# DEVELOPMENT OF LIGHTWEIGHT AGGREGATE CONCRETE AND AUTOCLAVED AERATED CONCRETE USING INDIGENOUS MATERIALS.

**MS STRUCTURES DISSERTATION**

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# Dedication

I dedicate my research work to

Dr. Rao Arsalan Khushnood, the most inspirational person in my life

And

To my parents, brothers, friends & to my beloved youngsters

Ahmad Shair & Fateh Shair

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**ABSTRACT**

In this study, we used local resources to construct eco-friendly and thermally efficient lightweight concretes with a variety of stoichiometries. Three types of lightweight aggregates expanded shale, expanded slate and expanded clay were selected to achieve the goals of structural lightweight aggregate concrete (LWAC). Cellular and porous concrete in the form of Autoclaved Aerated Concrete (AAC) with fly ash as sand replacement was developed for non-structural units. Furthermore 5, 10, 15 and 20% of sawdust was replaced with fly ash in AAC to study the enhanced properties. Test results indicates that the hardened density of lightweight aggregate concrete reduces 23% as compare with normal-weight aggregate concrete (NWAC). Similarly, the compressive strength of lightweight aggregate concrete using expanded shale fall in the range of structural compressive strength in accordance with ACI 213. The thermal efficiency of LWAC using expanded shale is 70% enhanced as compare to NWAC. The hardened density of AAC reduces to about 68% in compare with NWAC. Similarly, the compressive strength of AAC fall in the range of non-structure concrete strength in accordance with ACI 213. The thermal efficiency improves up-to 66%. The incorporation of 25% wood waste in AAC also shows good thermal efficiency. Conclusively, the recipes for lightweight structure and non-concretes developed and the utilization of fly ash and wood waste is a useful source of raw materials for the building industry; an environmentally responsible solution for the disposal of fly ash and sawdust would contribute to the conservation of natural aggregate reservoirs.

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| | |
|---|---|
| **AAC** | Autoclaved Aerated Concrete |
| **AAC-SD** | Autoclaved Aerated Concrete with Saw Dust |
| **ACI** | American Concrete Institute |
| **ASTM** | American Society of Testing of Materials |
| **EDS** | Electron Dispersive Spectroscopy |
| **ET** | Expression Tree |
| **GEP** | Genetic Expression Programming |
| **LWAC** | Light Weight Aggregate Concrete |
| **LWAC-EC** | Light Weight Aggregate Concrete Expanded Clay |
| **LWAC-SH** | Light Weight Aggregate Concrete Expanded Shale |
| **LWAC-SL** | Light Weight Aggregate Concrete Expanded Slate |
| **SEM** | Scanning Electron Microscopy |
| **XRF** | X-Ray Fluorescence |
| **W/C** | Water to Cement ratio |
| **OPC** | Ordinary Portland Cement |

**CHAPTER 1**

# INTRODUCTION

## 1.1 General

Because of the rapid development in industrialization, global data on solid waste production suggest a higher buildup of industrial wastes. Due to environmental and economic issues, these outputs require suitable methods for optimal recycling and usage. Furthermore, natural sand resources are diminishing globally as a result of excessive use by the building sector, which has resulted in diminished natural sand reservoirs and irreversible environmental destruction[1]. For the long-term evolution of concrete, several research investigations have been conducted to replace natural aggregates with artificial and recycled aggregates[2]. The use of resources derived from solid waste as a substitute for natural aggregate (sand) in conventional normal strength concrete provides an environmentally friendly and long-term solution to the problem of wood waste disposal, as well as the potential to improve the thermomechanical characteristics of composites made from cement. Diverse researchers have studied waste materials such as waste polyethylene and rubber fragments[3], a mixture of water treatment sludge and wood waste, and a blend of the two. [4], waste paper and sawdust[5], sandwiched newspaper[6,7], and coconut fiber[8].

