Evaluation of performance of foam produced with different methodologies for use in foam concrete production

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Abstract. For the production of foam concrete which finds applications in many areas, generally as a function of its relatively lightweight, the use of stable and quality foam is the key requirement. However, the literature available on the influence of characteristics of foaming agent and foam on the properties of foam concrete are rather limited. Hence a more systematic research is needed in this direction. The present work focuses on the relative performance evaluation of foam (initial foam density, foam stability, viscosity of surfactant solution and bubble size) using a typical synthetic surfactant and additive using two different foam production methodologies namely stirrer and foam generator. Comparative studies on foam production methods indicated that foam produced based on compressed air method (foam generator) is of better quality with lesser liquid fraction and drainage compared to that of foam produced with stirrer. Also studies have proved that there is a strong relationship between viscosity of surfactant solution, initial foam density, foam stability and bubble microstructure.

1 Introduction
It is a well-known fact that pure liquids cannot foam and the presence of surfactant is essential for making and stabilising a foam [1,2]. One traditional and most familiar way of preparing foam is by using a dispersion technique, which consists of mechanical shaking of surfactant solution or whipping a surfactant solution mechanically with a high speed stirrer or fan [3]. Researchers [4,5] have proved that the mean bubble size of foam produced decreased with increase in rotational speed of stirrer. However, the most widely used method of foam production for use in concrete is compressed air method where the foam is generated by mixing compressed air and surfactant solution in high density restrictions [6]. Hence, in order to compare the influence of foam production methods on the behaviour of foam, two different foam production methods selected for the present study are mechanical method (high speed stirrer) and compressed air method (foam generator). The relative characteristics of foam and surfactant solution viz., initial foam density, bubble size and viscosity of surfactant solution produced with a synthetic surfactant and additive has been studied for two different foam production methods.

2 Experimental Program

2.1 Materials and Methods
This study investigates two different foam production methodologies using a synthetic surfactant namely Sodium lauryl Sulphate (SLS) and an additive namely Carboxy Methyl Cellulose (CMC). As
discussed earlier, mixing speed is important in case of stirrer method (M1), hence for the present study maximum speed of 1136 rpm was adopted for M1. Similarly for generator method (M2) the pressure at which the foam is generated was varied from 353 kPa to 490 kPa. For evaluating the relative characteristics of foam, a range of SLS concentration from 1% to 10% and CMC concentration from 0.1% to 0.3% were adopted. The initial foam density was measured immediately after its generation while the stability of foam was assessed by free drainage test prescribed by Def-Standard 42-40 [7]. A drainage pan of 1612 ml nominal volume with a conical base rounded to accept externally a 12.7 mm bore by 25 mm long polymethyl methacrylate tube with a 1.6mm bore brass cock at its lower end was used. The pan was filled with foam and the volume of the solution drained was measured at various time intervals. The influence of addition of additive CMC on viscosity of surfactant solution was measured using Anton Par Rheometer with the speed of rotation varied from 150 to 200 rpm at constant temperature of 25°C. Bubble microstructure was studied by placing a thin layer of foam on a glass plate (immediately after the generation of foam) under optical microscope and the images captured were analyzed with a computer with image analysis software (Image J) [8].

3 Results and Discussion

3.1 Initial foam density
The initial foam density of foam produced with stirrer (Method M1) and foam generator (Method M2) are shown in Figure 1. The initial foam density of foam produced using stirrer (Method M1) decreased significantly with increase in SLS concentration up to 7% beyond there was not much variation. The reason for this behaviour could be ascribed to the production of foam with relatively good quality (more amount of air and lesser liquid fraction) at higher SLS concentration. The variation in initial foam density with CMC concentration was very less compared to that with SLS concentration. The variation of initial foam density of foam with SLS concentration produced using foam generator (Method 2) also showed trend similar to that of foam produced using method M1. Also it is noticed from Figure 1, that the effect of variation of CMC concentration on initial foam density is more significant unlike foam produced using method M1. This shows that the potential of CMC in improvement of quality of foam (reduction of liquid fraction) is utilized to a greater extent in foam produced using foam generator based on compressed air method.

