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APPLICATIONS OF LIGHTWEIGHT FOAM CONCRETE IN COLD FORMED STEEL CONSTRUCTION FOR AFFORDABLE HOUSING IN PAKISTAN

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Abstract

Foam concrete is a cementitious material with entrained air and is used for its excellent thermal, acoustic, fire resistant and lower weight reduction properties. It is used in wall elements, floor/roof screeds, sunken portion filling and base material for roads. Cold formed steel construction is a form of construction where thin metal sheets are rolled, stamped, pressed in different shapes under low temperature (cold working). The sections are used in beams, joists, columns, and floor decking. This paper explains effective ways in which foam concrete can be used along with cold formed steel to make an affordable home in Pakistan for low income population.
Objective of the paper includes finding a stable foam mix and making a mix design of foam concrete with a suitable density and compressive strength. Furthermore, the research demonstrated that foam concrete is also thermally efficient.
The main method used in the research is laboratory work carried out to produce foam concrete samples with different densities. They were tested for compressive strength and a sample with a density of 1530 kg/m^3 and compressive strength of 1280 psi was selected for further testing. Further testing included thermal conductivity tests and compressive strength with cold formed steel windows to show the composite behavior of the structure. All tests were done in NUST H 12 Islamabad structure lab.
Results showed that foam concrete can be used with cold formed steel construction to make a simple house with extremely good thermal conductivity results. Further research is advised on the detailed economic analysis of the system proposed.

Keywords: foam-concrete; construction; thermal-conductivity; housing.

1. INTRODUCTION

This Foam concrete by definition is a cementitious material with a minimum of 20% entrained air in the shape of foam (Deijk, 1992). Foam concrete is a lightweight concrete in which coarse aggregate is replaced with air voids. In simple words it can also be considered an aerated mortar. The foam is generated separately before mixing with the help of a foam generator machine and then added to the cement slurry in order make the foam concrete. The foam is produced with a liquid chemical called the foaming agent that is added with water to make foam in the foam generator. This foaming agent makes a foam with tiny bubbles that are not easily broken during the mixing process and retain their shape.

1.1 Advantages of Foam Concrete.

The main advantages of foam concrete are summarized below:

i) Weight reduction: One of the main advantage of the foam concrete is that it reduces the overall weight of the structure. In civil engineering terms it means that the dead load is drastically reduced which decreases the loads on a structure and this results in a lowering of reinforcement need for the structure which is not only economical for any project but is beneficial for our environment as well.

ii) Excellent thermal properties: Foam concrete has small pores with air in them that act as a buffer for the heat and is used as an insulator in many practical applications like roof or floor lining under tiles and wall filler in cold formed steel construction projects.

iii) Good acoustic value**:** In places like lecture halls, restaurants, coffee shops, libraries and even in residential buildings, the noise level has to be kept at a minimum. The only effective way of doing it to make the building as sound proof as well. In the modern world today, there are studies done to check for the acoustic value of different dwelling spaces. Foam concrete has exceptional acoustic properties as well. There it can be used for that purpose in a variety of buildings.

iv) Fire resistant: Foam concrete due to its excellent thermal properties is also fire resistant and resists fire much more than normal concrete.

v) Reduced cost: In a lot of applications, foam concrete has a lower price because of the added volume of air in the entire mix. The air increases the volume with a fraction of the cost. Similarly, foam concrete does not require specialized labor or equipment except for one machine.

vi) Easy and affordable to produce: This research aims to prove that the foam concrete is not an expensive thing to produce and can be easily produced anywhere. If the process is carefully planned it can be made quite affordable.

vii) High flow: Foam concrete typically uses a high water to cement ratio and has a lot of flow because of the air bubbles as well. This is particularly beneficial in its application as a filler material because is engulfs all the plumbing of anything that it is used in.

2. OBJECTIVES

i) To make a FC mix with a suitable density and compressive strength so that it can be used as a structural member in cold formed steel construction.

ii) To find a way of making a stable foam without the use of foam generator machine.

iii) To demonstrate that the mix is thermally efficient.

iv) To demonstrate that the mix can not only be used in cold formed steel construction but it adds to the structural value of the system.

