Study on the Effect of Soil as a Filler in Foamed Concrete

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Abstract The problem of concrete waste disposal poses a major challenge to the engineers working in the construction industry. In this scenario, soil can be envisaged as an eco-friendly building material. Soil-based foamed concrete is a novel lightweight construction material consisting of cement, soil, water, and foaming agent. The form of concrete with random air-voids created within the volume by the action of foaming agents is known as foamed concrete. It is characterized by its high flowability, low cement content, low aggregate usage, and excellent thermal insulation. It also possesses characteristics such as high strength-to-weight ratio and low density. Foamed concrete is considered as an economical solution in the fabrication of large-scale lightweight construction materials and components such as structural members, partitions, filling grades, and road embankment infills mainly due to its easy production process from manufacturing plants to final position of the applications. In this paper, the effect of partially replacing conventional cement with two different types of clayey soil is explored and reported. The results indicate that the strength of soil-based foamed concrete satisfies the minimal strength requirement for a building block as per Indian Standards (IS) specifications along with significant improvement of thermal characteristics. Water absorption and density properties are also reported.

Keywords Soil · Foamed concrete · Compressive strength · Thermal conductivity

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M. Latha Gali and P. Raghuveer Rao (eds.), *Construction in Geotechnical Engineering*, Lecture Notes in Civil Engineering 84,
https://doi.org/10.1007/978-981-15-6090-3_2

1 Introduction

A right building material promises a healthy living environment. Building materials strongly influence the indoor climate as well as the quality of living. It is being widely accepted that the use of concrete as a building material is no more a sustainable method. Hence, researchers have started exploring the feasibility of soil-based concrete in modern buildings. Soil-based building materials for construction purpose have been in use for centuries. Soil can be molded into any shape or size with least effort.

Clay has been selected as the material for study owing to various factors including the commercial considerations, its natural availability and recyclable nature. Clay has a porous structure filled with air in the voids in dried state. Hence, it possesses great thermal insulation properties which is largely useful to regulate the temperature inside the living space. Bing and Cong (2014) discuss the effects of foam content and silica fume on the physical properties of soil-based foamed concrete. Soft clay and protein-based foaming agent were used in their study. Their experimental results show that the properties such as thermal conductivity, water absorption, density, and compressive strength decrease with increase in volume of foam; but are improved by silica fume content.

In this paper, the properties of foamed concrete blocks prepared using two types of clay soil are evaluated.

2 Experimental Details

2.1 Materials and Mix Proportion

Two types of clay were blended with cement for the experiment; swelling clay (bentonite), and non-swelling clay (kaolinite). Synthetic foaming agent under the commercial name Ebassoc and Portland Pozzalana cement was used. Throughout this experimental study, tap water was used to produce all foamed concrete specimens. The properties of bentonite and kaolinite found out as per IS are presented in Table 1.

Table 1 Properties of soil

Sl. no.	Properties (%)	Swelling clay (Bentonite)	Non-swelling clay (Kaolinite)
1	Free swell index	1900	14.28
2	Plastic limit	54.5	30
3	Liquid limit	291	64
4	Plasticity index	236.5	34
5	Specific gravity	2.67	2.68

2.2 Specimen Preparation

Nandi et al. (2016) discuss the procedures for preparing foamed concrete specimens. Cement and soil were mixed in dry state. Foam is prepared by adding 30 ml foaming agent in 1000 ml of water and the mix is then agitated mechanically. 0.4 m^3 of foam was added for every 1 m^3 of concrete. Photograph of foam is shown in Fig. 1. The water-cement ratio was fixed as 0.55 for obtaining a good consistency for the concrete. Foam is added during the wet mixing of concrete. Cube specimens of size 15 × 15 × 15 cm were prepared and water cured for 7 and 28 days. Photograph of samples prepared is shown in Fig. 2. Seven different mixes were used by varying the type and proportion of clay used as mentioned in Table 2. The cured specimens were tested for density, compressive strength, water absorption, and thermal conductivity.

