



INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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Thesis Title: ***Studies on the Influence of Admixtures on Various Properties of Foam Concrete and Assessment of Its Sustainability Measure***

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SHORT ABSTRACT

Almost 40% of the world's total energy demand is utilized to overcome the heat flow and acquisition via surface coating and building wall units. Using materials with low thermal conductivity (T.C) during design and construction of building will help to reduce this energy consumption to a great extent. Foam concrete (FC) which is classified as lightweight concrete (Density 400-1850 kg/m³) can be considered as one of the suitable material for thermal insulation. It is a cement paste or mortar with air voids entrained by suitable foaming agent. Though low self-weight is considered as a basic property of lightweight foamed concrete but the other additional properties like high flowability, minimal consumption of aggregates, controlled low strength and excellent thermal insulation increases the use of FC in building construction. For instance, the thermal conductivity of LFC typically is 5% to 30% of that of normal weight concrete and range from 0.1 to 0.7 W/mK for dry density values of 400 to 1600 kg/m³ respectively. Summarization of studies have highlighted the influence of surfactant and foam parameters viz., type of surfactant, dosage of surfactant, foam production technique, foam density, foam capacity, foam stability and bubble microstructure on these exemplary properties of foamed concrete. Hence, selecting appropriate surfactant which provides a stable good-quality foam is the crucial requirement for FC.

The first phase of this study evaluates the role of Xanthan Gum (XG) as an additive in the performance improvement of foam produced with two different surfactants, viz., Hingot (Natural surfactant) and Nonylphenol ethoxylate (NPE) (Synthetic surfactant). Different characteristics of foam and surfactant, such as initial foam density, foam drainage, foam bubble microstructure, surface tension, and viscosity of surfactants, are experimentally evaluated. Hingot surfactant due to its more surface active nature reported its surface tension value 15% lesser than that of NPE. Addition of XG resulted in a 10-fold increment in viscosity for both Hingot and NPE surfactant solutions. The above enhancement in viscosity lead to substantial reduction in bubble size and an increment in lamella thickness. Besides enhancement in viscosity due to XG addition, the lower surface tension value of Hingot surfactant also contributed to the reduction in lamella drainage time and bubble coalescence rate thus improving foam stability. For instance, mere

0.1% addition of XG reduced the drainage of Hingot foam from 90% to 42% at the end of 30 minutes. Further considering the effect of the addition of XG on FC properties, 38 % to 88% reduction in spread flow is noted for FC mixes produced with NPE and Hingot foam. Adding to above, Hingot based FC mixes shows higher demoulding time when compared to that of NPE because of retarding nature of saponin present in Hingot solution which was further intensified with the addition of XG. Besides improvement in foam performance, a substantial increase in compressive strength and reduction in thermal conductivity of FC is also observed due to XG addition, indicating that foam bubble microstructure has a significant impact. For instance, addition of XG resulted in substantial increase of 51% and 22% in compressive strength of Hingot FC and NPE FC respectively. The best thermal performance is reported for the FC samples prepared with Hingot surfactant and 0.1 % dosage of XG as foam stabilizer. The cost analysis indicates that the production of Hingot surfactant (₹6.83/litre) is significantly more cost-effective than that of NPE surfactant (₹61.56/litre). Therefore, it can be concluded that Hingot + 0.1XG may serve as a cost-effective and better substitute for NPE surfactant.

