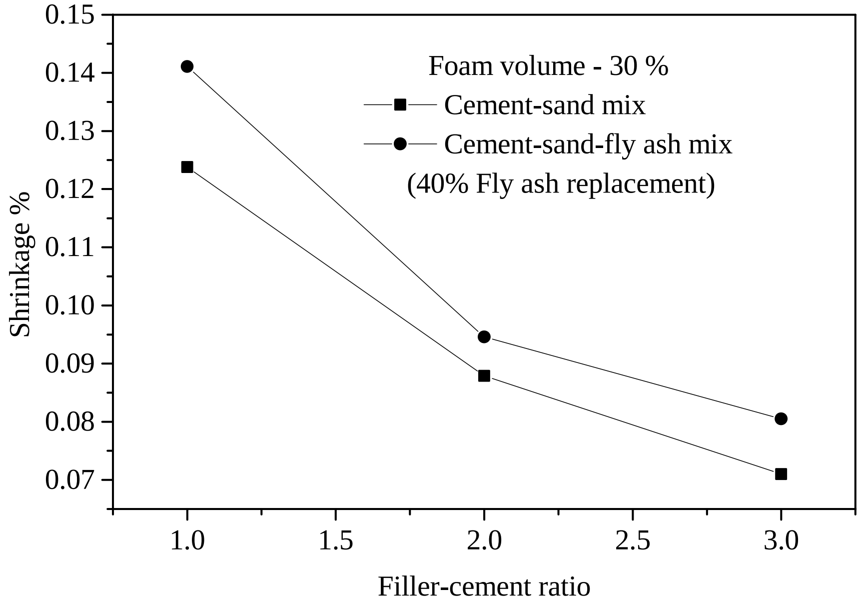


Fig 1 Effect of filler-cement ratio on shrinkage of foam concrete

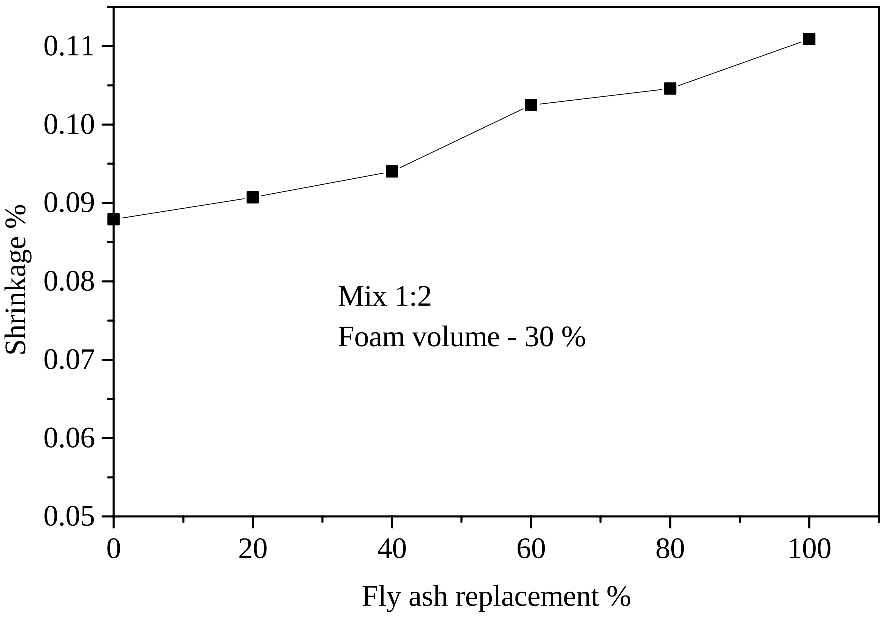


Fig 2 Effect of fly ash replacement on shrinkage of foam concrete

