Construction and Building Materials 170 (2018) 679–689

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Evaluation of heat resisting behaviour of basalt fibre reinforced FG tiles

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HIGHLIGHTS

- Flyash, an industrial waste material act as the best alternative source to cement in concrete.
- Geopolymer, a cement-free technique reduces global warming.
- Reduction of heat loss in buildings through insulative flyash based geopolymer tiles.
- Energy conservation is the best solution for preventing energy shortage.

ARTICLE INFO

Article history:
Received 16 August 2017
Received in revised form 7 March 2018
Accepted 13 March 2018

Keywords:
Heat dissipation
Thermal shock
Basalt fibre
Titanium dioxide
Sustainable

ABSTRACT

The earth's temperature gets raised to a higher level due to global warming, which creates a distressed environment for the people to survive. Geopolymer, which is intrinsically a thermal resistant building material that, can give a better solution to make a comfort zone than Ordinary Portland Cement. Geopolymer along with insulative fibre and admixture makes it more suitable for thermal application. This paper presents in detail about the results of an experimental investigation that are carried out to predict the heat resisting behaviour of flyash-based geopolymer (FG) tiles intended for thermal applications in buildings. For this purpose, several tests such as steady state temperature, furnace heat resistance, open to sky, flame resistance, heat dissipation, thermal shock resistance, thermogravimetry analysis and thermal conductivity are carried out on geopolymer tiles. From the test results, it is found that geopolymer cube prepared with 0.5% basalt fibre to the mass of mix and 0.5% titanium dioxide to the mass of flyash gives higher compressive strength of 33.10 MPa with the dry density of 1961 kg/m^3 and it shows a better thermal effect with the temperature drop of 8.4 °C. This enhancement is mainly due to the strong oxidizing property of titanium dioxide and high temperature withstanding capability of basalt fibre after undergoing high temperature processes.

1. Introduction

In each sector of Indian economy including agriculture, domestic, industry, transport and commercial, the consumption of energy in all forms is steadily rising all over the country. Energy conservation is often the most economical solution to energy shortage. It is the practice of decreasing the quantity of energy used while achieving a similar outcome. This practice may result in an increase of financial capital, environmental value and human comfort. It is found that buildings consume 50% of total human energy use by which it is clear today that the building sector contributes significantly to global warming [1]. Concrete becomes a major component for the development of our infrastructure in which Portland cement plays a dominant role in concrete for construction. Portland cement consumes 10–11 EJ of energy annually which is approximately 2–3% of global primary energy use during its production, 1 tonne of cement produces 1 tonne of CO_2 which leads to a major environmental hazard [2]. Cement industry is under pressure to reduce both the energy use and greenhouse gas emission and to seek a better alternative for cement.

Concrete can be made ecofriendly by utilizing waste materials from industry instead of cement. To reduce the building energy consumption as well as greenhouse gas emission, a novel technology with efficient and renewable energy supply system which is in high demand is preferred [3]. In 1979, Joseph Davidovits introduced a new term called geopolymer, a three-dimensional aluminosilicate material which is synthesized by polycondensation process from the reaction of a solid aluminosilicate with a highly concentrated aqueous alkali hydroxide and silicate solution [4]. Traditional concrete is a poor thermal insulator, so geopolymer

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https://doi.org/10.1016/j.conbuildmat.2018.03.110
0950-0618/

prefers pozzolanic materials like flyash, rice husk ash and metakaolin as source material which has an excellent thermal insulating property of its own [5]. Flyash is an industrial by-product which can be turned into an asset by using it along with the alkaline solution. Geopolymerization process utilizes the energy obtained in the natural chemical reaction that occurs between amorphous silica and alumina rich solids in highly concentrated hydroxide and silicate solutions at ambient or slightly elevated temperatures to form a highly stable material that has an amorphous polymeric structure with interconnected Si—O—Al—O bonds [6].

While subjecting geopolymer mortar and concrete to an elevated temperature of up to 500 °C with different types of coarse and fine aggregates, compressive strength of about 68% with basalt, 67% with granite, 81% with natural sand and 89% with crushed sand are achieved and it showed a good fire resisting property without any spalling of concrete [7]. In GPC, the heat transfer is faster but the temperature gradient is less when compared to OPC and there is no spalling and only a minor crack formation is seen at 800–1000 °C. After exposing to 1000 °C, the mass loss is of 4.8% and the strength loss is found to be 21–29%. But for OPC, spalling occurs at 800–1000 °C and the surface cracks starts to appear at 450 °C and it enlarges at 1000 °C [8]. At high temperature, geopolymer specimen attains higher compressive strength of 66% and its heat transfer is found to be faster in panel which is reinforced with steel mesh and there is only less damage. From this it is found that GPC shows superior fire endurance when compared to control specimen [9].

