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RATIONAL PROPORTION FOR MIXTURE OF FOAMED CONCRETE DESIGN

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Abstract. This paper presents part of the results of laboratory work to design a lightweight foamed concrete made with Protein Agent 1 as foam, silica fume (SF) mineral admixture and superplasticizer (SP). Control of foamed concrete mixture made with foam containing only Ordinary Portland Cement (OPC) and SF, lightweight foam concrete mixture containing 10% of SF as a replacement for the cement in weight basis was prepared. SF is used to increase the compressive strength and for economical concerns. The foam concrete was cured at 70% relative humidity and ± 28°C temperature. The mechanical properties of a lightweight foam concrete with OPC are presented. The findings indicate that water absorption of aggregate is large in this case. However, the use of SF seems to be necessary for the production of cheaper and environment-friendly structural foamed concrete with compressive strength and control structural foamed concrete containing only OPC.

Keywords: Foam concrete mixed; mortar density; actual density; mechanical properties; compressive strength

Abstrak. Kajian ini membentangkan sebahagian hasil kerja makmal untuk reka bentuk konkrit ringan berbusa dengan Protein Agent 1 sebagai busa, silica fume (SF) sebagai bahan tambah dan *superplasticizer* (SP). Konkrit ringan berbusa terkawal dicampurkan dengan kandungan simen Portland biasa (OPC) dan silica fume, campuran tersebut pada kadar 10 peratus, dari berat simen sebagai bahan tambah akan disediakan. Silica fume digunakan untuk meningkatkan kekuatan mampat dan juga menjimatkan kos. Konkrit berbusa diawetkan pada kisaran 70 peratus kelembapan dan 28 darjah kandungan udara. Sifat mekanikal daripada struktur konkrit ringan berbusa juga didedahkan. Dapatan kajian menunjukkan bahawa serapan air dalam kajian besar adanya. Walaupun demikian, silica fume perlu digunakan untuk menghasilkan struktur ringan berbusa yang murah dan mesra alam, dengan kekuatan mampat dan kawalan struktur ringan berbusa menggunakan simen Portland biasa (OPC) sahaja

Kata kunci: Campuran konkrit berbusa; ketumpatan mortar; ketumpatan sebenar; sifat mekanikal; kekuatan mampat

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1.0 INTRODUCTION

Foam concrete is either a cement paste or mortar classified as lightweight concrete, in which air-voids are entrapped in mortar by a suitable foaming agent. It possesses high flowability, low self-weight, minimal consumption of aggregate, controlled low strength, and excellent thermal insulation properties. With proper control in dosage of foam, a wide range of densities (1600–400 kg/m^3) of foamed concrete can be obtained for application to structural, partition, insulation, and filling grades (Ramamurthy *et al.*, 2009).

Foam concrete is a lightweight material consisting of Portland cement paste or cement filler matrix (mortar), with a homogeneous void or pore structure created by introducing air in the form of small bubbles (Nambiar and Ramamurthy, 2007a).

Foam concrete consists of cement paste and voids, and the properties of both components have a measurable effect on the properties of the combined materials (Kearsley and Wainwright, 2001).

Foam concrete is produced under controlled conditions from cement, filler, water and a liquid chemical, that is diluted with water and aerated to form the foaming agent (Vine-Lott, 1985).

The first comprehensive review on cellular concrete was presented by Short and Kinniburgh in 1963, summarizing the composition, properties, and uses of cellular concrete, irrespective of the method of formation of the cell structure. Recently, Jones and McCarthy reviewed the history of uses of foam concrete, constituent material, its properties, and construction application, including some projects carried out worldwide. These reviews included functional properties such as fire resistance, thermal conductivity, and acoustical properties. However, data on fresh state properties, durability, and air-void systems of foam concrete are rather limited (Short and Kinniburgh, 1978).

The production of stable foam concrete mix depends on many factors such as selection of foaming agent, method of foam preparation and addition for uniform air-voids distribution, material section and mixture design strategies, production of foam concrete, and performance with respect to fresh and hardened state are of greater significance (Ramamurthy *et al.*, 2009).

According to Kearsley and Wainwright, 2001, both the 28-days and one year results indicate that the compressive strength of foam concrete is primarily a function of dry density and is little affected by the percentage cement replaced by ash. Based on the results of this investigation, it can therefore be concluded that replacing high proportions of cement with fly ash does not significantly affect the long-term compressive strength of well-cured foamed concrete.

