STUDY ON STRENGTH OF METAKAOLIN BASED FOAMED CONCRETE UNDER DIFFERENT ELEVATED TEMPERATURE

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ABSTRACT

Concrete is one of the widely used constructional material as it has high structural strength and stability. We do have a problem with cement production. Cement production will release a large amount of carbon-di-oxide which is the major cause of global warming and this will affect the atmosphere heavily. To avoid these problems and to make things efficient, we can go with lightweight concrete which is the expectation of the construction industry. While looking for environmental protection, the main suggestion for construction field is lightweight foamed concrete because it stands as the best thermal insulation material of external walls. When it comes to thermal insulation, another excellent heat resisting material which is used to improve the thermal insulation is Metakaolin and it is one of the effective Pozzolonic materials. In this experiment cement, fly ash, metakaolin, and protein-based foaming agent is used. Where cement is replaced with metakaolin by 5%, 10%, 15%. The specimens were exposed under the heat at 400°C, 500°C, 600°C for 3 hours. Test reports were taken for the compressive strength test (with temperature and without temperature) for the interval of 7, 14 and 28 days of curing. Specimens with different compositions were tested under normal temperature and above-mentioned temperatures for analyzing compressive strength on different time intervals. Compressive strength was taken under normal temperature and at elevated temperature; the results were compared to find the difference in strength. It is found that use of 10% of metakaolin gives high compressive strength and increasing in strength, after heating the specimen.

Keywords: foam concrete, metakaolin, class F fly ash, density, compressive strength, at elevated temperature.

INTRODUCTION

Foam concrete differs from the concrete in a way that it contains air bubbles rather than coarse aggregates. Thus, foam concrete is light weighted compared to conventional concrete. It is self-compacting and self-flowing concrete [1]. It has good thermal insulation and the density of foam concrete varies from 500 kg/m^3 to 1700 kg/m^3 [2]. Also, its compressive strength varies depending upon the density. Three types of foaming agent are there namely, synthetic based, organic based and protein based foaming agent (vegetable based and animal based). These foaming agents are essential for creating air bubbles and hence reducing the surface tension. In this experimental study, a vegetable-based foaming agent is used, in which air voids are smaller, uniform and foam density are high [1].

In cellular concrete, there will be a lot of air voids which occupies more than 80% material volume. As there are a lot of open pores, there is excessive water absorption and drying shrinkage which is a major problem in wet and cold conditions. Thus, to avoid all these problems, foam concrete is introduced. This contains air bubbles which help in the reduction of open pores [3]. Considering the density of foam concrete, greater w/c ratio directly reduces the bubble maintaining capacity and relative viscosity. This results in the bubbles to mix easily to become big ones. Also, there is higher strength when mixed with uniform air void size distribution [1, 5]. Foam concrete cannot be used in load bearing wall material considering its comparative less strength. Thus, the strength of foam concrete should be improved without affecting its performance of thermal insulation. In general, the mixture is made by using silica fume, fibers and fly ash. So that the mechanical and thermal properties of foam concrete will be made unique.30 - 70 % of the mixture is fly ash added in different variations. 5% to 15% of the weight of cement is replaced by metakaolin to increase the intensity of cement [2].

As the emission of Co2 is high in cement industries, the only way to reduce this is to use supplementary materials such as industrial wastes which are a replacement for cement or aggregate in concrete [4]. To reduce Clinker factor, supplementary cementitious materials, which will improve compressive strength, durability, and impermeability of concrete, is used. In the list of these supplementary cementitious materials such as silica fume, rice husk, fiber, there is one more material named metakaolin is used [14]. By de-hydroxylation of a crystal lined structure called kaolinite under 600-800 degree Celsius, metakaolin is obtained. Kaolinite is one of the clays that can be easily obtained from the earth's crust. The chemical formula of metakaolin is Al2Si2O7 and that of kaolinite is Al2(OH)4Si2O5. Metakaolin consists of silica and alumina that reacts with CH in an active form. Calcination is done below 800 degree Celsius to obtain metakaolin from kaolinite [4]. This calcination is used to enhance the strength in the initial stages of curing. The binding properties in the blended cement are increased by a chemical reaction that happens between MK and CH in the presence of water [10].

