

**STUDY ON FLEXURAL BEHAVIOUR OF LIGHTWEIGHT
CONCRETE BEAM BY PARTIAL REPLACEMENT OF CRUSHED
AUTOCLAVED AERATED CONCRETE (AAC) BLOCK AS COARSE
AGGREGATE**

Submitted in partial fulfillment of the requirements of the award of

Master of Engineering Degree in Structural Engineering

by

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**DEPARTMENT OF CIVIL ENGINEERING
SCHOOL OF BUILDING AND ENVIRONMENT**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with Grade "A" by NAAC

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **AYYAPPAN R (41380003)** who carried out the project entitled "**STUDY ON FLEXURAL BEHAVIOUR OF LIGHTWEIGHT CONCRETE BEAM BY PARTIAL REPLACEMENT OF CRUSHED AUTOCLAVED AERATED CONCRETE (AAC) BLOCK AS COARSE AGGREGATE**" under my supervision from August 2022 to May 2023.

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Submitted for the Viva-voce Examination held on

05/05/2023

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DECLARATION

I, **AYYAPPAN R (41380003)** hereby declare that the Project Report entitled **“STUDY ON FLEXURAL BEHAVIOUR OF LIGHTWEIGHT CONCRETE BEAM BY PARTIAL REPLACEMENT OF CRUSHED AUTOCLAVED AERATED CONCRETE (AAC) BLOCK AS COARSE AGGREGATE”** done by me under the guidance of **Dr. R. Nirmala** at **SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY** is submitted in partial fulfillment of the requirements for the award of Master of Engineering Degree in Structural Engineering.

DATE: 05-05-2023

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SIGNATURE OF THE CANDIDATE

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ABSTRACT

The construction industry has seen a significant improvement in construction techniques over the years due to an increase in demand for construction materials. Traditional methods of constructing structures were heavy and expensive due to high loading, but recent construction methods have shifted to lightweight materials to minimize cost and weight. Autoclaved Aerated Concrete (AAC) Blocks have gained popularity as a recently adopted lightweight construction material. However, the extensive usage of AAC Blocks has also led to a considerable increase in wastage. To address this issue, a study was conducted to compare the compressive strength and split tensile strength of nominal and lightweight concrete made from crushed AAC Blocks with different percentages of replacement (0%, 5%, 10%, and 15%) at 7, 14, and 28 days of curing. The results were compared to determine the optimal replacement percentage. The study also involved modelling and analysing a reinforced concrete beam using the finite element analysis software ANSYS. The beam was cast using both nominal and lightweight concrete, and its strength was tested using a loading frame with a hydraulic jack at one-third span from each support. The experimental results of the reinforced lightweight concrete beams were compared with the analysis results. Microscopic images of conventional and lightweight concrete with 10% replacement were captured using Scanning Electronic Microscope Tomography (SEM). The images were analysed to identify the hydration process of both concrete samples. According to the results of the compressive strength and split tensile strength tests, the lightweight concrete with 10% replacement exhibited a slight decrease in strength, with a decrease of about 5% in compressive strength and 21% in split tensile strength, when compared to conventional concrete. Additionally, the flexural behaviour of the beams showed that the 10% replacement resulted in a considerable decrease in deflection when compared to all other types of concrete.

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LIST OF ABBREVIATIONS

AAC	Autoclaved Aerated Concrete
C-AACB	Crushed Autoclaved Aerated Concrete Block
LWC	Lightweight Concrete
LWRC	Lightweight Reinforced Concrete
CC	Conventional Concrete
CRC	Conventional Reinforced Concrete
SEM	Scanning Electronic Microscopic Topography
FE-SEM	Field Emission Scanning Electronic Microscopic Topography
FEA	Finite Element Analysis
SCC	Self-Compacting Concrete
PCLWAC	Partially Compacted Lightweight Aggregate Concrete
SLWAC	Structural Lightweight Aggregate Concrete
LWAC	Lightweight Aggregate Concrete
AC	Aerated Concrete
SCLC	Self-Compacting Lightweight Concrete
C-S-H	Calcium Silicate Hydrogen
HPLWC	High-Performance Lightweight Concretes
SFRC	Steel Fiber Reinforced Concrete
RC	Reinforced Concrete
PLA	Pumice Lightweight Aggregate
EPS	Expanded Polystyrene Beads
LCMB	Lightweight Concrete Masonry Blocks
GP	Glass Powder
SCBA	Sugarcane Bagasse Ash
GFRP	Glass Fiber Reinforced Polymer
WPGA	Waste Polystyrol Glass Aggregate

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Concrete is a building substance that is composed of cement, sand (fine aggregate), gravel or crushed stone (coarse aggregate), chemical admixture and water. Once mixed, the concrete sets and becomes rigid, with Portland cement serving as the primary binder that holds together the coarse and fine aggregates. This results in a composite material that resembles synthetic stone, offering the added benefit of being easily shaped into intricate forms, something natural stone cannot always accommodate.

Concrete is one of the most widely used construction materials in the world and is the second most consumable product after water. Sometimes, a few fields need to use concrete with one or more of its properties to be enhanced. So, a special type of concrete is needed. There are several special concretes are introduced and created over the span of a few centuries. Some of the special concrete which is continually developed even today are bacterial concrete, reactive powder concrete, geo-polymer concrete, lightweight concrete, etc....

1.2 LIGHTWEIGHT CONCRETE

Lightweight concrete has a history that can be traced back more than two millennia and its technological progress is still ongoing. Even though lightweight concrete has been widely utilized and has demonstrated its technical capabilities in numerous applications, despite the passage of many years, there still exist uncertainties and doubts regarding its practical applications. In light of this, the characteristics of lightweight aggregates and various forms of lightweight concrete are widely discussed, with a specific focus on existing norms and guidelines.

Lightweight concrete is a type of concrete that incorporates an expansive component, which expands the mixture's volume while decreasing its weight or density. When lightweight concrete is placed on walls, the presence of large voids prevents the formation of laitance layers or cement films. This study focused on the

performance of LWC using Crushed Autoclaved Aerated Concrete blocks as a coarse aggregate. However, it is crucial to have a sufficient water-cement ratio to ensure adequate cohesion between cement and water. If the water content is not enough, it may cause a decrease in the bonding among the concrete particles, which can ultimately lead to a reduction in the strength of the concrete. Conversely, excessive water may cause the cement to run off the aggregate and form laitance layers, which can weaken the concrete's strength.

LWC is characterized by its significantly lower dry density, ranging from 300 kg/m³ to 1840 kg/m³, which translates to a weight reduction of 87% to 23% compared to conventional concrete. Its origins date back to the second century when the Romans used pumice as the primary aggregate in constructing 'The Pantheon'. As time passed, the application of lightweight concrete gradually expanded to other nations, such as the United States, United Kingdom, Sweden. LWC is widely recognized for its remarkable characteristics of having low density and thermal conductivity. The benefits include reduced dead load, faster construction times, and lower transportation and handling costs, which makes it an economically advantageous alternative in concrete construction that utilizes lighter materials.

LWC can be produced utilizing either natural or artificial aggregates like perlite, cinder, expanded shale, volcanic ash, and lightweight sintered fly ash aggregate. Crushed AAC block, which has high porosity and low specific gravity, is commonly used as a coarse aggregate in structural lightweight aggregate concrete. There are two types of lightweight aggregate concrete: partially compacted lightweight aggregate concrete (PCLWAC) and structural lightweight aggregate concrete (SLWAC). PCLWAC is primarily utilized for manufacturing precast concrete blocks or panels, as well as constructing cast-in-situ roofs and walls. To achieve the best thermal insulation and avoid cracking, PCLWAC should have adequate strength, low density, and low drying shrinkage.

SLWAC is a type of concrete that is fully compacted and has similar characteristics to those of normal reinforced concrete made with dense aggregate. Steel reinforcement can be used with SLWAC to create a strong bond between the steel and the concrete, and the concrete should provide sufficient protection against steel

corrosion. Nonetheless, the configuration and consistency of the aggregate fragments, along with the coarse texture of the fine aggregate, can produce a rugged mixture for SLWAC. Only the heavier types of lightweight aggregate are appropriate for use in building concrete.

1.2.1 Types of Lightweight Concrete

Based on the usage of the material, LWC classified into 3 types they are,

- The primary method of producing LWC is by completely removing the fine aggregate from the mix, which is referred to as no-fines concrete.
- Foamed or cellular concrete is the second most frequently used technique for producing lightweight concrete. It is also known as aerated, gas, or foam concrete.
- The third type of classification consists of Lightweight aggregate concrete .

Lightweight aggregate can be divided into two categories:

- Natural lightweight aggregates occur naturally and require only mechanical treatment, such as crushing and sieving, to be ready for use.
- Artificial lightweight aggregates are manufactured by subjecting naturally occurring materials or industrial by-products to thermal treatment.

1.2.1.1 No – fines Aggregate

No-Fines Concrete is a kind of lightweight concrete that omits fine aggregates or sand from the mixture, while it consists of coarse aggregate, cement, and water. The coarse aggregate used in this concrete is usually of a single size, passing through 20 mm and retained on 10mm. This concrete is gaining popularity due to its unique advantages over traditional concrete, such as being lightweight and architecturally attractive. However, there are also some limitations to using no-fines concrete that should be taken into consideration. The proper mix proportions for this type of concrete are also discussed in detail.

1.2.1.2 Lightweight Aggregate Concrete

Lightweight aggregate, which refers to a low-density coarse aggregate, is commonly employed in the production of lightweight concrete items such as structural concrete, pavement, and concrete blocks. The morphology of the

lightweight aggregate, whether it is angular, cubical, rounded, or otherwise, can significantly affect the workability of the concrete mixture. The building sector necessitates achieving a compressive strength of 3000-5000 psi to design precast, cast-in-place, or pre-stressed concrete. This objective can be conveniently accomplished using LWAC. The density of lightweight concrete relies on various factors such as mix proportion, air content, water demand, density, and moisture content of the lightweight aggregate. Structural concrete density can be effortlessly attained using lightweight aggregate concrete, which soaks up minimal water and has a low density, either similar to or lower than normal concrete. In comparison to other concrete types, the LWAC, structural lightweight concrete walls, slabs, and beams have an increased fire-resistance period. Table 1.1 presents the different materials used as a lightweight aggregate.

Table 1.1: Different Materials Used as Lightweight Aggregate

S.NO	Coarse Aggregate	Fine Aggregate
1	Clinker	EPS Beads
2	Sintered	Sintered Pulverized ash
3	Foamed Slag	Aluminium
4	Expanded Clays and Slag	Scoria
5	Expanded Slate	Leca
6	Pumice	Aglite
7	Palm oil Shell	Lytag
8	Diatomite	Foamed Slag
9	Wood Particles	Expanded Shale
10	Expanded Perlite	Expanded Glass
11	Expanded Vermiculite	Brick Bats
12	Brick Bats	Liapor
13	Coconut Shell	Fly Ash
14	scoria	
15	Ceramic Tiles	
16	Perlite	

1.2.2 Applications of Lightweight Concrete

- Lightweight concrete is commonly used in the construction of high-rise buildings.
- Decreases the weight of the concrete structure.
- Structural analysis allows for the downsizing of column and footing dimensions.
- Lightweight concrete exhibits a higher strength-to-weight ratio in structural components, which makes it a more efficient option.
- Suitable for various applications such as balconies, floors, and walls.

1.3 AUTOCLAVED AERATED CONCRETE

Traditional bricks have been the predominant building material in India for decades, widely used in the construction and building industries. However, with rapid urbanization and growing demand in the construction sector, there is a need for alternative building materials that can provide cost-effective and sustainable solutions. The material which is used in the traditional bricks causes environmental, ecological, and medical issues. To address the issue of environmental pollution and global warming caused by traditional red bricks, extensive research has been conducted worldwide to find alternative building materials. Among these alternatives, AAC blocks have emerged as a viable green construction material suitable for use in commercial, industrial, and residential buildings.

Autoclaved Aerated Concrete Blocks belong to the category of Lightweight Concrete and are a type of Aerated Concrete. AAC Blocks were initially developed in the 1920s by a Swedish architect and have since become a popular building material in Europe and other countries. The blocks are made from a blend of cement, fly ash, sand, water, and aluminum powder.

1.3.1 Manufacturing Process of AAC Block

The reaction between aluminium powder, calcium hydroxide and water causes hydrogen oxide to form. The resulting hydrogen gas creates foam and increases the volume of the mixture, resulting in the formation of voids in the concrete. Once the foaming process is complete, the hydrogen dissipates into the atmosphere and is replaced by air. The material solidifies but remains somewhat soft until it is cut into blocks and placed in a cylindrical chamber for a period of 11 to 12 hours.

The process of steam pressure hardening in AAC production involves subjecting the soft but solid material to high temperature and pressure. AAC blocks are manufactured through a process called autoclaving, in which the block is subjected to high-pressure steam curing. During this process, the raw materials mixture of cement, fly ash, sand, water, and aluminium powder undergoes a chemical reaction that produces calcium silicate hydrate, resulting in the block's high strength and lightweight properties. This process is carried out at a temperature of 190°C (374°F) and a pressure of up to 12 bar, causing the sand to react with calcium hydroxide to form the calcium silicate hydrate. Once the autoclaving process is complete, the material is immediately ready for use in construction. AAC has gained popularity in Europe and is rapidly gaining traction in other parts of the world due to its eco-friendly properties, including its ability to preserve fertile land and provide a solution for fly ash disposal. It is a particularly suitable material for use in green housing projects.

1.4 OBJECTIVE OF THE STUDY

The primary aim of this thesis is to,

- To evaluate the rheological properties of cementitious materials, aggregate blends, and AAC block waste as recycled aggregate for concrete production.
- To assess and compare the compressive, tensile, and flexural strengths of conventional concrete and lightweight concrete made by substituting a portion of coarse aggregate with crushed AAC block waste.
- To investigate and compare the flexural behaviour of conventional concrete beams and lightweight concrete beams made by partially replacing coarse aggregate with crushed AAC block waste.
- To analyze the interfacial bonding between the recycled AAC block waste and concrete using scanning electron microscopy and microscopic imaging techniques for both plain and lightweight concrete mixtures with partial replacement of coarse aggregate.
- To validate the experimental findings using finite element analysis software (ANSYS) and compare them with analytical results.

1.5 SCOPE OF STUDY

The scope of this project is,

- To investigate the characteristics, including density and compressive strength of low-density concrete fabricated with autoclaved aerated concrete blocks.
- To examine the benefits and limitations of incorporating AAC blocks into lightweight concrete.
- To analyse and contrast the outcomes of experimental testing and computational simulation of AAC block-reinforced lightweight concrete.

1.6 NEED FOR THE STUDY

Why concrete is needed to research?

- Concrete is a highly prevalent building material across the globe and is the second most consumed product after water. Despite its widespread use, there is still much to be explored and developed in the field of concrete technology. Further research is needed to improve the durability, sustainability, and cost-effectiveness of this material. Why lightweight concrete is needed to research?
- Special applications of concrete may require specific properties that are different from those commonly required for typical concrete structures. For example, some applications may require enhanced durability, increased strength, or unique aesthetic qualities. These applications can arise from the use of new materials or the need to improve upon existing materials. Ongoing research and development in the field of concrete technology are necessary to meet the demands of these special applications and to continuously improve the overall properties and sustainability of concrete.

Why AAC block is needed to research?

- With the increase in the number of buildings and structures constructed with autoclaved aerated concrete blocks, the disposal of resulting waste materials poses a significant challenge.
- AAC blocks differ from conventional clay bricks and cannot be reused as building blocks. The waste generated from AAC blocks typically comprises crushed stones (coarse aggregate) or powder.

- Therefore, there is a need to explore effective solutions for recycling AAC block waste and to identify potential applications for the resulting waste materials.
- The present study seeks to investigate the viability of reusing waste from AAC as an aggregate for concrete, precast concrete tiles, concrete blocks, and formwork blocks, as well as a cementitious supplementary material.

CHAPTER 2

LITERATURE SURVEY AND METHODOLOGY

2.1 GENERAL

Various literature studies related to the partial replacement of coarse aggregate with recycled materials and studied the properties of the recycled materials which affect the concrete properties are discussed in this chapter.

2.2 LITERATURE STUDY

Ilker and Tayfun (2010) the objective of this research was to explore the impact of aggregate type on the physical and mechanical characteristics of self-consolidating concrete (SCC) that incorporates lightweight aggregates (LWAs). Three types of coarse LWAs (pumice, volcanic tuff, and diatomite) and traditional limestone aggregate were studied. Various water-to-binder ratios and superplasticizer dosages were used to create SCLC mixtures with a constant powder content. The hardened concrete's mechanical properties (compressive and splitting tensile strength, modulus of elasticity, and abrasion resistance) and physical characteristics (capillarity, porosity, thermal conductivity, and dry unit weight) were assessed. The findings indicated that SCLC with LWAs had inferior mechanical and physical properties than SCC with traditional aggregates, with the exception of thermal properties.

Sundar Kumar and Ratna Kanth Babu (2010) the use of lightweight concrete with high load-bearing capacity is prevalent due to its ability to decrease the weight of a structure, allowing for the handling of larger precast elements. This investigation examined the mechanical properties of a lightweight composite material composed of fly ash and clay. It is widely acknowledged that the incorporation of fly ash and silica fume in concrete enhances its compressive, splitting tensile, and flexural strength. The study demonstrated an increase in the strength properties by 10% through the substitution of fly ash and silica fume. However, when the replacement ratio was increased to 20%, there was a reduction in the tensile strength for both compressive and flexural splitting. Furthermore, an excessive amount of fly ash can diminish the strength-enhancing effect and impede the subsequent secondary hydration process. In contrast, silica fume has desirable

features such as a high specific surface area, a significant amount of non-crystalline SiO₂, and small particle size, which facilitate cement hydration and improve homogeneity in concrete. The inclusion of this component leads to an increase in the durability and strength of concrete by promoting the formation of CSH gel hydrates.

Mohammadreza, et al (2011) the study aimed to analyse the impact of certain factors on high-strength and lightweight aggregate concrete by using the non-destructive testing technique of ultrasonic pulse velocity. Various concrete mix designs were prepared and tested at different ages, such as 7, 28, and 90 days. The study focused on investigating the influence of age, cement content, water-cement ratio, and slump on two different types of concrete. The non-destructive testing technique of ultrasonic pulse velocity was found to be a reliable method for assessing the strength and quality of concrete and proved to be a good choice for this study. The results and implications of the study were thoroughly discussed.

Saritha and Chamundeeswari (2011) this project involved an empirical investigation of two types of concrete - one made with thermoplastic plastic aggregates, and the other made with conventional aggregates. The M20 grade concrete mix design used in the study was partially replaced with thermoplastic plastic aggregates obtained from MS Plastics, located in Sedharapet, Pondicherry. The workability of lightweight concrete was observed to be inferior to that of conventional concrete, and hence to enhance it, microscopic air bubbles were introduced. Furthermore, the flexural strength and tensile strength values of partially lightweight concrete were found to be lower than those of conventional concrete, rendering the lightweight aggregate unsuitable for structures subjected to external forces. However, partially lightweight concrete with compressive strength values greater than 17.44 N/mm² can be utilized as structural concrete in certain circumstances.

Anurag (2012) In this article, the production process of AAC blocks was explored, which involves a combination of materials such as cement, sand or fly ash, lime, gypsum, and aluminium powder. The aluminium powder is used as a forming agent, which reacts with Ca (OH) and generates hydrogen oxides. This

chemical reaction leads to the formation of a significant number of voids in the concrete, resulting in the production of AAC blocks.