Fig. 1 Foam

Fig. 2 Cube specimens prepared for the study

Table 2 Mix ratio

Soil type	Mix no.	Proportion by weight (%)	
		Cement	Soil
Bentonite	C	100	0
	B1	80	20
	B2	60	40
	B3	40	60
Kaolinite	C	100	0
	K1	80	20
	K2	60	40
	K3	40	60

3 Results and Discussions

3.1 Compressive Strength

Compressive strength of different specimens at 7 days and 28 days is presented in. Table 3 and the graphical variation of 28 day compressive strength of specimens with varying soil proportion is shown in Fig. 3. It is clear that the compressive strength decreases with the increase in proportion of soil. Also kaolinite-based foamed concrete exhibits more strength than that of bentonite-based foamed concrete. All the specimens satisfy the minimal strength requirement for a building block as per IS 1077 (2007) that is 3.5 N/mm^2.

Table 3 Compressive strength of soil-based foamed concrete

Proportion by weight (%) (Cement: Soil)	7 days strength (N/mm^2)		28 days strength (N/mm^2)	
	Kaolinite	Bentonite	Kaolinite	Bentonite
100: 0	12	12	14.6	14.6
80: 20	8.6	6	13.5	11.8
60: 40	5.9	2.7	12.9	5.5
40: 60	2.7	2.4	5.6	3.8

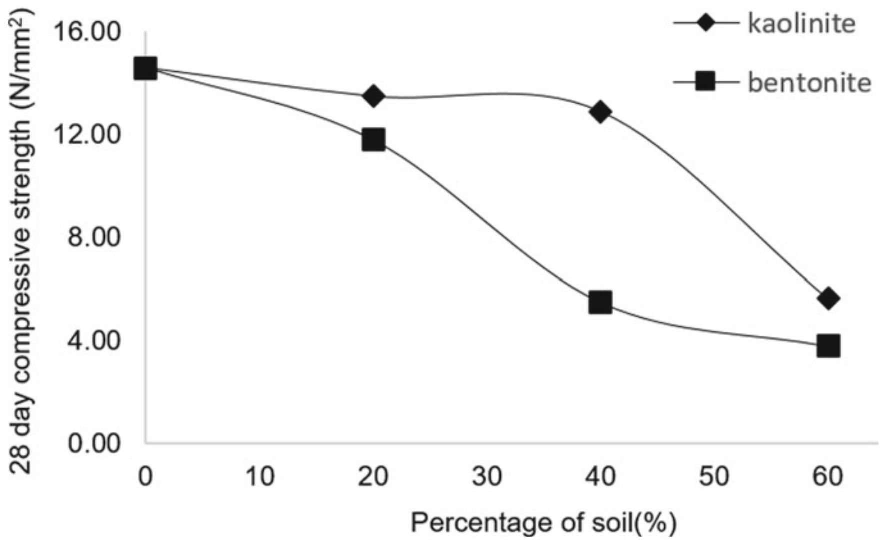

Fig. 3 Variation of compressive strength of specimens with percentage of soil added

3.2 Density

The bulk density of foamed concrete specimens is shown in Table 4 and the graphical variation of density of specimens with varying soil proportion is shown in Fig. 4. The density decreases with the increase in proportion of soil. Kaolinite-based specimens are more denser than bentonite-based specimens. This may be due to the high swelling characteristics of bentonite.

