EVALUATION OF THERMAL CONDUCTIVITY AND SOUND ABSORPTION COEFFICIENT OF CEMENT AND ALKALI ACTIVATED CONCRETE FOR ENERGY EFFICIENT SUSTAINABLE DEVELOPMENT

Submitted By

SURAJIT HORE

MASTER OF ENGINEERING IN CIVIL ENGINEERING

Specialization in

Structural Engineering

Class Roll No-002110402034

Examination Roll No-**M4CIV23007**

University Registration No.- 160046 of 2021-2022

Subject: Thesis

Under the guidance of

Prof. Dr. AMIT SHIULY

DEPARTMENT OF CIVIL ENGINEERING
FACULTY OF ENGINEERING AND TECHNOLOGY
JADAVPUR UNIVERSITY

JADAVPUR UNIVERSITY
DEPARTMENT OF CIVIL ENGINEERING
KOLKATA – 700032.

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DEPARTMENT OF CIVIL ENGINEERING
KOLKATA – 700032.

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It is hereby certified that this thesis "**EVALUATION OF THERMAL CONDUCTIVITY AND SOUND ABSORPTION COEFFICIENT OF CEMENT AND ALKALI ACTIVATED CONCRETE FOR ENERGY EFFICIENT SUSTAINABLE DEVELOPMENT"** has been prepared by **SURAJIT HORE (Class Roll No.-002110402034)** who has carried out this assignment work under my supervision and guidance.
I hereby approve this report for submission and presentation.

Dr. AMIT SHIULY
Associate Professor
Department of Civil Engineering,
Jadavpur University

Countersigned by

Dean
Faculty of Engineering Technology
Jadavpur University

Head of the Department
Department of Civil Engineering,
Jadavpur University

ACKNOWLEDGEMENT

I would like to express my special thanks of gratitude to my teacher **Dr. Amit Shiuly** Associate Professor, Department of Civil Engineering, Jadavpur University for gave me the golden opportunity to do this wonderful thesis work on "**EVALUATION OF THERMAL CONDUCTIVITY AND SOUND ABSORPTION COEFFICIENT OF CEMENT AND ALKALI ACTIVATED CONCRETE FOR ENERGY EFFICIENT SUSTAINABLE DEVELOPMENT"** and their able guidance and support in my thesis work**.**

I am also grateful to all the professors of Civil Engineering Department of Jadavpur University who helped me a lot. It is only for their constant suggestion that I have been able to finish my thesis work.

I am thankful to my family members for always standing by my side. Their blessings, motivation and inspiration have always provided me a high mental support. I am also thankful to my classmates for their assistance and cooperation during the course.

Date:

Place - Civil Engineering Department,

Jadavpur University, Kolkata.

Surajit Hore

Contents

Abstract

The thermal conductivity (TC) and the sound absorption coefficient (SAC) are the most important factors which can make the living zone, habitable area comfortable. Energy efficiency of the buildings greatly depend on these factors. Reduction in loss of heat and sound energy make the buildings energy efficient. Hence, it is important to determine the TC and the SAC of concretes in proper manner. There are several methods that can be used to determine the thermal conductivity and the acoustic properties of materials like concrete. In the present investigation, an attempt has been made to enlighten and determine the changes in thermal conductivity (TC) and the sound / acoustic absorption coefficient (SAC) of Cement Concrete (PCC) and Alkali Activated Concrete (AAC) with different target strength in accordance with IS: 456 :2000 and IS: 17452 :2020 given by BIS (Bureau of Indian Standards). The main focus of this study is to prepare different types of concrete which will be suitable and effective for using as the structural concrete maintaining minimum compressive strength of 17.0 Mpa, conforming to ASTM C 330/C 330 M (2014) and ACI 213R03 (2003) for structural light weight aggregate concrete for a curing age of 28 days. In this study average TC values in case of AAC samples are found as 0.843, 0.763 and 0.998 W/mK for M30, M25 and M20 grade concretes respectively. Average TC values in case of PCC sample are found as 1.843, 2.132 and 2.647 W/mK for M30, M25 and M20 grade concretes respectively. In case of PCC, maximum SAC values are found as 0.211, 0.169 and 0.151 for grades M20, M25 and M30 respectively. In case of AAC, maximum SAC values are found as 0.269, 0.223 and 0.219 of grades M20, M25 and M30 respectively. NRC values are obtained as 0.246, 0.266 and 0.288 in case of AAC of grades M20, M25 and M30 respectively. NRC values are obtained as 0.134, 0.131 and 0.116 in case of PCC of grades M20, M25 and M30 respectively. Average density (BD) values in case of ACC for M20, M25 and M30 grade concrete are found as 2167, 2115 and 2092 kg/m3 respectively. In PCC these values are observed as 2395, 2423 and 2477 kg/m3 respectively. The average compressive strength (CS) values in AAC for M20, M25 and M30 grade concrete are found as 20.92, 25.37 and 33.37 Mpa respectively. Similarly, in PCC these values are evaluated as 22.99, 31.31 and 40.95 Mpa respectively.

Chapter 1

1.0 Introduction

1.1 General

Concretes are prepared using cement or other cementitious binding material like geopolymer, as the chief constituent. When the concrete is prepared with cement, it is called as cement concrete (PCC) which are the traditional type of concrete that is prepared by mixing of coarse aggregate, fine aggregate, water and cement as binding material in specific proportions to obtain desired compressive strength (CS). Whereas, when the concrete is prepared with geopolymer with activation of silica by alkali, is called as alkali activated concrete (AAC) or sometimes as geopolymer concrete (GPC). The alkali activated concrete is prepared mixing different base materials like fly ash (FA), ground granulated blast furnace slag (GGBFS), metakaolin (MK), silica fume (SF) etc. as binding materials having silica and alumina compound and alkali like NaOH/KOH and Na_2SiO_3/K_2SiO_3 etc. as activating agent. In this context, it should be noted that for preparation of cement for using in PCC, needs a huge amount of natural resource i.e. Lime stone and exerts almost 1 MT of CO_2 (a greenhouse gas) in environment in production of each MT of cement [1][2]. The AAC may be taken as an environment friendly alternative, sustainable concrete material which can be used in construction

1.2 Need for present study

For every type of concrete the sound / acoustic and thermal insulation are the two major issues to be considered in building construction to meet the overall comfort conditions indoors and fulfill the energy - efficiency approaches. Energy conservation is required as the population in all through the world is growing and there are limited sources of natural energy. The amount of natural resources of the earth is very limited [3]. In order to keep the earth healthy i.e. green, conservation of this natural resources is very important. Buildings in the world are responsible for about one third of the total energy consumption and 30% of greenhouse gas emissions [3][4]. The main target of the researchers and the developers to develop the principle to construct the dwelling buildings which would consume minimum energy. Structures are the unavoidable part of human civilization as people spend almost 90% of their lives inside dwelling houses [5]. Most of our dwelling houses are made of concrete in floors, roofs or in walls. So, these are required to be designed to maintain the comfort against temperature and noise. Thus, there are requirements of using high performance thermal and acoustic materials to control the temperature and the noise respectively inside the houses to make it habitable for the residents maintaining a comfortable environment. Other than that, a perfect insulating material reduces the loss of energy, lower the environmental impact etc. Thermal insulation and sound or acoustic properties of concrete are generally ascertained by measurement of thermal conductivity (TC) and sound absorption coefficient (SAC) respectively. The TC of a material is the ability to conduct heat through it and is generally denoted by k [6]. More specifically, TC of a material is the quantity of heat transmitted through a unit thickness in a direction perpendicular to a surface of unit area due to unit temperature gradient under given conditions [7] . Thermal conductivity is the most important thermal property that affects heat transfer by conduction through concrete. It is evident that, concrete with low thermal conductivity reduces the heat transfer and reduces energy consumption in buildings. Thus, it is important to measure the thermal conductivity (TC) of concrete using suitable method. The steady state method is generally used for homogenous materials and advantageous as by this method, more accurate TC value can be obtained than that of the transient method. However, it takes more time to get the TC value. The transient method is generally used for heterogeneous materials. In the transient method, there is possibility to consider moisture content. However, in order to get precise results the test has to be repeated for several times. On the other hand, guarded hot plate method, conforming to ASTM C177/C177-13 [8] is said to an absolute method for determination of thermal conductivity. Further, the laser flash method is often used for highly conductive ceramics, metals, and some composites where the thermal conductivity of large specimens of refractory material is measured using hot-wire systems. This test conforms to ASTM C1113/C1113M-09(2013) (platinum resistance thermometer technique) [9], ISO 8894-1 (EN 993-14) Part 1: hot-wire methods (cross-array and resistance thermometer) [10] and ISO 8894-2 (EN 993-15), Part 2: hot-wire method (parallel) [11]. TC differs in different concrete with the use of different type of binders, aggregates, curing environments, etc. In case of PCC, the value of TC differs with the changes in use of aggregates, curing environments etc. , where as in case of AAC the TC depends upon type of binder, molarity of alkali, ratio of activator-alkali ratio, type of aggregates, duration and temperature of curing, relative humidity, type of added minerals etc. Similarly, the SAC of a material is defined as the ratio of the absorbed energy to the incident energy and it can also be defined as the ratio of all un-reflected energy to the incident energy. It is denoted by λ. Thus, the SAC (λ) = 1 – Er / Ei, where Er = reflected sound energy and Ei = both the transmission and reflected energy [12]. There is another parameter called Noise Reduction Coefficient (NRC), which is also used to understand the sound absorption capacity of concrete. NRC is the average of 4 (four) SAC readings, measured at 250 Hz, 500 Hz , 1000 Hz and 2000 Hz frequency respectively in 1/3rd octave band [13]. Higher porous concretes show higher sound absorbing properties. Sound absorption of a porous material is related to the energy loss through friction with the wall of the pore holes. [14]. When the sound waves moves though concrete, the sound energy changes and reduces due to absorption of sound energy. This absorption of sound in porous materials occur due to loss of momentum through the narrow passage of the pores. The reduction of sound energy is also termed as sound transmission loss (STL). This reduction happens due to reflection during its movement. Sound absorption coefficient can be assessed using transfer function in accordance with ASTM E1050-19. The sound frequency also influences the reduction in sound energy. At low frequencies, the STL is found as low [15]. Several researches have been carried out so far towards study of TC and SAC, which are the key parameters of thermal and sound insulation of different types of concretes like PCC and AAC.

1.3 Objective and scope of work

The objective of this study is to prepare different types of concrete which will be suitable and effective for using as the structural concrete with effective TC and SAC maintaining minimum compressive strength.

The scope of work includes several steps which are to be followed in this experimental study. The steps are:

(a) preparation of traditional and alkali activated concrete specimens in moulds through the mix design in accordance with code provision.
(b) analysis of general mechanical properties of the prepared concrete specimens like water absorption, density, void ratio and porosity.
(c) analysis of sound absorption of concrete blocks prepared and properly cured earlier.
(d) determination of thermal conductivity of prepared and cured concrete specimens.
(e) analysis of experimental results with the help of discussions and conclusions.

1.4 Organization of thesis

The thesis has been divided into five chapters. The table and figures have been presented in a sequence as they appear in the text.

In **Chapter 1** an attempt has been made to introduce the problem along with need for present research, scope and objectives of the work and organization of thesis.

Chapter 2 furnishes a detailed literature review on the relevant topic.

Chapter 3 presents experimental programs that are carried out in the laboratory.

Chapter 4 furnishes the detailed discussions and conclusions in regard to the test results obtained.

Chapter 5 depicts concluding remarks along with major findings, limitations and future scope of study.

References are furnished at the end.