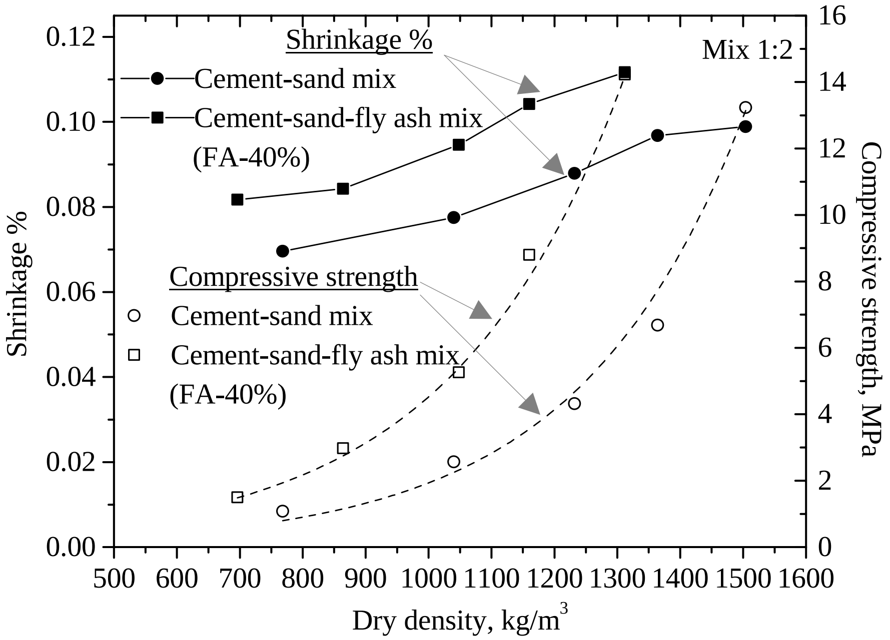


Fig 3 Variation of shrinkage and strength with density of foam concrete

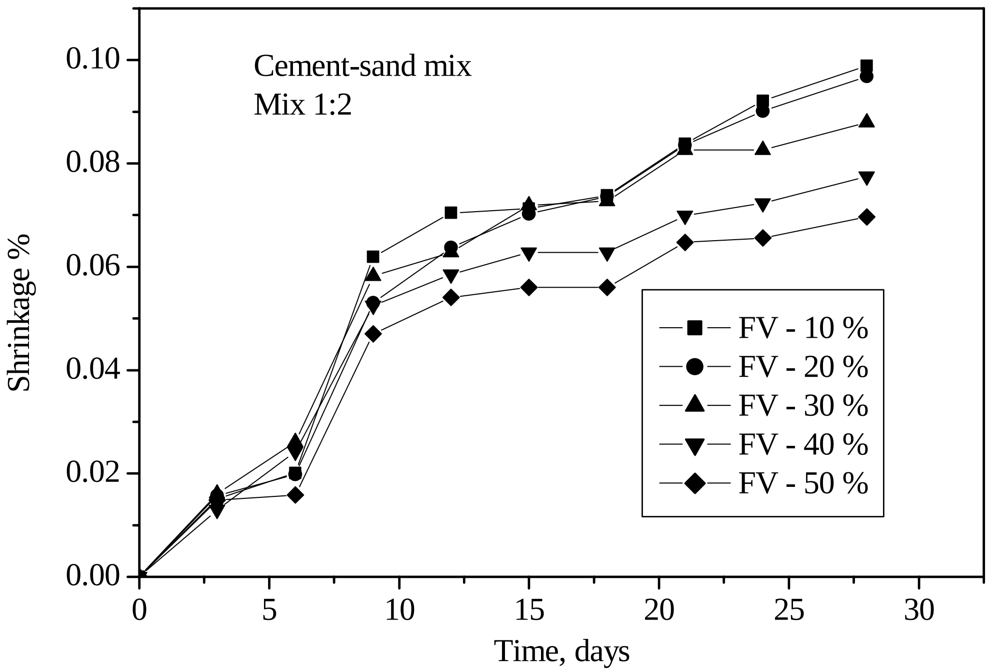


Fig 4 (a) Variation of drying shrinkage with time (Foam concrete with Cement-sand mix)