Having identified the best combination of surfactant and foam stabilizer (Hingot + 0.1% XG), in the next phase, studies on influence of various admixtures viz. Fly ash (FA) as filler replacement, Silica fume (SF) as binder replacement and Polypropylene fiber (PP) as admixture on the FC behavior prepared with aforementioned surfactant combination is carried out. FC with target fresh densities of 600 kg/m³ and 1000 kg/m³ are prepared and its performance across stability, consistency, compressive and split tensile strength, thermal properties and microstructure analysis is evaluated. Although all the mixes with target density 1000 kg/m³ are able to achieve the allowable density ratios (0.95 to 1.05) some of the mixes in 600 kg/m³ exceeded the allowable density ratio. This may be assigned to the higher foam volume content which leads to longer setting time of the FC mixes causing breakage of foam and instability in the fresh FC further leading to increment in the density of FC. Incorporation of FA, SF and PP fibres reduces the spread flow of the FC to a great extent and hence demands the use of Superplasticizer to maintain the flow. The most significant impact of addition of admixtures is observed on the hardened properties of FC i.e. compressive strength and split tensile strength especially with the incorporation of FA as a replacement to filler. Replacement of sand with 100% FA lead to 368% and 228% increase in compressive strength of FC with design densities 1000 kg/m³ and 600 kg/m³ respectively compared to base mix (FC without admixtures) when tested at 90 days. This strength is further increased when used in combination with other admixtures like SF and PP fibre. Similar trend of observations is reported in case of split tensile strength. The combination of 100%FA + 10%SF +0.4%PP fibre reported the highest compressive and splitting tensile strength of 9.83 MPa and 1.671 MPa respectively for density 1000 kg/m³at the testing age of 90 days. The corresponding strength for density 600 kg/m³ was 3.93 MPa and 0.661 MPa respectively. This can be ascribed to the synergistic effect of combination of all three admixtures along with pozzolanic reaction and superior particle packing ability leading to pore structure improvement and subsequent enhancement of the strength of the FC mixtures. Considering the effect of mix composition on thermal properties, density plays an important role as established in literature. For base mix, with the decrease in density from 1000 kg/m³ to 600 kg/m³, the Thermal Conductivity (TC) of FC decreases from 0.3435 W/mK to 0.2476 W/mK. These values are further reduced with the incorporation of the admixtures. For instance, the combination of 100 FA + 0.4% PP fibre reported TC of 0.2959 W/mK and 0.1973 W/mK for densities 1000 kg/m³ and 600 kg/m³ respectively. The improvement in concrete pore structure with reduced pore diameter due to particle packing effect of fine FA particles and creation of additional voids due to PP fibres addition contributes to the above mentioned decrease in TC. Based on the performance across various properties evaluated and taking into consideration the economic perspective of mixes, MF2PP2 (FC of 1000 kg/m³ density with 100 % FA + 0.4% PP fiber) and LF2PP2 (FC of 600 kg/m³ density with 100 % FA + 0.4% PP fiber) are selected as optimum mixes.

Though FC shows a promising future in terms of huge energy savings when compared to the conventional constructional materials, a detailed life cycle assessment and operational energy cost analysis of using FC as a building component with respect to Indian context needs to be carried out. Thus the third and final phase of this study provides an in-depth investigation on the performance of selected optimum mixes with densities 600 kg/m³ and 1000 kg/m³ as a walling material in G+3 residential building for operational energy analysis and its life cycle assessment. Further, comparative analysis of performance of FC with conventional walling materials like standard clay brick and AAC block is also carried out. To evaluate the sustainability of FC prepared using admixtures and hingt surfactant, life cycle assessment (LCA) approach as per the guidelines of ISO 14040 (2006), ISO 14044 (2006) standards is adopted. SimaPro software version 9.3.03 is used for modelling and analysis with the boundary condition limited to cradle to gate of the laboratory facility for 1m³ of FC serving as the functional unit. Results of the LCA analysis show that the total cumulative energy demand of preparation of 1 kg of Hingt solution is less than that of 1 kg of NPE surfactant solution. The environmental hazard analysis also favours Hingt as a sustainable and economical alternative to NPE surfactant. Results of LCA analysis of FC indicate that FC with densities 1000 kg/m³ and 600 kg/m³ performs better than AAC block and conventional clay brick. The distribution of the cumulative energy demand of production of various constituents involved in the FC production showed that, maximum cumulative energy demand can be observed for cement, which accounts for almost 70% of total embodied energy. The best performance considering all life cycle assessment categories is provided by the optimum mix of 600 kg/m³ i.e. LF2PP2 while the clay brick reportedly performed worst of all materials in all the environmental assessment indicators. When compared to AAC block, Mix LF2PP2 showed 33% lower cumulative energy demand and 27% lower global warming potential. On similar lines for Mix MF2PP2 the decrement in cumulative energy demand and global warming potential reported is 23% and 15% respectively when compared to AAC. It is to be also noted that when compared to AAC block and Clay brick, the performance of both the optimum mixes LF2PP2 and MF2PP2 is also better in other environmental impact assessment categories like eutrophication, human toxicity, marine and freshwater ecotoxicity etc.

Further, DesignBuilder software used in this study served as a suitable analysis tool for calculation of operational energy cost of the building. Simulation is carried out to calculate the total annual operational energy incurred when the selected optimum mixes are used as walling and roofing material for buildings across different cities like, Bangalore, Dehradun, Guwahati, Jodhpur, Mumbai and New Delhi representing the various climatic zones of India. Simulation results showed that, of all the materials used in the present study as a walling material, clay brick exhibited highest annual energy consumption while mix LF2PP2 reported the lowest annual energy consumption across all the cities. For instance, in case of New Delhi city mere use of LF2PP2 as a walling and roofing material instead of Clay brick walls provided us with 21% of saving in operational energy. Similarly, the saving for mix MF2PP2 with density 1000 kg/m³ is observed to be 16%. When compared with performance of AAC block LF2PP2 shows avg. annual energy saving of 11% while MF2PP2 results in savings of 4.5% when used as walling material in New Delhi city. The increased annual energy consumption of clay brick walls and AAC block wall can be attributed to its relatively higher thermal conductivity value, which allows higher average thermal transmittance through the structure.