Chapter 2

2.0 Literature Review

2.1 Previous researches on Thermal Conductivity of Concrete

2.1.1 On Cement Concrete

Delpak et al. (2002) investigated the relation between different percentage of damage and the TC of PCC samples [16]. Investigation showed that higher percentage of damage had higher TC value and vice versa and those different percentage of damage were influenced by different percentage of ultimate load or average compressive load applied on those concretes.

K.-H. Kim et al. (2003) found that there were 7 (seven) influencing factors on TC of PCC. Those were (i) age of PCC, (ii) water-cement (w/c) ratio, (iii) type of admixture used, (iv) aggregate volume fraction, (v) fine aggregate fraction, (vi) temperature and (vii) humidity. They proposed a quantitative equation to find the TC using those influential factors in case of PCC [17]. The study showed that, the aggregate volume fraction and the relative humidity (moisture condition) (RH) were the most influencing factors for TC of PCC and the w/c and the type of admixtures were found as the most influential for the cement mortar (PCM) and cement paste (PCP).

Demirboğa (2007) in his research observed the effect of replacement of cement by different type of admixtures like silica fume (SF), fly ash (FA), and ground granulated blast furnace slag (GGBFS) etc. in different proportions towards change in the value of TC in PCC [18]. In his study it was revealed that. the addition of mineral admixture reduced the densities of the PCC samples. The use of admixtures also decreased the compressive strength (CS) of the samples at early ages but CS of the samples were seen to be increased with prolonged ages of curing.

Asadi et al. (2018) reviewed the techniques that were most commonly used to measure the TC of PCC and the factors affecting the TC of PCC [6]. The review showed that, the TC of PCC sample were mostly measured using the (a) steady state method and the (b) transient method.

The study also revealed that, the TC of PCC in saturated condition had larger value than that of in dry condition. The TC in light weight concretes (LWC) was found 1.4 to 3 times lower than the normal weight concrete because the light weight concretes contain more air which had less TC value than moisture/water. Increase in 1% of moisture caused about 6% increase in TC. TC values were found decreased with increase in curing temperature beyond a limit. At about $500^{O}C$, the TC was found nearly 50% less than that of in ambient curing. LWC prepared with light weight aggregates (LWA) had more porosity. Increase in porosity by 1% caused a decrease in TC around 0.6%. The use of other cementitious binding material also caused reduction in TC in comparison to PCC. A relationship between the TC and the density of the PCC had also been suggested in the study.

J. Wang et al. (2020) in their study compared the thermal of PCC and recycled aggregate concrete (RAC) and recycled aggregate crumb rubber concrete (RCC) [19]. Test result showed that RCC had higher thermal resistance, larger SAC in comparison to PCC. Increase in replacement rate for the Recycled Aggregate by coarser (5-10 mm) recycled rubber material e.g. Crumb Rubber (CR) had reduced the TC of the PCC.

Pongsopha et al. (2022) investigated the effect of CR in light weight aggregate concrete (LWAC) by replacing the fine aggregate with CR and found that, there was a decrease in TC by 15% for the CR content around 50% [20]. The resulted TC range (0.363 – 0.310 W/mK) was found less than the TC of PCC prepared using nano silica in the research done by Saleh et al. 2021 [21]

Tasdemir et al. (2017) compared the TC values of different types of LWC using different LWA [7]. They found that lower unit weights of PCC, prepared using LWA had lower TC values and TC values were dependent on types of LWA. A mathematical expression to find the TC had been proposed for the PCC using expanded polystyrene (EPS), expanded perlite aggregate (EPA) and pumice aggregates (PA) in defined proportions.

Belkharchouche et al. (2016) studied the physical and mechanical properties of PCC using vegetable fibers which were used as heat insulator [22]. Saturated concretes were found to have larger value of TC than dry concrete as the TC of water (0.6 W/mK) was more than TC of air (0.026 W/mK). Addition of olive pomace (fiber) reduced the density of the PCC by 11% and thereby lowered the TC.

Gourlay et al. (2017) inspected the effect of water content on the thermal properties of hemp concretes (HC) (A type of concrete prepared using hemp material like coconut shell etc. which is a plant part and increases the porosity of the concrete. The non-fibrous fraction of the hemp stem called ‘‘shiv” or ‘‘hurd”) [23]. TC of HC was seen to be increased linearly with water content.

Yun et al. (2013) in their research tried to reduce the TC of LWC by replacing the coarse aggregate by glass bubbles (GB) and various types of LWA [24]. They found that the increase in hollow glass bubble fraction and LWA decreased the TC of the PCC.

W. Wang et al. (2017) investigated the influence of high temperature exposure of concrete containing FA and showed that, in concrete with 30% replacement of cement, the was reduced by 43.4% from 1.694 W/mk with a relative humidity (RH) of 45% within the temperature range from 20^{O}C to 550^{O}C [25]. A rebound of decrease in TC with increasing temperature was found near 350^{O}C. Increase in TC was observed with increase in RH.

2.1.2 On Alkali Activated Concrete

Parcesepe et al. (2021) investigated the mechanical strengths like CS, tensile strength (TS), TC etc. for GGBFS and SF incorporated AAC [26]. The research showed that, TC could be found to be increased by 25% for increase in temperature from -10^{O}C to 50^{O}C. Measured TC of 0.57 W/mK at 20^{O}C was found as 60% lower than PCC with same density of 1.57 gm/cc and 14% higher than foamed AAC with about half the density.

Feng et al. (2015) checked the physical properties like porosity, density TC of alkali activated mortar (AAM) using hydrogen peroxide (H_2O_2) as foaming agent [27]. The research revealed that the use of more water glass (sodium silicate i.e. Na_2SiO_3) and H_2O_2 had increased the porosity of samples and reduced the CS and TC of the AAC. The increase in curing temperature from 55^{O}C to 85^{O}C had increased the TC by making the sample denser.

Shahedan et al. (2017) compared the thermal properties of different types of AAC for increase in curing temperature [28]. TC of all concrete had been found to be decreased with increase in temperature to higher range since, higher temperature caused moisture loss and dissociation of physically bound water in AAC. TC was recorded as 50% at 800^{O}C in comparison to AAC at normal temperature.

Agustini et al. (2020) focussed on the effect of various water to solid ratio on TC of AAC samples [29]. TC values were found increasing upto 150^{O}C and then reducing. Water to geopolymer weight (w/g) ratio found to be influential for TC. For a w/g ratio of 0.22, minimum TC value of 0.25, was found at 50^{O}C with a density of 2114 kg/m^3. Higher w/g ratio decreased the CS values of the AAC samples.

Wongsa et al. (2018) examined the property of FA based light weight geopolymer concrete (LWGC) containing crushed clay brick aggregate (CCA) and pumice aggregate (PA) [30]. Use of CCA and PA had decreased the density of the LWGC and made the concrete lighter in weight along with reducing the TC of the samples in comparison to the LWGC made with natural aggregates (NA). Increase in temperature also showed reduction in density, CS and the TC of samples. A power equation had been prescribed to find the TC of the sample using the density of the sample. A minimum TC of 0.20 was found for using PA by 1%, but the density (BD) of the concrete was found as 1011 kg/ m^3.

Snell et al. (2017) compared the TC and the CS values of PCC and AAC with adjustment of paste percentages where paste percentage is the ratio of mass of paste to the summation of mass of paste and aggregates [31]. PCC samples were found to have higher TC values (1.07 W/mK) than that of in AAC (0.57 W/mK for dry sample and 0.47 W/mK for saturated sample). It was seen in the research that, decrease in paste percentage increased the TC and CS values in a linear trend in case of all types of concretes.

Stolz et al. (2018) studied the thermal properties of cellular concrete (concrete with air bubbles formed through foaming agent like H_2O_2, aluminium powder etc.) of different densities [32]. Alkali activated fly ash concrete (AAFA) contained lower value of TC in comparison to majority other materials of same density. TC values were increased by 20% (from 0.23 W/mk to 0.30 W/mK) upto a density of 1130 kg/ m^3 from 940 kg/ m^3along with increase in CS.

Z. Zhang et al. (2015) checked the TC of geopolymer foam concrete (GFC) using preformed foam and found that reduction in foam dosage from 16% to 0% increased the dry density from 585 kg/ m^3 to 1370 kg/ $m^3$and accordingly increased the TC from 0.15 W/mK to 0.48 W/mK [33]. TC had not such dependency on the thickness of the AAC samples.

Lu et al. 2014 checked the TC of AAC containing GGBFS and revealed that, 30% replacement of lime stone aggregate by graphite aggregate had increased the TC by 60% but decreased the CS before and after heating though there were increase in residual strength of AAC [34].

Chen et al. (2022) suggested that larger silica gel particles were more beneficial for thermal insulation [35]. Increasing aerogel content which played the role of insulating filler in geopolymeric foam concrete (GFAR). Lowest TC value of 0.133 W/mK was found for aerogel content of 20%.

Mahmoud et al. (2023) studied the thermal properties of modified AAC with different types of LWA like EPS, dolomite, vermiculite, light weight expanded clay (LECA) aggregates [36]. Use of EPS was found as the most effective admixture in comparison to dolomite, LECA and vermiculite, as the TC was found minimum as 0.45. AAC with 25% LECA content gave TC as 1.10. A relation between CS and the TC was also proposed in the research.

Perea et al. (2021) checked the SAC of AAC composite with different waste materials like EPS, corkwood, tire rubber (RB) etc. Lowest TC was found as 0.316 W/mK with a density of 1853 kg/ m^3, using 4% EPS in comparison to TC of 0.344 W/mK with a density of 1922 kg/ m^3, using 4% RB. So, the density of AAC was reduced using EPS [14].

2.2 Previous researches on Sound Insulation of Concrete

2.2.1 On Cement Concrete

H. Kim, Hong, and Pyo (2018) experimented to develop sound absorbable high performance using a frequency range from 0 to 3000 Hz using PU setup [37]. The research revealed that sound absorption coefficient (SAC) was increased with addition of aluminium powder and cellular fiber. The SAC value lied between 0 and 1, where 0 (zero) represented "no sound absorption" and 1 represented "100% absorption of sound". In PCC the SAC values were found lying within 0.05 to 0.10. The SAC was increased with reduction in porosity by replacement of smaller sized Zeolite with Silica Sand in preparation of PCC. Higher void ratio and higher frequency range were also found responsible for increase in SAC.

Oancea et al. (2018) checked the influence of thickness of the samples of sustainable PCC made by incorporating waste materials into the PCC made the PCC more sound absorbent where the SAC values were increased [38]. Increased thickness of samples increased the SAC values. Maximum SAC value was found using the PET (Polystyrene) granules (Corncob, Wool etc. were also tested) as waste in the PCC.

Amran et al. (2021) reviewed a wide range of sound absorbing concrete including measuring techniques and insulation characteristics of the used materials and found that polymer concrete possessed more SAC value than that of PCC [12]. Interconnected porosity gave an increased SAC.

Medina et al. (2016) analyzed the main parameters that influenced the acoustic / sound properties of LWC containing rubber aggregates replacing coarse aggregate upto 60% volume of concrete [13]. Use of Crumb Rubber (CR) and Plastic Fiber Crumb Rubber (FCR) increased the SAC by increasing the porosity, but decreased the density of the Crumb Rubber Concrete (CRC). For frequency range of 100-1600 Hz the SAC values were increased in concrete with CR. Increase in SAC was found more in FCR than that of in CR. With 80% substitution of coarse aggregate with FCR and frequency range 900-1000 Hz the SAC value was found 33%.