Mohd and Kamarudin (2012) the aim of this research was to examine the possibility of manufacturing foam concrete using a geopolymer system. To create lightweight concrete, the researchers used Class C fly ash and an alkaline activator solution made up of a combination of sodium silicate and NaOH. Foam was introduced to the geopolymer mixture, and the homogeneous mixture was then placed in a 50 mm mould and cured at two different temperatures (60°C and ambient temperature) for 24 hours. On days 1, 7, and 28, the samples were tested for strength, while numerous analyses were conducted to determine water absorption, porosity, chemical composition, microstructure, and XRD and FTIR.

According to the study, the highest compressive strength values for all tests were exhibited by the sample cured at 60°C (LW2). The compressive strength values recorded were 11.03 MPa, 17.59 MPa, and 18.19 MPa for days 1, 7, and 28, respectively. After 28 days, LW2 showed a decrease of 6.78% and 1.22% in water absorption and porosity, respectively. SEM analysis indicated that the matrix of LW2 was denser than that of LW1, which had micro cracks on the surface, leading to decreased compressive strength and increased water absorption and porosity. The heat-cured LW1 had a faster polymerization rate compared to the other sample.

Parhizkar, et al (2012) this study conducted experiments to investigate the properties of concrete made with volcanic pumice lightweight aggregates. The research compared mainly lightweight concrete made with natural fine aggregates to lightweight concrete made with both lightweight coarse and fine aggregates. The results showed that the lightweight concrete met the requirements for properties such as tensile strength and drying shrinkage.

Gary (2013) this paper concentrates on the mechanical characteristics of lightweight concrete (LWC) prepared with different materials and ratios, following American codal regulations. The research aims to investigate and contrast the compressive strength, splitting tensile strength, and flexural strength of various LWC blends. The significance of selecting an appropriate mix design for LWC based on its intended use and the desired characteristics is also discussed. The outcomes of

the study demonstrate that by meticulously selecting the materials and ratios in the mix design, the mechanical characteristics of LWC can be enhanced.

Roberto, et al (2013) A research program was conducted by Politecnico di Milano to study the influence of temperature on the mechanical damage of mixed-aggregate, silica-fume high-performance lightweight concretes (HPLWCs) in compression and tension. The program comprised 88 specimens prepared and tested for three different concrete mixes (normal-strength concrete, C30; lightweight concrete, LC40; and HPLWC, LC60), five temperature levels (20, 105, 250, 500, and 750°C), one thermal state (after cooling), and three tests for each case for repeatability. Furthermore, the thermal diffusivity of the materials was evaluated up to 750°C. The findings suggest that HPLWC is more sensitive to temperature than LWC, although its reduced thermal diffusivity may be advantageous for the fire resistance of reinforced concrete structures. Additionally, thermo-mechanical analyses of three common reinforced concrete sections (rectangular, T, and slab sections) validated the findings.

Sivalinga and Radha (2013) Steel fiber reinforced concrete (SFRC) has been widely used to reinforce and repair various structures, such as tunnels and pavements. With the increasing popularity of lightweight materials in structural applications, pumice stone has become a preferred raw material. Research indicates that incorporating 20% pumice aggregate and 1.5% fibers can exceed the target mean strength of M20 concrete. Furthermore, a mix with 40% pumice and 0.5% fibers can attain the average target mean strength of M20 concrete. The compressive strength of pumice concrete can be enhanced by increasing the fiber content, and the optimal strength is achieved at 1.5% fiber content. However, for various pumice content levels, exceeding this optimal fiber content results in decreased strength.

Jihad and Ali (2014) this paper provides an overview of the categorization of lightweight concrete. The classification is based on two factors - the method of production and the intended application of the concrete. The paper also highlights the various materials that can be used to produce lightweight concrete. There are three main types of lightweight concrete - lightweight aggregate concrete, aerated concrete, and no-fines concrete. By controlling the number of lightweight

aggregates, structural concrete can be obtained from lightweight aggregate concrete. Aerated concrete, on the other hand, eliminates the need for coarse aggregates, resulting in more uniform distribution of voids within the concrete.

Lakshmi and Ratnam (2014) the purpose of this research was to investigate the mechanical properties of M30-grade lightweight concrete using pumice stone as a partial replacement for coarse aggregate, in combination with mineral admixtures such as Fly Ash and Silica Fume. The study revealed that the partial replacement of natural coarse aggregate with 20% lightweight aggregate resulted in good compressive strength of the concrete. However, increasing the percentage of pumice aggregate reduced the density and compressive strength of the concrete. Moreover, the incorporation of mineral admixtures resulted in an increase in the compressive, split-tensile, and flexural strengths of the concrete. Therefore, the study concluded that lightweight aggregate is a feasible substitute for natural coarse aggregate and can be used in the construction industry.

Abhijitsinh, et al (2015) as the construction industry expands across the globe and sustainability becomes more important, the use of Expanded Polystyrene Concrete is becoming increasingly popular. This material is known for its low density, and eco-friendliness, as well as advantages such as improved heat and sound insulation, ease of construction, and affordability. Its popularity is reflected in its growing use in green buildings and sea structures worldwide. The flexibility to adjust the material's properties by modifying the production process and ingredients provide greater creativity while maintaining the fundamental principles of concrete design. Research shows that compressive strength decreases with a decrease in density, and the maximum strength is achieved at a density of 814.89 kg/m³.

Alexandre (2015) this study aimed to investigate the chloride ingress resistance of lightweight aggregate concrete (LWAC) produced using different types and proportions of lightweight aggregates, types of cement, and contents of supplementary cementitious materials such as fly ash and silica fume, such as well as various water-to-cement ratios and curing conditions. The study involved a comprehensive experimental analysis consisting of three non-steady-state tests to simulate different exposure conditions and penetration mechanisms. The results indicated that the chloride ingress resistance of LWAC is primarily influenced by the

cementitious paste, and high-performance LWAC with a compressive strength of 30-70 MPa can be produced. Regardless of the type of aggregate, the study proposed empirical relationships to estimate the diffusion coefficient of chlorides. The volume and initial moisture condition of the lightweight aggregate had little effect on the chloride resistance, and a long-term reduction of the diffusion coefficient was observed in less dense LWAC. Reasonable correlations between the non-steady-state tests were obtained. The study also revealed that the durability performance of LWAC cannot be reliably predicted based on its compressive strength, which is contrary to some European standards.

Rajeswari and Sunilaa (2015) this study investigated the compressive strength characteristics of lightweight aggregate concrete (LWAC) with partial substitution of coarse aggregate with a pumice stone at varying ratios (50%, 60%, and 70%) relative to conventional concrete. The results showed that the optimal compressive strength was attained at 60% replacement of coarse aggregate with a pumice stone. At this substitution level, the compressive strength of LWAC was found to be comparable to that of conventional concrete. The primary objective of the study was to determine the strength characteristics of LWAC and determine the appropriate substitution ratio for pumice stones. The lightweight nature of LWAC makes it suitable for various concrete and construction applications. The study concluded that using pumice as a partial substitute for coarse aggregate in LWAC is a viable option to achieve compressive strength similar to that of conventional concrete. The comparison was made using mix M25.

Glas, et al (2015) in this research, a new type of lightweight concrete called structural lightweight aggregate concrete (SLWAC) is proposed to balance low specific density and thermal conductivity with high mechanical properties. The SLWAC is designed to have a water-cement dosage of 0.35 and exhibits acceptable workability. The concrete shows excellent thermal properties with a low thermal conductivity of approximately 0.20 W/(m·K) and moderate mechanical properties with a compressive strength of around 34 MPa at 28 days (classified as LC30-33 under EN 206-1) and an apparent density of about 1250 kg/m³. The remarkably low thermal conductivity of the concrete in this strength class suggests potential applications for both structural and thermal insulation purposes.

Siva and Pankaj (2015) this paper present an experimental study on reinforced concrete (RC) beams reinforced with steel fibers. The flexural strength behaviour of the RC beams is investigated through a single-point load test conducted on a loading frame. During the test, the specimen undergoes cracking and ultimately fails, providing insights into the development of crack patterns and failure directions. The analysis of the cracks and their patterns during the failure condition is also studied in detail in this paper.

Muralitharan and Ramasamy (2017) the use of lightweight concrete in the construction industry has become increasingly popular due to its low density. Pumice lightweight aggregate (PLA) is a type of natural volcanic aggregate that has very low specific gravity. By utilizing PLAs, lightweight concrete with a density of up to 1450 kg/m³ can be produced, offering advantages such as sound insulation properties, a high strength-to-weight ratio, improved fire resistance, and better durability. Lightweight concrete also provides benefits such as reduced mass and improved thermal performance, particularly under cyclic loading conditions that are typically experienced during earthquakes. This study focuses on investigating the cyclic behavior of reinforced PLAC beams with M30 grade and dimensions of L=1500 mm, B=100 mm, and D=150 mm, in comparison to control beams.

Bhavana and Rambabu (2017) in this research, the potential of using a pumice stone, ceramic tile waste, and lightweight brick waste as partial substitutes for coarse and fine aggregates in lightweight aggregate concrete was explored. Pumice stone, formed by gas escaping from molten lava, is a lightweight aggregate, while ceramic tiles and lightweight bricks are known for their durability, low water absorption, high breaking strength, and fire resistance. Replacement ratios of 10%, 20%, and 30% were tested for both coarse and fine aggregates. The findings indicate that substituting 10% of the coarse aggregate led to an improvement in the compressive, tensile, and flexural strength values by 26.30%, 4.42%, and 26.24%, respectively, while replacing 10% of the fine aggregate led to an improvement in the compressive, tensile, and flexural strength values by 11.07%, 3.32%, and 9.63%, respectively.

Subramani and Ganapathy (2017) according to the study, during dynamic loading, lightweight concrete buildings exhibit more efficient lateral load systems compared to RCC members. This is attributed to the lower weight and smaller cross-

sectional areas of structural members in lightweight concrete, resulting in reduced lateral displacement and storey drift when exposed to dynamic loads. Furthermore, the study determined that response spectrum analysis is more effective than static analysis for all models examined.

Nagaswaram (2017) the aim of this project is to evaluate the properties of M25 grade concrete through the partial substitution of cement with fly ash at rates of 35% and 40%, and fine aggregate with thermocol at 0.2% and 0.3%. The findings reveal that the compressive strength of the concrete is substantially enhanced from 33.25 N/mm² to 35.5 N/mm² by utilizing 35% fly ash and 0.2% thermocol substitution, and further improves to 36.8 N/mm² with 40% fly ash and 0.3% thermocol substitution.

Tejeda and Ochieng (2018) this study aimed to investigate the viability of utilizing locally available scoria aggregates from the Lukenya area in Kenya to manufacture structural lightweight aggregate concrete (SLWAC). The scoria stones were collected, crushed to particle sizes ranging from 4.75 to 19 mm, and classified in accordance with ASTM C330 standards. Three distinct mix design approaches based on the standard ACI 211.2-98 for proportioning structural lightweight concrete were employed to design lightweight concrete with a target strength of 30 MPa. Physical and mechanical tests were conducted on the scoria aggregates to assess their suitability for producing structural lightweight concrete. The lightweight concrete was subjected to various assessments to evaluate its characteristics. The outcomes revealed that the absolute volume method was the most efficient mix design approach in terms of dry density, slump, and strength, including compressive, splitting tensile, and flexural strength. As a result, this study concludes that volcanic scoria possesses the potential to substitute artificial lightweight aggregates in the creation of structural lightweight concrete, and the absolute volume method is the most efficient mix design approach for this purpose.

Tongwei and Group (2018) the objective of this investigation was to analyze the influence of incorporating a foam stabilizer and polypropylene fiber (PPF) on the mechanical characteristics of lightweight foamed concrete. The study included producing lightweight foamed concrete with different foam agent proportions, ranging from 0 to 7wt%. The outcomes of the research revealed that an increase in

foam agent content led to a decrease in the density, thermal conductivity, flexural, and compressive strength of the concrete. This outcome was attributed to the generation of a substantial number of pores through the decomposition of foam agents. In comparison, samples with foam stabilizer inclusion showed better mechanical properties and lower thermal conductivity than those without foam stabilizers, owing to the enhanced pore structure. Furthermore, an appropriate quantity of PPF enhanced the flexural and compressive strength of the specimens. However, excessive PPF had an adverse effect on the mechanical properties.

Luciano, et al (2019) the current study focused on investigating the feasibility of developing a lightweight polymer concrete underground utility manhole by employing an epoxy-amine system and a combination of fine regular-weight and ultra-lightweight aggregates. Polymer concrete is a composite material that utilizes polymer as a binding material, which provides better tensile and cracking strength as well as enhanced resistance to chemicals compared to Portland cement-based concrete. The study aimed to optimize the composition of the polymer concrete by exploring whether the incorporation of ultra-lightweight aggregates could further enhance its mechanical performance. Two polymer concrete formulations were developed and evaluated for their mechanical properties. In addition, a numerical model was developed to simulate the performance of the polymer concrete manhole under typical soil loads. The simulation results indicated that the formulation with regular-weight aggregates and epoxy had better mechanical performance than the formulation with ultra-lightweight aggregates, allowing for a thinner wall thickness to sustain in-use service pressures.

Farheen and Syed (2019) the aim of this study was to evaluate the compressive and flexural strength of lightweight foamed concrete (LFC) by incorporating polypropylene fiber. The bond-to-sand ratio was set at 3:1, and a targeted density of 1500 kg/m³ was achieved. Two different volume fractions of polypropylene fibers, namely 0.25% and 0.40%, were added to the LFC mixtures at different curing ages of 7, 28, and 60 days. The mechanical properties of the samples were assessed according to ASTM standards. Results showed that the addition of polypropylene fiber significantly enhanced the flexural strength of LFC compared to the control sample. The optimal amount of fiber to achieve maximum flexural strength was found to be 0.25% volume fraction, although both fiber

concentrations showed improvement. Additionally, compressive strength was not significantly affected by the addition of polypropylene fiber.

Ram, et al (2019) the main objective of this investigation is to explore the impact of different dosages of Expanded Polystyrene Beads (EPS) on the production and properties of lightweight concrete. The study involves the addition of EPS beads in increments of 10% (based on the total volume of fine aggregate) to determine their effect on properties such as density and compressive strength. The results demonstrate that the optimal strength of 21 N/mm² for M20 grade concrete and a density of 19 kN/m³ can be achieved by replacing 40% of the fine aggregate volume with EPS beads. This innovative lightweight concrete formulation may be ideal for use in plain concrete structures requiring M20 grade concrete.

Anju, et al (2019) recent studies have shown that lightweight concrete can outperform conventional concrete in terms of its strength, workability, and durability, as well as its ability to withstand thermal, fire, and seismic events. Furthermore, lightweight concrete offers a potential solution for incorporating waste materials into concrete by partially replacing cement with recycled or waste aggregates. This review paper aims to provide a comprehensive overview of the influence of different lightweight aggregates on the various properties of lightweight concrete.

Sunday, et al (2019) this research aimed to explore the viability of using coconut shells as a construction material. To achieve this, the study evaluated the properties of concrete that incorporated coconut shells as a partial replacement for fine aggregate. The volume fraction replacements of fine aggregate with coconut shells were 10%, 20%, and 30%. The study investigated the effects of these replacements on the structural properties and behaviour of the concrete, including compressive strength, flexural strength, and water absorption rate. The findings indicated that as the volume fraction of coconut shell replacement increased, the density, compressive strength, and flexural strength of the concrete decreased, while its water absorption rate increased. Furthermore, as the volume fraction of coconut shell replacement increased, the cost of producing the concrete decreased.

Gopinath, et al (2019) research findings showed that there was a decrease in the density of concrete with an increase in the proportion of steel slag aggregate. Nonetheless, the inclusion of steel slag as a coarse aggregate resulted in enhanced

workability of the concrete due to the smooth surface texture of the slag particles. The study suggested that steel slag can be used as a partial substitute for coarse aggregate in concrete up to a limit of 30% without a substantial decrease in strength. Moreover, the utilization of steel slag in concrete can promote sustainable development by minimizing waste generation and conserving natural resources.

Muhammad and Bing (2019) additionally, the sorptivity of LAFC mixes decreased with increasing foam volume, indicating improved water resistance properties. Furthermore, the high-temperature resistance of LAFC mixes was also investigated, and the results showed that the mixes retained their shape and strength even after being exposed to temperatures of up to 600°C for 3 hours. The addition of SF further improved the mechanical and thermal properties of LAFC mixes. Therefore, the study concludes that LAFC can be a suitable alternative material for insulation and fire protection applications due to its improved thermal and high-temperature resistance properties, as well as its water resistance and lightweight characteristics.

Ashuvendra (2019) the results showed that the compressive strength of lightweight concrete decreased with increasing replacement percentage of pumice stone. However, at a 30% replacement level, the compressive strength was found to be similar to that of conventional concrete. The flexural strength and split tensile strength were also found to decrease with an increase in pumice stone replacement. The addition of GGBFS and Recron 3s improved the compressive and flexural strength of the lightweight concrete. Overall, the study suggests that pumice stone can be used as a partial substitute for natural coarse aggregate in the production of lightweight concrete, and the addition of mineral admixtures can improve its structural characteristics.

Mohammad (2020) this paper offers a comprehensive examination of Autoclaved Aerated Concrete (AAC) blocks as a promising and eco-friendly construction material. It highlights the benefits of AAC blocks compared to traditional building materials and analyzes their economic feasibility. Additionally, the paper presents recent global trends in the application of AAC blocks in the construction industry.

Athira, et al (2020) this paper offers a comprehensive review of Lightweight Concrete Masonry Blocks (LCMBs), examining their material properties, masonry performance, and testing methods used to evaluate their structural behaviour. It aims to consolidate the existing knowledge in this area and serve as a valuable reference for architects, engineers, and researchers interested in incorporating LCMBs in their construction projects.

Rajasekhar and Venkataramana (2020) the primary objective of this investigation was to compare the characteristics of nominal and lightweight concrete with M20 grade. The production of lightweight concrete was carried out by substituting a portion of the coarse aggregate with various percentages of pumice aggregate (0%, 15%, 30%, and 45%). The research focused on assessing the compression strength and split tensile strength of lightweight concrete. The results revealed that the replacement of 45% coarse aggregate with pumice aggregate resulted in the lowest compressive strength and a significant decrease in the weight of the concrete. As a result, it was concluded that the 45% replacement could only be applied for non-structural purposes. However, 15% and 30% replacements could be implemented for structural objectives.

Bharath and Kuldeep (2020) lightweight concrete is becoming increasingly popular in structural engineering. This study used mix M25 to create lightweight concrete by partially replacing cement and fine aggregate with fly ash and thermocol. Results showed that the compressive strength of the lightweight concrete was higher than that of conventional concrete when 10% sugarcane bagasse ash (SCBA) and 10% glass powder (GP) were used as replacements for cement, at 7, 14, and 28 days of curing. However, increasing the replacement percentages beyond 10% resulted in a decrease in compressive strength. The split tensile strength of the concrete also decreased when the replacement percentages were increased beyond 10%. The study concluded that SCBA and GP are effective partial replacements for cement in concrete, reducing construction costs. The optimum replacement percentage for cement by SCBA and GP is 10%, with further increases resulting in reduced concrete strength.