Objective of this research such as to design and selection lightweight foam for housing construction and construction industry, to determine the percentage of foam and superplasticizer also the criteria for construction industry, and to define and testing structure lightweight foam based on the semi load bearing performance.

In this paper, studies and classifications of foam concrete related to proportional mix design foamed concrete are also discussed.

2.0 BACKGROUND

In addition to Ordinary Portland Cement (OPC), Rapid Hardening Portland Cement (High Alumina and Calcium Sulfoaluminate) has been used for reducing the setting time and to improve the early strength of foam concrete. Fly ash and ground granulated blast furnace slag have been used in the ranges of 30%–70% and 10%–50%, respectively, as cement replacement to reduce the cost, enhance consistency of mixture, and reduce heat of hydration, while contributing towards long-term strength. Silica fume (SF) of up to 10% by mass of cement has been added to intensify the strength of cement (Ramamurthy *et al.*, 2009).

The water requirement for a mixture depends upon the composition and use of admixtures, and is governed by the consistency and stability of the mixture (Karl and Worner, 1993). At lower water content, the mixture would be too stiff, causing bubbles to break, while a high water content would make the mixture too thin to hold the bubbles, leading to separation of bubbles from the mixture and, thus, segregation (Nambiar and Ramamurthy, 2006a). Though super plasticizers are sometimes used (Jones, 2001), its use in foamed concrete can cause instability of the foam (Jones and McCarthy, 2006). Hence, compatibility of admixture with foam concrete is of paramount importance.

Foam concrete is produced either by pre-foaming method or mixed foaming method. Pre- foaming method comprises production of base mix and stable preformed aqueous foam separately, and then thoroughly blending foam into the base mix. In mixed foaming, the surface active agent is mixed with base mixture ingredients; foam is produced, resulting in cellular structure in concrete during the process of mixing (Byun *et al.*, 1998). The foam must be firm and stable so that it can resist the pressure of the mortar until the cement takes its initial set and a strong skeleton of concrete is built up around the void filled with air (Koudriashoff, 1949). The preformed foam can be either wet or dry foam. The wet foam is produced by spraying a solution of foaming agent over a fine mesh, has bubbles 2–5 mm in size, and is relatively less. Dry foam is produced by forcing the foaming agent solution through a series of high-density restrictions and simultaneously forcing compressed air into mixing chamber. Dry foam is extremely stable and has size smaller than 1 mm in size, which makes it suitable for easier with the base material for producing a pump able foam concrete (Aldridge, 2005).

3.0 PROPORTIONING AND PREPARATION OF FOAM CONCRETE

The trial and error process is often adopted to achieve foam concrete with desired properties (Nehdi *et al.*, 2001). For a given mixture proportion and density, a rational proportion method based on solid volume calculation was proposed by McCormick (1967). ASTM C 796-97 provides a method of calculation of foam volume required to make cement slurry of known w/c ratio and target density. For a given 28 days compressive strength, filler-cement ratio, and fresh density, typical mixture design equations of Nambiar and Ramamurthy (2006b) determine mixture constituents (i.e., percentage foam volume, net water content, cement content, and percentage fly ash replacement). Most of the methods help in calculation of batch quantities if the mixture proportions are known. Even though the strength of foam concrete depends on its density, the strength can be increased by changing the constituent materials for a given density. In addition, for a given density, the foam volume requirement depends on the constituent material (Nambiar and Ramamurthy, 2006b). Hence, for a given strength and density requirement, the mixture design strategy should be able to determine the batch quantities.

4.0 MATERIALS

These tests have shown that the production of foamed concrete with predictable densities and strengths is only possible with protein foam. This investigation was therefore conducted using only this type of foaming agent. All the materials used were produced in Malaysia, and only one source of protein agent, cement, and superplasticizer was used.

Foam concrete is produced under controlled conditions from cement, filler, water, and a liquid chemical (Vine-Lott, 1985) diluted with water and aerated to form the foaming agent. The foaming agent used was "NORAITE PA-1", manufactured in Malaysia, and which consists of additive agent. The foaming agent was diluted with water with a ratio of 1:33 (by volume), and aerated to a density of 75–80 g/L.