Fly-ash, cement, protein-based foaming agent and Metakaolin have been used in this experiment to create foam concrete. The production of concrete using industrial waste is not only effective regarding the protection of the environment but also for long-lasting performance [9]. The mixture was created by using fly ash, foaming agent, metakaolin and cement. Metakaolin was added to the mixture in a variable proportion such as 0%, 5%, 10%, and

15%. In each and every mixture, the compressive strength was checked and compared with various results to find the maximum compressive strength. The basic aim is to find compressive strength and thermal properties. It was found in two different stages, the specimen with temperature and without temperature. Both results were compared.

MATERIALS AND METHODS

A. MATERIAL USED

a) Binding material

Ordinary Portland cement (OPC) with grade 54 was used [6, 7] and has the specific gravity of 3.15.

b) Fly ash

Class F fly ash was used, which is pozzolanic in nature and lime content is very less in class F fly ash [5]. Here Cao (lime) % is less than 7%. It has the specific gravity of 2.7.

c) Metakaolin

Metakaolin is one of preferable pozzolanic material and has a specific gravity of 2.65. It is obtained from Kaolinite after a de-hydroxylation process. The modified Chapelle test is used to measure the amount of slaked lime that can be bound by metakaolin [11, 15].

d) Foaming agent

Foaming agent will be diluted by using water and followed by it will be aerated to create foam. A vegetable-based (protein) foaming agent was used with 1.2 specific gravity and 7.5 pH value [1, 6]. Once the foam is generated, foam density will be checked. Free drainage test is preferable to find the stability of the foam. Foaming liquid is obstructed to mix with air by foam generation pressure. Because the foam density is different from foam generation pressure.

e) Water

Water is known as the main lubricating agent and here also it has its own vital role in lubrication. It helps aggregate to get easily mixed with each other and also helps for better compaction [6]. Chemical reactions such as binding, hardening, and fabrication are highly dependent on water.

f) Foam generator

Foam generators are used to produce foam for lightweight concrete by using the required foaming agents in the merchandise. For creating trouble-free operations, corrosion resistant coated steel body is used along with a timer and emergency stop switch as shown in Figure-1 (a). Air compressor and lance units are also used. It gives the adjustable and flexible density of the foam. The generator consists of 1 hp single phase motor inside the machine, a foam inlet valve, a foam outlet valve, and pressure inlet valve as shown in Figure-1(b).

Figure-1. (a) Front side of foam generator (b) Back side of the foam generator.

g) Air compressor

Air compressor is used to produce air pressure in the foam generator, which is used for adjusting the density of the foam.

h) Specimen and mix preparation

Specimen with dimension 100×100×100 mm mould was used as shown in Figure-2(a) & (b). Where foam is directly mixed in the concrete mixer as shown in Figure-3 (a) & (b). Here pan type concrete mixer is used. For each mix, 45 cubes were cast and in total 140 specimens were casted. After normal curing was done in the interval of 7, 14 and 28 days, tests were done and the following results were found. Where mix proportion is shown in Table-1.

Table-1. Mix ratio proportion.

	Cement	Fly ash	w/c ratio	Foam and water
Foam concrete	1	1	0.45	1:8

Figure-2. (a) & (b) Casting of specimens.

Figure-3. (a) & (b) Foam from outlet valve to a concrete mixer.

RESULTS AND DISCUSSIONS

A. Compressive strength

A compressive test was done for 140 specimens in compression testing machine (CTM) have a maximum load capacity of 1000 KN. The size of the specimen is made as 100×100×100 mm cubes. Compressive strength was done for various densities 1200, 1300 and 1400 kg/m^3. The results were shown in Tables 3 to 6. The load will be applied gradually and compressive stress will be found under the applied load. This maximum compressive stress is known as the compressive strength of the material [8]. While building and designing structure, compressive strength test is conducted in common by engineers. Compressive strength was examined as shown in Figure-4.