Prathibha and Anila (2020) this research investigate the viability of utilizing cinder and brickbats as substitutes for coarse aggregates in regular concrete with

the objective of reducing its density and strength. The weight measurements show that the use of cinder as an aggregate replacement results in a lighter concrete mix compared to brickbats. Furthermore, substituting coarse aggregates with cinder not only reduces the weight of the concrete but also maintains its strength at both 50% and 100% replacement levels. On the other hand, when brickbats are used as a replacement, the achieved strength at 50% replacement is better than at 100% replacement, despite obtaining lightweight aggregate concrete. Thus, the study concludes that cinder can be used as a partial or complete substitute in areas where concrete is used primarily for insulation purposes, while brickbats can be used as a replacement material in regions where both strength and lightness are required.

Shu-Hua Xiao, et al (2021) this paper presents a study on the performance of reinforced concrete (RC) beams strengthened with composite bars comprising glass fiber reinforced polymer (GFRP) and steel fibers. The experimental setup involved testing the beams under a 2-point loading system with simple end conditions until failure occurred. During the loading process, a crack pattern was observed, and the results indicated that the beam underwent linear elastic bending, as evidenced by the graph included in the paper. The findings of this study provide insights into the behaviour of RC beams strengthened with GFRP and steel fiber composite bars, which can be useful for engineers and researchers working in the field of structural engineering.

Pankaj, et al (2021) this study presents an experimental investigation aimed at determining the optimal mix proportion of Sintered Lightweight Aggregate (SLWA) with different sizes and their impact on the fresh and mechanical properties of Lightweight Concrete (LWC). LWC mixtures were prepared using pre-soaked aggregates of two different sizes: 8-12mm and 4-8mm. The proportioning of these aggregates was found to be crucial in determining the density and strength of the resulting concrete. Four different aggregate mix ratios, namely 80:20, 60:40, 40:60, and 20:80, were examined to determine the fresh and hardened properties of the LWC. The findings showed that LWC made using the finer aggregate (4-8mm) had lower bulk density but higher mechanical properties compared to other mix ratios.

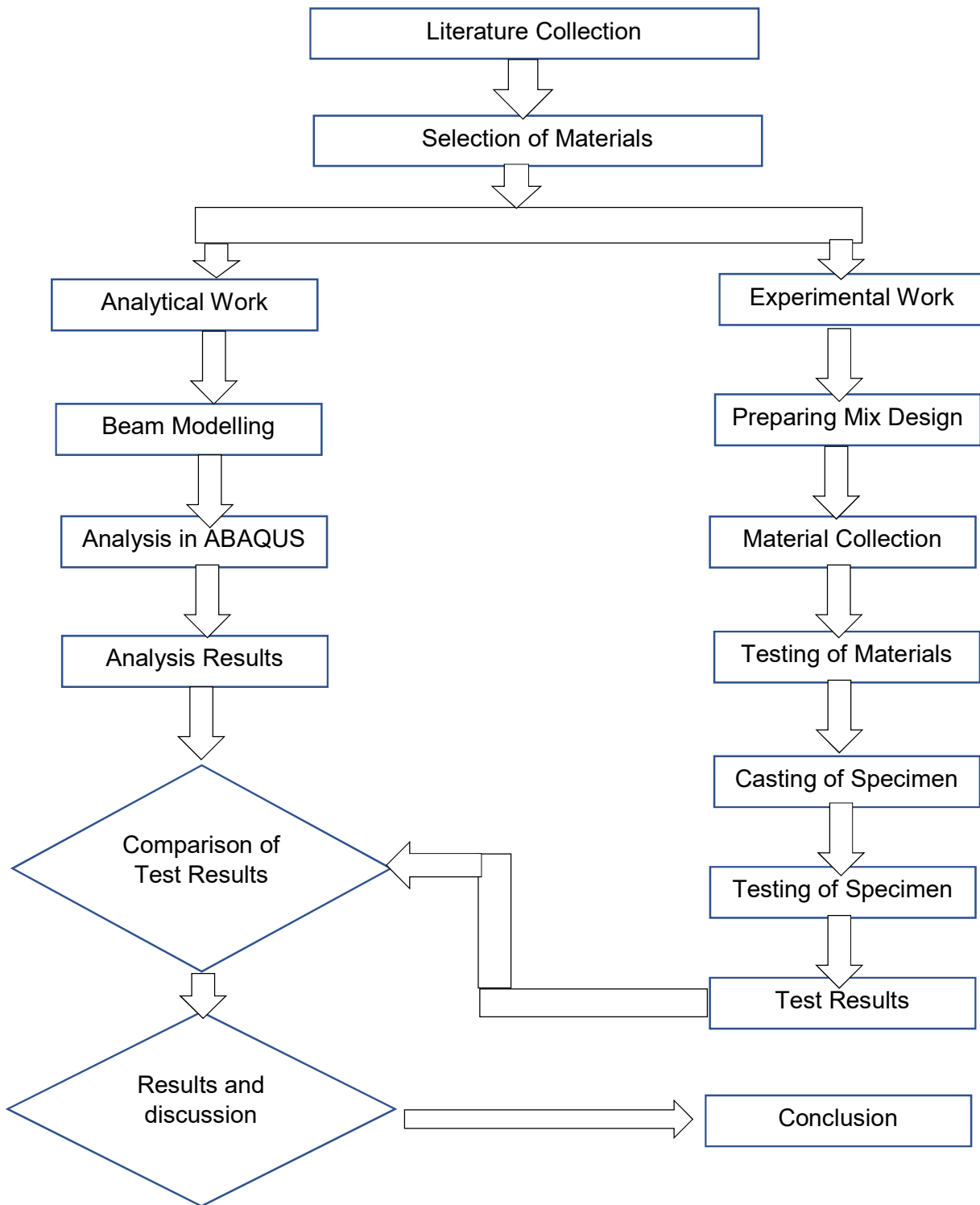
Muhammad, et al (2021) this article describes a study on the impact of incorporating Waste Polystyrol Glass Aggregate (WPGA) in concrete, particularly

on its compressive and flexural strength as well as its thermal conductivity over time. The concrete used in this research was made using conventional materials, with different levels of WPGA substitution to investigate its effect on thermal insulation. A total of 20 cubes and 10 prism specimens were utilized to evaluate the strengths and thermal resistance of the WPGA concrete. The findings indicate that an increase in the WPGA content resulted in a decrease in both the compressive and flexural strength of the concrete. With regards to thermal insulation, the concrete with 40% WPGA content exhibited a higher heat-insulating property than the normal concrete, with a significant difference in the time it took to reach 60°C temperature in the oven with thermocouples installed, i.e., 5 hours and 12 minutes for normal concrete and 9 hours and 13 minutes for 40% WPGA concrete.

Karthika and Vidyapriya (2021) the objective of this study was to explore the feasibility of utilizing pumice aggregate as a partial replacement for coarse natural aggregate in the production of lightweight concrete. The replacement percentages investigated were 50%, 80%, and 100%. Mix M30, combined with Coloplast SP430 admixture, was utilized in the preparation of both conventional concrete and pumice lightweight aggregate concrete. Pumice aggregate, with a lower density than natural aggregate, was incorporated to decrease the overall weight of the concrete. The compressive, split tensile, and flexural strengths of Pumice LWAC were assessed for each replacement level. The outcomes revealed that the optimal replacement level was 50% since greater replacement percentages resulted in diminished strength values. Consequently, pumice aggregate concrete can be employed in the fabrication of non-load-bearing wall panels, precast structures, lintels, sunshades, and partition walls, as well as in the construction of earthquake-resistant edifices.

2.3 METHODOLOGY

- This flowchart provides a step-by-step process for determining the various properties of concrete.
- The first step is to study the literature related to the material which is going to replace and identify the material properties which affect the concrete
- which helps in the selection of suitable replacement material.
- The study on determining the properties of materials to be conducted that can be useful in increasing the desirable properties of the concrete.
- The structural element (beam) is modelled using FEM software and analysis will be carried out.
- The mix design for M30 grade concrete will be done in this study.
- The casting of the specimen to conduct the experimental investigation for determining the properties of the concrete will be carried out.
- The results obtained from the experimental investigation will be compared with the results of the FEM software ANSYS.



CHAPTER 3

MATERIALS AND EXPERIMENTAL INVESTIGATION

3.1 GENERAL

This chapter briefing about the materials used in conventional concrete (CRC) and lightweight concrete (LWC) is partially replaced with crushed AAC block waste as coarse aggregate and those materials physical properties through laboratory tests and its results. After casting the concrete specimens, they will be tested in the laboratory to evaluate their compressive, split-tensile, and flexural behaviour.

3.2 MATERIALS

Concrete is a heterogeneous compound comprising of cement, fine aggregates, coarse aggregates, water, chemical admixtures, and mineral admixtures. Additionally, steel rod, welded wire fabric, and reinforcing fibers may also be used in concrete construction. The quality of these materials, their proper ratio, and the mixing process all have a substantial influence on the strength of the resulting concrete.

3.3 MATERIAL USED

3.3.1 Cement



Fig 3.1 Ordinary Portland Cement – 43 grades

Cement is a prevalent building substance. and plays an essential role in the building industry. There are several classifications of cement available in the market,

each with its unique properties suitable for specific conditions. When cement is mixture of water and sand, it forms a substance known as cement mortar. Cement concrete, on the other hand, is produced by mixing cement, water, and an inert aggregate like sand, gravel, or crushed stone.

Portland cement is a ubiquitous construction material, typically combined with locally-sourced small and large sized aggregates such as sand, gravel, or rock deposits. Joseph Asp Din is the one who introduced Portland cement in the year 1824. The advancement of the product leads to the current mode of Portland cement which provide different material properties and functional specifications namely impermeability, durability, strength, and other dimensional constraints.

In order to achieve a concrete mix that is both robust and cost-effective, it is essential to have a comprehensive understanding of the properties and performance of the constituents. Concrete ingredients can be divided into two categories: active and passive.

The dynamic cohort consist of cement and water, whereas the passive assemblage comprise fine and coarse aggregates. The passive assemblage is also sometimes called an inert matrix. Fig 3.1 shows the Ordinary Portland Cement – 43 grades

3.3.1.1 Physical Properties of Cement

- Fineness of cement
- Specific gravity
- Soundness
- Bulk density
- Consistency
- Loss of ignition
- Strength
- Heat of hydration
- Setting time

The above few are the substantial aspects of the cement but for my thesis, I needed a few of those substantial aspects. These are determined from the laboratory test results which are shown in Table 3.1,

Table 3.1. Physical Properties of Cement

S.NO	PHYSICAL PROPERTIES	RESULTS
1	Normal Consistency Test	32%
2	Fineness of cement	4.8%
3	Specific Gravity of cement	3.14
4	Setting Time (initial)	34 minutes
5	Setting Time (final)	615 minutes
6	Soundness of cement	5 mm

3.3.2 Fine Aggregate



Fig 3.2 M-Sand

Fine aggregate is defined as the portion of aggregate that passes through a 4.75mm IS sieve and is composed of sand, silt, and clay particles. Sand typically has a lower size limit of around 0.07 mm. Particles ranging from 0.06 mm to 0.002 mm are classified as silt, while particles smaller than 0.002 mm are called clay. A deposit consisting of sand, silt, and clay in approximately equal proportions is known as loam. Fig 3.2 Shows the M-sand used in this thesis.

The fine aggregate may be one of the following types:

- Natural sand refers to the small sized aggregate that is obtained from the natural breakdown of rocks or deposits resulting from the movement of water or glaciers.

Crushed stone sand refers to fine aggregates that are produced by crushing hard stones.

The role of the fine aggregate is described as

- Dimensional stability was provided to the mixture because of the fine aggregate
- Its quality will affect the hardening properties and mix proportions.
- The fine aggregate also influences the shrinkage of the concrete
- It also has an influence over resistance and the elastic modulus.

3.3.2.1 Physical Properties of Fine Aggregates

- Sieve Analysis
- Surface texture
- Water absorption
- Specific gravity
- Moisture content
- Bulk density
- Bulking
- Durability

The above few are the substantial aspects of the fine aggregate but for my thesis, I needed a few of those substantial aspects. These are determined from the laboratory test results which are described briefly below,

3.3.2.1.1 Specific Gravity and Water Absorption Test on Fine Aggregate

The determination of Density ratio is a useful test for identifying stones. Additionally, the water absorption test provides an indication of the strength of an aggregate. Aggregates with higher hygroscopicity rates are typically items with higher porosity are generally deemed unsuitable unless deemed acceptable through evaluation. based on their strength, impact resistance, and hardness, among other tests. Tests are conducted based on IS 2386 part 3 1963.



Fig 3.3 Specific Gravity and Water Absorption Test

Apparatus required

- Balance
- Oven
- A wide-mouthed vessel
- Hair drier
- Tray
- Airtight container
- Filter paper
- Funnel

Test Procedure

The determination of the density of an aggregate is a crucial test in the construction industry for identifying and selecting suitable materials. The procedure involves using a pycnometer, which is a specialized container for accurately measuring the volume of a substance. A representative sample of the aggregate, typically weighing 1 kg for particle sizes ranging from 10 mm to 4.75 mm, or 500 g for finer particles, is first submerged in deionized water at a controlled temperature of 22 to 32°C. Gentle agitation with a rod is used to eliminate any entrapped air bubbles on or within the aggregate during immersion.

After 24 +/- 1/2 hours of immersion redundant water is extracted from the specimen using filter paper, and the aggregate, along with any particulate on the filtration membrane, is subjected to warm airflow to desiccate surface moisture.

Care must be taken to ensure that the sample does not become too dry during this process. The sample is stirred periodically until it reaches a "free-running" state with no visible free surface moisture. The mass of the water-saturated and partially desiccated samples is then measured (weight A).

To determine the density of the aggregate, the pycnometer is first filled with distilled water to a known volume, and any entrapped air is removed by rotating the pycnometer and covering the orifice at the apex of the cone using a finger. The pycnometer is then refilling the container with deionized water to eliminate any foam from the top until the liquid level in the orifice becomes level. The pycnometer is desiccated externally and weighed (weight B).

The aggregate is then emptied into the pycnometer, ensuring that all of it is transferred, and the pycnometer is replenished with deionized water up to the equivalent level as prior. The pycnometer is then desiccated externally and weighed. (Weight C). The variance between the water temperature in the pycnometer during the initial and subsequent weighing should not surpass 2°C.

The remaining moisture in the sample is removed by baking within a temperature interval of 100 to 110°C for 24 +/- 1/2 hours. The sample in the tray is stirred periodically during this period to ensure uniform drying. After the drying process, the specimen is cooled within a hermetically sealed receptacle and weighed (weight D). Fig 4.3 shows the addition of fine aggregate with water in the pycnometer and it is weighted.

Calculation

$$A = 1000 \text{ g}$$

$$B = 3372 \text{ g}$$

$$C = 2754 \text{ g}$$

$$D = 990 \text{ g}$$

- Specific Gravity
$$= \frac{D}{A-(B-C)} = \frac{990}{100 (3372-2754)} = 2.61$$
- Water Absorption (Percent of dry weight)
$$= \frac{100(A-D)}{D} = \frac{100(1000-990)}{990} = 1.01 \%$$

Where,

A = Mass in grams of the partially desiccated, water-saturated sample,

B = Mass in grams of the pycnometer or gas jar housing the sample and replenished with deionized water,

C = Mass in grams of the pycnometer or gas jar occupied solely with deionized water, and

D = Mass in grams of the desiccated sample.

Results

- Specific Gravity of fine aggregate = 2.61
- Water Absorption of Fine Aggregate = 1.01%

3.3.2.1.2 Sieve Analysis

The sieve analysis of fine aggregate is a process utilized to determine the distribution of particle sizes present in materials like sand, silt, or clay that are smaller than 4.75mm in size but larger than 75 microns, as they pass through the former sieve and are retained by the latter. This test and results are conducted based on IS 2386 part1 1963 and IS 383. Fig shows how the sieve analysis test is done on fine aggregate.



(a)

(b)

Fig 3.4 Sieve Analysis on Fine Aggregate

Apparatus

- Sieve
- Balance

Test Procedure

The sample was prepared for weighing and sieving by air-drying it after either drying it at room temperature or heating it at 100-110°C. It was then weighed and sieved in succession, starting with the largest appropriate sieve, while ensuring that each sieve was clean before use. The sieving process involved shaking each sieve individually onto a hygienic tray for a minimum duration of two minutes, employing a diverse motion that encompasses back and forth, left to right, clockwise and counter-clockwise circular, and regular jolting.

The substance was kept in perpetual motion across the sieve surface, with direction changes occurring frequently, and particles were not forced through the sieve by hand pressure. Sieves with a mesh size greater than 20 mm facilitated the placement of fragments, whereas clumps of small particles were fractured via delicate pressure against the sieve's side utilizing fingers. The underside of the sieve was lightly brushed using a gentle bristle brush to clear the sieve apertures, while a fine camel hair brush was used to prevent the powder from aggregating and blocking the openings of the 150-micron and 75-micron IS sieves.

No rigid or dilapidated brushes were utilized, and no pressure was exerted on the sieve's surface to impel fragments through the mesh. Ultimately, the residual matter adhering to each sieve, together with any residue dislodged from the mesh, was quantified subsequent to the culmination of the winnowing technique. From Table 3.2 shown below, we can identify the zone fine aggregate after sieve analysis.

Table 3.2 Fine Aggregate Zone from Sieve Analysis

SIEVE SIZE	PERCENTAGE RETAINED	CUMULATIVE PERCENTAGE RETAINED		PERCENTAGE PASSING	PERMISSIBLE PERCENTAGE PASSING	
10 mm	0	0	0	0	100	90-100
4.75 mm	0.024	0.0024	0.0024	2.4	97.6	75-100
2.36 mm	0.344	0.0344	0.0368	36.8	63.2	55-90
1.18 mm	0.150	0.0150	0.0518	51.8	48.2	33-59
600 mic	0.180	0.0180	0.0698	69.8	30	8-30
300 mic	0.230	0.0230	0.0928	92.8	7.2	0-10
150 mic	0.050	0.0050	0.0978	97.8	2.2	
75 mic	0.022	0.0022	0.1	100	0	
Pan	1kg					

Result

In conformity with the classification standard of Zone II of Table 9 stipulated by IS 383.

3.3.3 Coarse Aggregate



Fig 3.5 20mm Size Coarse Aggregate

Aggregates that are predominantly detained by the 4.75 mm IS sieve and comply with the permissible specifications for the amount of fine material they contain are referred to as coarse aggregates. Fig 3.5 shows the 20mm size coarse aggregate.

The large aggregate could be any of the ensuing types:

- Crushed gravel or stone, which is obtained through the crushing of hard stone or gravel.
- Uncrushed gravel or stone that is produced as a result of the natural disintegration of rock.
- Partially crushed gravel or stone is obtained by blending the two aforementioned types.

Coarse aggregates are an essential component of building materials used in construction industries. They are classified based on their nominal size, which could be 40mm, 20mm, 16mm, and 12.5mm. The graded aggregate with a nominal size of 12.5mm implies that most of it can pass through the 12.5mm Indian Standard sieve. Coarse aggregates are a key component of concrete, which provides volume and strength to the final product. They are chemically inactive and serve as filler material, helping to create a homogeneous mass of concrete.

3.3.3.1 Physical Properties of Coarse Aggregate

- Specific gravity and density
- Soundness
- Shape and size
- Bulk density
- Surface moisture
- Elongation index
- Fineness modulus
- Silt content
- Water absorption

- Hardness

The previous paragraph highlighted various physical properties of coarse aggregates that can be determined through laboratory testing. However, for the purposes of a thesis, only a few of these properties may be necessary. These required properties can be obtained from the results of laboratory tests, which are briefly explained below.