3. LITERATURE REVIEW

Various studies from researchers around the world have explored the possibility of the usage of foam concrete. Some of them are listed below:

3.1 General Uses of Foam Concrete

In a study on light weight foam concrete in August 2017 by Assistant Professor Aswathy states that the light weight foam concrete can be used because of the following benefits:

i) It drastically reduces the dead load on the building.

ii) It does not require high workmanship or handling skill (like autoclave aerated concrete).

iii) It decreases the transport charges.

iv) It is environmentally friendly as compared to normal concrete blocks.

However, the study done by Aswathy also concludes that the density of the foam concrete can vary with the size of the sample. This aspect is not studies in this research as all the cubes were of similar size. This can have a huge impact on the result and is mentioned in the recommendation section of this report (Aswathy, 2017).

3.2 Real Life examples of Foam Concrete

There are many projects in which foam concrete is being used these days and the engineering community has realized and acknowledges its use

due to its low weight, quick pouring, and economical usage in many cases. Some of the examples are given below:

i) In the Hertfordshire Industrial Zone UK, foam concrete was used as a base material for the roads (Martin Decky, 2016).

ii) In the construction of Northwest Highway (route 14), Illinois USA, 13000 cubic meters of foam concrete was used with two densities: 590 kg/m^3 and 410 kg/m^3 (Martin Decky, 2016).

iii) In Schaumburg, Illinois the Central road of 3 km length was reconstructed that had a soft underlying soil. A 900 mm thick layer of 400 kg/m^3 and a 600 mm thick layer of 500 kg/m^3 was used that resulted in lower costs, lesser installation time and higher quality (Martin Decky, 2016).

iv) In South Africa, there is a deep-water port called the Richards Bay which handles around half of all the cargo ships passing through the country. It used a huge amount of foam concrete in 600 mm layers for filling and stabilisation of soil.

It can, therefore, be said that the use of foam concrete is very common in today's ever evolving world. The right range of density and attention to the design of the foam concrete can yield effective results in many situations where foam concrete proves itself to be more efficient and cost effective as compared to ordinary concrete.

3.3 Specification and Quality Control of Lightweight Foam Concrete

In a study by Ashish Kurweti in 2017 the foam for the foamed concrete is also produced by mechanical stirring without using foam generator and foamed concrete of different densities is produced. There are three mixes produced with the help of this foam and their compressive strengths, water absorption, and densities are calculated (Ashish Kurweti, 2017). The table below summarizes the results:

Table 3.1: Densities, Compressive Strengths, and Water Absorption results of the foamed concrete samples produced by mechanical stirring.

1 specimen= 3samples	Density (in kg/m^3)	Compressive strength (in N/mm^2)	Water absorption (in %)
Sample1	1036	3.82	12.01
Sample2	1033	3.86	11.90
Sample2	1034	3.90	12.03
Average of above three	1034.33	3.86	11.98

3.4 Summary

The literature review suggests that the foam concrete is being widely used around the world to cater for a number of problems including the weak soils or high heat transfer through structures. In our modern world with scarcity of resources and a constant need of environmentally friendly materials that are also economical, foam concrete can act as a material that does both. It is environmentally friendly and also economical. The only thing needed now is to streamline this process of making and applying the foam concrete in a proper way.

4. MATERIALS

The materials used the research are all obtained from the local market. All the materials were stored in air tight containers to prevent the moisture from contaminating the materials. More details of the materials used are given below:

4.1 Cement

The cement used in this research was manufactured by "Bestway Cement". It was Ordinary Portland Cement of Grade 53 Type-1 (Pakistan Standards PS-232-2008) manufactured under ASTM C150-04 and EN-196. To investigate the chemical composition of the cement used, X-Ray Fluorescence (XRF) analysis test was done from 'Institute of Environmental Sciences & Engineering' (I.E.S.E) in National University of Sciences and Technology Islamabad using Axios Advanced WD-XRF PA Nalyical using pressed pellet procedure, BET-Specific surface area along with Particle size distribution (PSD) by Laser granulometry is shown in Table 4.1 below:

Table 4.1: Chemical Composition of Cement.