Holmes et al. (2014) inspected the sound / acoustic performance of CR concrete panels in low (upto 500 Hz) and High (1000-5000 Hz) frequency ranges [39]. The SAC was found increased from 0.18 to 0.20 when the coarse aggregate was replaced by 15% CR of size 10-19 mm. The value of SAC was 0.14 when the size of the CR was 1-3 mm. the paper established that, SAC is dependent on the percentage and size of the CR in CRC. Higher range of frequency and higher temperature were also found responsible for the increase in SAC.

Gourlay et al. (2017) inspected the effect of water content on the thermal properties of Hemp Concretes (HC) (A type of concrete prepared using hemp material like coconut shell etc [23]. which is a plant part and increases the porosity of the concrete). SAC of HC was not seen to be affected by water content.

J. Wang et al. (2020) in their study compared the thermal of PCC and Recycled Aggregate Concrete (RAC) and Recycled Aggregate Crumb Rubber Concrete (RCC) [19]. Test result showed that peak value of SAC was found around 1000 Hz and valley value was found near 250 Hz. RCC had higher larger SAC in comparison to PCC.

Pongsopha et al. (2022) investigated the effect of CR in Light Weight Aggregate Concrete (LWAC) by replacing the fine aggregate with CR and found that, there was an increase in SAC of value 0.311 for the CR content around 50%, since CR increased the void in the concrete and absorbed the sound waves in void by converting that to sound energy [20]. The SAC was also found dependable on the frequency range of the sound. Reinforced Light weight aggregate concrete (RLWAC) was found more effective than LWAC in case of sound absorption.

2.2.2 On Alkali Activated Concrete

Luna-Galiano et al. (2018) investigated the sound absorption properties of porous geopolymeric foam using SF as pore generating agent in AAC [40]. Higher amount SF addition in AAC exhibit higher SAC which was correlated with open porosity. With 100% SF use the SAC was increased from 0.27 from 0.20 with 80% SF use. Increase in curing temperature from $40^{O}C$ to $70^{O}C$ also increased the SAC from 0.20 to 0.26 in 2500 Hz frequency.

Chen et al. (2022) suggested that larger Silica Gel particles were more beneficial for acoustic / sound insulation. Increasing aerogel content which played the role of insulating filler in Geopolymeric Foam Concrete (GFAR) [35]. Sample with 20% aerogel content and 0.67% H2O2 content Higher SAC values were found as 0.51 for higher thicknesses of 50 mm in comparison to 0.49 for 20 mm sample. SAC was found increasing also in higher frequency range.

Mahmoud et al. (2023) studied the acoustic properties of modified AAC with different types of LWA like EPS, dolomite, Vermaculite, light weight expanded clay (LECA) aggregates [36]. Use of 100% LECA was found as the most effective admixture with SAC maximum of 0.82 at 800 Hz in comparison to EPS and Vermaculite. But, for structural use purpose AAC with 25% LECA content gave SAC 0.71 at 800 Hz with good CS.

Perea et al. (2021) checked the SAC of AAC composite with different waste materials like EPS, Corkwood, Tire Rubber etc.[14]. Highest SAC was found as 0.707, using sample with 4% EPS content near 500 Hz frequency.

Z. Zhang et al. (2015) checked the TC of geopolymer foam concrete (GFC) using preformed foam and found that reduction in foam dosage from 16% to 0% increased the dry density from 585 kg/ m^3 to 1370 kg/ m^3[33]. SAC of the samples were found dependable on the thickness of the samples where higher thickness caused higher SAC. SAC value was increased in frequency range of 800-1600 Hz with 30% FA substitution by SF. Foam content between 5%-15% increased the SAC value in frequency range 600-1000Hz. Thin AAC specimen with 70% FA and 30% SF of thickness 25 mm exhibited an huge acoustic absorption rate from 1.0 in the low frequency region of 40–150 Hz.

2.3 Critical Appraisal of Literature

There are several researches conducted previously by different researchers for investigation of thermal and sound insulation properties of traditional concrete (PCC) as well as for alkali activated concrete (AAC). In these experiments the different constituents of the concretes were modified to achieve the desired results in regard to lesser thermal conductivity (TC) and sound absorption coefficient (SAC). However, there are some lacunas in these researches which can be broadly studied in future. The lacunas are stated as:

(a) There is no research on comparative study of PCC and AAC as structural concrete in consideration of thermal and sound insulation properties.

(b) Researches on preparation of PCC and AAC which would have lower value of TC and SAC in light of energy efficiency as well as higher CS simultaneously. These type of concretes would be very important for using these concretes in structural works in future.

Chapter 3

3.0 Experimental Program

3.1 Materials

Ordinary Portland cement (OPC) with a specific gravity of 3.15 of 53 grade (ASTM C150) was used as binding material in case of cement concrete. River sand (RS) with a specific gravity of 2.65 was used as fine aggregate, Crushed Granite (CG) Stone Chips of size 20 mm and 10 mm with a specific gravity of 2.75 was used as coarse aggregate for preparation of cement concrete specimens. For preparation of AAC, fly ash (FA) of type F and ground granulated blast furnace slag (GGBFS) were used as the binding materials, sodium hydroxide (NaOH) in the form of pellets and sodium silicate (Na_2SiO_3) from local chemical vendors were used as activators along with similar aggregates that were used for preparation of cement concrete. Sikament 2000, a commercially used plasticizer manufactured by Sika, was used in amount of 0.5% w/w of cement and 3% w/w of total binding materials in case of cement concrete and alkali activated concrete respectively. Potable water, that was available in Laboratory, was used for preparation of concrete specimens. The properties of the binding materials are shown in Table 1 to 2. Sieve analysis of all aggregates are shown in Table 3 to 5.

Table : 1 (Physical Properties of Binding Materials)

Item	**Cement**	**Fly Ash**	**GGBFS**	**Sand (Fine Agg.)**	**Stone Chip (Coarse Agg.)**
Fineness Modulus	-	-	-	3.46	7.3 – 9.3
Specific Gravity	3.15	2.10	2.32	2.65	2.75
Specific Surface (cm^2/gm)	3358	3312	3284	-	-
Water Absorption (%)	-	0.1-0.2	4.10	0.38 – 0.67	0.46 – 0.88
Colour	Blackish Grey	Blackish Grey	Yellow	Yellow	Grey

Table : 2 (Chemical Properties of Binding Materials by XRF analysis)

Chemicals Present	Cement (%)	Fly Ash (%)	GGBFS (%)
CaO	62.93	0.88	29.27
SiO_2	19.58	55.16	37.23
Al_2O_3	6.85	27.18	21.90
MgO	0.81	0.76	9.84
Fe_2O_3	3.58	5.24	0.34
SO_3	2.44	-	-
Na_2O	0.8	0.18	0.16
K_2O	0.5	1.59	1.33

The XRF analysis had been carried out in laboratory at Kalyani and the data set were supplied to us.

Sieve analysis have been performed in the laboratory for the sand for determination of zoning of fine aggregate as per Table 9 of IS: 383-2016 [41]. Sieve analysis have been also performed in the laboratory for combination of 20 mm and 10 mm sized stone chips to find the grading of coarse aggregates conforming to Table 7 of IS: 383-2016 [41]. The results of the sieve analyses are given in Table 3 to Table 5.

Table : 3 (Sieve analysis of Fine Aggregate of 1000 gm of sample)

I.S Sieve Size	Weight Retained (gm)	%age Weight Retained	Cumulative %age Weight Retained	Cumulative %age Weight Passing
10 mm	0	0	0	100
4.75 mm	31.00	3.10	3.10	96.90
2.36 mm	78.10	7.81	10.91	79.09
1.18 mm	201.50	20.15	31.06	68.94
300 micron	338.20	33.82	95.63	4.37
150 micron	22.80	2.28	97.91	2.09
Pan	20.90	2.09	100	0

This result for sand used as fine aggregate shows that the sand used as fine aggregate belongs to Zone – II, conforming to Table 9 of IS: 383- 2016 [41].

Table : 4 (Sieve analysis of 20 mm Coarse Aggregate of 2000 gm sample)

I.S Sieve Size	Weight Retained (gm)	%age Weight Retained	Cumulative %age Weight Retained	Cumulative %age Weight Passing
40 mm	0	0	0	100
20 mm	840.80	42.01	42.01	57.99
10 mm	1065.20	53.26	95.27	4.73
4.75 mm	94.60	4.73	100.00	0
Pan	0	-	-	-

This result shows that the sand used as fine aggregate belongs to Zone – II, conforming to Table 9 of IS: 383- 2016 [41].

Table : 5 (Sieve analysis of 10 mm Coarse Aggregate of 1000 gm sample)

I.S Sieve Size	Weight Retained	%age Weight Retained	Cumulative %age Weight Retained	Cumulative %age Weight Passing
20 mm	0	0	0	100
10 mm	114.30	11.43	11.43	88.57
4.75 mm	816.50	81.65	93.08	6.92
2.36 mm	64.30	6.43	99.51	0.49
Pan	4.90	0.49	100.00	0

This result shows that the stone chips used as coarse aggregate conforms to Table 7 of IS: 383-2016 and used in a mix proportion of 20% : 80% for 20 mm and 10 mm stone chips respectively.

3.2 *Mix Proportion*

Mix designs were analyzed for preparation of the above mentioned two types of concrete specimens. CC specimens were prepared in accordance with IS:456: 2000[42] and AAC specimens were prepared in accordance with IS:17452: 2020 [43].

The quantities of materials used for preparation of specimens as per mix designs are tabulated in Table 3 and Table 4.

Table 6: (Mix Design for Cement Concretes per Cum)

Concrete Grade	Cement (Kg)	Sand (Kg)	Coarse Agg. (20 mm) (Kg)	Coarse Agg. (10 mm) (Kg)	Water (Kg)	Plastcizer (% of Cement)	W/C Ratio
M-20	390.94	678.35	408.83	759.26	187.65	0.5%	0.53
M-25	407.93	672.96	405.58	753.23	187.65	0.5%	0.48
M-30	426.48	667.07	402.03	746.63	187.65	0.5%	0.44

Table 7: (Mix Design for Alkali Activated Concrete per Cum)

Concrete Grade	Fly ash (Kg)	GGBFS (Kg)	NaOH (10M) (Kg)	Na2SiO3 (8% Na2O) (Kg)	Sand (Kg)	Coarse agg. (20 mm) (kg)	Coarse agg. (10 mm) (Kg)	Added Water (Kg)	Plastcizer (% of Binder)	W/B ratio
M-20	53.02	279.03	63.55	103.70	595.68	292.38	682.23	50.28	1.0%	0.45
M-25	60.85	320.20	72.65	118.52	549.44	270.27	630.63	41.44	1.5%	0.42
M-30	60.85	320.20	72.65	118.52	573.92	282.56	659.30	17.44	2.0%	0.40

W/B ratio means water to binder ratio in concrete.

3.3 *Preparation of Specimen*

In order to prepare the test specimens, all raw materials were dry mixed in a pan mixer for 2-4 minutes before water was added. The mixing then continued for another 5–8 min. The specimens were prepared differently depending on the type of test. 3 nos. 100 mm cubes were prepared for each type of concrete for the test of compressive strength (CS) of the concretes. For testing of thermal conductivity (TC) and the sound absorption coefficient (SAC), concrete blocks were casted in iron mould of size 400 mm X 400 mm X 50 mm. To show the texture of the concrete cylindrical specimens of size 100mm diameter and 200 mm height were casted and were cut by using mechanical cutter. All the specimens were casted into 3 equal layers and each layer was compacted for 25 times by the blow of a steel rod of diameter 16 mm followed by a vibration on a vibrating table for 1 min to remove air bubbles. After 24 hours, the specimens were demoulded. After that, the cement concrete specimens were cured in water reservoir at room temperature of 28^{O}C for 28 days and AAC specimens were cured at 60^{O}C in furnace for 2 days for thermal curing then AAC specimens were kept at room temperature of 29^{O}C for another 26 days.