3.3.3.1.1 Specific Gravity and Water Absorption Test on Coarse Aggregate

The specific gravity of a stone is a valuable indicator for its identification. In addition, the water absorption test provides an assessment of the aggregate's strength. Aggregates with high water absorption rates are usually more porous and are generally not considered suitable unless they pass other tests, such as strength, impact resistance, and hardness. These tests are conducted in accordance with the IS 2386 part 3 1963 standard.

Apparatus required

- Balance
- Oven
- Wire basket
- Two soft absorbent cloths
- Tray
- Airtight container
- Water-tight container

Test Procedure

To perform the water absorption test, a representative sample of the coarse aggregate, it shall be soaked in pure and uncontaminated water at a temperature ranging between 22°C and 32°C in a wire basket. There should be a minimum of 5 centimeters of water above the upper edge of the basket. Before immersing the sample, the specimen is subjected to an intensive cleansing process to eliminate any minute fragments and debris. In order to dislodge any trapped air in the sample, the basket holding it is elevated by 25 millimeters above the bottom of the container and permitted to descend 25 times at a frequency of roughly one descent per

second. Throughout this process, the basket holding the aggregate is constantly submerged in the water, and after the procedure is complete, the basket is still kept in the water for a duration of approximately 24 hours, with an acceptable range of plus or minus half an hour.

After the immersion and waiting period, the basket and sample are jolted and weighed in water within the temperature range of 22°C to 32°C. If weighing needs to be done in a different tank, the basket and sample are jolted 25 times in the new tank before weighing to ensure accuracy (weight A). Following a brief period of drainage, the basket, together with the aggregate, is taken out of the water. The aggregate is subsequently delicately discharged from the basket onto a parched fabric. The empty basket is returned to the water, jolted 25 times, and weighed in water (weight B).

The aggregate is then cautiously moved from the basket onto a fabric that is free of moisture, and delicately dried on the surface by using the fabric. Once the aggregate is emptied onto the first dry cloth, it is carefully moved onto a second dry cloth after the first cloth no longer removes any moisture. The aggregate is dispersed over the second cloth, not exceeding one stone's thickness. It is then left open to the air, sheltered from direct sunlight or any other origin of thermal energy for no less than 10 minutes or until it manifests as completely dehydrated on the surface. During this period, the aggregate is rotated at least once, and in case of difficulty, a mild flow of air at room temperature can be used to speed up the drying process. Finally, the aggregate is weighed (weight B).

After weighing the aggregate (weight B), it is placed in a shallow tray and put inside an oven with a temperature range of 100°C to 110°C for 24 +/- 1/2 hours. Once the time is up, the aggregate is taken out of the oven, allowed to cool in an airtight container, and then weighed again (weight C).

Calculation

$$\text{Specific gravity} = \frac{C}{B-A} = \frac{2.520}{2.520-1.62} = 2.739$$

$$\text{Water absorption} = \frac{100(B-C)}{c} = \frac{100(2.540-2.520)}{2.520} = 0.79\%$$

Where,

A = the weight of the aggregate when fully immersed in water, measured in grams ($A_1 - A_2$) = 1.62 kg

B = the weight of the aggregate in grams when it is surface dry but still saturated with water = 2.520 kg

C = the mass in grams of the aggregate after it has been dried in an oven at a specified temperature for a specific duration until it reaches a constant mass = 2.520 kg.

Results

- Specific gravity of coarse aggregate = 2.739
- Water absorption of coarse aggregate = 0.79%

3.3.4 Crushed Autoclaved Aerated Concrete (AAC) Block



Fig 3.6 Crushed AAC Block

AAC (Autoclaved Aerated Concrete) block is a lightweight and thermally-insulated building material used for constructing walls, floors, and roofs. It is produced by mixing natural raw materials such as cement, fly ash, lime, gypsum, sand, and aluminum powder in a specific ratio. The mixture is then poured into moulds and placed in an autoclave where it is cured and hardened under high pressure and temperature. This process creates numerous tiny air pockets within the block, making it lightweight and highly insulating. AAC blocks are environmentally friendly, have excellent sound insulation properties, and are resistant to fire, pests, and weathering, making them ideal for use in various types

of construction projects. Fig 3.6 shows that the AAC block waste is crushed as coarse aggregate

3.3.4.1 Physical Properties

- Water absorption
- Specific gravity
- Compressive strength
- Fire resistance
- Dry density
- Sound
- Thermal conductivity
- Colour

The previous paragraph listed various physical properties of Crushed AAC Block. However, for my thesis, I require only a subset of those properties. Some of these properties can be obtained from the manufacturing factory, while others must be determined through laboratory tests. Table 3.3 presents the properties of the AAC block. The following section provides a brief description of some laboratory tests that were conducted.

Table 3.3 Properties of AAC Block

S.NO	PROPERTIES	RESULTS
1	AAC Blocks Size	600 mm (L) x 200 mm (H) x 225 mm (W)
2	Compressive Strength	Above 3 N/mm ²
3	Dry Density	550 – 650 kg/m ³
4	Thermal Conductivity	0.122 W/ (M – K)
5	Sound	37 – 42 dB for 225 mm thickness block
6	Fire Resistance	4 – 6 hrs
7	Colour	Light Grey

3.3.4.1.1 Specific Gravity and Water Absorption Test on Crushed AAC Block

Measuring the specific gravity is a valuable technique to identify stones. Furthermore, the water absorption test provides insight into the strength of an aggregate. Aggregates with high water absorption rates are typically more porous and may not be suitable unless they meet acceptable standards for strength, impact resistance, hardness, and other tests. The IS 2386 part 3 1963 standard is followed during testing. As depicted in Figure 3.7, the crushed AAC block was immersed in water and weighed.



Fig 3.7 Specific Gravity and Water Absorption Test

Apparatus required

- Balance
- Oven
- Wire basket
- Two soft absorbent cloths
- Tray
- Airtight container
- Water-tight container

Test Procedure

To perform the water absorption test, a representative sample of the coarse aggregate, it shall be soaked in pure and uncontaminated water at a temperature ranging between 22°C and 32°C in a wire basket. There should be a minimum of 5 centimeters of water above the upper edge of the basket. Before immersing the sample, the specimen is subjected to an intensive cleansing process to eliminate any minute fragments and debris. In order to dislodge any trapped air in the sample,

the basket holding it is elevated by 25 millimeters above the bottom of the container and permitted to descend 25 times at a frequency of roughly one descent per second. Throughout this process, the basket holding the aggregate is constantly submerged in the water, and after the procedure is complete, the basket is still kept in the water for a duration of approximately 24 hours, with an acceptable range of plus or minus half an hour.

After the immersion and waiting period, the basket and sample are jolted and weighed in water within the temperature range of 22°C to 32°C. If weighing needs to be done in a different tank, the basket and sample are jolted 25 times in the new tank before weighing to ensure accuracy (weight A). Following a brief period of drainage, the basket, together with the aggregate, is taken out of the water. The aggregate is subsequently delicately discharged from the basket onto a parched fabric. The empty basket is returned to the water, jolted 25 times, and weighed in water (weight B).

The aggregate is then cautiously moved from the basket onto a fabric that is free of moisture, and delicately dried on the surface by using the fabric. Once the aggregate is emptied onto the first dry cloth, it is carefully moved onto a second dry cloth after the first cloth no longer removes any moisture. The aggregate is dispersed over the second cloth, not exceeding one stone's thickness. It is then left open to the air, sheltered from direct sunlight or any other origin of thermal energy for no less than 10 minutes or until it manifests as completely dehydrated on the surface. During this period, the aggregate is rotated at least once, and in case of difficulty, a mild flow of air at room temperature can be used to speed up the drying process. Finally, the aggregate is weighed (weight B).

After weighing the aggregate (weight B), it is placed in a shallow tray and put inside an oven with a temperature range of 100°C to 110°C for 24 +/- 1/2 hours. Once the time is up, the aggregate is taken out of the oven, allowed to cool in an airtight container, and then weighed again (weight C).

Calculation

$$\text{Specific gravity} = \frac{C}{B-A} = \frac{2.270}{2.070-1.222} = 0.65$$

$$\text{Water absorption} = \frac{100(B-C)}{c} = \frac{100(2.270-2.070)}{2.070} = 9.66\%$$

Where,

A = the weight of the aggregate when fully immersed in water, measured in grams (A₁-A₂) = 1.222 kg

B = the weight of the aggregate in grams when it is surface dry but still saturated with water = 2.270 kg

C = the mass in grams of the aggregate after it has been dried in an oven at a specified temperature for a specific duration until it reaches a constant mass = 2.070 kg.

Results

- Specific gravity of coarse aggregate = 0.65
- Water absorption of coarse aggregate = 9.66%

3.4 EXPERIMENTAL INVESTIGATION

3.4.1 Mix Design

The method used for the formulation of M30-grade concrete conforms to the standards outlined in IS: 10262 - 2019. The mix proportion obtained for the nominal M30 grade is 1:1.36: 2.49 with a w/c ratio of 0.43.

3.4.1.1 Mix Proportion

In the study, crushed AAC block was employed to partially substitute coarse aggregate within the range of 0%, 5%, 10%, and 15%. Moreover, suitable mix proportions were determined based on the test mixes. The investigation utilized the M30 grade with IS: 456-2000 design mix. Table 3.4 exhibits the mix proportions for both M30 Grade conventional and lightweight concrete that partially substitute crushed AAC block.

Table 3.4 Mix Proportions of M30 Grade Conventional and Lightweight Concrete with Partial Replacement of Crushed AAC Block

S.NO	SAMPLE	CEMENT	FINE AGGREGATE	COARSE AGGREGATE	CRUSHED AAC BLOCKS	WATER
1	A (0%)	450 kg/m ³	605 kg/m ³	1116 kg/m ³	0 kg/m ³	197 Lit
2	B (5%)	450 kg/m ³	605 kg/m ³	1060 kg/m ³	23 kg/m ³	197 Lit
3	C (10%)	450 kg/m ³	605 kg/m ³	1005 kg/m ³	46 kg/m ³	197 Lit
4	D (15%)	450 kg/m ³	605 kg/m ³	949 kg/m ³	69 kg/m ³	197 Lit

3.4.2 Concrete Specimen Casting Process

The term casting generally refers to the process of creating a solid object by pouring a liquid or semi-liquid material into a mould or form and allowing it to solidify. In the case of concrete, casting involves the formation of a solid, three-dimensional object or shape by combining cement, water, aggregates, and other additives.

To cast concrete elements, one needs to follow these steps:

- **Formwork preparation:** A form or mould is prepared based on the required The dimensions and geometry of the concrete member. The form can be made of various materials, such as wood, steel, or plastic.
- **Reinforcement placement:** In some cases, reinforcement such as reinforcing steel bars or mesh are positioned within the formwork to furnish supplementary durability to the concrete element.
- **Concrete mixing:** The concrete mixture is prepared by mixing cement, water, aggregates, and additives in the correct proportions. The mixing can be done manually or by using a concrete mixer.
- **Pouring:** The concrete mixture is poured into the formwork, taking care to avoid any air pockets or voids.

- Consolidation: The concrete mixture is consolidated or compacted to ensure that it is fully distributed throughout the formwork and there are no voids or air pockets. Consolidation can be done using tools such as vibrating screeds, poker vibrators, or rollers.
- Curing: After the concrete is placed, it is allowed to undergo a curing process for a specific duration, usually 28 days, to attain the desired strength and durability.
- Demoulding: Once the concrete has hardened, the formwork is removed, and the concrete element is released.

It is understood that proper execution of the casting process is essential for the safety and durability of concrete structures. The casting process is a critical step in the production of concrete elements, as it ensures that the final product is of the desired shape, size, and strength. Fig 3.8 shows that the Cube, Cylinder and Beams Mould with oil applied.

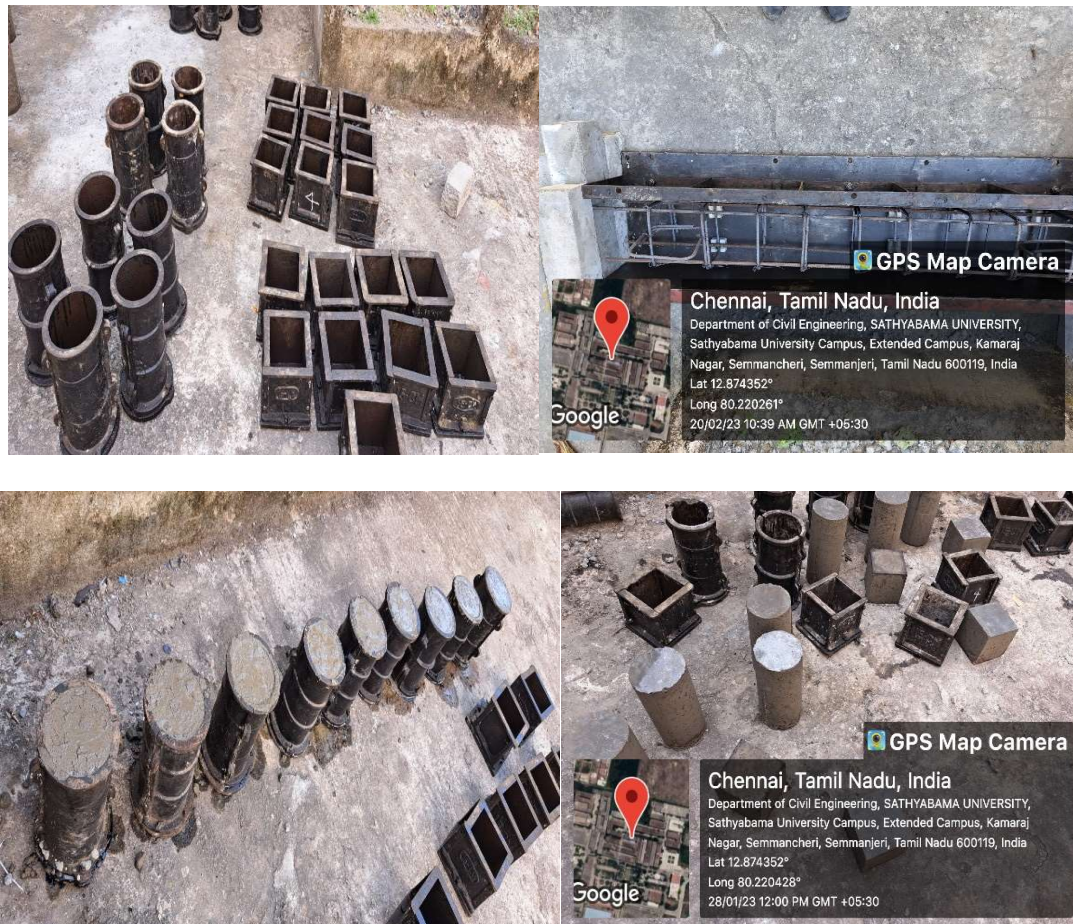


Fig 3.8 Casting Process

3.4.3 Reinforced Concrete Beams

Reinforced concrete is a highly important construction material that finds widespread use in Diverse engineering constructions, including edifices, bridges, hydroelectric and nuclear power stations, water treatment facilities, containment structures, and docks, among others, require it for safety and durability. Its properties of economy, efficiency, strength, and stiffness make it an attractive option for a diverse array of building and construction projects, creating direct and indirect employment opportunities. To design a dependable, viable, and secure edifice, it is crucial to understand the behaviour of structural elements during applied action. There are several approaches for examining the behavior of structural components.. One common approach is to experimentally study the behaviour of reinforced concrete beams at a macroscopic level. In contrast to theoretical computations that predict the internal distribution of compressive and tensile stresses, as well as deformations and deflections in beams, experimental techniques involve actual measurements of these parameters on physical structural elements. Another method involves finite element modelling, which provides an estimate of the behaviour of the element and allows for an evaluation of the experimental outcomes and finite element analysis results through a comparative analysis, thereby complementing the experimental results. Fig 3.9 Shows the Beam's Longitudinal and cross-section view.

3.4.3.1 Modelling of RCC Beams

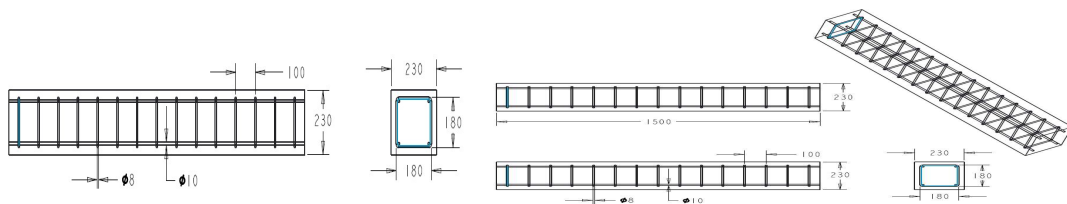


Fig 3.9 Beam Longitudinal and Cross-Section View



(a)

(b)



(c)

Fig 3.10 RCC Beam (a) Mould setup (b) Concrete Beam Casting (c) Curing

3.4.4 Experimental Tests and Results

The test on Fresh Concrete is,

- Slump Cone Test

The various test on hardened concrete is,

- Comparison of weight
- Compression Test on Concrete
- Split Tensile Strength of Concrete
- Young's Modulus of Concrete
- Flexural Behaviour on RC beam

The tests are conducted on concrete specimens to study microscopic images,

- Field Emission – Scanning Electronic Microscope Topography (FE-SEM)

3.4.5 Test on Fresh Concrete

3.4.5.1 Slump Cone Test

The objective of conducting a slump cone test on concrete is to evaluate its rheology or fluidity, which is a critical property of fresh concrete. The workability of

concrete refers to its ability to be placed and molded with ease, and concrete that exhibits good workability can be readily placed and compressed without any issues of segregation or compaction. Workability is capacity working without any extra labour and strength loss. The concrete strength depends upon the water percentage. Water percentage and measurements of slump are obtained from this test.. It is the vertical height of the fresh concrete compared to its mould height. Fig 3.11 shows the slump cone test on fresh concrete.

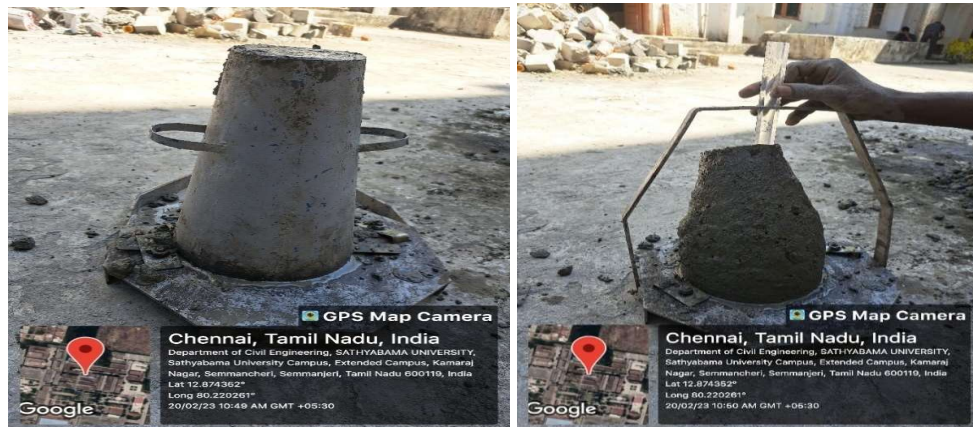


Fig 3.11 Slump Cone Test

The workability is determined by using the slump cone test in fresh concrete. The code book IS: 1199-1959 is required

- Slump cone
- Tamping rod
- Metallic sheet

Procedure

- Before starting the test, thoroughly clean the mould and ensure that its inner surface is free from moisture and old concrete residue.
- Place the mould on a smooth and clean surface and compact each layer of concrete using a tamping rod, making 25 equal strokes for each layer.
- Use a trowel to level the surface of each layer and remove any excess concrete.
- With caution and meticulousness, the vertical extractions are made from the concrete after compacting each layer.
- Allow the fresh concrete to subside and the difference in height between the top

of the slump cone and the highest point of the deformed concrete surface is measured to determine the degree of deformation.