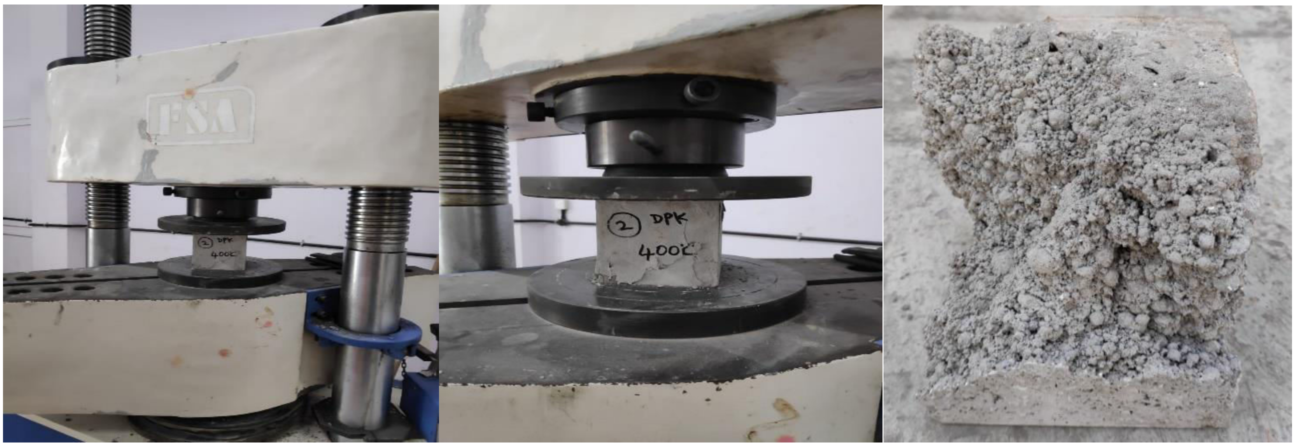

Figure-4. Compressive strength test (a) compressive strength test in CTM (b) failed specimen (c) Air bubbles inside the failed specimen.

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B. Specimen at elevated temperature (hot test)

Specimens were tested under normal temperature and as well as hot temperature. After heating the specimen in the electric furnace as shown in Figure-5, the specimen tends to cool then it will be tested to find the compressive strength. The maximum temperature of the furnace is 1500°C. Specimens were heated at different temperatures such as 400°C, 500°C, and 600 degree Celsius. Compressive strength test is taken under each temperature and this process is repeated for different composition of mixtures used (Such as 0%, 5%, 10% & 15% of Metakaolin). These tests were continuously taken at the intervals of 7 days, 14 days and 28 days. Compressive strengths were compared [12, 13] and it is helpful to find where the compressive strength is maximum in normal temperature (without temperature) or an elevated temperature. The results are mentioned in the below table 2 to 5.

Figure-5. (a) Electric furnace (b) Specimen inside the electric furnace.

Table-2. Compressive strength result for 0% of metakaolin.

Compressive strength in MPa												
Density	**1100 kg/m^3**			**1200 kg/m^3**			**1300 kg/m^3**			**1400 kg/m^3**		
Duration	**7 Days**	**14 Days**	**28 Days**	**7 Days**	**14 Days**	**28 Days**	**7 Days**	**14 Days**	**28 Days**	**7 Days**	**14 Days**	**28 Days**
Normal	1.1	1.9	3.2	2.2	2.8	4.7	3.9	4.5	5.9	6.2	7.5	9.2
400°C	0.8	1.2	1.4	1.8	2.1	4.3	3.1	4.1	5.7	5.4	6.5	8.8
500°C	0.67	1	0.9	1.5	1.9	3.9	2.76	3.1	5	4.7	5.8	8.1
600°C	0.52	0.89	0.67	1.42	1.65	3.2	2.52	2.84	4.5	4.2	5.4	7.5

Table-3. Compressive strength result for 5% of metakaolin.