During preparation of Sample for M30 grade AAC only GGBFS was used as binding material. In M20 grade and M25 grade AAC GGBFS and FA were used in a mix proportion of 80% : 20%. Photographs of the processes for preparation of AAC are shown by Photo 1 - 3.

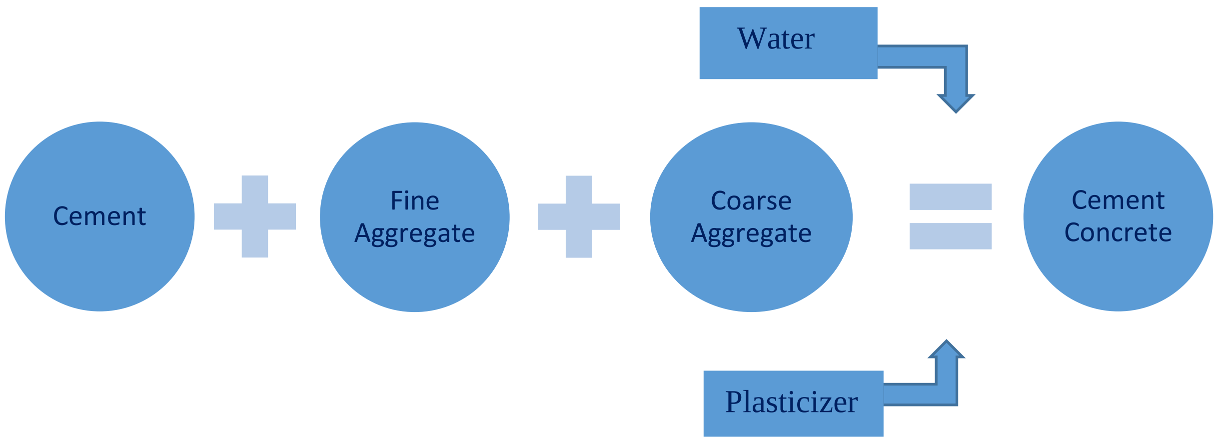


Fig. 1 Flowchart showing preparation of cement concrete (PCC)

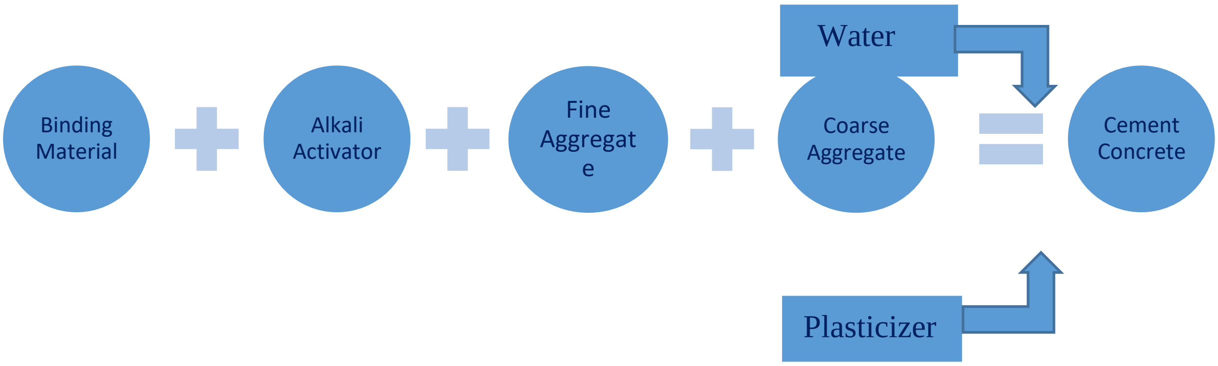


Fig. 2 Flowchart showing preparation of alkali activated concrete (AAC)

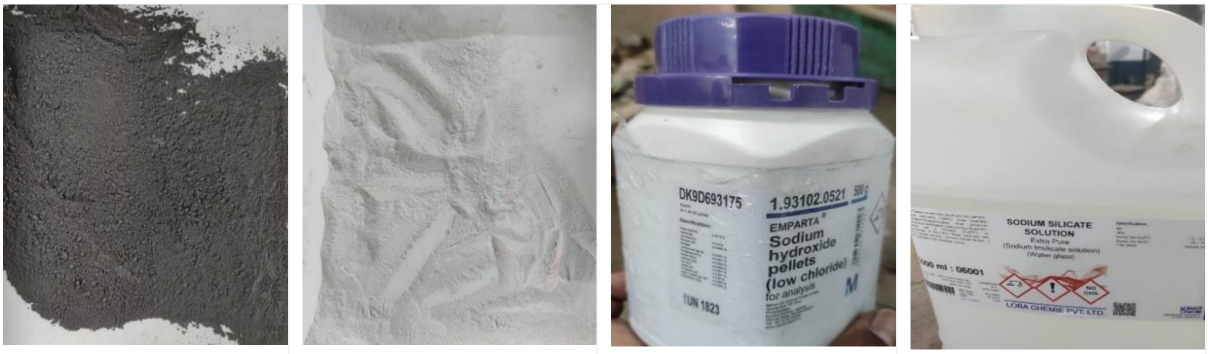


Photo 1. (a) **(b)** **(c)** **(d)**

Fig. 2(a) shows dry FA, (b) shows dry GGBFS, (c) shows NaOH pellets, (d) shows Na_2SiO_3 solution

Photo 2. (a) **(b)** **(c)** **(d)**

Photo 2(a) shows preparation of FA concrete, (b) shows moulding of FA concrete cube, (c) shows preparation of GGBFS concrete, (b) shows moulding of GGBFS concrete cube.

Photo 3. (a)	**(b)**

Photo 3(a) shows heat curing of AAC cube samples in oven at $60^{O}C$ (b) shows demoulding of concrete cubes

3.4 Testing Processes

At 28 days from the date of casting of specimens several tests were performed in the laboratory, on the specimens and the average value of 3 (three) specimens was taken as the result.

3.4.1 Water Absorption, Porosity and Bulk Density Test

The water absorption, porosity and bulk densities of the concrete specimens were determined as per ASTM C642-13 and calculated using Eqs. (1), (2) and (3).

Water Absorption (in %) (e) = $\frac{[Ws-Wds]}{Wds}$ x 100 ….(1)

Porosity (in %) (n) = $\frac{[Ws-Wds]}{\rho w \text{ x } Vs}$ x 100 ….(2)

Bulk Density (D) = $\frac{Ws}{Vs}$ ….(3)

where; W_{ds} = mass of oven dry concrete specimen in air (in g), W_s = mass of SSD specimen in air (in g), V_s = volume of SSD sample in air and ρ_w = Unit mass of water (in g/cc) and SSD = saturated surface dry conditioned.

Table 8: (Calculation of Void Ratio, Porosity and Bulk Density of PCC)

Type of Concrete	Grade of Concrete	Bulk Weight (W) (kg)	Wds (kg)	Ws (kg)	Ww (kg)	Void Ratio (e)	Porosity (n)	D (kg / cum)
PCC	M 20 -1	2.395	2.325	2.375	0.050	0.053	0.050	2395
	M 20 -2	2.380	2.275	2.335	0.060	0.064	0.060	2380
	M 20 -3	2.410	2.375	2.420	0.045	0.047	0.045	2410
	M 25 -1	2.440	2.385	2.425	0.040	0.042	0.040	2440
	M 25 -2	2.435	2.370	2.410	0.040	0.042	0.040	2435
	M 25 -3	2.395	2.290	2.350	0.060	0.064	0.060	2395
	M 30 -1	2.480	2.440	2.480	0.040	0.042	0.040	2480
	M 30 -2	2.465	2.435	2.465	0.030	0.031	0.030	2465
	M 30 -3	2.485	2.450	2.485	0.035	0.036	0.035	2485

Table 9: (Calculation of Void Ratio, Porosity and Bulk Density of AAC)

Type of Concrete	Grade of Concrete	Bulk Weight (W) (kg)	Wds (kg)	Ws (kg)	Ww (kg)	Void Ratio (e)	Porosity (n)	D (kg / cum)
AAC	M 20 -1	2.150	2.110	2.250	0.140	0.163	0.140	2150
	M 20 -2	2.205	2.160	2.295	0.135	0.156	0.135	2205
	M 20 -3	2.145	2.090	2.245	0.155	0.184	0.155	2145
	M 25 -1	2.120	2.090	2.260	0.170	0.205	0.170	2120
	M 25 -2	2.115	2.075	2.235	0.160	0.191	0.160	2115
	M 25 -3	2.110	2.075	2.230	0.155	0.184	0.155	2110
	M 30 -1	2.070	2.055	2.275	0.220	0.283	0.220	2070
	M 30 -2	2.105	2.085	2.280	0.195	0.243	0.195	2105
	M 30 -3	2.100	2.070	2.275	0.205	0.259	0.205	2100

3.4.2 Compressive Strength Test

Compressive strength (CS) of the cubical specimens were tested in conformity with IS: using digital compressive strength testing machine on 28 days from the date of casting of the specimens. The results are shown in Table 10 and Table 11. The photographs of compressive strength testing are shown by Photo 4.

Photo 4 (a)

Photo. 4 (b)

Photo. 4 (a) shows crushing of cube specimen (b) shows compressive Strength testing machine

Table 10: (Calculation of 28 day Crushing Strength of PCC)

Type of Concrete	Grade of Concrete	Peak Load (KN)	Cube Area (cm^2)	CS (N/mm^2 or Mpa)	Average CS (N/mm^2 or
PCC	M 20 -1	219.9	100.0	21.99	22.99
	M 20 -2	243.2	100.0	24.32	
	M 20 -3	226.5	100.0	22.65	
	M 25 -1	309.7	100.0	40.97	41.31
	M 25 -2	312.2	100.0	41.22	
	M 25 -3	317.4	100.0	41.74	
	M 30 -1	396.6	100.0	39.66	40.95
	M 30 -2	401.6	100.0	40.16	
	M 30 -3	430.3	100.0	43.03	

Table 11: (Calculation of 28 day Crushing Strength of AAC)

Type of Concrete	Grade of Concrete	Peak Load (KN)	Cube Area (cm^2)	CS (N/mm^2 or Mpa)	Average CS (N/mm^2 or Mpa)
AAC	M 20 -1 *	198.4	100.0	19.84	20.92
	M 20 -2 *	212.3	100.0	21.23	
	M 20 -3 *	216.8	100.0	21.68	
	M 25 -1 *	255.8	100.0	25.58	25.90
	M 25 -2 *	262.4	100.0	26.24	
	M 25 -3 *	258.8	100.0	25.88	
	M 30 -1 #	402.2	100.0	40.22	40.04
	M 30 -2 #	402.6	100.0	40.26	
	M 30 -3 #	396.4	100.0	39.64	

M30 grade AAC consists of only GGBFS. * M20 grade and M25 grade AAC consist of GGBFS and FA in proportion 80% : 20%.

3.4.3 Thermal Conductivity Test

For determination of thermal conductivity of concrete specimen using the Determination of steady-state thermal resistance method can be used with a heat insulating chamber, guarded hot plate apparatus etc. using stable heat source and thermocouples. For determination of acoustic properties of concrete specimen, ISO 10534-1 (standing wave ratio method) [44], ISO 10534-2 [45], ASTM E1050-12 (transfer function method for measurement of sound absorption coefficient, reflectance, acoustic impedance and admittance) [46] and ASTM E2611-09 (transient loss measurement) [47].