OPC from Cement Industries of Malaysia Berhad (CIMA Group), Kangar, Perlis Indera Kayangan, Malaysia, was used. The cement can be classified as MS 522, as well as BSEN 196. The OPC Type I cement produced by CIMA is packed under the brand name "Blue Lion" cement. The product is available in 50 kg/bag and in bulk form. Cement is a hydraulic binder and is defined as a finely ground inorganic material which, when mixed with water, forms a paste which sets and hardens by means of hydration reactions and processes which , after hardening retains its strength and stability even under water. Ordinary Portland Cement (OPC) is one of several types of cement being manufactured throughout the world.

The cement quality and particles size distribution of all samples are shown in Table 1 and Figure 1.

Table 1 Cement quality

ITEM	CLINKER %	CEMENT %
Oxide Composition		
SiO_2	21.04	19.98
Al_2O_3	5.24	5.17
Fe_2O_3	3.41	3.27
CaO	63.31	63.17
MgO	0.85	0.79
SO_3	0.41	2.38

Continued **Table 1**

Total Alkalis	0.9	0.9
Insoluble Residue	0	0.2
Loss of Ignition	0.5	2.5
Modulus		
Lime Saturation Factor	0.93	0.96
Silica Modulus	2.39	2.37
Iron Modulus	1.9	1.58
Mineral Composition (%)		
C_3S	55.4	59.9
C_2S	18.53	12.71
C_3A	8.59	8.18
C_4AF	10.36	9.94
Free CaO (lime)	1.9	0
Compressive Strength, N/mm^2	**N/mm^2**	
3 days	38	
7 days	46	
28 days	56	

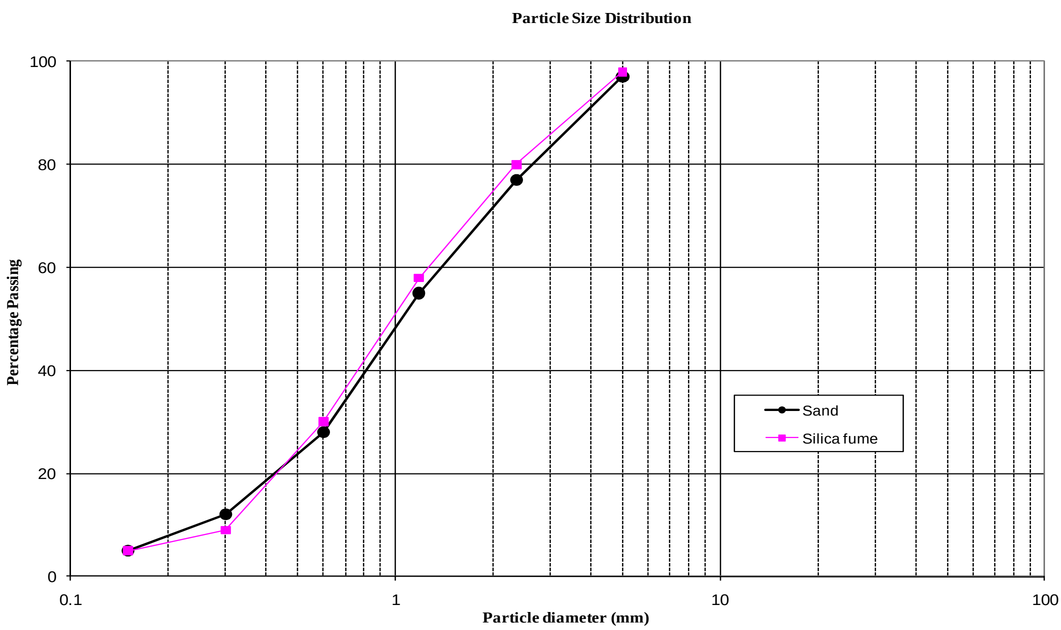

Figure 1 Particle size distribution

5.0 COMPOSITION AND MIXTURES

Based on the BS 812-103.1:1985, method for determination of particle size distribution, types of particle size distribution of sand and silica fume vary by sieving. All samples were cast with cement, sand, water, and foam content. The volume of mixture design, dry density, wet density, and mixture cement ratios are shown in Table 2. The first three mixtures contained only cement, sand, water, and superplasticizer with same w/c ratios. These mixtures were used to determine the cementing efficiency of the silica fume. Mixtures numbers 4 to 18 contained cement classified and SF with different percentages, Table 2. For each day, only one mixture (0.05 m^3) was prepared. In one mixture, a little amount of mortar underwent slump test to determine the mortar suitable for good bonding and mortar density. A good slump is approximately 18 to 20 cm, as shown in Figure 2. For this test, all of the sand used was approximately 1.0 m^3. After sieving, a storage tank was used to prevent water and chemical contamination prior to testing.