For a given SLS concentration, an increase in foam generation pressure reduces the initial foam density (IFD) significantly for foam produced using method M2 (Figure 2). Also it is to be noted that the effect of foam generation pressure is very predominant when compared to other parameters for foam produced using method M2. Hence for the foam generator model used for the present study, to
produce foam of good quality (lower liquid fraction) higher pressure is needed for sufficient mixing of air and liquid. Further, the experimental results indicated that the foam produced using generator is relatively drier foam and meets the ASTM C 796 requirement of initial foam density of 32 to 64 kg/m³ for use in preformed foam production [9].

3.2 Foam Stability
Figure 3 shows the percentage solution drained for foam produced using method M1 and M2 at 5 minute after foam generation. Foam produced using stirrer being wet foam evidently shows higher drainage. Percentage solution drained of foam produced using both the methods reduces significantly with increase in SLS and CMC concentration. The reduction in percentage solution drained or improvement in stability of foam could be ascribed to the production of good quality of foam (with lesser liquid fraction) at higher levels of SLS and CMC concentration. In particular, the addition of CMC has resulted in enhancement of viscosity of surfactant solution and production of stable foam with smaller size bubble microstructure as explained in upcoming sections. Furthermore the reduction in solution drained due to addition of CMC is more predominant for foam produced using method M2 which could be again attributed to efficient role of CMC in foam produced based on compressed air method when compared to that of stirrer. Also the early rate of drainage in the first five minutes is very low for foam produced using method M2 compared to that of M1. In addition it is to be noted that the effect of variation of SLS and CMC concentration is more significant on foam drainage when compared to that of initial foam density. Figure 4 shows the variation of percentage solution drained with SLS concentration and foam generation pressure (FGP) at fixed level of 0.2% CMC concentration. Similar to earlier observations on the effect of FGP on IFD, the foam drainage reduces significantly with increase in FGP.

![Figure 3](image3.png)  
**Figure 3.** Variation of percentage solution drained with SLS concentration for M1 and M2 at 5th minute after foam generation (490 kPa)

![Figure 4](image4.png)  
**Figure 4.** Variation of percentage solution drained with foam generation pressure for M2 (CMC 0.2%)

Hence again from stability point of view, it is preferable to choose higher SLS, CMC concentrations and higher FGP for the foam generator used. However it was observed that adoption of FGP beyond 490 kPa resulted in interrupted foam production affecting the foam output rate. Hence for the current foam generator model the recommended pressure was restricted to 490 kPa.

3.3 Viscosity of surfactant solution
The viscosity of surfactant solution is plotted in Figure 5. It is noticed from Figure 5 that the viscosity of surfactant solution at low levels of SLS and CMC concentration is very less and this got enhanced significantly with increase in SLS and CMC concentration. Furthermore, results indicated that the significant increase in viscosity of SLS surfactant solution with increase in SLS concentration was achieved only in presence of CMC. This could be attributed to the tight packing of surfactant molecules achieved due to the addition of CMC which thereby enhanced the viscosity of surfactant
solution significantly [10]. Hence as the viscous surfactant solution can result in stable foam with smaller bubble microstructure as discussed in upcoming sections, it is preferable to adopt higher SLS and CMC concentration. However as the viscosity of surfactant solution can also affect the workability of foamed concrete mix, the optimization of CMC dosage must also consider the workability and stability of foamed concrete mix.

Figure 5. Variation of viscosity of surfactant solution with SLS concentration at various CMC

Figure 6 (a) Stirrer method M1

Figure 6 (b) Generator method M2

Figure 6. Variation of average bubble size with SLS concentration for M1 and M2 (490 kPa)

Figure 7. Variation of bubble size with foam generation pressure for M2 (CMC 0.2%)

3.4 Bubble size

Figure 6 (a, b) shows the variation in average bubble diameter of foam produced using methods M1 and M2. It is observed for both M1 and M2 that the adoption of higher SLS and CMC concentration results in foam with reduced bubble diameter. The reduction in bubble size could be attributed to the increase in viscosity of surfactant solution due to addition of CMC. Hence the above results are in agreement with the earlier observations by other researchers [11] that highly viscous surfactant solution can produce foam with smaller bubble microstructure [12, 13].