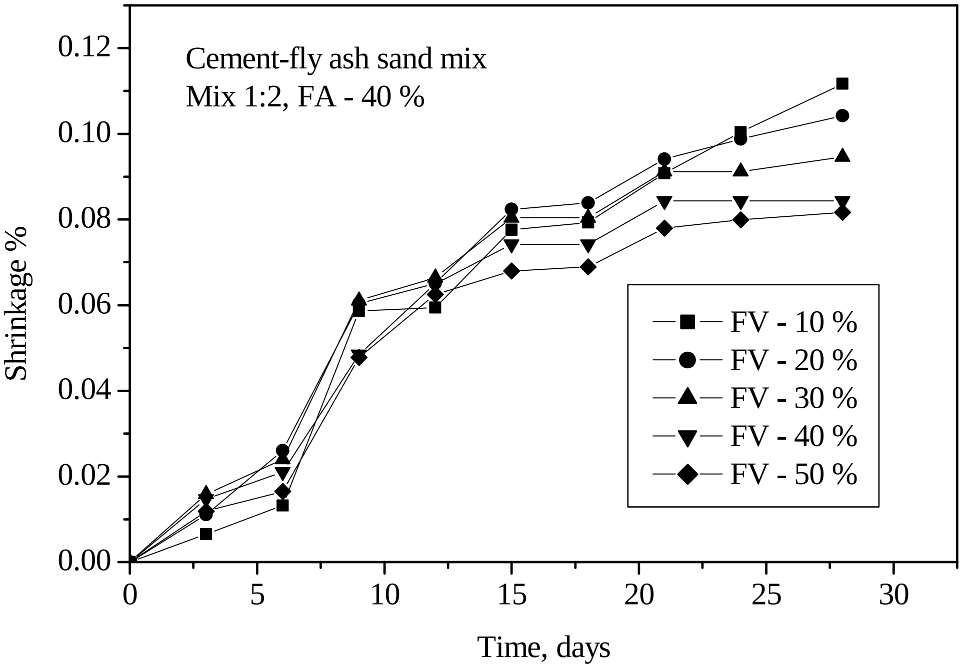
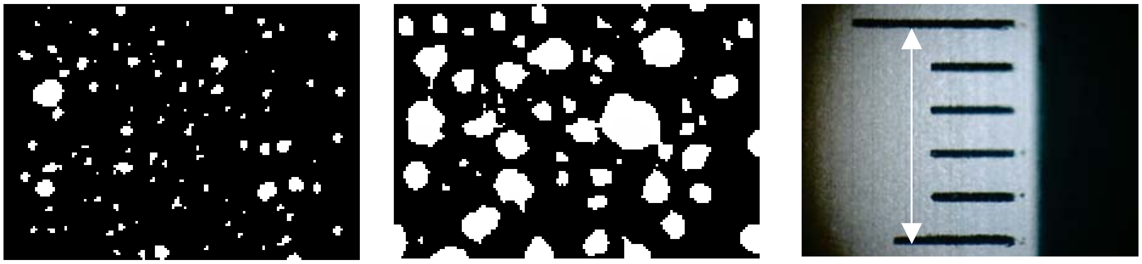


Fig 4 (b) Variation of drying shrinkage with time (Foam concrete with Cement-fly ash-sand mix)



(a) 10 % Foam Volume (b) 50 % Foam volume (c) Scale

Fig 5 Typical binary images using an optical microscope showing air-void distribution