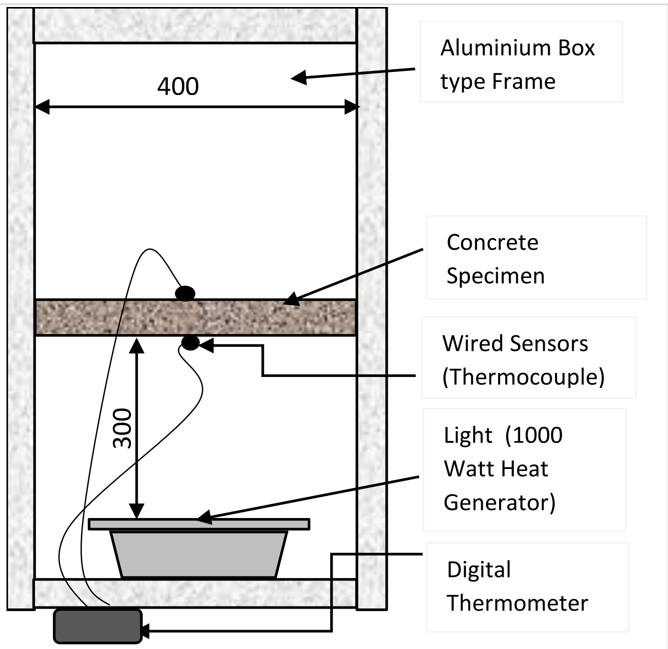


Fig. 3 shows setup for TC test

Thermal Conductivity (TC) testing for the samples were conducted by placing the prepared concrete block inside the test setup. A 1000-watt light source was placed over the specimen at a fixed height of 350 mm from the top surface of the specimen. The sensors for testing the TC of the specimen were fixed at the top and bottom surface of the specimen. The test setup containing sample was covered with insulator material by all sides including top and bottom. Temperature of the vacant space within the top surface of the sample and the light source is raised to a fixed temperature of 60^{O}C with the help of the 1000-watt power source by switching it on for some time. The cut off temperature was set to 60^{O}C. Simple method for thermal conductivity determination in laboratory is used. This method is based on temperature difference measurement between two surfaces of specimen when one of surfaces is heated.

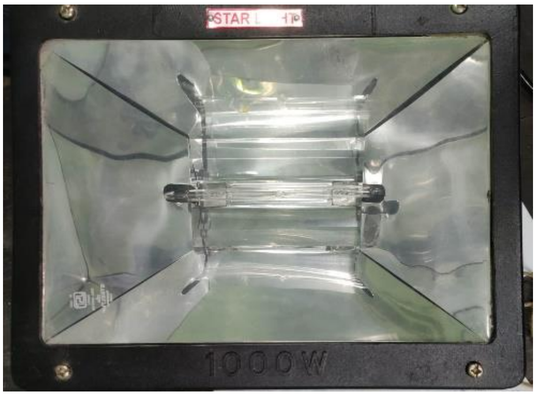


Photo 5 (a)

Photo. 5 (b)

Photo. 5 (c)

Photo. 5 (d)

Fig 5 (a) shows 1000 W heat source (b) shows thermal meter and thermocouples (c) sample initial reading (d) shows heat flux meter.

The temperature readings that were found by the sensors fixed at the top and bottom of the sample were recorded by to find the temperature loss between the top and bottom surface of the particular concrete sample. [16] Heat flux at the light face of the specimen (Q/ A, in watt / sqm) is measured using solar power meter.

The formula that was used for calculation of the TC (λ) of concrete specimens in the laboratory is given in formula (4).

$$\lambda = \frac{Q}{A} \cdot \frac{\Delta X}{\Delta T} \qquad \text{....(4)}$$

This formula can be used for unidirectional heat flow (energy), where Q is rate of energy, A is area of heating surface, ΔX is distance between points of temperature measurement i.e the thickness of the samples since the thermocouples are fixed at the two end surfaces of each specimen and ΔT is temperature difference.

For thermal test experiment is carried out in a heat insulating chamber with tightly placed concrete specimen of size 400 x 400 x 50 mm size. Heat is generated from 1000 watt light source, placed at the bottom. The distance between top of light source and the bottom face of the specimen is kept as 300 mm. the ambient temperature has been recorded as 28^{O}C before commencement of the test. Emissivity of the halogen light glass and concrete specimen is assumed as 0.85. Stefan-Boltzmann constant is used as 5.67×10^{-8} W/m^2K^4. The radiation heat flux density is estimated to equal as 133.63 kW/m^2. Temperatures are measured at every minute.

3.4.4 Sound Absorption Coefficient Test

Sound Absorption Coefficient (SAC) testing for the samples were conducted by placing the prepared concrete block inside the test setup. A speaker (microphone) was placed over the specimen at a fixed height of 350 mm from the top surface of the specimen to generate sound wave. The apparatus for testing the flow of sound intensity through the specimen were placed at the top and bottom surface of the specimen simultaneously. The test setup containing sample was covered with insulator material by all sides including top and bottom. The sound intensity readings in 3rd Octave band were recorded by the Picolo II instrument / apparatus by placing the instrument at the top and bottom of the sample simultaneously. [13]

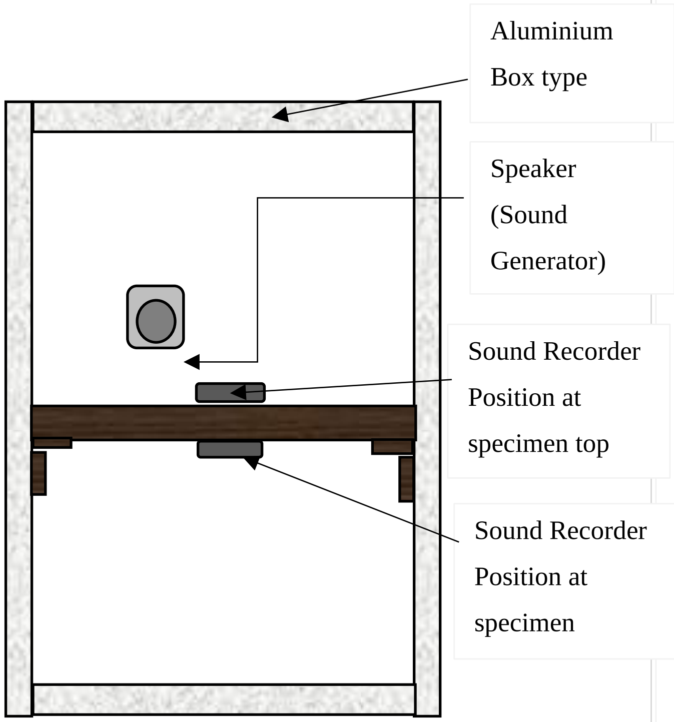


Fig. 4 shows setup for SAC

Sound waves were recorded at one minute time frame by playing the sound waves continuously for one minute. in **L_{eq}** (Equivalent continuous sound level) form, which denotes the steady sound pressure level which, has the same total energy as the actual fluctuating noise a steady flow of sound energy within a given period of time. The formula was used for calculation of the SAC (α) of concrete samples in the laboratory is given in formula (5).

$$SAC(\alpha) = \frac{Absorbed\ Sound\ Energy\ (Ea)}{Incident\ Sound\ Energy\ (Ei)} = \frac{Incident\ Sound\ Energy\ (Ea) - Residual\ Sound\ Energy\ (Er)}{Incident\ Sound\ Energy\ (Ei)} \quad (5)$$

	
Photo. 6 (a)	**Photo. 6 (b)**

Photo. 6 (a) shows recording of sound generated by microphone and 6 (b) shows sound pressure meter

From these readings the difference between sound intensities between the top and bottom surface of the specific concrete sample and the SAC of the concrete specimen was calculated.