- The slump value provides information about the workability of the fresh concrete.
- If the fresh concrete slumps uniformly, it is considered a true slump. If one-half of the fresh concrete slides down, it is known as a collapsed slump. A shear slump occurs when there exists a disparity in altitude between the summit of the mold and the mean measurement of the slump..
- Table 3.5 shows the slump value of fresh concrete with 0%, 5%, 10%, and 15% replacement of coarse aggregates with crushed AAC blocks.

Table 3.5 Slump Values of Fresh Concrete with 0%, 5%, 10% and 15% Replacement of Coarse Aggregates by Crushed AAC Blocks

PERCENTAGE OF CRUSHED AAC BLOCKS	SLUMP (mm)
0	75
5	69
10	40
15	64

3.4.6 Tests on Hardened Concrete

3.4.6.1 Comparison of Weight

After being removed from the mould, the cubes were weighed before being stored for curing. The cubes were weighed once more after 28 days of drying. Table 4.6 displays the Average Cube Specimen Weight Before and After Curing for both conventional and lightweight concrete and Table 3.7 displays the dry density of conventional and lightweight concrete.

Table 3.6 Average Weight of Cube Specimen Before and After Curing For both Conventional and Lightweight Concrete

% CRUSHED AAC BLOCK REPLACEMENT	AVERAGE WEIGHT BEFORE CURING	AVERAGE WEIGHT AFTER CURING	AVERAGE
0	8.162 kg	8.219 kg	8.191 kg
5	7.920 kg	7.886 kg	7.903 kg

10	7.669 kg	7.753 kg	7.711 kg
15	7.512 kg	7.489 kg	7.500 kg

Table 3.7 Dry Density of Conventional and Lightweight Concrete

S.NO	PERCENTAGE OF CRUSHED AAC BLOCK REPLACEMENT	DRY DENSITY IN kg/m ³
1	0	2426.96
2	5	2341.62
3	10	2284.74
4	15	2222.22

3.4.6.2 Compression Test on Concrete



Fig 3.12 Cube Specimen in Compression Testing Machine

Apparatus Required

- Non-porous enamel tray
- Trowel
- Cube Mould of size 150mm x 150mm x 150mm
- Platform Vibrator
- Compression Testing Machine
- Balance to Measure Weight

Procedure

- The specified amounts of cement, fine aggregate, and coarse aggregate are placed in a tray made of enamel, which does not absorb water, and are mixed together using a trowel for a duration of 1 minute.
- The required amount of water is added to the blend and blended thoroughly until a consistent hue is achieved is achieved.
- The mixing duration should be between 3 to 4 minutes.
- The freshly mixed concrete is immediately poured into a cube mould with dimensions of 150mm x 150mm x 150mm. The concrete is compacted using a tamping rod in a standard-specific manner.
- The mould is placed in a chamber with a temperature of 24°C + 2°C for 24 hours.
- The specimens are extracted from the formwork and submerged in clean water for curing for 28 days.
- Table 3.8 displays the average compressive strength values of both conventional and lightweight concrete for 7, 14, and 28 days.
- Fig 3.12 depicts the compressive testing machine used for testing cube specimens.

Table 3.8 Average Compressive Strength of both Conventional and Lightweight Concrete for 7, 14 and 28 days

S.NO	PERCENTAGE OF CRUSHED AAC BLOCKS REPLACEMENT	AVERAGE COMPRESSIVE STRENGTH IN N/mm ²		
		7 days	14 days	28 days
1	0	17.77	34.21	35.47
2	5	16.66	29.99	31.7
3	10	20.36	32.59	33.84
4	15	17.25	31.92	33.99

3.4.6.3 Split Tensile Strength of Concrete



Fig 3.13 Cylinder Specimen in Split Tensile Strength Test

Apparatus Required

- Compression Testing Machine
- Two Packing Strips of Plywood 30 cm long and 12 mm wide

Theory

Although concrete is strong in compression, it is relatively weak in tension because of its fragile quality, and it cannot resist direct tensile forces. When concrete is subjected to stretching forces, it tends to develop cracks. Therefore, it is essential to determine the stretching forces of concrete to estimate the stress level at which concrete structural elements may experience cracking.. To determine the tensile strength of concrete, a cylinder specimen is tested using a compressive testing machine, as shown in Figure 3.13.

Procedure

- Following 7 days of the curing process, the concrete sample is extracted from the water and dried with a dry cloth to remove any surface water.
- On each end of the specimen, two diametrically opposite lines are drawn to ensure they are on the same axial plane.
- Recorded before the testing process.
- Adjust the compression testing apparatus to the specified capacity..

- A plywood strip is fixed on the lower plate and the specimen is placed on it, ensuring that the marked lines are vertical and centered over the bottom plate.
- A supplementary plywood strip is situated over the sample, and the top plate is lowered to come in contact with the plywood strip.
- A load is applied ranging from 990 kg/min to 1485 kg/min.
- The load at which the specimen breaks, known as the breaking load P, is recorded.

Formula Used

As per IS 456 2000, the indirect tensile strength of concrete is $0.7 \times \sqrt{f_{ck}}$

The split tensile strength is calculated using the formula

$$T_{sp} = \frac{2 \times p}{\pi \times D \times L}$$

Where,

- P = Applied Load
- D = Diameter of the Specimen
- L = Length of the Specimen

Observation

Length of the Specimen = 30cm = 300 mm

Diameter of the Specification = 15 cm = 150 mm

The average split tensile strength of both conventional and lightweight concrete for 7, 14, and 28 days can be observed in Table 3.9.

Table 3.9 Average Split Tensile Strength of both Conventional and Lightweight Concrete for 7, 14 and 28 days

S.NO	PERCENTAGE OF CRUSHED AAC BLOCKS REPLACEMENT	AVERAGE SPLIT TENSILE STRENGTH IN N/mm ²		
		7 days	14 days	28 days
1	0	1.57	2.16	2.9

2	5	1.41	1.97	2.54
3	10	1.83	2.09	2.28
4	15	1.74	1.95	2.51

3.4.6.4 Young's Modulus of Concrete

Young's modulus is an essential material aspect that quantifies the resistance of concrete to deformation when subjected to tensile or compressive stress. It is the quotient of the applied stress to the strain in the elastic region of the stress-strain curve. However, determining the value of the E_c 's modulus can be influenced by various factors, such as the age and curing conditions of the concrete, its type and strength, and the testing method used. The compressor meter test conducted on a compression testing machine, as illustrated in Fig 3.14, is a widely accepted and reliable method for measuring Young's modulus of concrete.



Fig 3.14 Young's Modulus Test on Concrete

Apparatus Required

- Compressometer assembly with dial gauge
- Test specimen
- Scale
- Compression testing machine

Procedure

- Four cylindrical specimens with a diameter of 150 mm and a height of 300 mm are prepared under standard conditions.
- The dimensions of each specimen are measured after curing to determine their average diameter and height.
- The sample is then placed in a testing machine and aligned vertically and centrally on the loading plate with the load cell positioned above the specimen.
- A compressive load is applied to the specimen at a rate of 0.2 MPa/s until the load reaches approximately 40% of the expected maximum load, typically between 30 and 50 MPa.
- During loading, the deformation of the specimen is measured at several load levels, such as 20%, 40%, 60%, and 80% of the expected maximum load using a strain gauge or extensometer.
- The stress-strain curve is plotted using the load and deformation data, with the curve being linear up to the elastic limit of the material.
- The gradient of the linear part of the stress-strain curve is then calculated to determine Young's modulus of the concrete by dividing the stress by the strain.
- The process is then repeated for the remaining specimens, and the average Young's modulus is calculated.

Table 3.10 Stress and Strain Values of M30 Grade Conventional Concrete

Load (KN)	Stress (N/mm²)	Change in length (mm)	Strain	Young's modulus (Mpa)
25	1.414	0.014	4.69×10^{-5}	30129
50	2.829	0.028	9.4×10^{-5}	29911
75	4.244	0.041	1.39×10^{-4}	30529
100	5.658	0.056	1.87×10^{-4}	30144
125	7.073	0.071	2.36×10^{-4}	29872

150	8.488	0.085	2.85×10^{-4}	29712
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Table 3.11 Stress and Strain Values of M30 Grade Lightweight Concrete with 5% Replacement of Coarse Aggregate

Load (KN)	Stress (N/mm ²)	Change in length (mm)	Strain	Young's modulus (Mpa)
25	1.414	0.015	4.91×10^{-5}	28754
50	2.829	0.030	9.84×10^{-5}	28729
75	4.244	0.045	1.49×10^{-4}	28321
100	5.658	0.060	1.98×10^{-4}	28441
125	7.073	0.073	2.43×10^{-4}	29050
150	8.488	0.091	3.01×10^{-4}	28124

Table 3.12 Stress and Strain Values of M30 Grade Lightweight Concrete with 10% Replacement of Coarse Aggregate

Load (KN)	Stress (N/mm ²)	Change in length (mm)	Strain	Young's modulus (Mpa)
25	1.414	0.015	4.85×10^{-5}	29152
50	2.829	0.029	9.51×10^{-5}	29721
75	4.244	0.043	1.43×10^{-4}	29514
100	5.658	0.056	1.87×10^{-4}	30120
125	7.073	0.074	2.45×10^{-4}	28771

150	8.488	0.087	2.89×10^{-4}	29321
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**Table 3.13 Stress and Strain Values of M30 Grade Lightweight Concrete
with 15% Replacement of Coarse Aggregate**

Load (KN)	Stress (N/mm ²)	Change in length (mm)	Strain	Young's modulus (N/mm ²)
25	1.414	0.015	4.92×10^{-5}	28712
50	2.829	0.030	9.98×10^{-5}	28321
75	4.244	0.044	1.46×10^{-4}	28911
100	5.658	0.058	1.94×10^{-4}	29025
125	7.073	0.074	2.45×10^{-4}	28847
150	8.488	0.089	2.97×10^{-4}	28542

Results

Young's Modulus of Conventional concrete specimen = 30049.5 N/mm²

Young's Modulus of LWC - 5 specimen = 28569.83 N/mm²

Young's Modulus of LWC - 10 specimen = 29433.16 N/mm²

Young's Modulus of LWC - 15 specimen = 28726.33 N/mm²

3.4.6.5 Flexural Behaviour of RC Beam

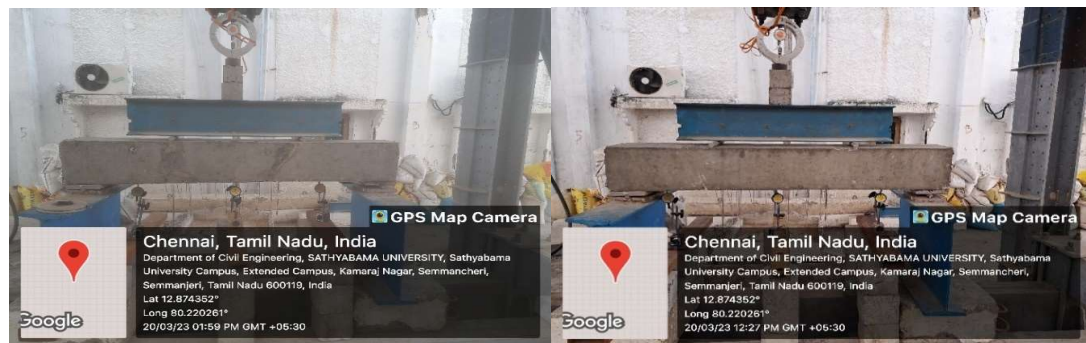
All four structural beam elements underwent a 4-point bending configuration test, with the pure bending span and the shear span both measuring 1400 mm in length. The vertical load was applied under displacement control, with a rate of 1 mm/min, until visible concrete crushing and spalling occurred on the top surface of the beams. In order to quantify the midspan deflections and loading point deflections of the beam, three linear variable differential transformers (LVDTs) were installed in the

pure bending span. For the strengthened beams, the LVDT arrangement was designed based on the strengthened scheme's configuration for each beam. Fig 3.15 displays the casted RCC beams that were tested on the Hydraulic loading frame machine, and Fig 3.16 illustrates the development of fissures in the RCC beams after the load was applied.



(a) Conventional Beam

(b) LWRC - 5



(c) LWRC - 10

(d) LWRC - 15

Fig 3.15 RCC Beams in Four-point Loading

Apparatus Required

- RC beam specimen
- Loading frame
- Hydraulic Jack
- Load Cell for the measurement of load
- LVDT (or) dial gauges for the measurements of deflections

Procedure

- The RC beam has a square shaped profile of 230x230mm and a length of 1500mm, reinforced with 4 10mm diameter bars (2 top, 2 bottoms) and 6mm diameter stirrups spaced at 100mm c/c.
- A specific concrete mixture was employed for fabricating the beam and reference specimens, the specimens, after casting, were marked with a grid line and coated with a layer of white-wash to aid in identifying and marking the pattern of cracks that may form on their surface.
- The beam was subjected to testing by means of a universal testing apparatus or a loading mechanism with 2-point loading to produce flexure failure, and deflections were measured using dial gauges fixed at three locations.
- Load was applied gradually using a hydraulic jack and a proving ring to assess the load level, with displacement measurements were recorded at regular intervals during the testing of the beam. The first cracking load and corresponding deflections were recorded, followed by further load application leading to crack propagation and widening.
- The ultimate level of the load was reached before failure, and The bending moment corresponding to the load level was ascertained.
- Theoretical moment of resistance to cracking was computed and compared against the experimental outcomes.
- Stresses developed in concrete and steel during the linear cracked phase were computed using the principles of strength of materials, and the deflection of the beam under load was calculated using the Modulus of Elasticity of the RC beam, which was obtained by substituting the experimental deflection value into the formula.
- The experimental results for the four beam specimens are presented in Table 3.14.



(a) Conventional Beam

(b) LWRC – 5



(c) LWRC - 10

(d) LWRC - 15

Fig 3.16 RCC Beams crack pattern

Table 3.14 Experimental Deflection Results for Four Beam Specimens

Sl.No	Load (KN)	Displacement in 'mm'			
		B1-CRC	B2 – LWRC - 5	B3 – LWRC - 10	B4 – LWRC - 15
1	10	0.24	0.24	0.18	0.21
2	20	0.32	0.30	0.28	0.3
3	30	0.50	0.52	0.45	0.48
4	40	0.77	0.70	0.7	0.73
5	50	1.01	0.98	0.92	0.97
6	60	1.32	1.25	1.21	1.28
7	70	1.75	1.63	1.60	1.58

8	80	2.10	2.12	1.98	2.04
9	90	2.50	2.27	2.18	2.27
10	100	2.73	2.62	2.40	2.59

3.4.7 Microscopic Images Investigation

3.4.7.1 Field Emission – Scanning Electronic Microscope Topography (FE-SEM)

FE-SEM is a potent imaging technique with a wide range of applications in many disciplines, including biology, nanotechnology, materials science, and many more. It functions by using an electron beam that is focused onto a sample, and the images that are produced give precise topographical and morphological details about the sample's surface. FESEM provides various benefits over conventional scanning electron microscopes (SEM), including increased surface sensitivity, better contrast, and higher resolution. It is a useful tool for a variety of applications because it also enables the imaging of non-conductive samples without the need for a conductive coating.

After 28 days curing of my concrete cylinder specimen at 0% and 10% replacement of coarse aggregate is chipped at the inner side of the specimen and used those chipped specimens to carry out the FE-SEM test in the laboratory. Few images are obtained at 50 micrometres and 260 micrometres for sample 1 and sample 2 respectively. Fig 3.17 shows the SEM images of the cylinder samples with 0% and 10% replacement.

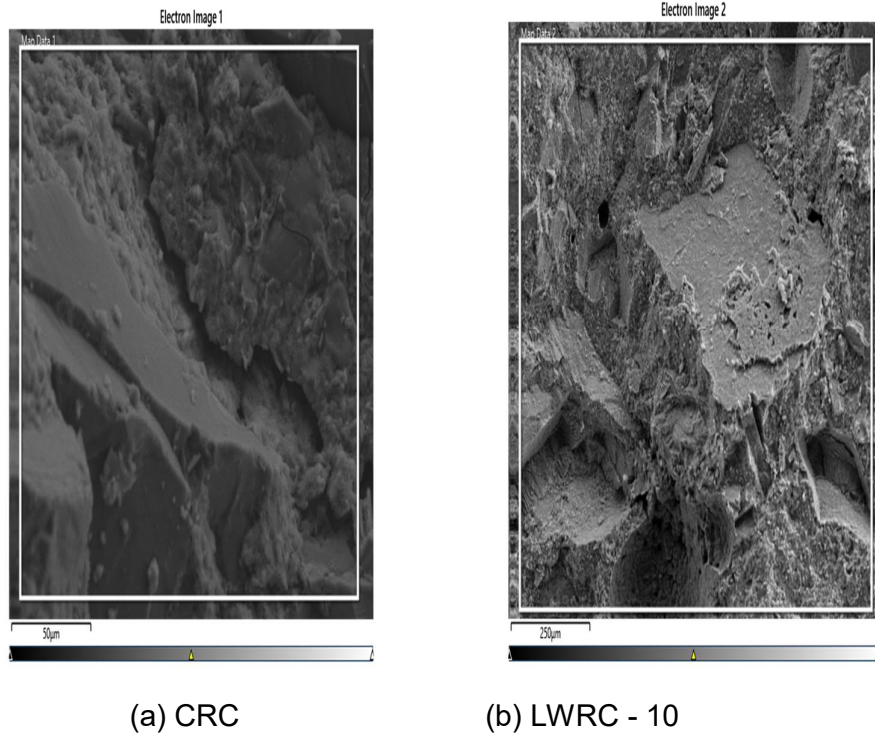


Fig 3.17 FE-SEM Images

SEM images were taken from the cylinder specimens with 0% and 10% replacement of crushed AAC block after 28 days of curing, as shown in Figure 3.17. Sample 1 images were taken at 50 micrometres and Sample 2 images were taken at 250 micrometres.

CHAPTER 4

ANALYTICAL INVESTIGATION

4.1 ANSYS

The ANSYS Mechanical software is a powerful tool that employs finite element analysis techniques to create computer models of various components, structures, electronics, and machines. It enables engineers and designers to analyse and evaluate the performance of these models under different conditions, such as mechanical loading, temperature variation, fluid flow, and electromagnetism. Using ANSYS Mechanical, it is possible to simulate and analyse the potency, tenacity, flexibility, thermal dissipation, and other characteristics of these models. The software provides a comprehensive solution for performing structural and thermal simulations, and it is widely used in various industries, such as aerospace, automotive, civil engineering, and electronics, to name a few.

Engineers use ANSYS to assess the efficacy of a product under various conditions without the need to physically build test products or conduct crash tests. This is achieved by breaking down the product into smaller components that can be modelled and tested individually using finite element analysis techniques. ANSYS allows engineers to assess how a product will operate under varying specifications, including mechanical loading, temperature variation, fluid flow, and electromagnetism. The software provides a comprehensive solution for performing structural and thermal simulations, and it is extensively employed in a broad range of industries, including aerospace, automotive, civil engineering, electronics, and numerous others.

