A Review on the Effect of GGBS on Aerated Concrete Building Blocks

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Abstract - *Aerated concrete (AC) is either a cement or lime mortar, classified as light weight concrete, in which air-voids are entrapped in the mortar matrix with the aid of suitable air entraining agent. Aerated concrete is relatively homogeneous when compared to normal concrete, as it does not contain coarse aggregate phase. In this study aluminium powder is used as air entraining agent to make aerated concrete. It has many advantages when compared with conventional concrete such as reduced dead load, good sound insulation and considerable savings in material as a result of air voids with in aerated concrete. But the major problem faced by the AC is that it is notorious for its insufficient strength and high water absorption leading to problems during the construction phase. To tackle such problem the paper examines the effect of properties of AC developed by partially replacing cement with Ground Granulated Blast Furnace Slag (GGBS)*

Key Words: Aerated concrete (AC), light weight concrete, Ground Granulated Blast Furnace Slag (GGBS), cellular concrete, masonry blocks.

1. INTRODUCTION

Aerated concrete is either a cement or lime mortar, classified as lightweight concrete, in which air-voids are entrapped in the mortar matrix by means of a suitable aerating agent. Broadly speaking aerated concrete falls into the group of cellular concrete (microporite being the other). The prominent advantage of aerated concrete is its lightweight, which economises the design of supporting structures including the foundation and walls of lower floors. It provides a high degree of thermal insulation and considerable savings in material due to the porous structure. By appropriate method of production, aerated concrete with a wide range of densities (300± 1800 kg/m^3) can be obtained thereby offering flexibility in manufacturing products for specific applications (structural, partition and insulation grades). There have been several investigations on the properties of aerated concrete in the past. Although aerated concrete was initially envisaged as an insulation material, there has been renewed interest on its structural characteristics in view of its lighter weight, savings in material and potential for large scale utilisation of wastes like pulverised fuel ash. Hence, it was felt essential to compile and review the available literature on aerated concrete.

1.1 Classification of aerated concrete

a. Based on the method of pore-formation

Air-entraining method (gas concrete): Gas-forming chemicals are mixed into lime or cement mortar during the liquid or plastic stage, resulting in a mass of increased volume and when the gas escapes, leaves a porous structure. Aluminium powder, hydrogen peroxide/ bleaching powder and calcium carbide liberate hydrogen, oxygen and acetylene, respectively. Among these, aluminium powder is the most commonly used aerating agent. Efficiency of aluminium powder process is influenced by its fineness, purity and alkalinity of cement, along with the means taken to prevent the escape of gas before hardening of mortar. In the case of Portland cements with low alkalinity, addition of sodium hydroxide or lime supplement the alkali required.

Foaming method (foamed concrete): This is reported as the most economical and controllable pore-forming process as there are no chemical reactions involved. Introduction of pores is achieved through mechanical means either by pre-formed foaming (foaming agent mixed with a part of mixing water) or mix foaming (foaming agent mixed with the mortar). The various foaming agents used are detergents, resin soap, glue resins, saponin, hydrolysed proteins such as keratin etc.

Combined pore-forming method: Production of cellular concrete by combining foaming and air-entraining methods has also been adopted using aluminium powder and glue resin.

b. Based on the type of binder

Aerated concrete is classified into cement or lime based depending on the binder used. Attempts have also been made to use pozzolanic materials such as pulverised fuel ash or slate waste as partial replacement to the binder or sand.

c. Based on the method of curing

Aerated concrete can be non-autoclaved (NAAC) or autoclaved (AAC) based on the method of curing. The compressive strength, drying shrinkage, absorption properties etc. directly depend on the method and duration of curing. The strength development is rather slow for moist-cured products. Autoclaving initiates reaction between lime and silica/alumina bearing ingredients. The other variables of significance are the age and condition of the mix at the start of the curing cycle and rates of change of temperature and pressure. Autoclaving is reported to reduce the drying shrinkage significantly and is essential if aerated concrete products are required within acceptable levels of strength and shrinkage.