Chapter 4

4.0 Results and Discussions

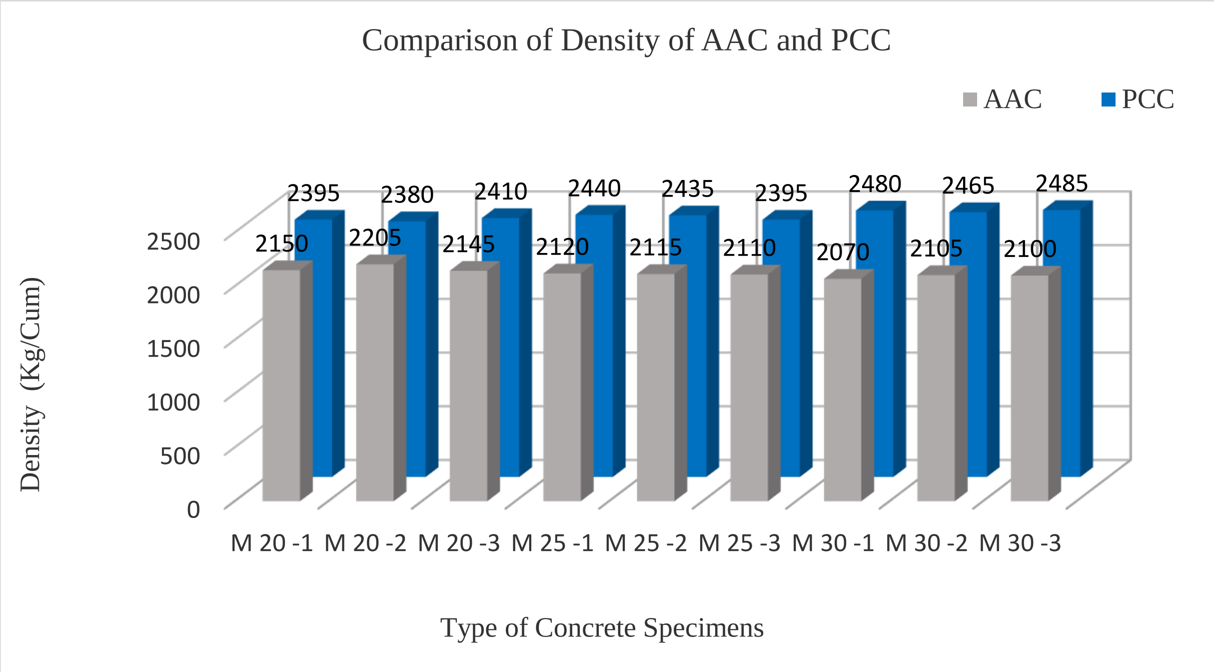


Fig 5 shows the comparison of BD between PCC and AAC

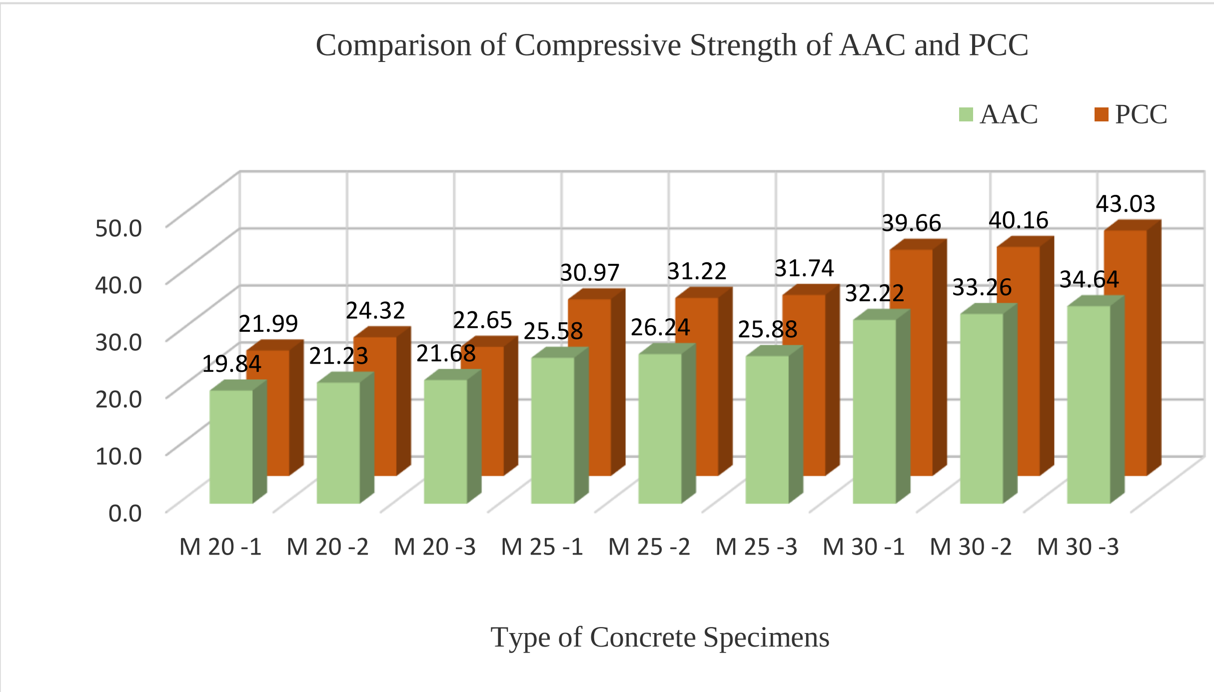


Fig. 6 shows the comparison of void ratio (in %) between PCC and AAC

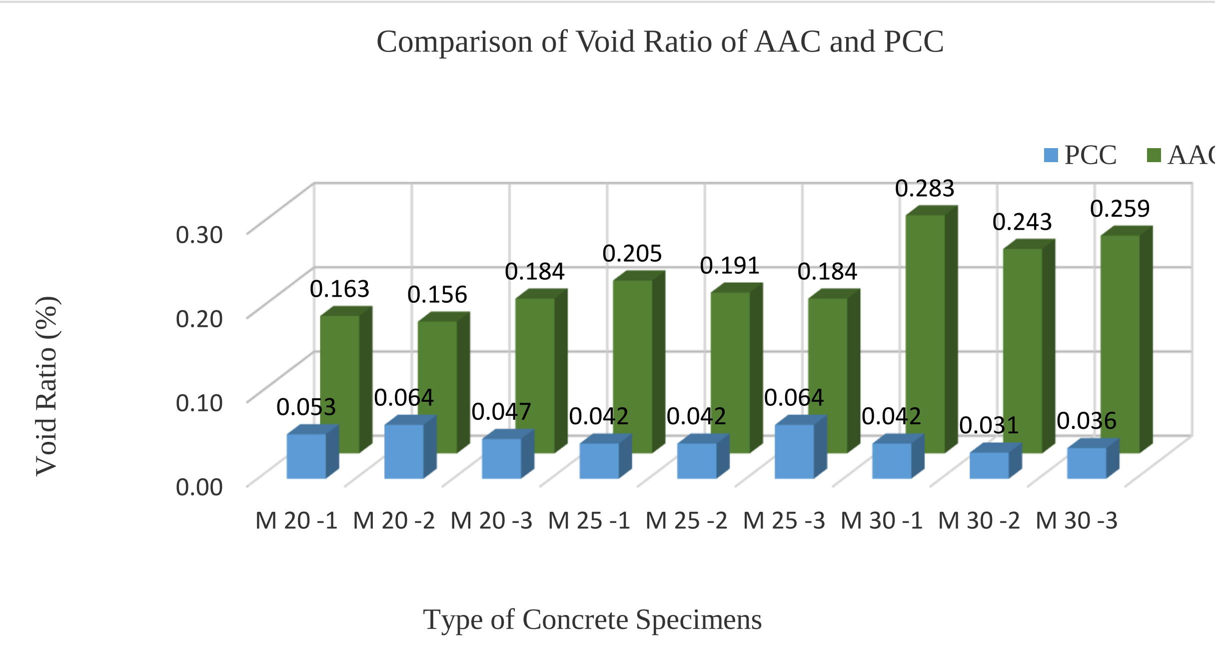
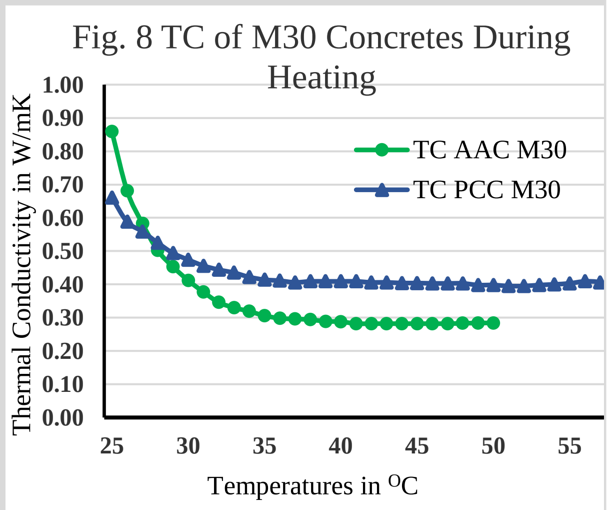


Fig. 7 shows the comparison of CS between PCC and AAC



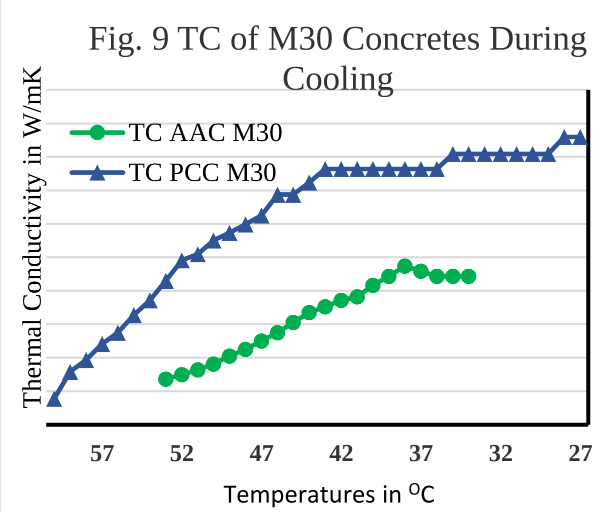


Fig. 8 & 9 show comparison of TC between PCC and AAC during heating and cooling respectively for M30 grade of concretes

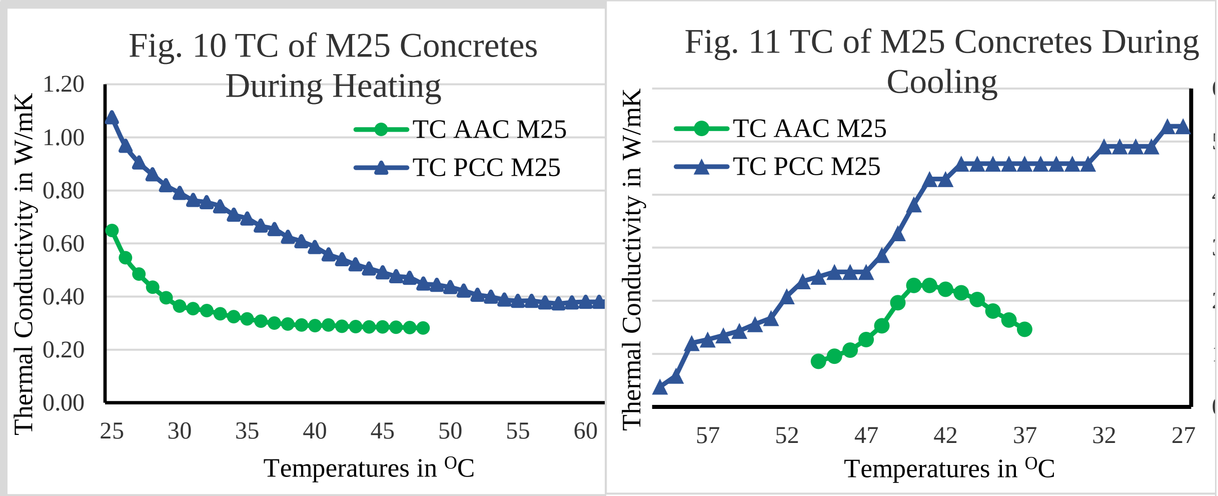


Fig. 10 & 11 show comparison of TC between PCC and AAC during heating and cooling respectively for M25 grade of concretes

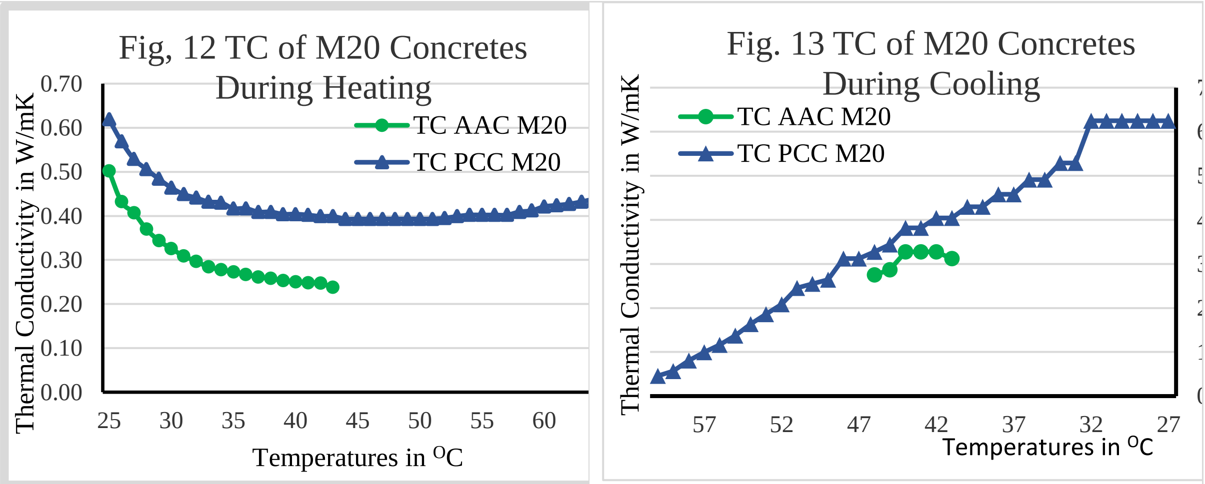
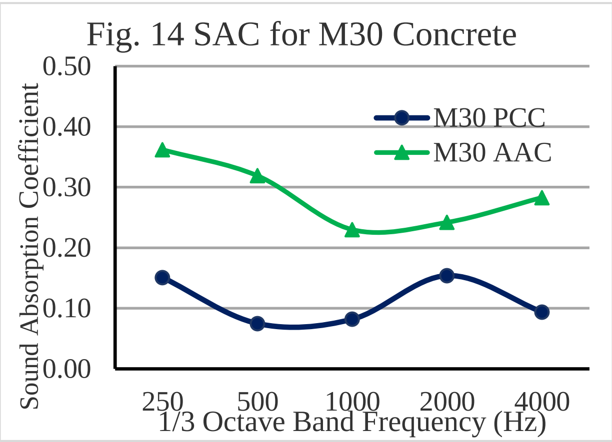
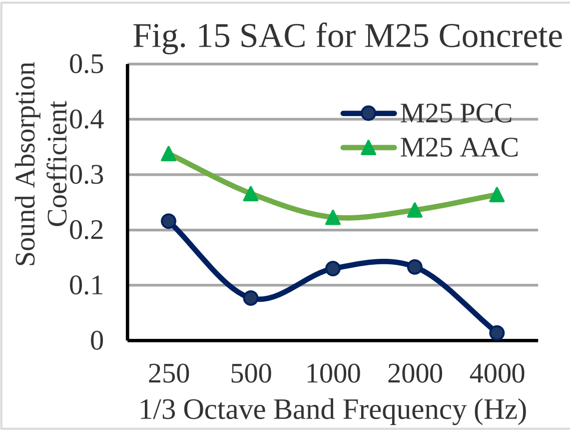
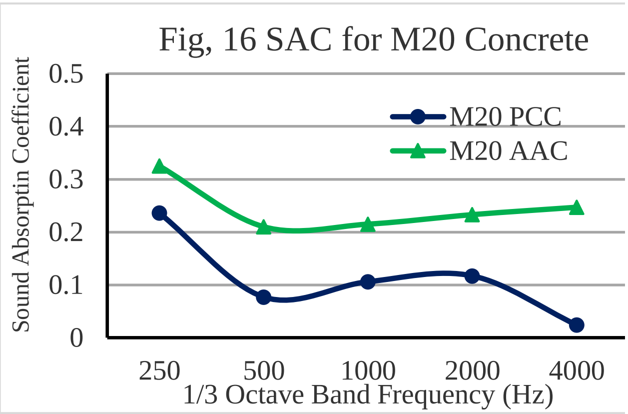