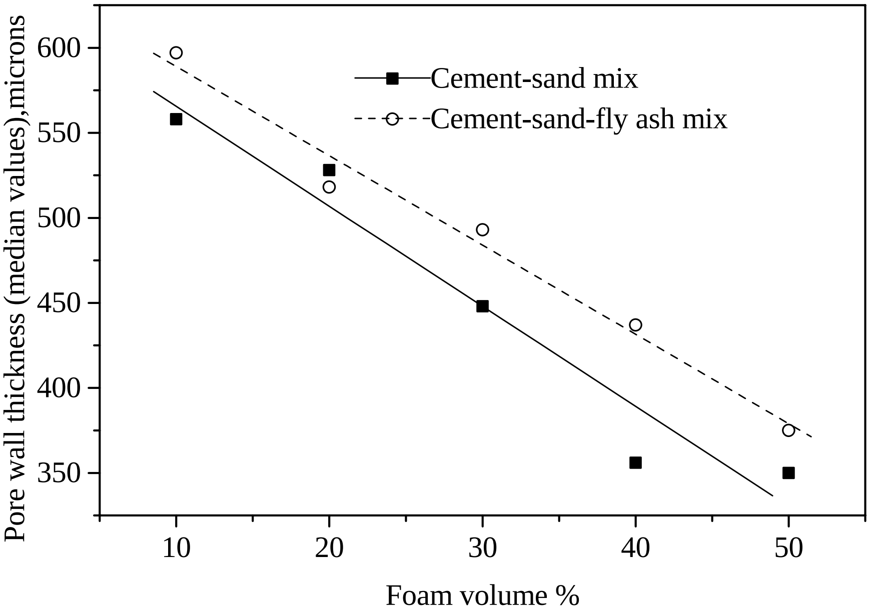


Fig 6 Variation of pore wall thickness with foam volume

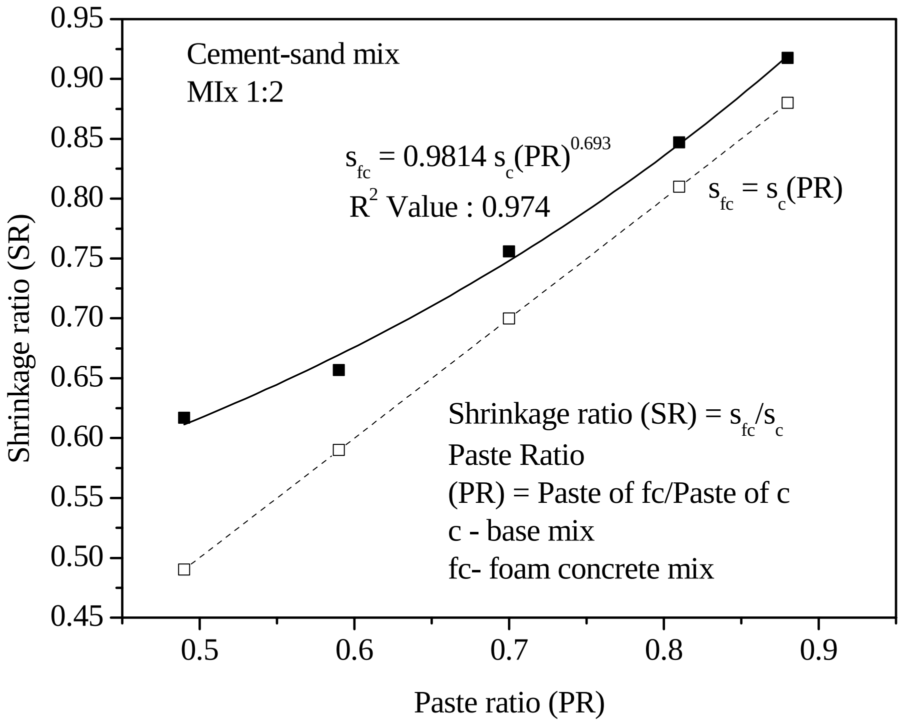


Fig 7 (a) Influence of paste content on shrinkage for cement-sand mixes

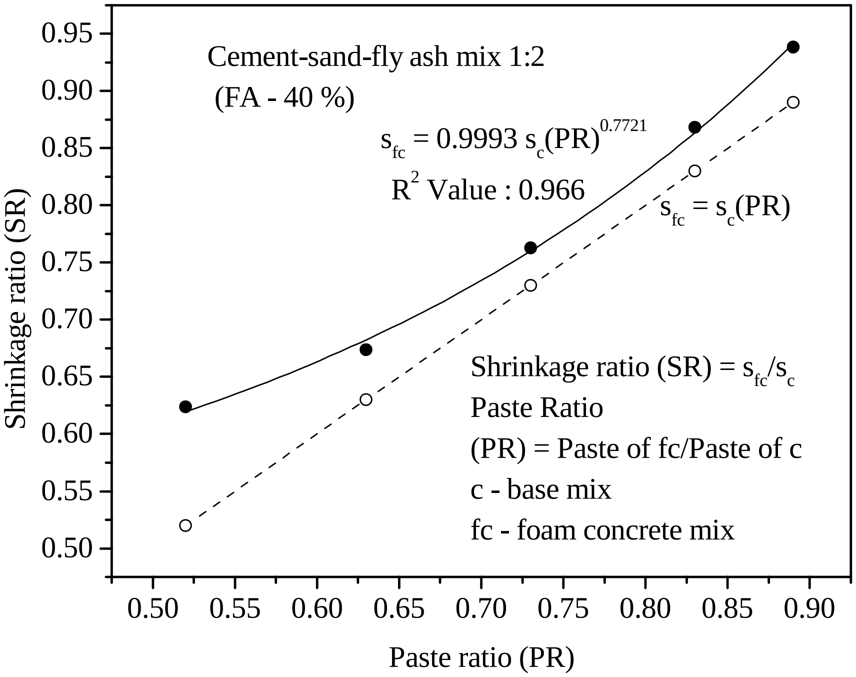