1.2 Functional properties

a. Water absorption and capillarity

Aerated concrete being porous, there is a strong interaction between water, water vapour and the porous system and there exists various moisture transport mechanisms. In the dry state, pores are empty and the water vapour diffusion dominates, while some pores are filled in higher humidity regions. Capillary suction predominates for an element in contact with water. These mechanisms make it difficult to predict the influence of pore size distribution and water content on moisture migration. The water vapour transfer is explained in terms of water vapour permeability and moisture diffusion coefficient whereas capillary suction and water permeability characterise the water transfer. It has been shown that the water transmission property is better explained by sorptivity than by permeability.

b. Durability

AAC mainly consists of tobermorite, which is much more stable than the products formed in normally cured aerated concrete, and hence it is durable. However, aerated concrete has high porosity, allowing penetration by liquids and gases. This may lead to the damage of the matrix. Freeze-thaw reactions are reported to be significant at higher degrees of saturation, the sample becomes brittle and cracks completely. Protective precautions using bitumen-based materials are necessary when sulphate attack is anticipated. Carbonation can lead to increase in density but it is not very serious unless the exposure to CO2 is too severe.

c. Thermal conductivity

Thermal conductivity depends on density, moisture content and ingredients of the material. As thermal conductivity is largely a function of density, it does not really matter whether the product is moist cured or autoclaved as far as thermal conductivity is concerned. The amount of pores and their distribution are also critical for thermal insulation. Finer the pores better the insulation. As the thermal conductivity is influenced by the moisture content, it should not be reported in oven dry condition.

d. Fire resistance

In practice, the fire-resistance of aerated concrete is more than or as good as ordinary dense concrete and hence its use does not involve any risk of spread of flames. An important reason for such behaviour is that the material is relatively homogeneous, unlike normal concrete where the presence of coarse aggregate leads to differential rates of expansion, cracking and disintegration. The good fire resisting property of aerated concrete is where its closed pore structure pays rich dividends, as heat transfer through radiation is an inverse function of the number of air-solid interfaces traversed. This coupled with their low thermal conductivity and diffusivity gives an indication that aerated concrete possesses better fire-resisting properties.

e. Acoustical properties

Aerated concrete does not possess unique or significant sound insulation characteristics. The reason is that transmission loss (TL) of air-borne sound is dependent on the mass law, which is a function of frequency and surface density of the component. The sound insulation, like thermal and fire insulation, is affected by the closed porous structure.

2. LITERATURE SURVEY

Aerated concrete masonry blocks can be made as precast building blocks and are used in residential construction, hospitals, office buildings and university accommodations. Aerated concrete masonry blocks have many advantages in comparison to conventional concrete: lighter weight (typically weigh one-sixth to one-third of conventional concrete), lower building costs and provides thermal and acoustic insulation. Aerated concrete masonry block is an ideal construction material for walls in many residential and office buildings.

Buildings close to Aerated concrete production facilities benefit from short transportation and minimal shipping costs, especially since this concrete's lighter weight makes it easier to transport than regular concrete. However, Aerated concrete itself has an initial cost per unit higher than ordinary concrete. In addition, the small number of manufacturing facilities could make using it very expensive for projects where the material must travel long distances from a manufacturer.

The current production methods are also increasing the carbon footprint in the environment due to autoclaving technique. So a better manufacturing process that is cost effective and environmental friendly has to be introduced.

2.1 STUDIES ON AERATED CONCRETE MASONRY BLOCKS

Cai et.al. (2016), investigated the objective of reducing the negative impacts on environment and utilizing the secondary resource of tailings, the possibility of preparing AAC by using iron tailing. The results indicated that the increasing content of iron tailing has negative effect on the mechanical property of AAC, and the finer of iron tailings can effectively enhance strength of AAC blocks. The increasing content of iron tailing obviously reduces the amount of calcium silicate hydrates; meanwhile, the finer of iron tailing accelerated the decomposition of white mica during the autoclaving process and has slight negative effect on crystallinity of tobermorite. It is also suggested that Al and Mg ions in iron tailings got into the structure of tobermorite during the hydrothermal reaction.