To use ANSYS, the user first specifies the dimensions of the object and adds information about its physical properties, such as weight, pressure, and temperature. Then, the software can simulate and analyze various effects over time, including motion, cyclic loading, cracks, fluid dynamics, thermal distribution, and electromagnetic performance. This allows users to test and evaluate how a product will operate in varying circumstances without requiring to physically build and test prototypes.

ANSYS develops simulation software used to model and analyze structures, electronics, and machines. Engineers and designers can use ANSYS Mechanical to simulate and evaluate the performance of their designs under different conditions such as mechanical loading, temperature variation, fluid flow, and electromagnetism. ANSYS is widely used in various industries, including aerospace, automotive, civil engineering, and electronics. Additionally, ANSYS offers software for data management, academic research, and teaching.

4.1.1 Advantages

- ANSYS is a simulation software that is capable of importing 3D and 2D geometries from various CAD software integrated with modeling tools such as Design Modeller and Space Claim.
- ANSYS is known for its accurate and realistic simulations due to the range of contact methods, simulations that account for time-dependent effects, and material models that consider nonlinearity..
- ANSYS has the capability to consolidate different physical phenomena into a single platform and carry out analyses, such as thermal analysis with structural and fluid flow analysis with thermal and structural.
- ANSYS aim is a product that incorporate multiple physical phenomena on a single platform.
- ANSYS can optimize geometrical design, and boundary conditions, and analyze the product's behaviour under various criteria.

4.1.2 Disadvantages

- The disadvantage is that the simulation is only as good as the input and the representation of the process. It takes time and skill to build a command of the simulation environment and the simulated elements.
- The simulation output may provide vexing and seemingly contradictory results. When explaining the results, expect to be challenged regarding the validity of inputs and the processing assumptions. As much as we might want it to be otherwise, the simulation is not reality.

4.1.3 Uses of ANSYS

- Ansys develops simulation software for designing and testing products, semiconductors, and other systems. Its software is used to create simulations that assess factors like durability, temperature, fluid dynamics, and electromagnetic properties.
- ANSYS is a software company that specializes in developing and providing engineers with finite element analysis software. This software enables engineers to create and analyze computer models of structures, electronics, and machine components. ANSYS software allows engineers to simulate various attributes of these models, such as robustness, resilience, flexibility, temperature distribution, electromagnetic interaction, fluidity, and other traits. By using ANSYS software, engineers can accurately analyze and optimize designs before constructing physical prototypes, saving time and reducing costs.

4.2 FINITE ELEMENT ANALYSIS METHOD

FEM is a numerical approach utilized to tackle engineering and mathematical physics problems. Its applications commonly involve analyzing problems related to mechanics of deformable bodies, thermal convection, hydrodynamics, diffusion, and electric potential. These problems can be complex and require analytical solutions to boundary value problems. FEM offers a solution by dividing the problem domain into smaller elements. Each element is represented by a set of algebraic equations that are solved numerically to approximate the solution. This approach is extensively used in industry and research to design and optimize a variety of engineering systems and structures.

To elaborate further, the FEM is a computational approach used to solve intricate problems in engineering and mathematical physics. The method divides the problem domain into a finite number of subdomains or finite elements and then uses mathematical equations to approximate the behaviour of the unknown function within each element. The equations are then combined to form a system of algebraic equations that can be solved numerically using computers. This approach allows engineers and scientists to analyze a wide range of systems and structures with varying complexity, including those involving multiple physical phenomena. The FEM has become a widely used tool in industry and research due to its ability to optimize designs and predict the behaviour of structures and systems under various conditions.

To obtain a solution for the entire problem, the simple equations representing the countable elements are combined into a system of simultaneous equation. FEM utilizes vibrational methods from the euler-lagrange equation to approximate the solution by reducing an affiliated error function.

4.2.1 Working of FEA

When running a finite element analysis (FEA) simulation, the first step is to generate a mesh, which consists of numerous small elements that make up the 3D object being analysed. The mesh is created to convert the physical object into mathematical points, which are used to perform calculations. Modulating the mesh density of the complexity required for the simulation. Computations are executed for each discrete element or node present in the mesh, and the outcomes are synthesized to furnish a comprehensive analysis of the structure.

In an FEA simulation, the mesh represents the physical object through a series of mathematical points, which are analysed to provide results. As the mesh is a collection of discrete points, interpolation is required between these points to obtain approximate values. These approximations are typically accurate enough to provide useful results. The mesh is made up of nodal points where mathematically derived data, and these points tend to be concentrated around zones of transformation or boundaries in the object's design.

4.2.2 Application of FEA

- Examination of the structural integrity of an advertising roof sign under wind pressure loads of 120km/h.
- Structural analysis of a mechanism experiencing gyroscopic effects.
- Evaluation of the structural integrity of an articulated seat under varying loads from the actuators.

4.2.3 Advantages of FEA analysis

- Finite element analysis (FEA) provides detailed and comprehensive results, allowing for the prediction of physical responses at any location, even those that may have been overlooked in an analytical approach.
- FEA enables secure simulation of conceivably hazardous, reliable simulation of unsafe load scenarios and failure mechanisms.
- Optimization of the model is achievable with FEA, as Multiple failure modes or physical events can be examined in a single model.

- FEA allows for concurrent computation and visualization of a wide range of substantial aspects such as stress or temperature, enabling designers to analyze performance and explore Potential alterations.
- FEA can be used to extrapolate previously obtained experimental findings through parametric analysis of validated models.
- FEA has a comparatively small investment cost and provides rapid calculation time for most applications.

4.3 STRUCTURAL ANALYSIS

ANSYS structural analysis software enables engineers to simulate a wide range of structural behaviours and phenomena, including linear static analysis for calculating stresses and deformations, modal analysis for studying oscillation features and state of the art time dependent non-linear analysis that considers complex dynamic effects. The software can comprehensively model and analyze every structural aspect of a product, providing designers with the ability to optimize designs and identify potential issues in a virtual environment, minimizing the need for costly physical prototypes. ANSYS software allows for the safe simulation of destructive or dangerous load conditions, and the simultaneous calculation and visualization of a wide range of physical parameters, allowing for rapid performance analysis and design optimization. Additionally, ANSYS software provides the ability to extrapolate experimental results through parametric analyses of validated models, resulting in lower investment and quicker calculation times for most applications.

4.4 PROCEDURE ANALYSIS

ANSYS may be a finite component modelling software system for the numerical resolution of a large sort of mechanical issues. It will perform structural analysis (linear & non-linear), thermal analysis, magnetic attraction issues, Fluid analysis, etc.

It is straightforward to perform analysis with the user interface technique. A graphical interface is developed, which makes the software system easy.

Finite element analysis solution can be divided into 3 main stages:

- Pre-processing stage
- Solution
- Post-processing

4.5 PRE-PROCESSING STAGE

In the pre-processing stage, the subsequent major steps area unit involved

- Import or Create geometry (using Creo Parametric)
- Define element type (Tetrahedrons)
- Define material properties (Concrete M30, Biaxial Geo Grid, & Steel Fiber)
- Meshing
- Applying Loads
- Applying constraints, i.e., boundary conditions (fixed support etc.)

4.6 SOLUTION

- Solving problem

4.7 POST-PROCESSING

- One of the foremost necessary steps is to look at the results of the analysis to know how the applied masses affect our design.
- Using this post-processor, we can see Deformation, Stress, etc.

4.8 ANALYSIS USING ANSYS SOFTWARE

In ANSYS a linear, 1D component existing in 3D space or the X-Y plane. These deformations consist of axial stretch, curvature change (bending) and torsion.

A mesh is a configuration of discrete or finite elements established on top of a Finite Element Analysis (FEA) model. In ANSYS meshing is the process of dividing the geometry into finite element model or mesh. Fig 4.1 shows the workspace in ANSYS software.

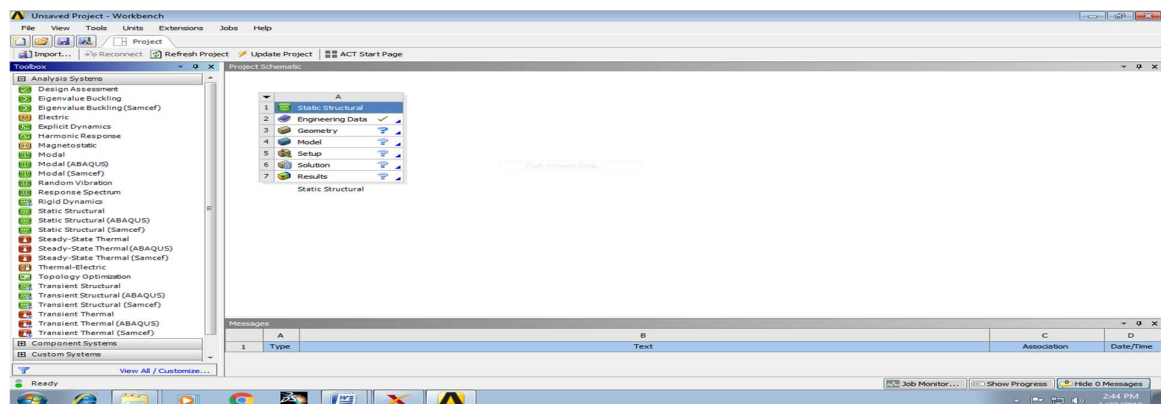


Fig 4.1 ANSYS - Work Bench

4.8.1 Modelling Framework

The principal focus of this research is to develop a modelling methodology that precisely represents the bending behaviour of beams. Several aspects of practical and theoretical importance are encompassed, including material modelling approaches, choice of element type, several interfaces, meshpartitioning, convergence analysis and boundary condition.

4.8.2 Part module

The first step in the modelling of the finite element is to define the part parts. The following Fig shows the sections to be modelled in this study. The dimension of the beam is 230mm x 230mm and the length of the beam is 1500mm. Fig 4.2 Shows the Reinforcement model.

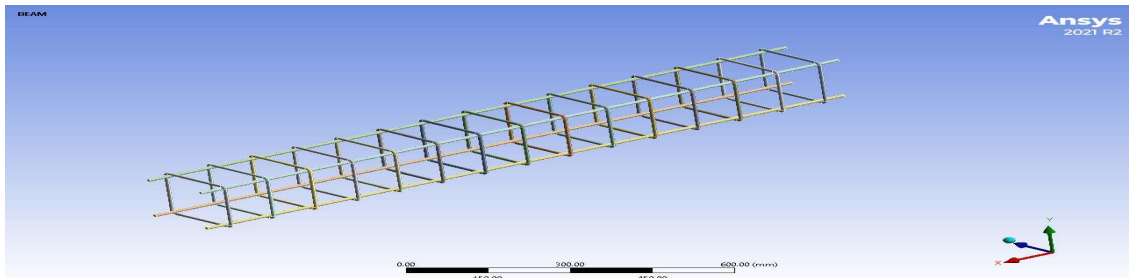


Fig 4.2 Reinforcement Details

4.8.3 Property Module

In finite element modelling, defining the material and section properties is a crucial step. This involves specifying the characteristics of the material being used, such as its yield stress, and determining the appropriate section thickness. For example, a composite beam may be made up of both concrete and structural steel, each with its own distinct properties.

To accurately model the beam, the properties of both materials must be defined and assigned accordingly. This information is typically stored in a table, such as Table 4.1, which outlines the properties of conventional and lightweight concrete beams used in ANSYS analysis. This allows for a comprehensive and accurate simulation of the structural behavior under various load conditions.

Table 4.1 Properties Used in ANSYS Beam RCC Models

PROPERTIES	PERCENTAGE REPLACEMENT			
	0%	5%	10%	15%
Compressive Strength at 28 days	35.47 Mpa	31.7 Mpa	33.84 Mpa	33.99 Mpa
Young's modulus	30.04 Gpa	28.56 Gpa	29.43 Gpa	28.72 Gpa
Poisson's Ratio	0.177	0.15	0.146	0.166

4.8.4 Load module

The step-by-step approach is a useful method for capturing changes in loading, boundary conditions, component interactions, and other modifications that may occur during the analysis process. In finite element modelling, the load module is used to assign boundary conditions, specifically the Mechanical - Displacement/Rotation type in the form of a step. Figure 4.3 depicts a beam model with a Two-Point load, while Figure 4.4 illustrates the support condition in the beam model.

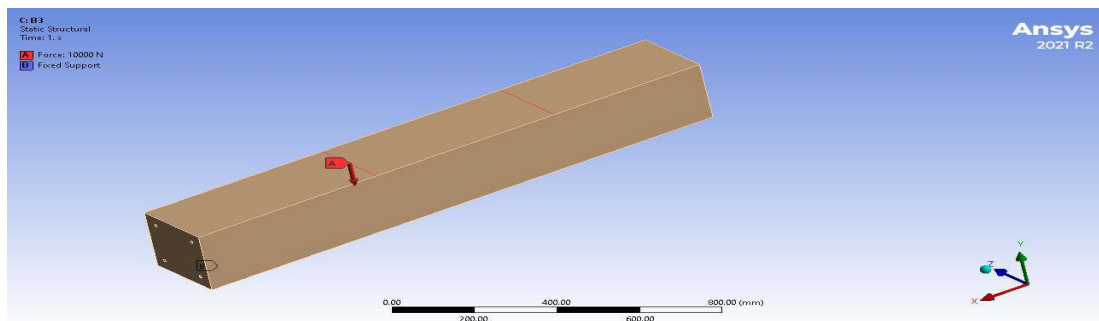


Fig 4.3 Two-Point Load in beam model

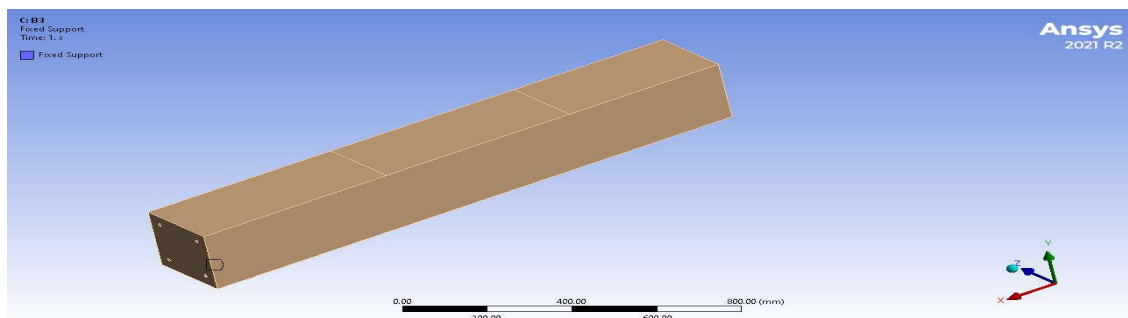


Fig 4.4 Support condition in beam model

4.8.5 Mesh module

The meshing process is an essential step in finite element analysis that involves dividing the model into small elements to facilitate numerical calculations. Abaqus offers a convenient meshing technique that doesn't require pre-defined mesh patterns, making it accessible to users of varying expertise levels. However, meshing complex geometry can be a challenging and frustrating task. To overcome this, meshing algorithms and software have been improved, leading to the development of cleaner and more uniform meshing techniques for structural analysis. The focus of this post is on the use of toolsets to enhance mesh quality during the partitioning or division process. In this particular analysis, ANSYS was used to mesh beams, and Fig 4.5 illustrates the meshing of an RCC beam model.

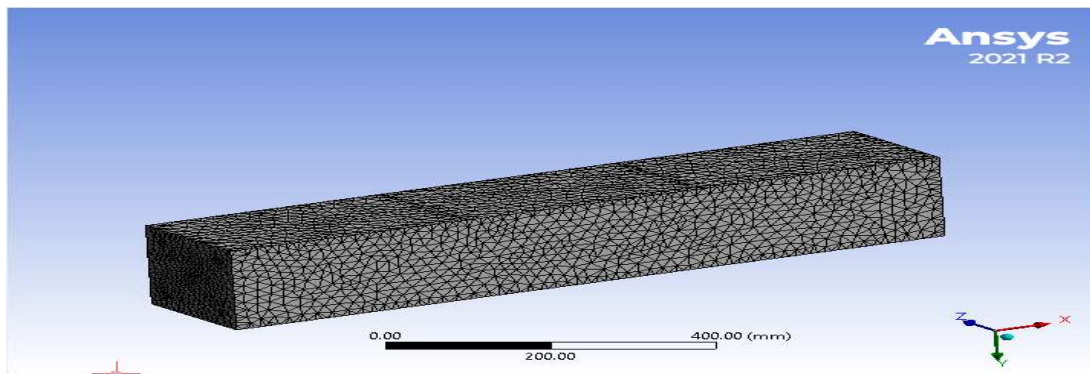


Fig 4.5 Meshing of RCC Beam

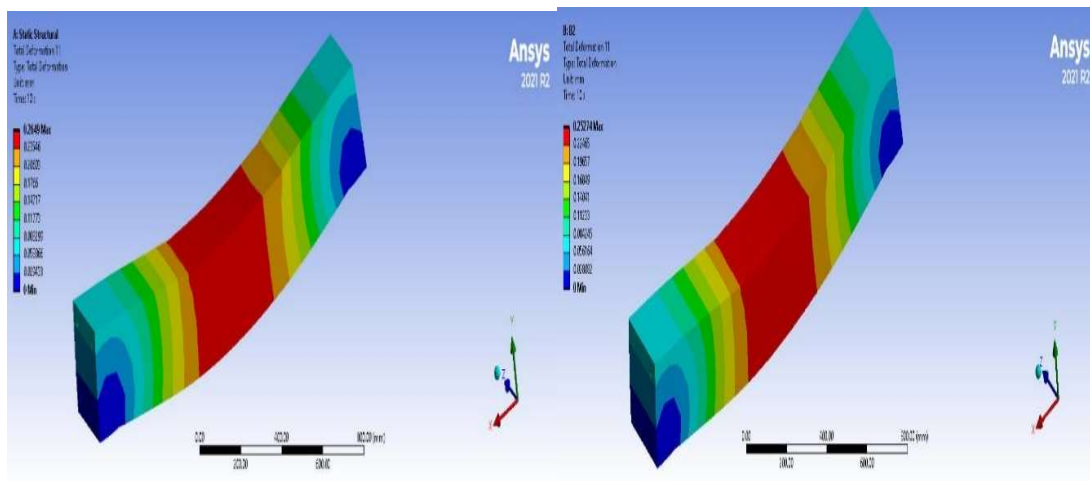
4.9 Analysis Results

Table 4.3 Analytical Results for Four Models

SL NO	Load (KN)	Displacement in 'mm'			
		B1-CRC	B2 – LWRC - 5	B3 – LWRC - 10	B4 – LWRC - 15
1	10	0.216	0.252	0.222	0.231
2	20	0.529	0.505	0.444	0.462
3	30	0.794	0.758	0.666	0.694
4	40	1.051	1.010	0.888	0.925
5	50	1.324	1.263	1.110	1.157
6	60	1.589	1.516	1.332	1.388
7	70	1.854	1.769	1.555	1.620

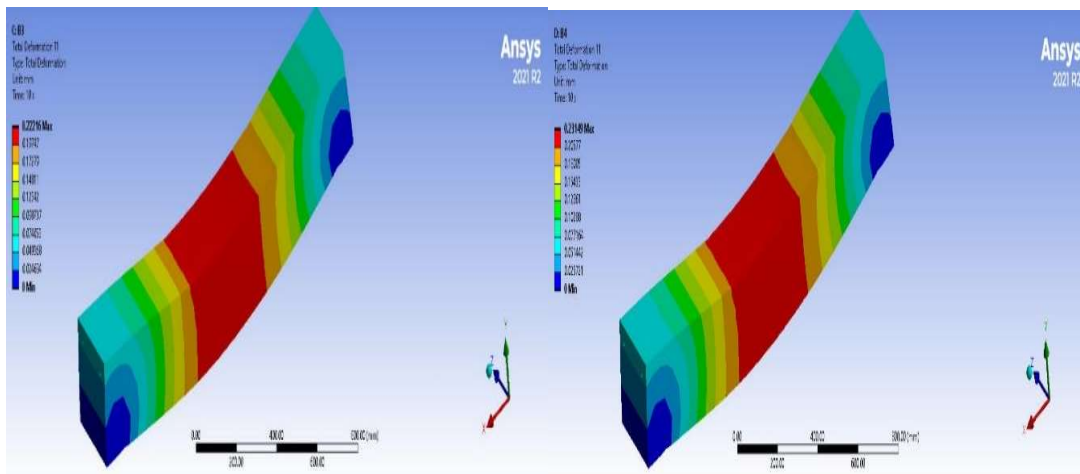
8	80	2.119	2.021	1.777	1.851
9	90	2.384	2.274	1.999	2.083
10	100	2.649	2.527	2.221	2.314

Models of four beams with varying percentages were created in ANSYS, and material properties obtained from experimental investigations of conventional and lightweight concrete specimens were applied to the models. The beams were subjected to loads, and their deflection (in mm) and deflected beam images were obtained. Table 4.3 and Fig. 4.6 shows the Analytical results and images.