SiO_2	19.17
TiO_2	0.28
Al_2O_3	4.96
Fe_2O_3	3.21
MnO	0.04
MgO	2.23
CaO	65.11
Na_2O	0.57
K_2O	0.51
P_2O_5	0.77
LOI	3.85
BET	1.1
Particle Size	16.2

4.2 Foaming Agent

The foaming agent used in this research is named "Advafoam Crete" and is manufactured by 'Al Mutathawir Insulation Materials Industries L.L.C. in Sharjah, United Arab Emirates. It is a high quality foaming agent liquid with light yellow colour and is used for all type of lightweight screeeds. The advantages advertised on the product are as follows:

- Weight reduction
- Good thermal insulation
- Good acoustic value
- Does not attack iron or steel
- Low water absorption
- Fire resistant
- Resistant to organic growth
- Roof falls can be formed with greater ease
- Chloride free
- Economical to use

The main advantage of this foaming agent is that it is relatively cheap and easy to use. The general properties of Advafoam Crete are as follows:

Table 4.2: General Properties of the Advafoam Crete foaming agent

Appearance	Light yellow liquid
Specific Gravity	1.1 at 20 degree Celsius
Chloride Content	Nil
Nitrate Content	Nil
Solubility in water	Infinite
Freezing point	Less than 0 degree Celsius
Flash point	None
VOC	14.9 less water

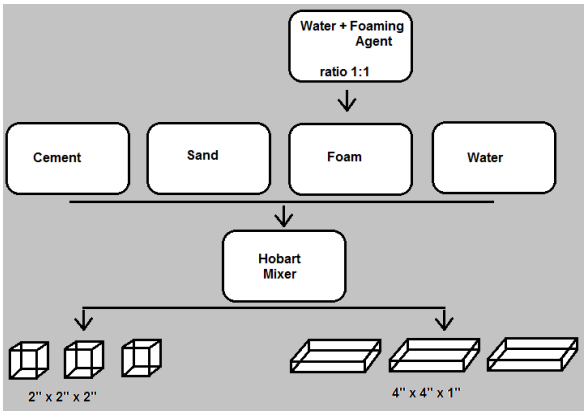
4.3 Sand

The sand used in this research was all obtained from the sand reserved of an area called Lawrencepur in Punjab Pakistan. The usage was done after cleaning the sand to get rid of any organic matter that might alter the properties of the mix. Fineness Modulus (FM) of the sand was found using ASTM C-136 and the result was 2.01.

5. EXPERIMENTAL PROCEDURE

The research was done in disciplined manner in the structural laboratory of National University of Sciences of Technology Islamabad with controlled environment inside the laboratory. The experimental procedures were carefully selected to mimic the field setting and are explained below:

Fig 5.1: Flow chart summarizing the formation of foam concrete in this research



5.1 Mixing method

In the field a special machine called the foam generator is used to generate foam that is then used in the foamed concrete. The foam generated by the foam generator is of consistent viscosity and is made in abundance by using a small amount of foam generator with a large amount of water.

However, for this research the foam generator machine was not available so another method was needed in order to obtain the foam needed for the foaming concrete. Therefore in order

to make the foam, a custom made drill bit was made using ordinary steel rebar and strips of metals. This drill bit was made small enough to be used in a bucket and wide enough for it to be able to stir the liquid forcefully in order to get a large volume of foam.

The drill bit had the following characteristics:

Length: 12 inches
Number of fins: 3
Area of each fin: 3 inch x 0.75 inch

The drill bit was connected with a drill and mechanical stirring of the foaming agent was done using the drill.

5.2 Thermal conductivity calculations

There are many different methods used to calculate the thermal conductivity of materials. Each method is suited for a range of materials and situations. These methods can be broadly categorized into two categories:

i) Steady state techniques: these techniques rely on the signals in the steady state. It usually takes a longer time to get to a steady state situation but this way of calculation is considered easier and is used a lot for solid concrete samples.

ii) Non-steady state techniques: these techniques rely on values from during the system is being heated up and are quite quick as compared to the steady state techniques. However, they are not usually used in the laboratories because the equipment is expensive.