Prakash et.al. (2013), studied the feasibility of using aerated concrete block as an alternative to the conventional masonry units. The paper focused on estimating physical, strength and elastic properties of Aerated concrete block units. They included Initial rate of absorption, density test, water absorption test etc. The present investigation has favoured to study all such properties. With the obtained results, it can be compared with the results of conventional masonry units.

Małyszko et.al. (2017), presents results of the experimental and numerical study of Brazilian tests on cylindrical and cubic specimens made of autoclaved aerated concrete. Failure mechanisms are discussed based on spatial finite element simulations and experiments with the digital image correlation and strain gauges. The simulations have been carried out using the constitutive model of isotropic plasticity with the Mohr Coulomb yield condition and the strain softening hypothesis. A new method of determining of elastic constants for the cylindrical specimen has been developed. The Young's modulus and the Poisson's ratio are determined by fitting the theoretical solutions into the displacement field obtained experimentally.

Yang et.al. (2015), tested 16 concrete mixes to create a high-performance aerated concrete. The obtained high-performance aerated concrete was compared with the minimum requirements specified in ASTM C 1693. From the regression analyses of the test data, 5 prediction models for dry density, compressive strength, stress–strain relationship, and thermal conductivity of aerated concrete were obtained. All concrete mixes tested showed enhanced workability and de foaming resistance, achieving self-compatibility performance. Mechanical properties prove that the developed high-performance aerated concrete can be used for practical application.

Li et.al. (2017), investigated the performance of autoclaved aerated concrete (AAC) masonry walls subjected to vented gas explosions with a total of nine full-scale in-situ tests. The testing data included overpressure time histories of vented gas explosions, displacement time histories, and damage characteristics of AAC masonry walls. It was found that the responses of masonry walls mainly depend on the peak value of overpressure and couple with the time history of gas explosion loads. Typical one-way or two-way flexural mode dominates the failure of AAC walls under vented gas explosions. In this paper the accuracy of numerical model in predicting the responses of masonry walls was verified with the testing data. Parametric studies were conducted to explore the influences of block strength, boundary condition and wall thickness on the performances of masonry walls. The results reveal both wall thickness and boundary condition have significant influences on the response of the masonry wall while block strength has limited effect on its performance. The results indicate that these predictions on one-way specimens agree well with the testing data, while the performance of two-way specimens is overestimated by using these three methods.

2.2 STUDIES ON EFFECT OF GGBS ON AERATED CONCRETE

Jay et.al. (2015), investigated the properties of lightweight geopolymer specimens aerated by aluminium powder. It has been established well that aluminium powder can be appropriately used for foaming of traditional concrete. Reaction between aluminium powder and alkali activator in geopolymers of this study caused high porous structures based on the weight ratios of constituent materials. Different specimens were made by changing sodium silicate to sodium hydroxide, and alkali activator to fly ash weight ratios. Fly ash was partially substituted by aluminium powder with 1.5, 3.0 and 5.0 wt.% in different mixtures. Results indicates that substituting of 5.0 wt.% of fly ash by aluminium powder in the specimens with alkali activator to fly ash weight ratio of 0.35 and sodium silicate to sodium hydroxide weight ratio of 2.5 causes the best foamed specimen with the lowest density. Compressive strength of all aerated specimens were in the range of 0.9–4.35 MPa, which is suitable for using as bricks, fire-resistant panels, buried pipeline and so on. SEM analysis was conducted to evaluate the microstructure of successfully aerated geopolymers. It was seen that in highly aerated specimens, the foaming reaction is too fast that prevents complete alkali activation of geopolymers and therefore, many unreacted fly ash particles remains.