Compressive strength in MPa												
Density	**1100 kg/m^3**			**1200 kg/m^3**			**1300 kg/m^3**			**1400 kg/m^3**		
Duration	**7 Days**	**14 Days**	**28 Days**	**7 Days**	**14 Days**	**28 Days**	**7 Days**	**14 Days**	**28 Days**	**7 Days**	**14 Days**	**28 Days**
Normal	2.4	3	4.1	3.2	3.9	5.8	5.4	6.3	8.5	7.2	8.9	10.8
400°C	3.7	4.2	4.9	5.1	4.9	6.4	7.1	7.2	9.3	8.5	9.7	12.2
500°C	3.1	3.6	4.1	4.4	4.5	5.7	6.3	6.7	8.7	7.8	9.2	11.4
600°C	2.5	2.9	3.8	3.3	3.8	5.2	5.1	6.1	8.3	6.9	8.5	10.7

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Table-4. Compressive strength result for 10% of metakaolin.

Compressive strength in MPa												
Density	**1100 kg/m^3**			**1200 kg/m^3**			**1300 kg/m^3**			**1400 kg/m^3**		
Duration	**7 Days**	**14 Days**	**28 Days**	**7 Days**	**14 Days**	**28 Days**	**7 Days**	**14 Days**	**28 Days**	**7 Days**	**14 Days**	**28 Days**
Normal	2.8	3.5	4.9	4.4	5	6.9	6.5	8.3	10.7	8.5	11.7	13.9
400°C	3.2	3.9	5.4	4.6	5.7	6.5	6.3	8.6	11.1	8.9	12	14.3
500°C	3.5	4	5.2	4.7	5.9	6.8	6.7	8.4	11.3	9.2	12	14.4
600°C	3.3	4.1	5.3	4.9	6.2	6.7	6.8	8.8	11.5	9.4	12.4	14.7

Table-5. Compressive strength result for 15% of metakaolin.

Compressive strength in MPa												
Density	**1100 kg/m^3**			**1200 kg/m^3**			**1300 kg/m^3**			**1400 kg/m^3**		
Duration	**7 Days**	**14 Days**	**28 Days**	**7 Days**	**14 Days**	**28 Days**	**7 Days**	**14 Days**	**28 Days**	**7 Days**	**14 Days**	**28 Days**
Normal	3.1	3.9	5.8	5.3	6.9	8	7.3	9.2	11.4	9.9	12.3	15.1
400°C	4.4	4.8	6.5	6.2	7.5	8.9	8.2	9.9	12.1	10.8	13	15.9
500°C	3.7	4.3	6	5.8	7	8.3	7.8	9.4	11.6	10.3	12.6	15.5
600°C	3.2	3.8	5.5	4.9	6.7	7.7	7.1	8.8	11	9.7	12	14.9

C. Comparison of results

The comparison is done for the density of 1400 Kg/m^3. Because the maximum strength is obtained in the density of 1400 kg/m^3 when compared to other three densities. While adding 0% metakaolin, the experimental result shows that there is a decrease in strength when the temperature starts increasing. In 5% metakaolin mixture, if the temperature is increased till 400°C, the strength also increases. But, when the temperature goes above 500°C, the strength starts decreases. In 10% Metakaolin mixture, the temperature increases the strength also gradually increases, there is no decrease in strength at any temperature (400°C, 500°C and 600°C). In 15% metakaolin, the maximum strength is obtained in normal temperature (without temperature) but, as it is like 5% of metakaolin the temperature increases to 500°C strength decreases gradually. The comparison results were shown in Figures 6 to 8.