Despite its known use stretching back over 2000 years, lightweight concrete (LWC) has sparked considerable curiosity and industry demand in recent years in a wide range of construction projects. Mineral admixtures, fibers, and a longer curing time are all excellent ways to prevent shrinkage cracking in LWC[9]. In terms of cost, utilizing LWC in floor slabs will lower total costs of tall buildings by reducing foundation volume, steel reinforcement, and vertical member cross-sections, which saves horizontal area [10].

LWC has a thermal conductivity of 0.2 to 1.0 W/m.K, as well as an oven-dried density of 300 to not more than 2000 kg/m3 and a cubic compressive strength of 1 to more than 60 MPa. These values might be compared to typical weight concrete with 1.6 to 1.9 W/m.K, 2100 to 2500 kg/m3, and 15 to greater than 100 MPa[11].

The physical and mechanical properties of lightweight aggregates are superior to those of aggregates resulting from naturally occurring processes, such as pumice aggregate. They can also be synthesized artificially from natural sources or by products[12]. Expanded clay (EC) aggregates are produced by expanding natural clay in a 1200 degree rotary kiln. In simple concrete, the normal weight aggregate zone is often stronger than the matrix and the interfacial transition zone due to the significance of aggregate-matrix interactions (ITZ). On the other hand, lightweight aggregates are the weakest components of a concrete mixture, which has a considerable effect on the elastic and mechanical characteristics of LWAC. According to the theory, the concrete's strength is dictated by the weakest component in the mixture. The study of aggregate characteristics and their influence on lightweight high-strength concretes. When aggregates are the most stiff concrete component, stresses are transferred via the aggregates and mortar. If the aggregate particles are weaker than the mortar phase of the concrete, stress transmission occurs through the matrix and fractures spread through the aggregate particles. Lightweight aggregates are hence weaker than ITZ aggregates[13,14]. The internal curing action of LWAC enhances the cement matrix's hydration. Due to the fact that the elastic and mechanical properties of LWAC are directly connected to the characteristics of its component materials, the elastic and mechanical properties of LWAC may be predicted, the lightweight aggregates' density and volume fractions allow LWAC to perform similarly to standard weight concrete[15,16].

Aerated concrete is a form of lightweight concrete. Sometimes, aerated concrete is referred to as cellular concrete[17]. According to the method of production, it may be split into two classes. There are two forms of aerated concrete: foamed concrete (non-autoclaved aerated concrete (NAAC)) and autoclaved aerated concrete (AAC). I Foamed concrete is produced by injecting stable foam into a foundation mixture of cement paste or mortar (cement + water or cement + sand + water) or by adding a specific air-entraining ingredient known as a foaming agent. ii) As seen in Figure 1, AAC is manufactured by combining a precise quantity of aluminum powder and other additives with a slurry of finely ground high silica sand, cement or lime, and water. The history of foamed concrete is much longer than that of lightweight aggregate concrete[20]. Foamed concrete is a rather ancient material, with its earliest known use reaching back to the 1920s. Foamed concrete was not regarded as a suitable building material until the late 1970s [21]. Prior to then, the AAC dates back around 100 years. In 1914, Swedes discovered a combination of cement, lime, water, and sand that could be made into hydrogen gas by adding aluminum powder to the cement slurry. In the past, inventive individuals sought to introduce air to concrete using whipped egg whites, yeast, and other unusual substances. According to sources, foamed concrete was created in Europe more than six decades ago and has been on the worldwide market for more than two decades[21]. Foamed concrete provides good flowability, low self-weight, low aggregate usage, controllable low strength, and good thermal insulation. Foamed concrete has a wide range of density (1600-400kg/m3), which may be used for applications including filling, insulating, partitioning, and structural support with proper foam dosage control[22]. Wood waste has been identified as a severe danger, particularly due to landfill space restrictions and environmental concerns, as its accumulation in factories, mills, and household activities increases annually. To ensure its correct and safe disposal, there is a high demand because of its ability to be reused and its ability to be an effective tool application, a good example of this is cement-based composites. Regarding the possible effects of wood waste on the AAC, there is still a large gap to be filled. To help address such environmental issues, wood waste is replaced by fly ash in AAC.