(a) CRC

(b) LWRC - 5



(c) LWRC - 10

(d) LWRC - 15

Fig 4.6 Deflection Results from ANSYS analysis

CHAPTER 5

RESULTS AND DISCUSSION

This chapter discussed the effects of replacing 5%, 10%, and 15% of the coarse aggregate with crushed AAC block on the properties of conventional concrete, including density, compressive strength, split-tensile strength, and deflection behaviour of concrete specimens and beams.

5.1 CONCRETE DENSITY

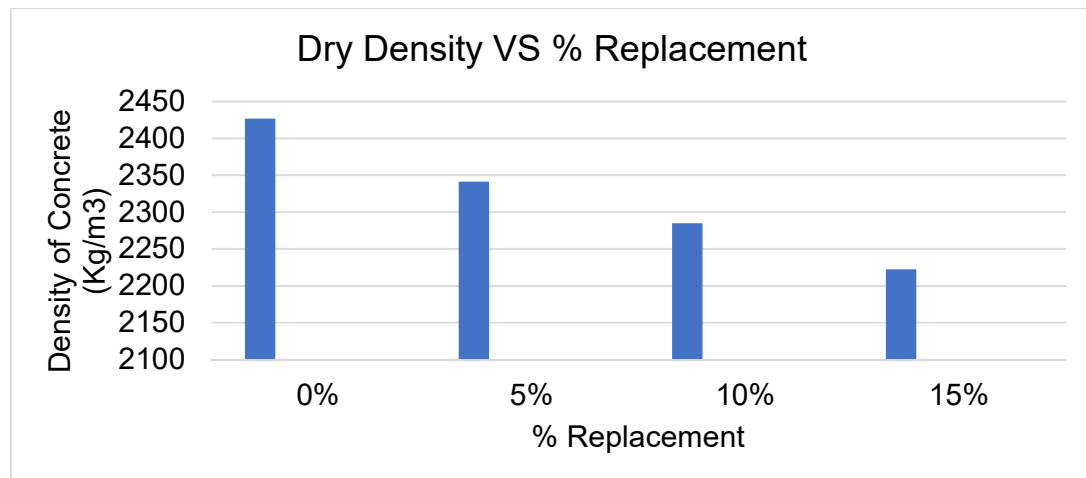


Fig 5.1 Comparison between Dry Density of Conventional and Lightweight Concrete

The various concrete cube specimen's density was plotted in the graph with different mixes [i.e... 0%, 5%, 10% and 15%] replacement in the x-axis and corresponding Dry density [kg/m^3] in the y axis and compared are shown in figure 5.1. It clearly shows that the increase in percentage replacement of coarse aggregate by crushed AAC block reduces the concrete density by about 86 kg/m^3 compared to the conventional concrete. So, it is in line with the lightweight concrete concept of reducing dead weight.

5.2 COMPRESSIVE STRENGTH AND SPLIT-TENSILE STRENGTH TEST

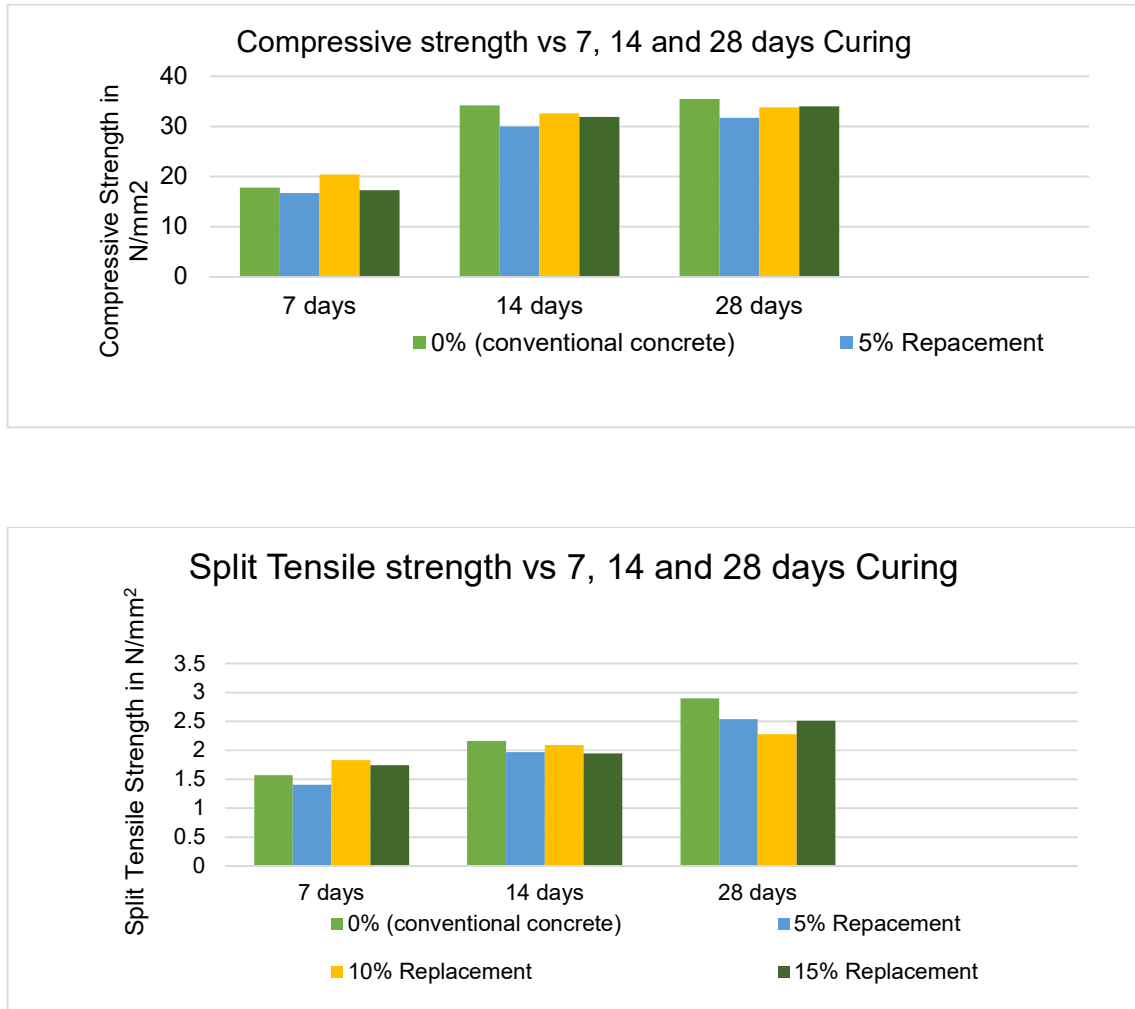


Fig 5.2 Comparison between Compressive Strength and Split-Tensile Strength of Conventional and Lightweight Concrete

The various concrete cube and cylinder specimen's compressive strength and split-tensile strength are plotted in the graph with the 7, 14 and 28 days of curing period in X-axis and the corresponding compressive and split-tensile strength in Y-axis and the results are compared as shown in the figure 5.2. it clearly shows that the compressive strength of 10% crushed AAC block replacement of coarse

aggregate provides a significant increase in compressive strength of 2.59 N/mm^2 after 7 days of curing compared to conventional concrete but it shows a slight decrease in compressive strength of about 1.6 N/mm^2 after 14 and 28 days of curing compared to conventional concrete.

In case of split-tensile strength 10% replacement of crushed AAC block as coarse aggregate shows significant increase in split-tensile strength compared to conventional concrete after 7 days of curing but it provides decrease in the split-tensile strength on 14 and 28 days of curing compared to conventional concrete. But if we observe the Figure 5.2 we can see that the split-tensile strength of 5% and 15% percentage shows very slight decrease of about 0.20 N/mm^2 and 0.39 N/mm^2 compared to conventional concrete.

5.3 FLEXURAL BEHAVIOUR OF RCC BEAMS

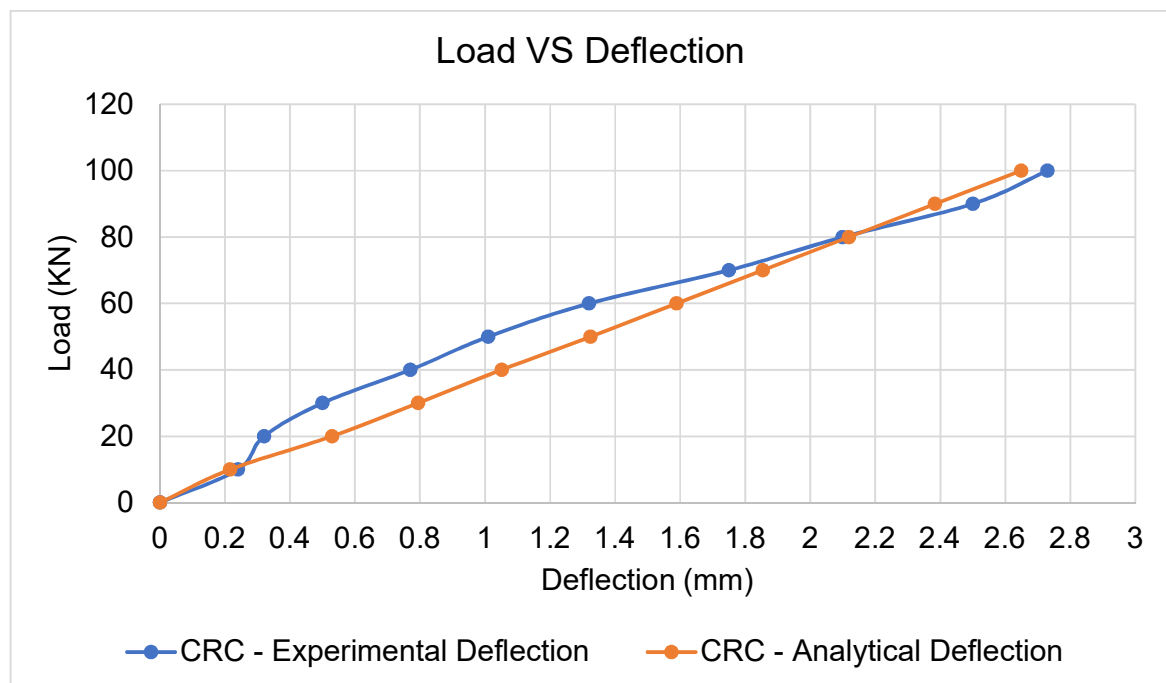


Fig 5.3 Comparison between Load Vs Deflection for Experimental and Analytical Results of Conventional Concrete

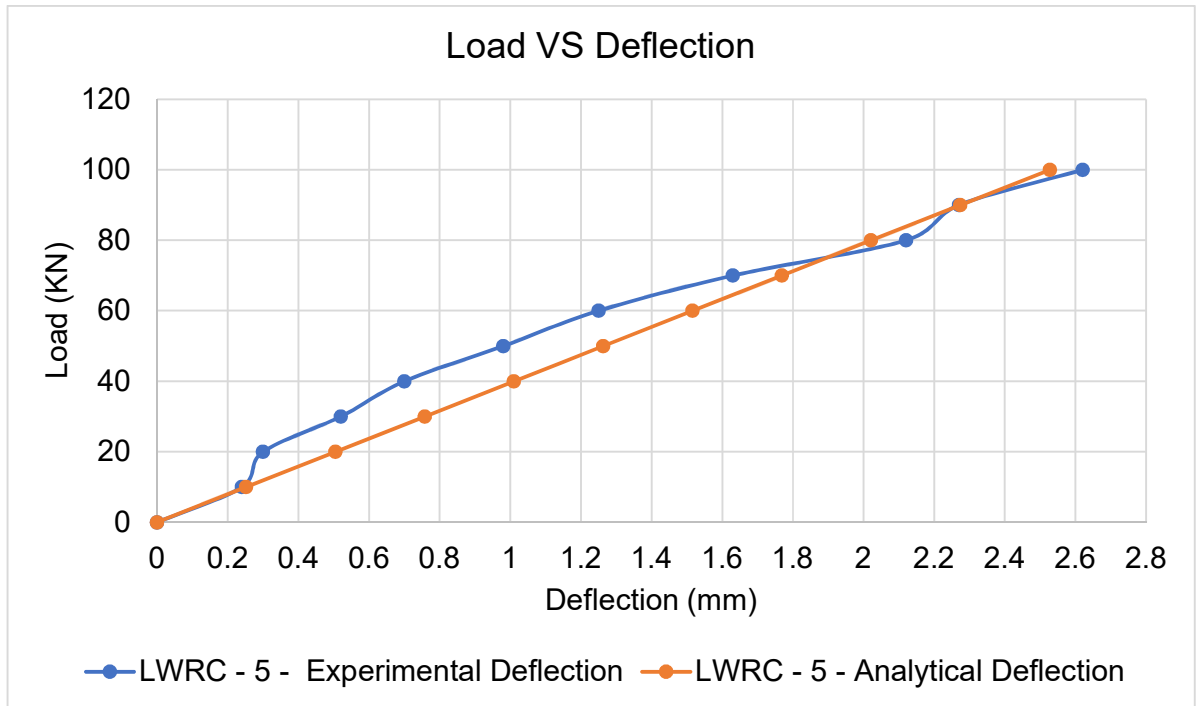


Fig 5.4 Comparison between Load Vs Deflection for Experimental and Analytical Results of Lightweight Concrete With 5% Replacement

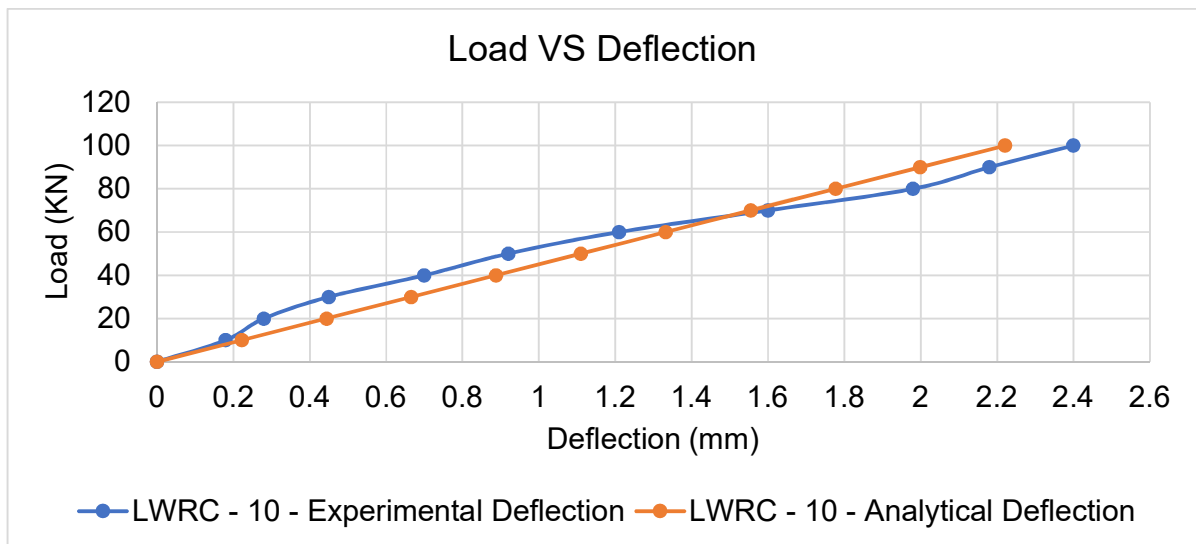


Fig 5.5 Comparison between Load Vs Deflection for Experimental and Analytical Results of Lightweight Concrete With 10% Replacement

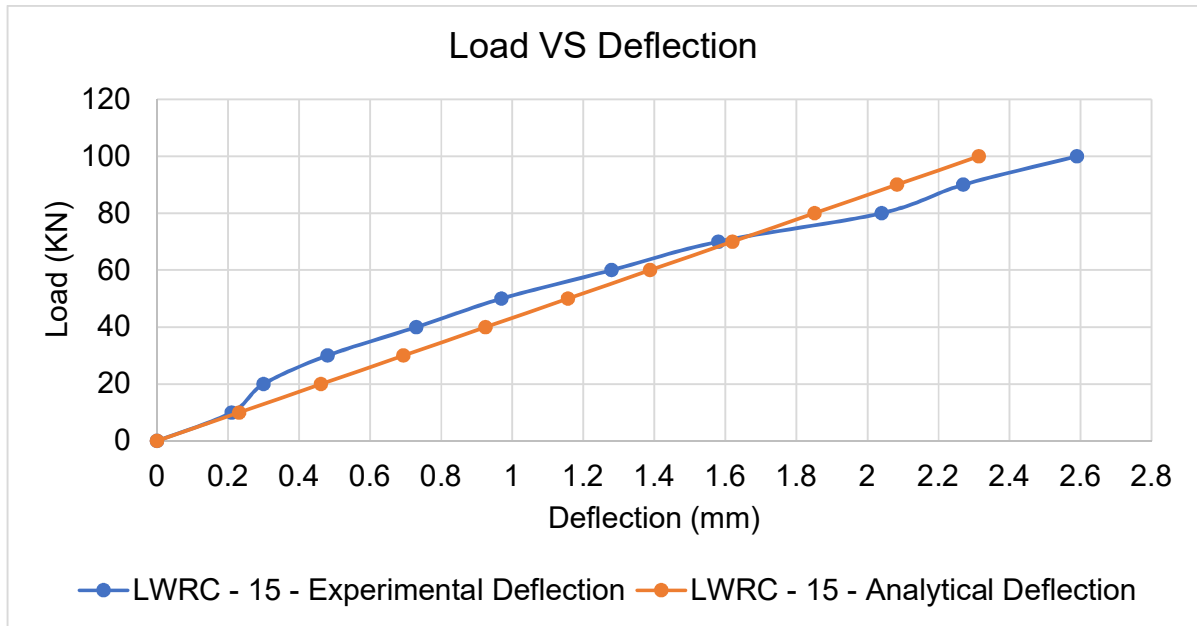


Fig 5.6 Comparison between Load Vs Deflection for Experimental and Analytical Results of Lightweight Concrete With 15% Replacement

The deflection values of four different beam models with varying percentages were compared in both experimental and analytical results. The ANSYS software was used to create the beam models, and the material properties were obtained from experimental investigations of conventional and lightweight concrete specimens. Deflection and deflected beam images were obtained after the beams were subjected to loads.