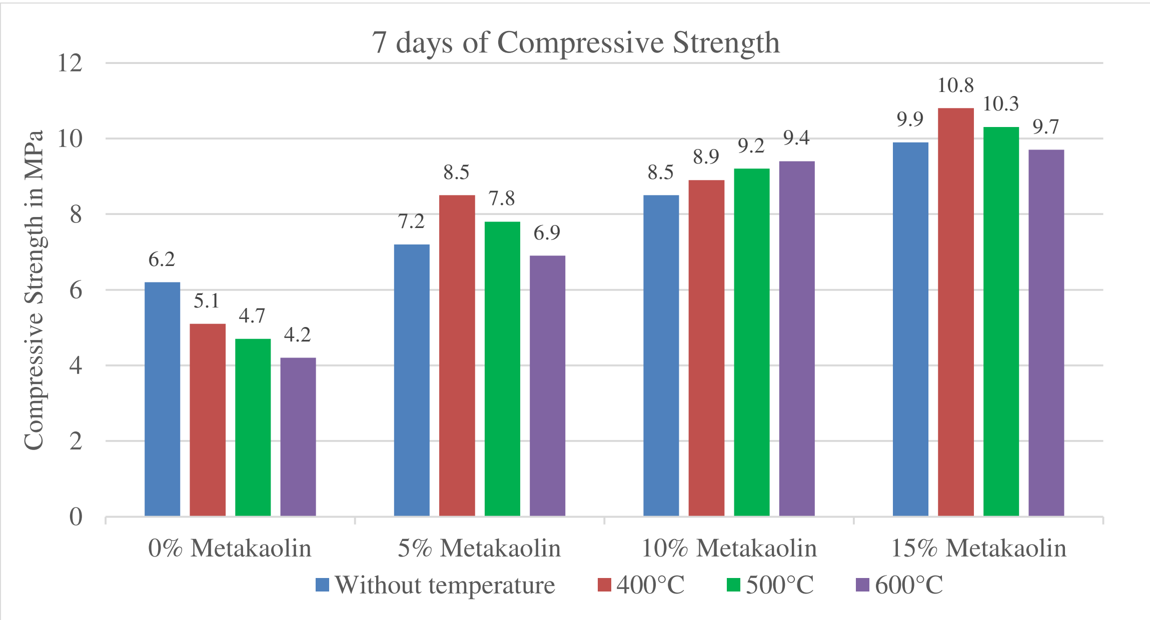

Figure-6. Compressive strength for the density of 1400 Kg/m^3.

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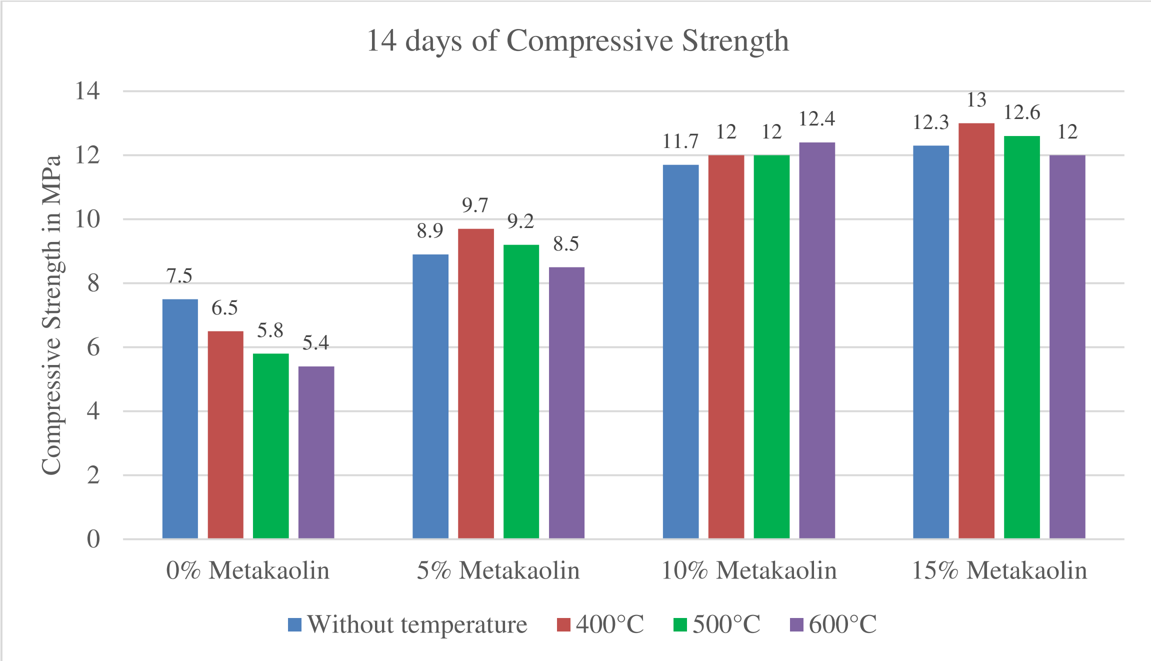

Figure-7. Compressive strength for the density of 1400 Kg/m^3.

