Effect of Using Soap Nut as Natural Foaming Agent on Mechanical Properties and Pore Distribution of High Strength Aerated Concrete

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Abstract. Aerated concrete is a type of concrete that contains pore in its matrix structure. This pores could provide spaces for water absorption which makes aerated concrete more durable toward freeze-thaw cycle. Many methods have been studied in forming an aerated concrete and using soap nut as aerating agent is more sustainable than other chemically formulated agent. Forming of pore inside concrete not only improve freeze-thaw cycle durability but also as places to store healing agent in concrete. This is important in developing a self-healing concrete especially a microbial induced healing. This paper aims to study the effect of using soap nut in high strength concrete. Four types of high strength concrete samples were prepared which are Control sample, AE2 with 2% of aerated soap nut, AE4 with 4% of aerated soap nut and AE6 with 6% of aerated soap nut. Total of 3nos. of 100mm cubes and 3nos. of 50mm cubes from each type of samples were prepared. Cubes samples of 100mm dimension were tested for water absorption and compressive strength while cube samples of 50mm dimension were split and analysed for pore distribution. The results showed that increase in addition of soap nut in concrete mixture resulted in decrease of compressive strength but minimal effect on its water absorption rate. Pore formation and dispersion were optimum in concrete with 4% and 6% inclusion of soap nut. In conclusion, 4% of aerated soap nut in high strength concrete present the optimum characteristic in producing well-dispersed pores of high strength aerated concrete.

1. Introduction
Aerated concrete is a lightweight cellular concrete with randomly distributed air voids throughout the entire structure which is commonly made of cement paste or mortar [1,7-8,11-12,14]. Void is created within the concrete matrix either by preforming the foam before mixing with dry components of concrete or by autoclaving mixture of cement and aluminium [4]. Commonly foam concrete has low strength and lightweight which mostly researched as non-load bearing structure [5,7]. Existence of pores within the concrete provide additional insulation and increase in durability toward freeze-thaw cycle [15]. This is due to pores that reduce propagation of energy and absorptivity for the concrete. Recent researches are heading towards increasing the durability of the concrete by enabling it to self-heal [13]. This can be achieved by introducing self-healing agent such as bacterial self-healing agent. However, formation of CSH in aging concrete reduce pores which resulted in less efficient bacterial healing agent [2]. Hence, this paper aimed to study the viability of high strength concrete to be incorporated with foam to create...
pores for use in bacterial self-healing concrete. Recent research on high strength mortar provide a viable matrix structure to be embedded with pores [3,16]. High strength of mortar could compensate the strength reduction due to pores hence resulting in concrete of practical strength. Furthermore usage of natural source which is soap nut serve as sustainable alternative to synthetically produced agent [14].

2. Materials and Methods

2.1. Mix design and process

High strength concrete mix composition contained ordinary Portland cement with fine aggregates of sizes ranging from 600-1180 μm. This dry material is added with water of 0.2 water-to-cement ratio and superplasticizer Sika® ViscoCrete® 2044 of 2% by cement weight. Soap nut was added to the mix according to type of sample. AE2, AE4 and AE6 were added with aerated soap nut of 2%, 4% and 6% of cement weight respectively.

| Constituents          | Control sample (g) | AE2 (g) | AE4 (g) | AE6 (g) |
|-----------------------|--------------------|--------|--------|--------|
| Ordinary Portland Cement | 1167               | 1167   | 1167   | 1167   |
| Soap Nut              | -                  | 23.34  | 46.68  | 70.02  |
| Water                 | 233                | 233    | 233    | 233    |
| Superplasticizer      | 23.34              | 23.34  | 23.34  | 23.34  |
| Fine Aggregates (600-1180 μm) | 1167               | 1167   | 1167   | 1167   |

2.2. Testing and analysing

Water absorption test was carried out on 100mm cube sample at the age of 28 days. Samples were immersed in tap water for 24 hours prior to drying in oven at 100°C for another 24 hours. Weight of samples after immersion, \( W_w \) and after drying, \( W_d \) was recorded. Rate of water absorption is calculated based on the following equation.

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\text{Percentage of water absorption, } \% = \frac{W_w - W_d}{W_d} \times 100\%
\]

For compression test, it was carried in accordance with the standard of BS EN 12390-3 on 100mm cube after water absorption test. Mean value acquired from 3 cube samples were analysed and presented in this paper. Sample of 50mm cube were used in visual pore analysis. Three samples from every type of samples were split prior to visual analysis. Photos of each samples is taken and analysed for pore location and quantification.