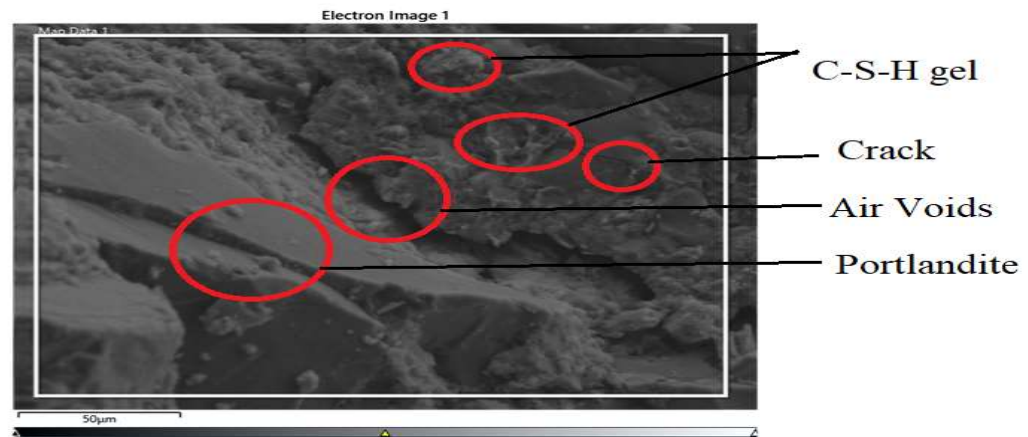
The results were plotted in a graph with Deflection (mm) in X-axis and corresponding Load (KN) in Y-axis and compared from Figure 6.3 to Figure 6.6. The load deflection curve on the figure was linear for analytical results, but it was not clearly linear for experimental results, which showed a gradual increase in deflection over the load increase up to 70 KN. The experimental deflection values were slightly higher compared to analytical deflection.

The conventional concrete beam had slightly higher deflection values compared to the other beam specimens, namely LWRC -5, LWRC – 10, and LWRC - 15, in both experimental and analytical results. LWRC - 10 had less deflection compared to the other beam specimens.

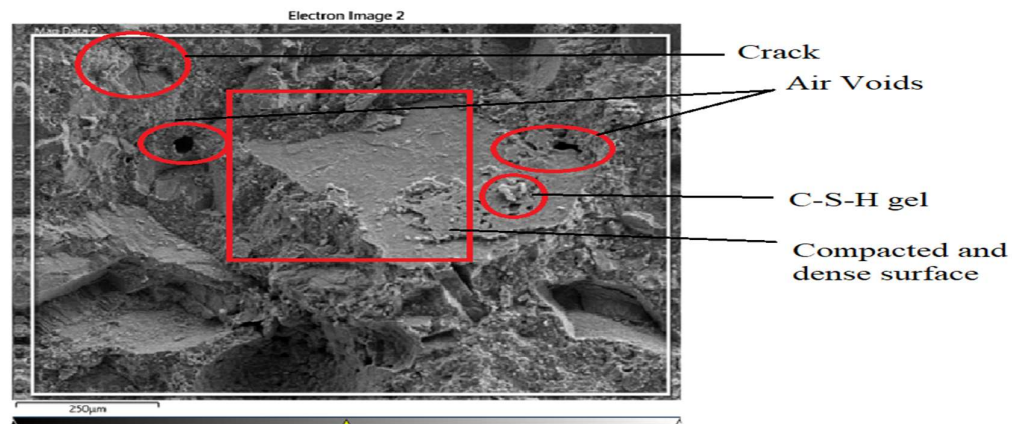
Analytical results showed a linear pattern because deflection values were calculated under empirical formulas and analysed based on optimum environmental

conditions. On the other hand, experimental results showed varying degrees of deflection values due to testing of the beam under uncontrollable conditions.

5.4 FIELD EMISSION SCANNING ELECTRONIC MICROSCOPE TOPOGRAPHY (FE-SEM)



(a)– CRC



(b)- LWRC - 10

Fig 5.7 FE-SEM Images

In this section, the microstructural analysis of both lightweight and conventional concrete is discussed. Samples from both types of concrete were examined, with a focus on the interactions between the different phases of the materials.

Upon examination of sample 2, inconsistencies were found in the way the materials were interacting with one another. Ruptures, cracks, and interstices were observed in the lightweight concrete, which could weaken the material and reduce its overall strength.

Additionally, numerous air voids of varying sizes were present. In contrast, upon examination of sample 1, a very dense formation of CH gel, a small amount of C-S-H gel, and minimal cracking were observed. These factors contributed to a very dense and compacted concrete, which was stronger than sample 2.

Based on these observations, it was concluded that partial replacement of AAC block could provide a lightweight concrete that is nearly as dense and compacted as conventional concrete.

However, the high presence of air voids in the lightweight concrete could also contribute to internal curing conditions, which could be beneficial for the overall strength and durability of the concrete.

CHAPTER 6

SUMMARY AND CONCLUSION

6.1 SUMMARY

- The various literature reviewed related to the partial replacement of industrial-manufactured Autoclave Aerated Concrete (AAC) Blocks Waste and identified the research gap.
- After conducting the literature survey, the objective, scope and need for this project are formulated.
- The process of selection of materials for the partial replacement of coarse aggregate is completed by keeping in view the utilization of waste materials in the preparation of concrete.
- The properties of the materials to be used for the preparation of lightweight concrete, the flexural behaviour of the lightweight concrete beam partially replaced with crushed AAC Block as coarse aggregate, interfacial bonding of crushed AAC block with the Cement and other material in concrete through SEM analysis test will be carried out in this study.
- The results from both laboratory tests and the analysis of the specimen using FEM software ANSYS will be compared and the findings of the study are concluded.

6.2 CONCLUSION

- The chapter describes a study that compared the properties of lightweight concrete made with crushed autoclaved aerated concrete (AAC) blocks as a substitute for conventional coarse aggregate with those of conventional concrete. The study examined the hardened properties, flexural behaviour, composition, and microstructural properties of both types of concrete.
- From the materials physical properties test found that the fine aggregate and coarse aggregate used in both types of concrete was suitable for their intended application, based on IS code standards. However, they noted that the water absorption of crushed AAC blocks was 8% higher than that of conventional coarse aggregate, which is not desirable according to IS code standards.

- The study also concluded that replacing 10% of the coarse aggregate in conventional concrete with crushed AAC blocks resulted in a 5% and 21% decrease in compressive and split-tensile strength, respectively, compared to conventional M30 grade concrete. From the FE-SEM analysis we can conclude that the decrease in strength is attribute to the high air voids, observable cracks, and less dense and compacted surface of the crushed AAC blocks compared to conventional coarse aggregate.
- Furthermore, the study suggested that the strength development in conventional concrete may be a reason for its superior performance in hydration process compared to lightweight concrete with 10% replacement of coarse aggregate by crushed AAC blocks. The presence of C-S-H and CH gel was also found to offer significant bearing resistance against the compressive load on CRC samples.
- According to the load deflection curve, it can be observed that the experimental deflection values are higher than analytical deflection values up to 70 kN, and the analytical curve is linear due to undisturbed conditions. On the other hand, the experimental curve is non-linear.
- The experimental investigation indicated that the flexural behaviour of the concrete was influenced by the replacement of crushed AAC blocks. As the replacement percentage of AAC blocks increased, the deflection value decreased, and the design mix was anticipated to have less deflection with 10% replacement of AAC blocks. However, when the replacement percentage of AAC blocks exceeded 10%, the deflection value increased.
- The study concluded by noting that the use of crushed AAC blocks as a coarse aggregate substitute in concrete not only helps recycle waste materials but also creates new information about the use of Lightweight Aggregate (LWA) as an internal curing agent and producing lightweight concrete products with added value.

REFERENCES

1. Abdulkadir Kan and Ramazan Demirboğa, "Effect of cement and EPS beads ratios on compressive strength and density of lightweight concrete", Indian Journal of Engineering & Materials Sciences Vol. 14, April 2007, pp. 158-162.
2. Abhijitsinh Parmar and Chahil Joshi, Urvish Patel, Avadh Vaghasiya, Aditi Parmar and Akshay Joshi "Light Weight Concrete Using EPS Beads and Aluminium Powder", Proceeding of 3rd Afro - Asian International Conference on Science, Engineering & Technology AAICSET-2015.
3. Alexandre Bogas and Augusto Gomes, "Non-steady-state accelerated chloride penetration resistance of structural lightweight aggregate concrete", Cement & Concrete Composites, Vol. 60, 2015, pp. 111–122.
4. Anju Lakshman and H. Bosky Devi, Manju Dominic, "Influence of Lightweight Aggregates on Various Properties of Concrete", International Journal of Engineering Research & Technology (IJERT), Vol. 8 Issue 02, February-2019.
5. Bharath V B and Kuldeep Singh Solanki and Savitha S Biradar, "Experimental Study on Light Weight Concrete by Partial Replacement of Cement and Fine and Fine Aggregates by Fly and Termocal", International Journal of Trend in Scientific Research and Development (IJTSRD) Vol. 4 Issue 5, August 2020.
6. Bhavana N and Rambabu C, "Study of mechanical properties of lightweight aggregate concrete by using pumice stone, ceramic tiles and CLC lightweight bricks", international research journal of engineering and technology (irjet), vol. 04, 2017.
7. Davorin Kralj, "Experimental study of recycling light weight concrete with aggregates containing expanded glass", Process Safety and Environmental Protection, Vol.87, 2009, pp. 267–273.
8. Farheen, Syed Viqar Malik and Manasa S, "A Study on Strength of Lightweight Foamed Concrete by Using of Polypropylene Fibre", Journal of Architecture & Technology", Vol. 09, Issue 06, 2019, pp 36-40.

9. Campione. G, Miraglia N and Papia M, "Mechanical properties of steel fibre reinforced lightweight concrete with pumice stone or expanded clay aggregates", Concrete reinforced deformed steel fibers, part I: Bond-slip mechanisms', Vol. 91 (5) ,435–446.
10. Glas, D. J., Yu, Q. L., Spiesz, P. R., and Brouwers, H. J. H. "Structural lightweight aggregates concrete". In H-B. Fischer (Ed.), Tagungsbericht / IBAUSIL, 19. Internationale Baustofftagung, Weimar, Bundesrepublik Deutschland, Vol. 2, September 2015, pp. 1375-1382.
11. Gopinath M, Nisha R, Rathnapriya R and Dhivya B, "An experimental study on light weight concrete by partial replacement of coarse aggregate with steel slag", international journal of current engineering and scientific research (ijcesr), vol. 6, 2019.
12. Gunasekaran K and Kumar P S, "Lightweight Concrete Using Coconut Shells as Aggregate, Proceedings of International Conference on Advances in Concrete and Construction", ICACC-2008 7-9, February, 2008.
13. Hari Tyagi And Rishabh Mahure, "Durability Study on Lightweight Aggregate Concrete Using Autoclaved Aerated Concrete (AAC) Blocks as Partial Replacement of Coarse Aggregate", 2018 Ijcr | Vol. 6, April 2018.
14. Haque M N and Al-Khaiat H, Kayali O, "Strength and durability of lightweight concrete" Cement & Concrete Composite, Vol. 26, 2004, pp. 307–314.
15. Ilker Bekir Topçu and Tayfun Uygungog lu (2010), "Effect of aggregate type on properties of hardened self-consolidating lightweight concrete (SCLC)" Construction and Building Materials, Vol. 24, 2010, pp.1286–1295.
16. Jamal Alduaij, Khalid Alshaleh, Naseer Haque M and Khalid Ellaithy "Lightweight concrete in hot coastal areas", Cement & Concrete Composites, Vol.21.1999, pp. 453-458.
17. Jihad Hamad Mohammed and Ali Jihad Hamad, "Materials, properties and application review of Lightweight concrete", Rev. Téc. Ing. Univ. Zulia. Vol. 37, 2014, pp.10 – 15.
18. Jize Mao and Koichi Ayuta, "Freeze–Thaw Resistance of Lightweight Concrete and Aggregate at Different Freezing Rates", Journal of Materials in Civil Engineering, Vol. 20, 2008.

19. Karthika R B and Vidyapriya V, "Experimental study on lightweight concrete using pumice aggregate", *Materials Today: Proceedings* Vol.43 2021, pp.1606–1613.
20. Khandaker M and Anwar Hossain, "Properties of volcanic pumice based cement and lightweight concrete", *Cement and Concrete Research*, Vol. 39, 2004, Pp. 283-291.
21. Lakshmi Kumar Minapu and M K M V Ratnam, "Experimental Study on Light Weight Aggregate Concrete with Pumice Stone, Silica Fume and Fly Ash as a Partial Replacement of Coarse Aggregate", *International Journal of Innovative Research in Science, Engineering and Technology*, Vol. 3, 2014.
22. Luciano Leonardi and Teresa M. Pique, "Design and Assessment of a Lightweight Polymer Concrete Utility Manhole", *Advances in Materials Science and Engineering*, Vol. 2019, pp 1-12.
23. Mohammadreza Hamidian, "Mahdi Shariati, M. M. K. Arabnejad and Hamid Sinaei (2011), "Assessment of high strength and light weight aggregate concrete properties using ultrasonic pulse velocity technique", *International Journal of the Physical Sciences* Vol. 6, 2011, pp. 5261-5266.
24. Mohd Mustafa Al Bakri Abdullah and Kamarudin Hussin, "Fly Ash-based Geopolymer Lightweight Concrete Using Foaming Agent", *Int. J. Mol. Sci.* Vol. 13, 2012, pp. 7186-7198
25. Muhammad Riaz Ahmad and Bing Chen, "Experimental research on the performance of lightweight concrete containing foam and expanded clay aggregate", *composites Part B*, Vol. 171, 2019, PP. 46–60.
26. Muhammad S. Khan, Mateeullah, Ali A. J. Khattak, Muzamil Yaqoob, Kashif Alam, "Strength and Thermal Conduction Assessment of Lightweight Aromatic Hydrocarbon Waste Polystyrol Glass Concrete", *Journal of Engineering Science and Technology* Vol. 16, 2021, PP. 1082 – 1097.
27. Muralitharan R S and Ramasamy V, "Development of lightweight concrete for structural applications", *Journal of Structural Engineering* Vol. 44, No. 4, October - November 2017 pp. 1-5.
28. Nagaswaram Roopa K. Supriya et al, "Experimental Study on Light Weight Concrete by Partial Replacement of Cement and Fine Aggregate with Fly Ash and Thermocol", *IJSTE - International Journal of Science Technology & Engineering* Vol. 3, 2017.

29. Osman U'nala and Tayfun Uygunog'lua (2007), "Investigation of properties of low-strength lightweight concrete for thermal insulation" Building and Environment Vol.42, 2007, pp.584–590.
30. Pankaj Dhemla, B L Swami and Prakash Somani, "Experimental Investigation of Light Weight Concrete Using Sintered Fly Ash Aggregates", Earth and Environmental Science, Vol.795,2021 pp 1-12.
31. Parhizkar T, Najimi M and Pourkhorshidi A R, "Properties of volcanic pumice-based cement and lightweight concrete", Cement and Concrete Research Vol. 34 2004, pp.283 – 291.
32. Prathibha A R and Dr. Anila kumar. C.P, "Comparative Study on Strength Properties of Light Weight Aggregate Concrete with Partial Replacement of Coarse Aggregates with Crushed Cinder and Brick Bats", International Research Journal of Engineering and Technology (Irjet), E-Issn: 2395-0056 Vol. 07, 2020.
33. Rajasekhar M and Venkataramana K, "experimental investigation on structural lightweight concrete by partial replacement of coarse aggregate using pumice aggregate", International Journal of Engineering Applied Sciences and Technology, Vol. 4,2020, Pp. 429-433.
34. Rajeswari S and Dr. Sunilaa George, "Experimental Study of Light Weight Concrete by Partial Replacement of Coarse Aggregate Using Pumice Aggregate", International Journal of Scientific Engineering and Research (IJSER), Vol. 4, 2016.
35. Ram kumar P, Anjan B. K, Arjun V, "Assessment of Lightweight Concrete Using Expanded Polystyrene Beads", International Journal of Innovative Technology and Exploring Engineering (IJITEE), Vol. 8 2019.pp 3234-3237.
36. Roberto Felicetti, Pietro G. Gambarova and Patrick BamonteThermal, "mechanical properties of light-weight concrete exposed to high temperature," Fire and Materials", April 2013.
37. Saritha. B and J.Chamundeeswari, "Experimental Study Of Light Weight Concrete By The Partial Replacement Of Coarse Aggregate By Thermo Plastics", International Journal of Engineering Trends and Technology (IJETT) ,Vol. 1, 2011, pp1-12.
38. Sivalinga Rao, Radha Ratna Kumari Y, Bhaskar Desai V, Swami B L P, "Fibre Reinforced Light Weight Aggregate (Natural Pumice Stone) Concrete"

- International Journal of Scientific & Engineering Research Vol. 4,2013, pp 158-161.
39. Subramani T, Ganapathy R, Manoharan V, Balamurugan M and Murugesan R, “Design and Analysis Of Light Weight Concrete Building Using ETAB With Respect To Dynamic Loading”, International Journal of Emerging Trends & Technology in Computer Science (IJETTCS), Vol. 6,2017.
 40. Sundar Kumar P and Ratna Kanth Babu M J, “Experimental Study on Lightweight Aggregate Concrete”, International Journal of Civil Engineering Research Vol. 1, 2010, pp. 65–74.
 41. Sunday U. Azunna and Farah N. A. A. Aziz et al, “Characterization of lightweight cement concrete with partial replacement of coconut shell fine aggregate”, SN Applied Sciences 1:649, 2019.
 42. Tejiona Tangomo Frank Roland and Ochieng Abuodha Silvester, “Properties of Lightweight Concrete made with Volcanic Scoria from Kenya, as Coarse Aggregates”, International Journal of Innovative Science and Modern Engineering (IJISME) Vol.5, 2018.
 43. Tongwei Liu and Guopu Shi, “Lightweight foamed concrete with foam agent addition”, Materials Science and Engineering, Vol. 490, 2019, pp. 032 -033,
 44. Van der Wegen G.J.L and Bijen J.M.J.M, “Properties of concrete made with three types of artificial PFA coarse aggregates”, The International Journal of Cement Composites and Lightweight Concrete, Vol.7, August 1985.
 45. Yasar et.al, “Strength properties of lightweight concrete made with basaltic pumice and fly ash”, Materials Letters, Vol. 57, 2003, pp.2267–2270.
 46. Yun Bai, Ratiyah Ibrahim, and P.A. Muhammed Basheer, “Properties of lightweight concrete manufactured with fly ash, furnace bottom ash, and Lytag”, International Workshop on Sustainable Development and Concrete Technology, Pp 78-88.
 47. IS 456: 2000, Plain and Reinforced Concrete – Code for Practice (Fourth Revision).
 48. IS 383: 2016, Specification for coarse and fine aggregates from natural sources for concrete (second revision)
 49. IS 516: 1959, Method of test for strength of concrete
 50. IS 8112: 2013, Specification for 43 grade ordinary Portland cement (Second revision)