Table 4 Bulk density of soil-based foamed concrete

Proportion by weight (%) (Cement: Soil)	Density (kg/m^3)		Percentage increase of Kaolinite Specimens over Bentonite Specimens (%)
	Kaolinite	Bentonite	
100: 0	1840	1840	0.00
80: 20	1805	1731	4.27
60: 40	1767	1598	10.58
40: 60	1681	1455	15.53

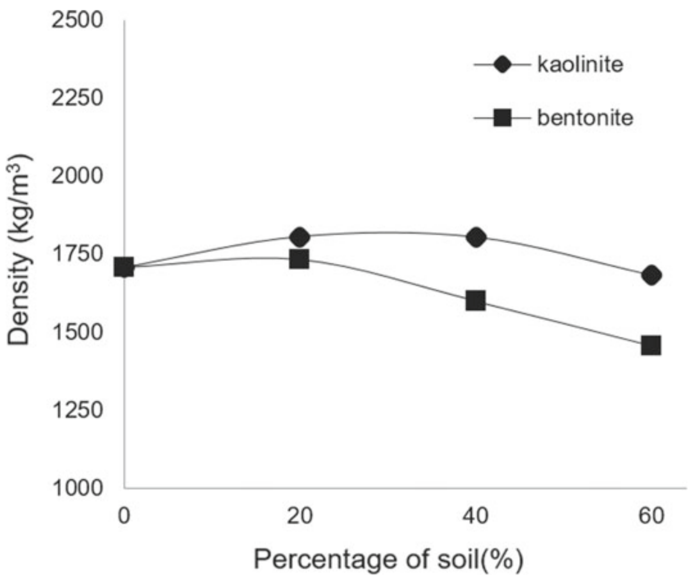

Fig. 4 Variation of density of specimens with percentage of soil added

3.3 Thermal Conductivity

Thermal conductivity of specimens is measured as per ASTM D5334 using portable thermal resistivity meter. Photograph of thermal resistivity meter is shown in Fig. 5. The thermal conductivity values of specimens are shown in Table 5. Thermal conductivity decreases with the increase in proportion of soil and this is due to the thermal insulation characteristics of clay in its dry state. However for both the soils specimens with 20% soil exhibits higher thermal conductivity than that of ordinary foamed concrete specimen. As per IS 3346 (2004), thermal conductivity of foamed concrete varies from 0.53 to 0.63 W/mK as the density ranges from 1400 to 1800 kg/m^3. However for the same density of soil-based foamed concrete the thermal conductivity values are much lesser.

Fig. 5 Thermal resistivity meter

Table 5 Thermal conductivity

Proportion by weight (%) (Cement: Soil)	Thermal resistivity (W/mK)	
	Kaolinite	Bentonite
100: 0	0.038	0.038
80: 20	0.043	0.049
60: 40	0.040	0.037
40: 60	0.034	0.033

Table 6 Percentage of water absorption

Proportion by weight (%) (Cement: Soil)	Water absorption (%)	
	Kaolinite	Bentonite
100: 0	2.24	2.24
80: 20	2.42	5.20
60: 40	3.68	11.04
40: 60	14.45	14.49

3.4 Water Absorption

The water absorption values of different specimens are enlisted in Table 6. The water absorption values increases with increase in soil proportion for specimens prepared out of both clays. As per IS 2185 (Part IV) (2008) the water absorption values for preformed foam cellular concrete blocks shall not be more than 10% by mass. The specimens C, K1, K2, and B1 exhibit water absorption values within the limit as per IS.

4 Conclusions

The study was carried out to look into the scope of usage of soil as a filler in foamed concrete for which two clays, say kaolinite and bentonite were selected. The following conclusions were drawn from the study conducted:

1. Compressive strength decreases with increase in soil content. However, all the specimens satisfy the minimal strength requirement for a building block as per IS.
2. Thermal insulation property increases with increase in soil content. Both the clays exhibit almost similar thermal properties.
3. Water absorption of foamed concrete increases whereas density decreases with increase in soil content for both clays. Kaolinite-based foamed concrete exhibits lesser water absorption than bentonite-based foamed concrete.

4. Kaolinite-based foamed concrete exhibits better strength characteristics than the other and hence it can be used for making building blocks, pavement base, etc.
5. Bentonite-based foamed concrete is light in weight and hence can be used for low-density applications like construction of non-load bearing walls, backfill for retaining walls, etc.

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