3. Results and Discussion

3.1. Testing and analysing

Figure 1 shows the water absorption rate of samples are mostly in decreasing trend. The rate of water absorption is between 2% to 3% which is too small for comparison. The difference of rate between Control samples and AE2 is 0.12% while 0.27% between Control samples and AE4. For comparison between Control samples and AE6, the difference is the largest which is 0.87%. However, the rate is very low compared to other researches on foam concrete which is 20 – 35% of absorption rate [9][14]. This may be due to higher packing density of concrete mixture surrounding the pore that inhibit absorption. Overall, the difference of water absorption for all sample is in the range of 0.1 to 0.9% which is negligible. These indicate that addition of soap nut has minimal effect on the water absorption rate of concrete.
3.2. Compressive strength

Figure 2 shows the result of compressive strength for all samples. Result shows a decreasing trend of strength recorded as the addition of soap nut is increased. Compressive strength for Control sample, AE2, AE4 and AE6 are 105.4 MPa, 82.9 MPa, 76.4 MPa and 56.1 MPa respectively. Overall, the compressive strength of all samples are classified as high strength as they are above 40 MPa. The downward trend indicates the change of microstructure of concrete due to addition of soap nut. Reduction of compressive strength by almost half or 46.8% is due to addition of 6% soap nut. Smallest reduction was recorded by AE2 at 21.3% and AE4 recorded 27.5% reduction as compared to Control sample.

4% of soap nut addition in concrete indicates the optimum value as it increase the pores volume but less reduction as compared to 6% addition. This is due to less pores formed compared to 6% of soap nut but higher compressive strength. 2% addition of soap nut in AE2 shows that addition of soap nut into concrete alters its microstructure and reduce the strength by 20%. Addition of less than 2% may have negligible effect on strength of concrete. However, based on percentage of soap nut addition, the amount of pores created in AE2 would be less as compared to AE4 but the difference in strength is only 7.8%. In comparison with other type of aerating agent, reduction of compressive strength due to soap nut is lower compared aerating admixture which recorded more than 40% reduction [7]. Overall, it can be concluded that 4% addition of soap nut in concrete produced the optimum compressive strength.

3.3. Visual pore identification and analysis

Figure 3 shows split surface of sample AE2, AE4 and AE6. This figure is further analysed to distinguish and locate the pores formed in every sample. Based on Figure 4, no. of pores increased as the amount of soap nut is increased. Sample AE2 indicated very minimal amount of pores formed as compared to sample AE4 and AE6. Based on Figure 5 and 6, average no. of pores formed in AE2 is 18 nos. that is equal to area of 13.5mm² per 2500mm² area. Largest amount of pores recorded in sample AE6 while AE4 has slightly less area of pores but almost similar number of pores. Most pore produced in AE4 and AE6 has diameter of 0.5 – 1mm and 0 – 0.5mm but AE6 produced more quantity of larger pores which resulted in greater average area of pores per 2500mm².
Pores in AE2 are mostly large which is in range of diameter 1-3mm. However, less number of small diameter pores were observed in the sample. This indicates that percentage soap nut in AE2 produced foam in small diameter and was unable to retain the shape during mixing. This resulted in merger of foam forming large diameter foam and less pore quantity. Overall the distribution of pores were quite uniformed in sample AE4 and AE6 while pores in sample AE2 is localized. This is due to vast number of small diameter pore formed throughout these samples. This indicates that the amount of soap nut of more than 4% produced higher number of small diameter pores that survive mixing process and not coalescing.

The number of pores formed also shows an inverse proportionality with the trend observed in compressive strength. Less number of pores formed in the concrete caused less reduction of strength. Pores create weak points inside concrete matrix which loosened the matrix that resist compressive action in concrete. In term of water absorption rate, the development of pore within the concrete matrix has less effect due to lack of interconnectivity between pores that hinder the propagation of water which result in low water absorption rate. This is opposite to typical aerated concrete which has closely positioned pores with interconnectivity [6]. This resulted in aerated concrete having higher water absorption rate.

Pore numbers comparison between AE4 and AE6 shows marginal difference which is 15% even though the amount of soap nut is doubled in AE6 as compared to AE4. This indicates optimum amount of soap nut addition at 4% produced optimum number of pores in concrete matrix. Formation of pore in this concrete of preformed foam depends on the surface tension of soap nut and volume of foam produced prior to mixing. Surface tension of soap nut determined the ability of foam to retain its shape during mixing of concrete while volume of foam determined the amount of pores that would be created once it has hardened. As indicated by the result, optimum quantity and quality of foam is produced with 4% of soap nut as doubling the soap nut amount caused marginal increased in pore numbers.

Figure 3. Visual photograph of sample AE2 (a, b and c) AE4 (d, e and f), AE6 (g, h and i).
Figure 4. Pore identification of sample AE2 (a, b and c), AE4 (d, e and f), AE6 (g, h and i).

Figure 5. No. of pore identified for sample AE2 (a, b and c), AE4 (d, e and f), AE6 (g, h and i).

Figure 6. Average area of pores formed for sample AE2, AE4, AE6.

4. Conclusions
It can be concluded that utilization of soap nut as natural foaming agent reduce the compressive of high strength concrete. However, it has minimal effect on water absorption rate of high strength concrete. Furthermore dispersion of pores at percentage of soap nut higher than 4% is quite uniform and well-distributed throughout the concrete. Optimum amount of 4% soap nut addition produced a practical
aerated high strength concrete which could be further investigated towards self-healing microbial high strength concrete.

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