One of the most common method used for the determination of thermal conductivity in concrete is called the "Guarded hot plate method" in which the sample of the solid concrete is place in between two plates and one of the plate is heated until the heat from the plate passes through the sample onto the other plate. Temperature on both the plates are monitored until it becomes constant, hence, this is a steady state technique. Then the thickness of the sample is used in a formula to calculate the thermal conductivity of the sample.
Thermal conductivity λ is given by the following equation:

$$\lambda = \frac{q \times d}{T_1 - T_2}$$

Fig 5.2: Equation of Thermal conductivity λ

q = quantity of heat passing through a unit area [W/m^2]
d = distance between two sides of sample [m]
T1= temperature on warmer side of the sample [K]
T2= temperature on the colder side of the sample [K]

The quantity of transferred heat q is given by:

$$q = \frac{Q}{A}\ (\frac{W}{m^2})$$

Q = quantity of heat passing through a base area [W]
A = base area of the sample [m2]

The apparatus used in this research mimics the properties of this steady state methods. There is no hot plate but there is a heat source in the shape of the bulb in the upper compartment that gives heat to the upper chamber of the apparatus and the only way the heat can go is through sample into the chamber below. There was a temperature sensor (in this case a thermocouple) in each of the compartments. The thermal conductivity was compared with a similar sample of mortar without any foam.

5.3 Mixing Regimes

A total of six formulations were studied as shown in table 5.1 below. Water cement ratio was changed three times to get different strengths and then the amount of foam was changed with each water cement ratio in order to see the changes due to the amount of foaming agent used in the system.

Table 5.1: Mix formulations with cement sand ratios

S.No	Cement	Sand	Foam	W/C
1.	2	3	60	0.5
2.	2	3	60	0.6
3.	2	3	60	0.7
4.	1	1	60	0.5
5.	1	1	60	0.6
6.	1	1	60	0.7

6. RESULTS & DISCUSSION

The main test done in this research was the compressive test because the tensile capacity of foam concrete is low and our main concern is to utilize the compressive strength of foam concrete within the cold formed steel structure.

Table 4.1: Results of Compressive Strength tests

S No.	Formulation ID	Density (kg/m^3)	Comp. Strength
1	2-3-0.5	1415	763
2	2-3-0.6	1380	721
3	2-3-0.7	1311	693
4	1-1-0.5	1530	1280
5	1-1-0.6	1505	1205
6	1-1-0.7	1460	1186

The results were consistent with the assumption that with increase in the density of the samples, the compressive strength will also increase. After assessing the results, mix # 4 was selected as the mix to work with because it had the highest strength and a suitable density. This mix was then taken further for more testing of the heat transfer properties and the usage of foam concrete in cold formed steel construction.

Results of the thermal conductivity are as follows:

- Thermal conductivity of mortar: 2.2 W/m.K
- Thermal conductivity of FC: 0.78 W/m.K

The low thermal conductivity clearly shows that FC mix is thermally efficient and can be used to in a home to result in low heating and air conditioning costs.

The main aim of this research is to give another aspect to house construction in Pakistan. If cold formed steel construction houses are made with the use of foam concrete to produce a composite structure, it can be made with relative ease and in an extremely short amount of time as compared to orthodox construction practices. The resulting structure will have a much lower thermal conductivity which means that the hot air outside the house with not come in and vice versa. This will greatly reduce the heating/cooling costs and dwelling will be easy to use in extreme temperatures.

6.1 Conclusions

The main conclusions from this study are explained in a summarized point form below:

i) Making foam concrete is easy: There is a misconception in Pakistan that foam concrete requires a lot of skilled labor, expert engineers and specialized equipment. However, this is not the case. It is very easy to make and quite affordable in terms of the raw materials needed and the machinery is not that expensive either.

ii) Foam concrete has a wide range of applications: There is a huge range of applications in which foam concrete can be used. Some of the examples are filling the sunken portions of washrooms in buildings because foam concrete engulfs and encapsulates all the plumbing and due to low water absorption it also seals the system, that too, without any compaction equipment. Similarly it can be used to strength weak soil, to fill the side of retaining walls, and even as a subgrade layer under road networks.

iii) In the special case of cold formed steel construction it is feasible to use foam concrete as it does not interfere with the main purpose of the cold formed steel construction which is to be light. In fact it eliminates the main problem associated with cold formed steel construction which is heat transfer through the walls.

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