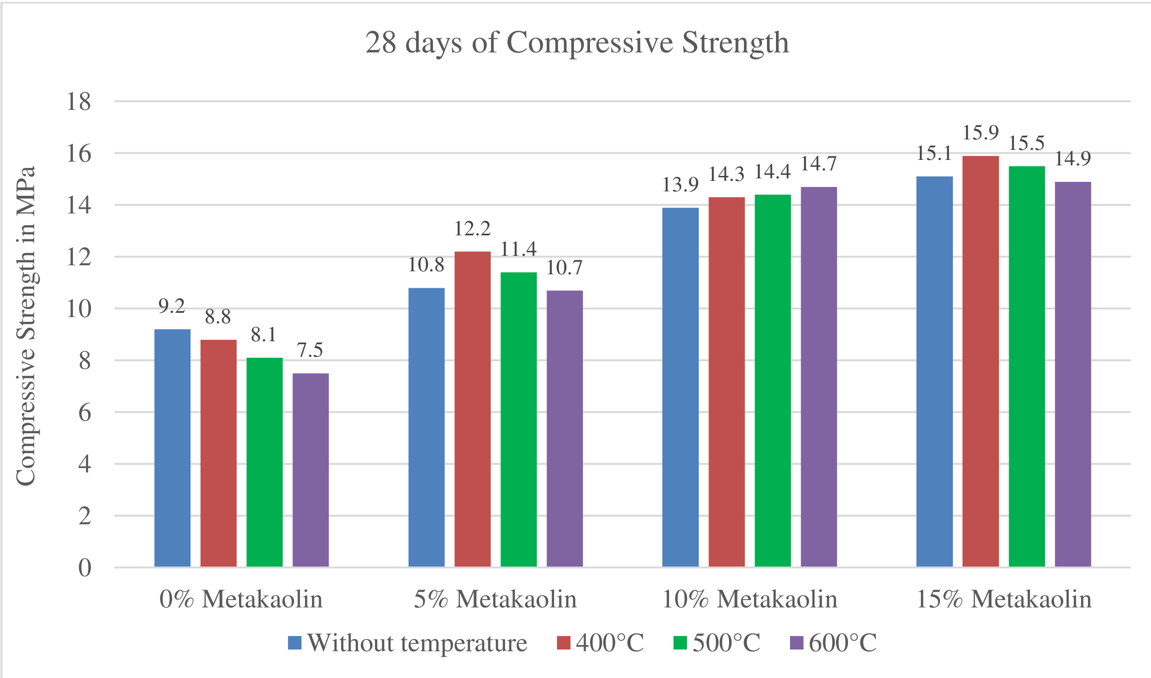

Figure-8. Compressive strength for the density of 1400 Kg/m^3.

CONCLUSIONS

In this experimental study, the strength and properties of foamed concrete have been investigated by the addition of protein based foaming agent along with a varying percentage of metakaolin is determined. Based on the outcome results, the following conclusions are made,

- Coarse aggregate is fully replaced by air voids, which is produced by a protein-based foaming agent in foam generating machine which helps to reduce the self-weight of the structure. And, cement is replaced with metakaolin gives high compressive strength and thermal properties.
- The mixture contains 0% of metakaolin gives maximum compressive strength (without temperature) of 9.2 MPa. But, after exposing the specimen at elevated temperature, the strength decreases a lot.
- In 5% metakaolin mixture, if the temperature is increased till 400°C, the strength also increases. But, when the temperature goes above 500°C, the strength starts decreases.

- In 10% of Metakaolin mixture, if the temperature increases the strength also gradually increases.
- In 15% of metakaolin mixture, the maximum strength is obtained in normal temperature (without temperature) 15.1 MPa. But, if the temperature increases to 500°C, strength decreases gradually as it is like 5% of metakaolin.
- Finally, the mixture contains 10% of metakaolin gives constant compressive strength in both (with and without temperature). And there is no decrease in strength at any temperature (400°C, 500°C and 600°C).

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