Fig 7 (b) Influence of paste content on shrinkage for cement-fly ash-sand mixes

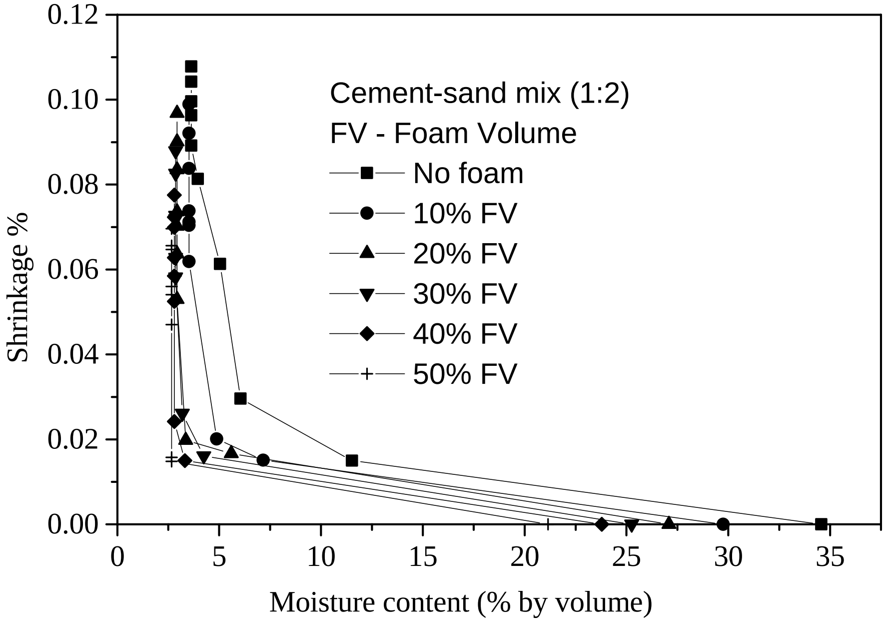


Fig 8(a) Relationship of shrinkage with moisture content for cement-sand mix

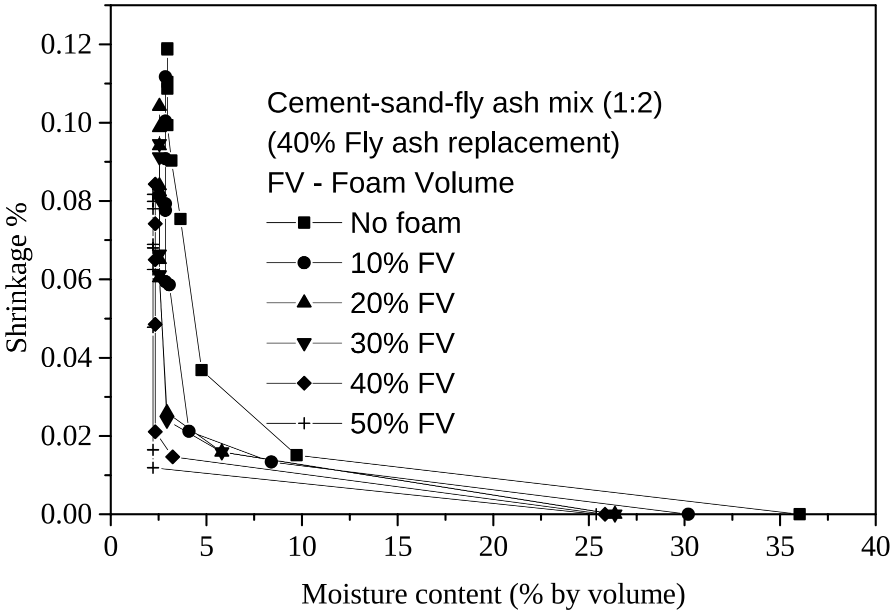


Fig 8(b) Relationship of shrinkage with moisture content for cement-sand-fly ash mix