Further some admixture materials are added to improve the heat resisting property of geopolymer. Titanium dioxide (TiO_2) in anatase form enhanced the photo activity property against some environmentally hazardous compounds [10]. It is an interesting compound that has excellent properties such as chemical stability, non-toxicity and reasonable price. Along with its hydrophilic and self-cleaning property, the maintenance cost of the building is also reduced while using it along with building materials [11]. It is studied that 2% of nano titanium dioxide increased the thermal stability of acrylic polymer and 1.6% $nTiO_2$ increased the anti oxidation property, endothermic effect and fire protection properties [12]. Titanium dioxide is more efficient in increasing the thermal stability of polymer. It is also used as heat resistance sealants-based on liquid and solid phase modes by processing Ammonium Titanyl Sulfate (ATS) [13]. The effect of temperature on heat transfer coefficient of titanium dioxide in ethylene glycol-based nanofluid and the basic thermophysical properties such as thermal conductivity, viscosity, density, specific heat and forced convection heat transfer are tested. The maximum increase is of 28.5% with the base fluid at 1.5% volume concentration at 70 °C working temperature [14].

Controlling cracks in concrete is the main aspect to increase the fracture toughness of the brittle matrix through bridging action for both micro and macro cracking of the matrix [15]. From the literature study, it is found that basalt fibre has more advantages such as ecofriendly, non-toxic, thermal insulation, low price, lightweight, good adhesion, excellent corrosion resistance, stability at high temperature, high elastic modulus and strength when compared to all other fibres, that can make it more suitable as construction material and also as thermal insulating material [16,17]. Basalt fibres are mainly produced from basalt rocks when melted at 1400 °C. It's young's modulus is in the range of 100–110 GPa which is higher than E-glass (76 GPa) and the tensile failure stress is in the range of 4.15–4.8 GPa which is also greater than E-glass (3.45 GPa). Due to these properties in most of the applications, glass is replaced by basalt. Both have a thermal conductivity in the range of 0.031–0.038 W/mK. However, while subjecting to high temperature, basalt has an operating temperature of about 650 °C and higher softening temperature of about 1050 °C. But for E-glass, operating temperature and softening temperature is of only 450 °C and 600 °C [18]. For the above mentioned properties, basalt fibre in chopped form is added to the mix to produce fibre reinforced concrete with good heat resistance [17]. The mechanical properties such as compressive strength, tensile strength, and flexural strength are increased automatically while adding basalt fibre to the fresh mix [19].

Several techniques have been implemented previously to make the building structure thermally insulative. Some insulative coatings can be given throughout the surface using rutile titanium dioxide, sericite powder, talc and hollow glass beads as filler material. 12% of mass of titanium dioxide showed reflectivity of above 90%, and the temperature difference is of 24 °C [20]. Thermal conductivity of 0.0744 W/mK with the compressive strength of 0.82 MPa is obtained while using hydrogen peroxide as a foaming agent for the purpose of insulation [21]. By adding sodium hypochlorite (NaOCl) as foaming agent, the compressive strength of 3.1 MPa is obtained [22]. With the addition of 5% aluminium powder, the compressive strength of about 0.90–4.35 MPa is achieved [23]. Oil palm shell-based geopolymer concrete gives a thermal conductivity value of about 0.58 W/mK [24]. Phase Change Material (PCM) is used for making insulation panels with a compressive strength of 8 MPa and thermal conductivity of 0.46 W/mK [25]. The reduction in strength is recorded as 18%, 21.8% and 20.7% corresponding to its densities of 1700, 1400 and 1100 kg/m^3 in newspaper sandwiched aerated lightweight concrete [26]. Micro metre sized hollow glass bubbles are added to the normal concrete to reduce the thermal conductivity. Addition of less than 20% of glass is suggested in order to satisfy the mechanical soundness [27]. Bio-based composites are the materials which has low heat transfer coefficient that is suitable for insulation purpose [28]. Expanded perlite aggregate (EPA), silica fume (SF) and flyash are used as thermal insulating material in lightweight concrete. EPA is found to be more effective in reducing the thermal conductivity than SF and flyash. The maximum reduction due to 100% EPA replacement is 43.5% [29]. Pumice aggregate decreased the density and thermal conductivity of concrete up to 40% and 46%, respectively. Increasing the cement dosage in the mixtures increased both density and thermal conductivity of the concrete [30]. Unit weight of concrete can be reduced significantly by replacing natural aggregate by EPA and the air dry density of the concrete is reduced to a minimum of 392 kg/m^3 [31].

In the present work, basalt fibre and titanium dioxide are added in proper proportion to improve the heat resisting property of flyash-based geopolymer tiles with an improved strength. Further various thermal tests such as steady state temperature, furnace test, open to sky test, flame test, heat dissipation test, thermal shock resistance, thermogravimetry analysis and thermal conductivity are carried out to find the best heat resisting specimen.

2. Materials and methods

2.1. Material

Dry flyash of class F-type (CaO < 10%) obtained from Thoothukudi Thermal Power Plant is used for this research work. The average size of flyash particle is found to be 10 μm, and the oxide composition is conformed according to the ASTM C 618 [5,32] and it is shown in Table 1. The energy level of elements in flyash is analyzed using XRD test in Panalytical X'Pert Powder X'Celerator Diffractometer. In the above test, the Cu-Kα X-ray is generated at 30 mA and 40 kV and the range of 2θ is fixed from 10° to 80° and the test result is clearly shown in Fig. 1. From the analysis, it is found that numerous peaks of mullite ($3Al_2O_3SiO_2$) and quartz (SiO_2) in the crystalline phase are observed and the higher inten-