Fig. 12 & 13 show comparison of TC between PCC and AAC during heating and cooling respectively for M20 grade of concretes

Generally, smaller TC indicates better thermal insulation. Insulators require low TC because they reduce the conduction of heat whereas concrete requires a high TC as this high TC in concrete reduces the expansion stresses within concrete material which was reported by Van Riessen et al. (2009) [48]. In the research of K.-H. Kim et al. (2003) [17], it has been reported that the TC of concrete is dependent on the aggregate volume fraction, moisture content, water-cement ratio, temperature and humidity. In this study the average TC values of PCC have been found within range of 1.396 -2.005 W/mK. The results are comparable to the previous researches. These values are observed closer to the study of Yun et al. (2013) [24], where it was found as 2.25 W/mk for PCC samples without increasing the void. Lu et al. (2014) showed the TC values in the range of 1.79 – 2.31 W/mK with respect to change in fly ash (FA) content [34]. The results are also comparable to the results of the study of Asadi et al. (2018) [6] where, the TC of normal weight concrete (NWC) was reported within a range of 0.6–3.3 W/mK. The TC has been found increased with the in porosity in case of PCC specimens, which satisfies the study of Gourlay et al. (2017) [23], Belkharchouche et al. (2016) [22]. Maximum porosity is found as 0.035 in M20 grade PCC and corresponding value of TC is found as 2.647 W/mK. The porosity has been found minimum with value of 0.035 in M30 grade PCC and corresponding value of TC is found as 1.843 W/mK. But in case of AAC opposite relations are found in this study. Maximum porosity is found as 0.207 in M30 grade PCC and corresponding value of TC is found as 0.843 W/mK. The porosity has been found minimum with value of 0.144 in M20 grade PCC and corresponding value of TC is found as 0.998 W/mK. The average TC values of M30 grade AAC have been found as 0.843 W/mK. This value is very much similar to the result of the study of Oyebisi et al. (2022) [49] where the TC was found as 0.92 W/mK for M30 grade AAC. In this study the average TC values of AAC have been found within range of 0.763 -0.998 W/mK as shown in Fig. 8-13. The results are comparable to the previous researches comparable to the results of the study of Asadi et al. (2018) [6] where, the TC of light weight concrete (LWC) was reported within a range of 0.2–1.9 W/mK. Wongkvanklom et al. (2021) [50] also found the TC of AAC with no foam content, as 1.62 W/mK. The CS values of AAC and PCC samples have been found decreasing with decrease in BD in light of the research paper of Tasdemir et al. (2017) [7] In case of AAC the BD and CS values for M30 and M20 grade concrete are found as 2477 kg/m^3, 2395 kg/m^3, 33.37 Mpa and 20.92 Mpa respectively. In case of PCC the corresponding values are observed as 2092 kg/m^3, 2167 kg/m^3, 40.95 Mpa and 22.99 Mpa respectively. The CS values are found to be better for all grades of concrete in PPC in comparison to the AAC samples. Increase in porosity cause the reduction in TC of the samples in case of AAC. Reduction in TC provide better thermal insulation but decrease the TC as well. Belkharchouche et al. (2016) [22]. Sound insulation of concrete can be ascertained by analyzing the of sound transmission loss (STL) in concrete. Generally, materials with a large volume of voids inside the concrete exhibit better STL because the existence of voids inside causes sound energy to reflect within them and convert into other forms of energy. Uthaichotirat et al. (2020) reported that, at low frequencies, the STL is normally low because the sounds have better penetration. It signifies that, they can pass through objects at low frequencies [15]. Analysis of sound absorption coefficient (SAC) can also check the penetration of sound through a material.







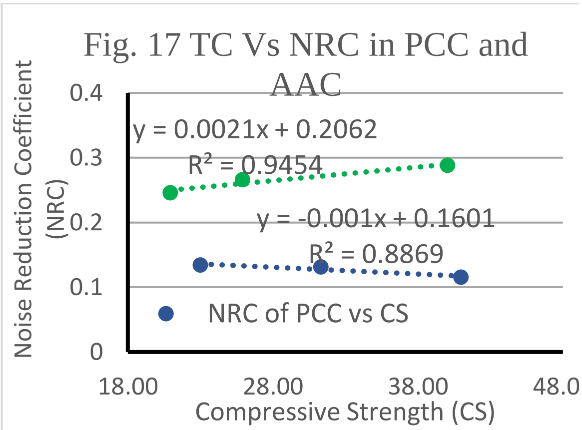


Fig. 14, 15 & 16 show comparison of SAC between PCC and AAC for M30, M25 and M20 grade of concretes and Fig. 17 shows comparison of NRC w.r.t CS in PCC and AAC

the acceptance criteria of concrete in regard to the sound insulation point of view. Amran et al. (2021) observed that the SAC of normal concrete was in the range of 0.05 – 0.10, whereas the SAC of polymer concrete lied within 0.90-1.00 [12]. This study also reported that, geopolymer concrete (GPC), activated with hydroxide, had more SAC value than PCC due to more porosity. Mastali et al. (2018) showed that fibre reinforced alkali activated slag foam concrete can have a SAC of 0.99 [51]. In the study of H. Kim, et al. (2018), it was reported that the SAC with zero value indicate sound reflecting concrete, whereas the SAC value of 1 (one) indicated perfect sound absorbable concrete. The literature also reported that the SAC of normal concrete lied within 0.05 – 0.10 and peak in SAC depends on higher void ratio [37]. Flores Medina et al. (2016) reported that the inclusion of crumb rubber (CR) to increase porosity of concrete decreased the CS but increased the noise reduction coefficient. The concrete with no CR content showed the CS as 47.78 Mpa and NRC as 0.035, but adding 60% CR reduced the CS to 17.71 Mpa and increased the NRC to 0.057 [13]. Mahmoud et al. (2023) observed a peak in SAC around 950 Hz for PCC and around 800 Hz for GPC with dolomite content [36]. Oancea et al. (2018) reported that AAC has more SAC value than PCC leading to better sound absorption in AAC. Increase in thickness of sample increased the SAC and a peak was found near 1000 Hz in this study [38]. In our study SAC in case of PCC SAC values have been found within 0.075 - 0.154, 0.014 – 0.216 and 0.024 – 0.236 for M30, M25 and M25 grade of concretes respectively. In case of AAC concrete these values are found as 0.23-0.362, 0.210 – 0.325 and 0.223 – 0.338 for M30, M25 and M25 grade of concretes respectively. The SAC values, found in PCC are almost in line of the results from the study of Amran et al. (2021) [12]. The SAC values, found in AAC are more than that of the SA values found in case of PCC which is in line of the result of the study of Oancea et al. (2018) [38]. But, these values of SAC can be increased more with use of different admixture to increase porosity in concretes. We have found a valley near 500 Hz. similarly in line of the study of Oancea et al. (2018) In case of PCC a peak has been observed near 2000 Hz and in case of AAC near 4000 Hz. [38]. These results have been found slightly differed from previous researches. The NRC values are calculated as 0.116, 0.139 and 0.134 in case of PCC specimens of grade M30, M25 and M20 respectively and 0.288, 0.266 and 0.246 for AAC specimens of grade M30, M25 and M20 respectively. The calculated NRC values in this paper for PCC specimens are found higher than the NRC value of 0.035, which was reported in the literature of Flores Medina et al. (2016) for reference concrete with no rubber content [13].