Figure 7 shows the variation of average bubble diameter with SLS concentration at fixed level of 0.2% CMC concentration. A percentage reduction of 17% in average bubble diameter was observed for variation in FGP from 353 to 490 kPa at higher levels of SLS concentration. The reduction in bubble sizes could be ascribed to improvement in viscosity of surfactant solution at higher FGP. Comparison
of bubble sizes of foam showed that the stirrer foam which is basically a wet foam (with liquid fraction 20%) has finer bubble structure (Figure 6 (a) compared to dry foam produced using foam generator. Dispersion of more volume of air per unit volume of surfactant solution in dry foam could be the reason for coarser bubble structure in dry foam with lesser liquid fraction [14]. However at very high SLS and CMC concentrations foam produced by method M2 is found to have relatively smaller size bubbles compared to M1. Hence, in order to produce foam with smaller bubble size microstructure, higher surfactant concentration is needed for generator method M2 (Figure 6 (b)).

3.5 Correlation between viscosity of surfactant solution, initial foam density and foam stability
A scatter plot showing the relation between viscosity of surfactant solution and initial foam density of foam produced with methods M1 and M2 are plotted in Figure 8. It was observed that an increase in surfactant concentration (at a constant CMC concentration) associated with some increase in viscosity resulted in significant reduction of the initial foam density up to SLS concentration of 7% after which there is not much variation for foam produced with both methods M1 and M2. This trend of reduction in initial foam density with increase in SLS concentration could be attributed to the significant improvement in quality of foam due to increase in surfactant concentration. On the other hand, the significant increase in viscosity of surfactant solution achieved due to increase in CMC concentration (at a constant SLS concentration) did not result in much variation in initial foam density (% reduction in IFD less than 4%) for method M1. However for method M2, significant increase of 208 % in viscosity achieved due to increase in CMC concentration from 0.1 to 0.3% at constant SLS concentration of 10% resulted in 32% reduction in initial foam density.

![Figure 8](image)

**Figure 8.** Variation of Initial foam density with viscosity of surfactant solution for M1 and M2

![Figure 9](image)

**Figure 9.** Variation of percentage solution drained with viscosity of surfactant solution for M1 and M2

Hence based on the above observations it can be concluded that the influence of increase in viscosity achieved due to addition of the CMC on improvement of quality of foam (reduction of liquid fraction) is realized to a greater extent in foam produced using foam generator based on compressed air method. The relation between viscosity and percentage solution drained at 5th minute after foam generation for foam produced with stirrer (M1) and generator (M2) are plotted in Figure 9. Similar to discussion on foam density, it was observed that an increase in surfactant concentration (at a constant CMC concentration) associated with some increase in viscosity resulted in significant reduction in percentage solution drained for both M1 and M2. Furthermore, the significant increase in viscosity of surfactant solution achieved due to increase in CMC concentration (for a constant SLS concentration) resulted in significant reduction in foam drainage. It could be observed apparently for foam produced with M2, that the percentage solution drained is reduced significantly to less than 1% particularly at higher concentration of CMC which confirms the earlier observation that role of CMC in foam quality
improvement is more efficient in compressed air method of foam production. The reason for reduction
in drainage due to increase in viscosity of surfactant solution could be ascribed to the cushioning effect
of viscous lamellae around the bubble and reduced bubble size which improved foam stability.

4 Conclusions
Following conclusions are drawn based on the present study.
Based on comparative studies on foam production methods, it can be concluded that foam produced
based on compressed air method (foam generator) is of better quality with lesser liquid fraction and
drainage compared to that of foam produced with stirrer. Also the potential of CMC in improvement
of quality of foam (reduction of liquid fraction) is utilized to a greater extent in foam produced using
foam generator based on compressed air method. Studies on relative foam behaviour for two different
foam production methods indicated that the initial density and drainage of foam produced using both
the methods (M1 and M2) decreased significantly with increase in surfactant concentration resulting in
relatively good quality of foam with lesser liquid fraction and more stability. For the compressed air
method of foam production, the effect of FGP is predominant compared to that of other foam
production parameters. Hence it is recommendable to adopt higher levels of SLS, CMC concentration
and FGP to produce highly viscous surfactant solution which can result in stable foam with lesser
liquid fraction and smaller bubble size microstructure.

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