## 1.2 Problem Statement

Studies showed, that the behavior of concrete characteristics by substituting three types of lightweight aggregate for the traditional coarse aggregate in the concrete combination and changing the matrix of conventional concrete in two different ways. When buildings are design, the engineer fallow Building code of Pakistan and design it for ultimate, serviceability and for earthquakes events and cannot consider the reduction in the dead load and energy consumption and use conventional concrete on site while the density of conventional concrete is bit high which ultimately increase the dead load and energy demand for the buildings.

## 1.3 Research Objectives

The inquiry emphasis to:

1. Development of light-weight aggregate concrete using local aggregates reserves of Pakistan.
2. Development of light-weight cellular concrete with integration of indigenous low density wood waste in replacement to fly ash.
3. Optimization of light-weight concrete considering compressive strength, hardened density and energy perspective for structural and non-structural purposes.

### 1.4 Research Significance

Researchers successfully attempted to develop optimized light weigh concrete for structure and non-structure element and thermal energy storage light weight aggregate concrete with sufficient structural and thermal properties, utilizing light weight aggregate (LWA) as a supporting materials However their research lack in-depth study of macro encapsulation procedure, modified encapsulation layer paste (MELP) and achieving acceptable range of mechanical properties through modification of interfacial transition zone (ITZ) rather than using hard encapsulation shell.

### 1.5 Research Methodology

To develop a structural lightweight aggregate concrete and autoclaved aeriated concrete using wood waste following procedure was adopted:

- For this study local aggregates of Pakistan were used comprising of shale, slate and clay.
- These aggregates were bloated in rotatory kiln at 1200$^{o}$C to obtained expanded and porous lightweight aggregates.
- AAC was developed using locally available materials using fly ash as filler in the cellular concrete to obtained lighter product.
- AAC was also developed replacing fly ash with wood waste to examine the influence of wood waste on the characteristics of AAC.
- Characteristic hardened densities were calculated and in comparison to ordinary concrete to minimize the densities in structural and non-structural concrete.
- Characteristic All concretes' compressive strength was determined using a compression machine.
- Characteristic The split tensile strength of each mixture was determined using a compression machine and standard techniques..
- Thermal conductivity was checked using thermal incubator.
- $CO_2$ emission was calculated using AutoDesk Ecotect 2011.
- XRF was performed to study the oxide nature of all lightweight aggregates and fly ash used in current study.
- SEM was performed to study the morphologies of cellular and non-cellular concretes.

- GEP based analysis was carried out for lightweight aggregate concrete to develop compressive strength base equation.
- The results were compared with normal weight concrete to develop lighter concrete for structural and non-structural units.

## 1.6 Research Scope

Scope of this research was specific to the optimization of density comparing the different light weight concrete using indigenous materials to develop low density light weight concrete for structural and non-structural units. Moreover, the scope is limited to mechanical testing and thermal analysis on different kind of recipes being used for investigation.

## 1.7 Thesis Organization

This document is organized step by step from brief introduction to the title and methodology steps in first chapter. 2nd chapter composed of literature review, 3rd chapter presents impregnation process in details and various tests employed on different light weight aggregates concrete and thermal energy storage light aggregate concrete. 4th chapter of thesis document present detailed discussion over the previous chapter testing procedure and finding. Chapter 5th compiles conclusions and recommendations.

CHAPTER 2

# LITRATURE REVIEW

This chapter will comprise of previous research done on selected type of concrete. the previous research regarding lightweight aggregate concrete and autoclaved aerated concrete is discussed in detail.

## 2.1 Light Weight Concrete

The consistent increase in earth's surface temperature, owing to Greenhouse effect, has led to serious environmental concerns, economy and sustainability issues. Due to increase in energy consumption of built infrastructure, use of Heating Ventilation and Air conditioning (HVAC) systems increases for maintaining required level of thermal comfort. However, this resulted in serious environmental concerns along with increased operational cost of building structures. This increased energy consumption of built infrastructure due to said reason has put pressure on structural engineers to develop suitable insulation techniques to ensure not only occupant comfort but also to reduce the use of HVAC systems in building structures. Normal cement concrete has a self-weight of 2200 to 2600 kg/m3. This is one of the most significant disadvantages of traditional cement concrete, as its large weight makes it an uneconomical structural material. To improve the structural efficiency of concrete, efforts have been made to lower the weight of ordinary cement concrete. Light weight concrete is a cement concrete with a self-weight ranging from 300 kg/m3 to 1850 kg/m3.