Fig. 18 TC Vs SAC at 250 Hz Sound Source for PCC

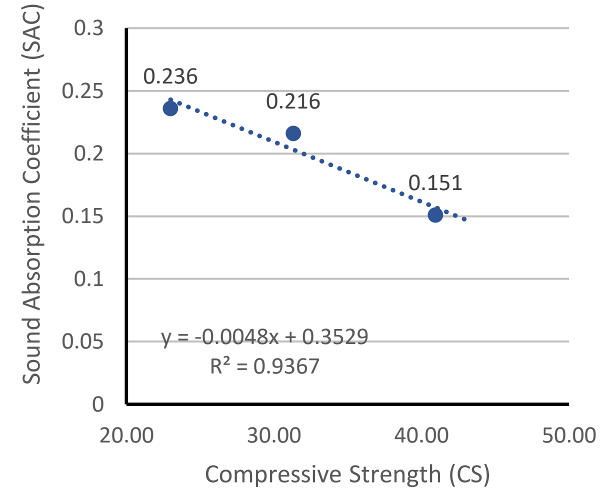


Fig. 19 TC Vs SAC at 250 Hz Sound Source for AAC

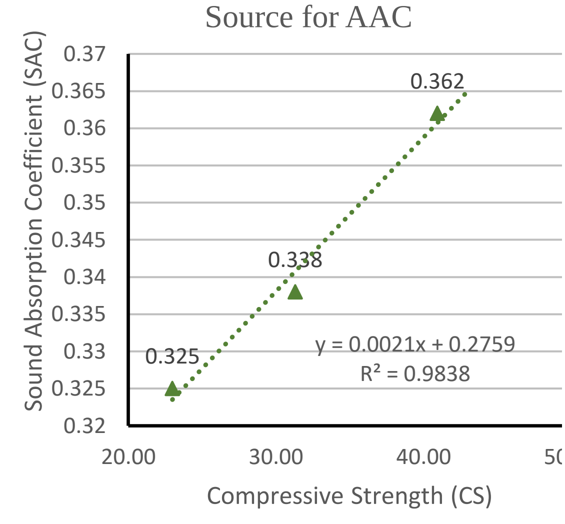


Fig. 20 TC Vs SAC at 500 Hz Sound Source for PCC

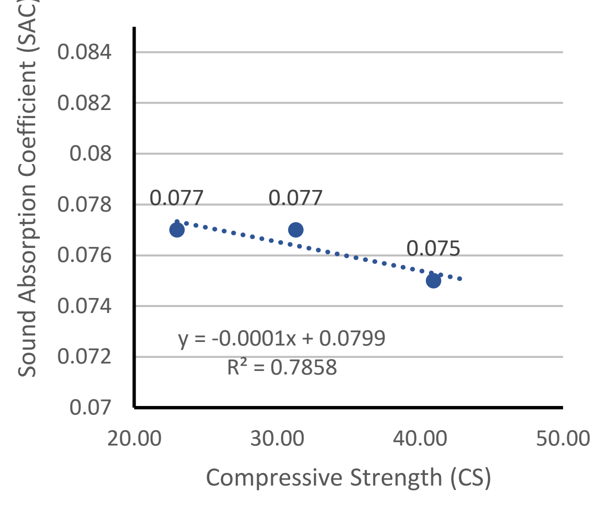


Fig. 21 TC Vs SAC at 500 Hz Sound Source for AAC

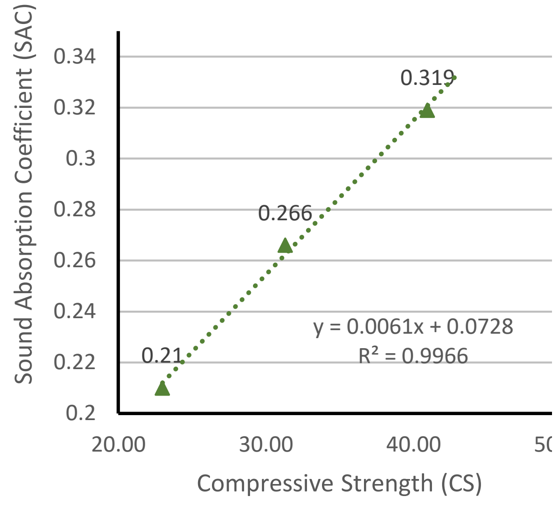


Fig. 22 TC Vs SAC at 1000 Hz Sound Source for PCC

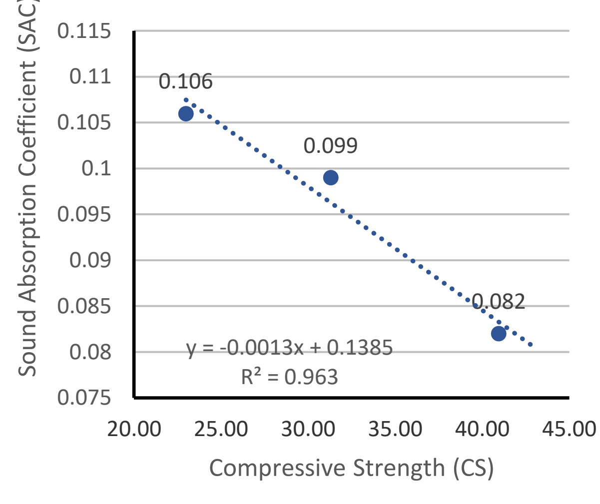
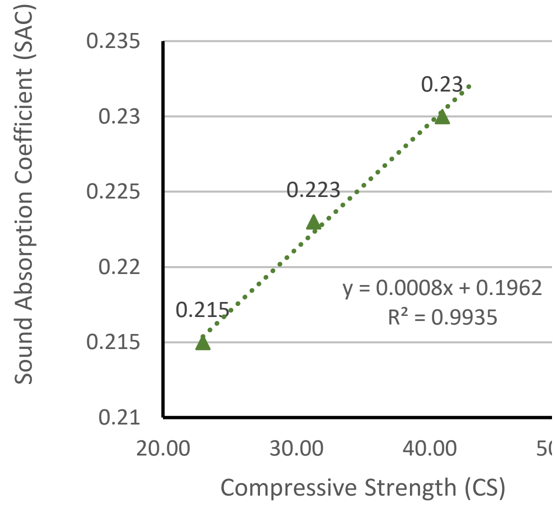


Fig. 23 TC Vs SAC at 1000 Hz Sound Source for AAC



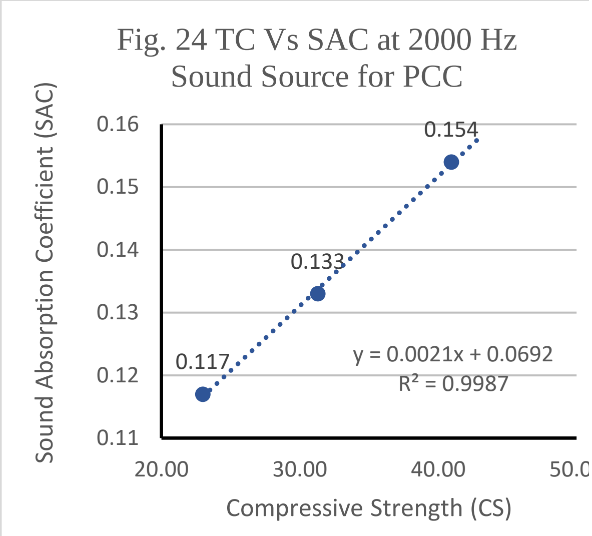


Fig. 24 TC Vs SAC at 2000 Hz Sound Source for PCC

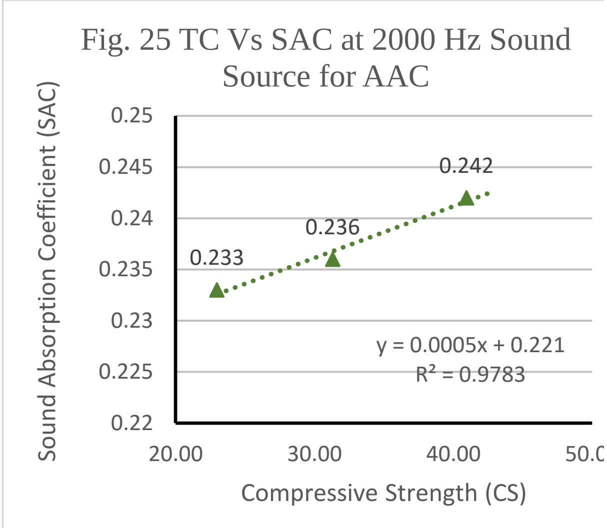


Fig. 25 TC Vs SAC at 2000 Hz Sound Source for AAC

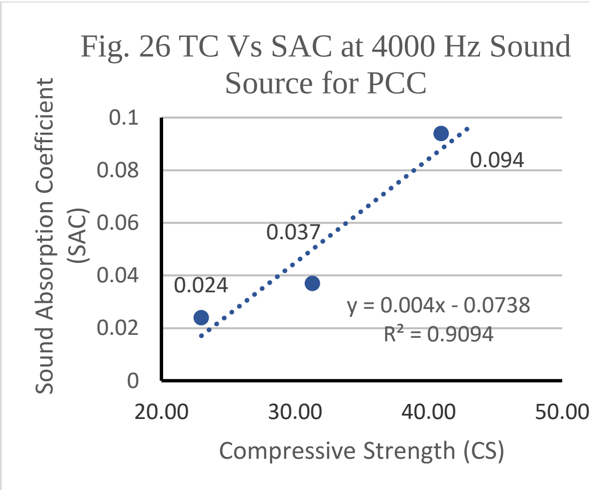


Fig. 26 TC Vs SAC at 4000 Hz Sound Source for PCC

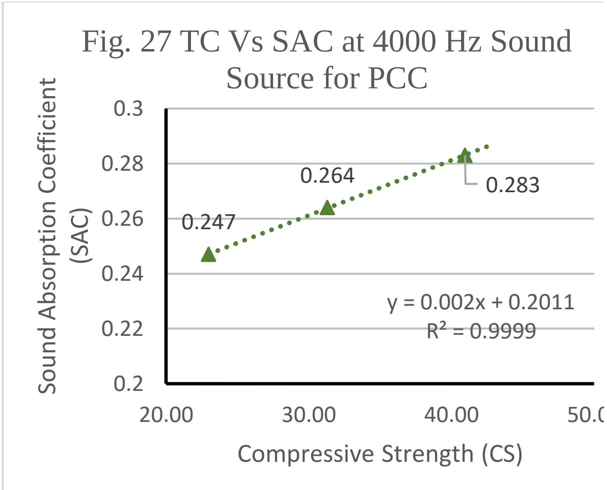


Fig. 27 TC Vs SAC at 4000 Hz Sound Source for PCC

Fig. 17 to 26 shows the SAC values recorded for PCC and AAC specimens at different sound pressure levels.

Chapter 5

5.0 Conclusion

5.1 General

In the present study, an attempt has been made to enlighten and determine the changes in thermal conductivity (TC) and the sound / acoustic absorption coefficient (SAC) of cement concrete (PCC) and alkali activated concrete (AAC) with different strength in accordance with IS: 456 :2000 and IS: 17452 :2020. The main focus of this study is to prepare different types of concrete which will be suitable and effective for using as the structural concrete with effective TC and SAC maintaining minimum compressive strength.

5.2 Major Findings

- Test result shows that TC has reduced value in case of AAC than that of in PCC. This is probably due to presence of more voids in AAC. Higher void causes more air in the sample. Air has less TC than the concrete materials. For this reason, TC has reduced in AAC.
- Average void ratio (in %) are yielded as 0.055, 0.049 and 0.036 for grades M20, M25 and M30 respectively in case of PCC and 0.168, 0.193 and 0.261 for grades M20, M25 and M30 respectively in case of AAC
- The TC of concrete has been found to be dependent on the grade of concrete. Higher grade of concrete has higher TC values. This happens since, density of concrete increases with increase in grade of concrete causing presence of lower porosity and voids.
- Average densities (BD) are evaluated as 2395, 2423 and 2477 kg/m^3 for grades M20, M25 and M30 respectively in case of PCC and 2167, 2115 and 2092 kg/m^3 for grades M20, M25 and M30 respectively in case of AAC
- TC varies with the increasing thickness of the sample.

- Average TC values in case of AAC samples are found as 0.843, 0.763 and 0.998 W/mK for M30, M25 and M20 grade concretes respectively. These values are lower than the values found in PCC samples.
- Average TC values in case of PCC sample are observed as 1.843, 2.132 and 2.647 W/mK for M30, M25 and M20 grade concretes respectively.
- The TC values of AAC show that these concretes can be used as replacement of PCC towards energy efficiency as well as for less environmental impact consideration.
- CS values found in case of PCC are found with comparatively better values than that of in case of AAC. But, all types of concrete in this study have achieved the target strength. Again, in AAC CS values have been found to be higher when only GGBFS is used in place of combination of GGBFS and FA.
- The concretes prepared in this study show that the strengths of these concretes are more than the minimum strength (17.0 Mpa) requirement for structural concretes in conformity to ASTM C 330/C 330 M (2014) [52] and ACI 213R03 (2003) [53] for structural light weight aggregate concrete for a curing age of 28 days. Hence these concretes can be used in structural works.
- In M20 grade of concrete, sudden rise in sound absorption coefficients (SAC) values are seen near 500 Hz frequency. Similar rise in case of M25 and M30 graded concretes are seen near 2000 Hz sound frequency. It may be due to
- SAC values for PCC and AAC show almost same value in M20 grade of concrete in all frequency ranges. But, in M25 and M30 grade concretes AAC shows better SAC value than PCC near 1000 Hz frequency.
- Maximum SAC values are found as 0.211, 0.169 and 0.151 in case of PCC of grades M20, M25 and M30 respectively.

- Maximum SAC values are yielded as 0.269, 0.223 and 0.219 in case of AAC of grades M20, M25 and M30 respectively.
- NRC values are obtained as 0.246, 0.266 and 0.288 in case of AAC of grades M20, M25 and M30 respectively.
- NRC values are obtained as 0.134, 0.131 and 0.116 in case of PCC of grades M20, M25 and M30 respectively.
- This study has tried to prepare PCC and AAC which may have significantly low TC and high SAC values maintaining its minimum CS values for individual grades, so that these concretes can be used as structural concrete in accordance with energy efficiency and comfort towards habitable environment.

5.3 Limitations

The scope of study was limited to produce concretes which would have effective TC and CS and also would achieve the target compressive strength. Only a limited number of specimens in this study have been prepared and tested, which may be improved in further works.

5.4 Future Scope

This work may further be extended by preparation of a greater number of specimens with modification of ingredients. A large number of tests should have to be carried out with modernized equipment and setup towards production of energy efficient concrete for the benefit of the mankind.

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