Table 2 Composition of the mixtures

Mixture No	Target Density (kg/m³)	w/c	Composition of the mixtures (in kg)			Added water (Litre)	Silica Fume (SF)
			Cement	Sand	Water		
1	1150	0.45	18.88	28.32	8.5	0	0
2	1150	0.45	18.88	28.32	8.5	0	0
3	1150	0.45	18.88	28.32	8.5	0	0
4	1150	0.45	18.88	28.32	8.5	0.5	10%
5	1150	0.45	18.88	28.32	8.5	0.5	10%
6	1150	0.45	18.88	28.32	8.5	0.5	10%
7	1150	0.45	18.88	28.32	8.5	0	10%
8	1150	0.45	18.88	28.32	8.5	0	10%
9	1150	0.45	18.88	28.32	8.5	0	10%
10	1150	0.45	18.88	28.32	8.5	0.75	10%
11	1150	0.45	18.88	28.32	8.5	0.75	10%
12	1150	0.45	18.88	28.32	8.5	0.75	10%
13	1150	0.45	18.88	28.32	8.5	0	15%
14	1150	0.45	18.88	28.32	8.5	0	15%
15	1150	0.45	18.88	28.32	8.5	0	15%
16	1150	0.45	18.88	28.32	8.5	0.5	15%
17	1150	0.45	18.88	28.32	8.5	0.5	15%
18	1150	0.45	18.88	28.32	8.5	0.5	15%

6.0 TEST CONDUCTED

The proportion of the control mixture with foam was 1:1.5:0.45 by mass of OPC, sand, and water respectively. The approximate quantity of OPC was 18.88 kg for one mixture foam concrete. For structural concrete, the control concrete was modified using 10% SF as OPC replacement. Table 3 presents the composition of the concrete mixtures produced and tested. For control mixture, fresh density was around 2025 kg/m^3. Slump workability value was 19.0 cm. After using the foam, the new fresh density decreased to 1263 kg/m^3.

The compressive strength of foamed concrete was determined from 100 mm cubes. The cubes were cast in steel moulds, demoulded after 24 h, wrapped in polythene wrapping, and stored in a room with constant temperature room of ± 28° C up to the day of testing. Before testing, each cube was unwrapped and weighed.

Figure 2 Slump test

7.0 RESULTS AND DISCUSSION

The compressive strength of paste mixtures containing SF is plotted as function of time in Figure 3. This graph clearly shows that the compressive strength of SF mixtures increased over a much longer period than the mixture containing no SF. The gain in strength for 3 and 7 d is 2.81 N/mm^2 and 3.40 N/mm^2, respectively, and 4.87 N/mm^2 for 28 d. For control, the strength for 3 and 7 d is 3.15 N/mm^2

and 2.81 N/mm², respectively, with 3.41 N/mm² for 28 d. This difference in strength remains approximately the same for all ages of testing. These results show a trend similar to the observation for the mixtures containing SF.