## 2.2 Types of Lightweight concrete

Depending on the technique of production, the lightweight concrete can be divided into the following categories:

Table 2.1 Groups of light weight concrete

| *No Fines Concrete* | *Light weight aggregate concrete* | *Aerated concrete* | |
|---|---|---|---|
| | | *Chemical Aerated (Gas forming)* | *Foaming mixtures* |
| Gravel | Clinker | Aluminum powder method | Preformed foam |

| | | | |
|---|---|---|---|
| Crushed Stone | Foamed slag | Hydrogen peroxide method | Air entrained foam |
| Coarse Clinker | Expanded shale | Bleaching powder method | |
| Sintered pulverized fuel ash | Expanded clay | | |
| Expanded clay or shale | Pumice | | |
| Expanded slate | Expanded slate | | |
| Foamed slag | Sintered pulverized fuel ash | | |
| | Exfoliated vermiculate | | |
| | Expanded perlite | | |
| | Organic aggregates | | |

### 2.2.1 No-Fines Concrete

No-fines the term "concrete" refers to a kind of lightweight concrete that is made up of cement and fine aggregate. Void regions develop throughout its bulk in a manner that is uniformly distributed. When applied to a wall, this particular kind of lightweight concrete keeps its big spaces and does not produce laitance layers or cement film. These are its primary distinguishing traits. Concrete without particles is often used for load bearing and non-load bearing applications in the construction of exterior walls and partitions. The addition of more cement results in an increase in the no-fines concrete's compressive strength. However, it is very sensitive to the chemical make-up of the water. A lack of cohesiveness between the particles in the concrete may be caused by an insufficient amount of water, which can then lead to a loss of the concrete's strength. In a similar manner, an excessive amount of water may cause the cement film to run off the aggregate and produce laitance layers. This leaves the majority of the concrete deficient in cement, which in turn decreases its strength.

### 2.2.2 Porous Lightweight Aggregate Concrete

In place of regular concrete, this lightweight concrete is made using an aggregate that is both porous and lightweight and has a low specific gravity. Natural lightweight aggregates include pumice, scoria, and everything else of volcanic origin. Artificial lightweight aggregates include expanded blast-furnace slag, vermiculite, and clinker aggregate. Both natural and artificial lightweight aggregates may be used. The high porosity of this lightweight aggregate, which contributes to the material's low specific gravity [23], is the primary distinguishing feature of the material. According to the purpose for which it will be used, lightweight aggregate concrete may be separated into two distinct categories. The first kind is known as partly compacted lightweight aggregate concrete, while the second variety is known as structural lightweight aggregate concrete. The partly compacted lightweight aggregate concrete serves primarily two objectives, the first of which is for the production of precast concrete blocks or panels, and the second is for the construction of cast-in-situ roofs and walls. The primary criterion for this kind of concrete is that it must have sufficient strength in addition to a low density in order to achieve the highest possible level of thermal insulation. Additionally, it must have a low drying shrinkage in order to prevent cracking[24]. Concrete made of structurally lightweight aggregate is completely compacted in a manner that is similar to that of conventionally reinforced concrete made of dense aggregate. It is possible to utilize it in conjunction with steel reinforcement in order to achieve a strong connection between the concrete and the steel. It is expected that the concrete will provide sufficient protection against the steel's corrosive effects. It is common for concrete mixtures to be on the harsh side because of the form and texture of the aggregate particles as well as the coarse nature of the fine aggregate. When it comes to lightweight aggregate, the denser kinds are the only ones that may be used in structural concrete [25].