Samson et.al (2017), investigated the performance of blended metakaolin-ground granulated blast furnace slag (MK-GGBS) foam concrete (FC) presenting acceptable thermomechanical performance for use as self-bearing insulation material. First, a binder composition used for MK-GGBS FC production was identified. Fourteen paste formulations were produced and analyzed to determine the best proportions of MK, GGBS and activator to be used in an alkali-activated material (AAM) FC matrix. Certain requirements were specified for the fresh paste (initial setting time >180 min) and solid materials (high compressive strength and moderate shrinkage) to be used for FC production. The optimized mix was then employed for AAM FC production by using an $H_2\,O_2$ blowing agent (gas-foaming method). The influence of two main parameters ($H_2\,O_2$ and surfactant contents) on AAM FC properties (density, porous structure, thermal conductivity and compressive strength) were investigated. FC density mostly depends on $H_2\,O_2$ content. The FC porous structure depends strongly on both $H_2\,O_2$ and surfactant contents. High surfactant content FCs have a thin homogenous porous structure. At constant density, FC compressive strength depends on the surfactant content. An optimized surfactant content maximizing FC compressive strength at constant density was identified.

2.3 STUDIES ON PROPERTIES AND APPLICATION OF AERATED CONCRETE

Amran et.al. (2015), provides a review of foamed concrete constituents, fabrication techniques, and properties of foamed concrete. In order to produce foamed concrete with high consistency and stability, it is recommended to reduce the volume of foam agent, using a partial replacement of cement by either fly ash or silica fume, and lightweight aggregates, which reduces the process of heat of hydration. The compressive strength is considered as the primary function of the desirable density design. Foam agents produce a uniformed distribution of pores, where they decrease the segregation problem in an early state, prevent the ingression of chloride, prohibit sulfate attack and increase the time range during fire while enhancing its fire resistance.

Chaipanich et.al. (2015), analyzed the different properties and the durability of autoclaved aerated concrete (AAC) masonry blocks and contains the following sections: the types of lightweight concrete, history, utilization, manufacturing, mechanism of AAC, physical properties, mechanical properties, microstructure, characterizations, thermal conductivity and durability of AAC. The utilization of AAC as masonry blocks is also mentioned. The physical properties section describes the bulk density of AAC and the relation to the air voids. The mechanical properties section describes the compressive strength and flexural strength of the AAC, the relationships with the physical properties and the hydration products. The microstructure section describes the pore size formed and the morphology of the AAC microstructure characterized through the use of scanning electron microscopy (SEM) while the other characterization section involved the use of X-ray diffraction and thermogravimetric analysis techniques. The durability section of the chapter describes the freeze-thaw resistance of the AAC.

3. CONCLUSIONS

The following conclusions were drawn from the literature study and discussion.

The thermal conductivity of AAC concrete has a direct relationship with its physical properties. The thermal conductivity of aerated concrete is observed to increase slightly with addition of supplementary cementitious material in concrete, due to the increased unit weight of the concrete. Pore structure of the lightweight aggregates, density of concrete and the cement matrix has an effect on the thermal conductivity of concrete. The compressive strength and the thermal conductivity of AAC concrete are reduced with the decrease in bulk density.

Since the AC has voids, which are large due to the formation of the initial reaction for aeration, it is expected to be frost resistant. However, the degree of saturation is important for freeze-thaw reactions, as aerated concrete is susceptible to liquid and gas penetration due to its high porosity that may cause damage to the concrete. The maximum degree of saturation is reported to be in the range of 20-40%. With a higher degree of saturation, the concrete would be become brittle and crack completely. Aluminium powder affects the mechanical properties of aerated concrete based on the surface area and the reactivity of the Al particle. It is studied that the influence of Al content on porosity, density and compressive strength of aerated concrete. The porosity is increased upto 0.4% Al powder and further increase in Al reduces the porosity. But the density is reduced at 0.4% and then followed by an increase. Compressive strength is increased as the porosity is decreased. Dry density and compressive strength was observed to decrease with increase in Al content by weight of cement. This reduction is due to the increase in tiny bubbles that are formed by the reaction of Al with cement.

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