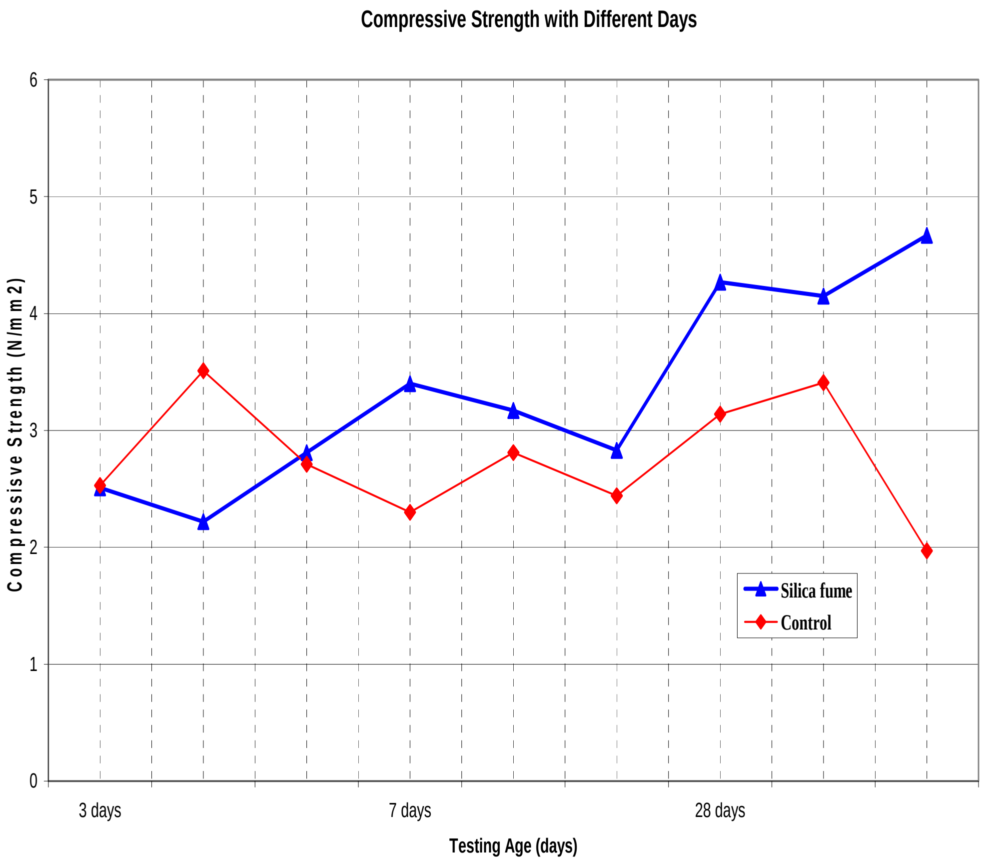

Figure 3 Compressive strength of paste containing silica fume

As far as ultimate compressive strength is concerned, there is no apparent significant difference between the mixture with SF and the control. These results indicate that the classification of the SF does not improve its effectiveness as far as contribution towards compressive strength is concerned. This test used 10% SF for increasing the strength. The SF should comprise more than 10% to show a highly different in compressive strength.

Table 3 Mixture design sheet for foam concrete

No.	Descriptions	Value	Units	Note
1	Volume	**0.05**	m^3	
2	Dry density	**1050**	kg/m^3	
3	Density difference	**100**	kg/m^3	
4	Wet density	**1150**	kg/m^3	
5	Solid Mass	**57.5**	kg	
6	Estimated foam mass	**1.8**	kg	
7	Actual Mixture Mass	**55.7**	kg	
8	Mixture cement ratio	**1 : 1.5 : 0.45**		
9	Cement	**1**		
10	Sand	**1.5**		
11	Water	**0.45**		
12	*Total ratio*	**2.95**		
13	**Cement**	**18.88**	kg	
14	**Sand**	**28.32**	kg	
15	**Water**	**8.50**	kg	
16	Additional water	**-**	L	
17	Total mortar weight	**55.7**	kg	
	Slump	**19.0**	cm	
18	Mortar density	**2025**	kg/m^3	As Measured
19	Mortar volume	**0.028**	m^3	
20	Estimated foamed volume	**0.022**	m^3	
21	Estimated foam volume	**22**	liters	
22	Foam density (Actual)	**78.2**	g/L	
23	Foam weight in mixture	**75–80**	g/L	
24	Actual density	**1263**	kg/m^3	As Measured
25	Foam flow rate	**7.40**	L/s	
26	Time of foaming	**8.15**	s	
27	Percentage of foam	**43.21**	%	

8.0 CONCLUSIONS

The results for the 28 days test indicate that the compressive strength of foamed concrete is primarily a function of dry density, and only minimally affected by the percentage of cement replaced by SF. Based on the results of this investigation, it can be concluded that replacing high proportions of cement with SF does not significantly affect the long-term compressive strength (in this case, 28 days) of well-cured foamed concrete. The results can be used to predict the strength of foamed concrete of different densities and ages.

The results presented in this paper show that although the foamed concrete mixtures with high silica fume content might need a longer period to reach their ultimate strength, this strength was observed for all samples. Similar results for SF indicate that the cost of foamed concrete mixtures could be reduced by replacing large volumes of cement without significantly affecting the long-term strength.

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