### 2.2.3 Aerated Concrete

Aerated concrete is similar to aerated mortar in that it does not include coarse aggregate but does contain fine aggregate. In most cases, the production of aerated concrete entails adding air or another gas to a cement slurry that is combined with fine sand. In typical industrial applications, powdered fuel ash or some other kind of siliceous material takes the place of sand, and lime is often used in lieu of cement [26]. There are two different ways to get the aerated concrete ready to use. The first approach involves using a chemical process in order to introduce the gas into the mixture while it is still in its plastic state. In the second approach, air may be included by either whipping in air with the assistance of an air-entraining agent or by mixing in stable foam first. The first technique is the one that is often used in precast concrete factories. In these establishments, the precast units are then autoclaved in order to manufacture concrete that has a reasonably high strength and a minimal drying shrinkage. The second technique is used mostly for in-situ concrete, which is ideal for insulating roof screeds or pipe lagging. Researchers from a variety of institutions examined how well wood waste performed in cement-based composites. When compared to the reference specimen, the incorporation of wood waste in concrete resulted in a significant reduction in the thermal conductivity values (by 23.2 percent). This was discovered by Sales et al., who conducted an investigation into the thermal properties of cement-based composites that contained wood waste. The scientists came to the conclusion that this significant reduction in heat conductivity was caused by wood waste modified lightweight concrete composites' low density and high porosity [27]. Oyedepo et al. conducted research on the use of wood waste as a replacement for natural fine aggregate (0, 25, 50, 75, and 100 wt percent) in normal weight concrete. They discovered that replacing more than 25 percent of the sand in concrete had a negative impact on the mechanical strength and density properties of the concrete [28]. While utilizing wood waste as a replacement of sand in concrete at different levels (10, 20, 30, and 40 percent), similar findings were reported by several other investigators. These researchers suggested using wood waste up to 10 percent as a replacement of sand because it presented better results in terms of the density and strength properties of concrete [29]. It was also looked at whether or not wood waste may be used as a substitute for fine aggregate (between 0 and 15 percent) [30]. The author came to the conclusion that the introduction of wood waste into cement-based composites produced superior outcomes in terms of the thermal and mechanical characteristics of the composites. Over the period of the last several years, the innovation of lightweight aggregate concrete has received more attention (LWC). Lightweight concrete offers the advantages of lowering construction costs, making construction easier, and being a comparatively "green" building material [31]. Lightweight concrete also has the benefit of reducing carbon emissions. Because of its physical structure, lightweight aggregate (LWA) results in the transition to lightweight concrete parts that have increased thermal insulation qualities [32]. As a result, it contributes to the enhancement of the energy efficiency of building structures. According to the aforementioned research, it is abundantly obvious that no prior study has been done on the incorporation of wood waste into AAC.

**Chapter 3**

# EXPERIMENTAL INVESTIGATION

This chapter will comprise of experimental work in detail followed for current study. The method and approaches used for different tests is discussed in detail with relevant standers and specifications.

## 3.1 Materials procurement-development of light weight aggregate concrete

Materials conforming to the following specification were utilized from the development of light weight aggregate concrete.

### 3.1.1 Light weight aggregates (LWA)

#### 3.1.1.1 Expanded shale

Synthetic porous LWA, conforming to ASTM 330-17 manufactured from shale was procured from PCSIR Karachi. The LWA was highly porous and the bulk density was found to be 826.19 kg/m$^3$. The absorption capacity of LWA in 24-hr was found to be 4.21%.

Fig 3.1 Expanded Shale

#### 3.1.1.2 Expanded slate

Similarly, synthetic porous LWA, conforming to ASTM 330-17 manufactured from slate was procured from PCSIR Peshawar. The LWA was highly porous was determined that the bulk density was 800 kg/m$^3$. The absorption capacity of LWA in 24-hr was found to be 13%.

Fig 3.2 Expanded Slate

#### 3.1.1.3 Expanded Clay

The light weight aggregate expanded clay used was synthetically manufactured from clay aggregates while heating them at temperature ranging from 1000$^o$ C to 1200$^o$ C. The LWA was highly porous and the bulk was discovered that the density was 680 kg/m$^3$. The absorption capacity of LAW in 24-hr was found to be 26%.

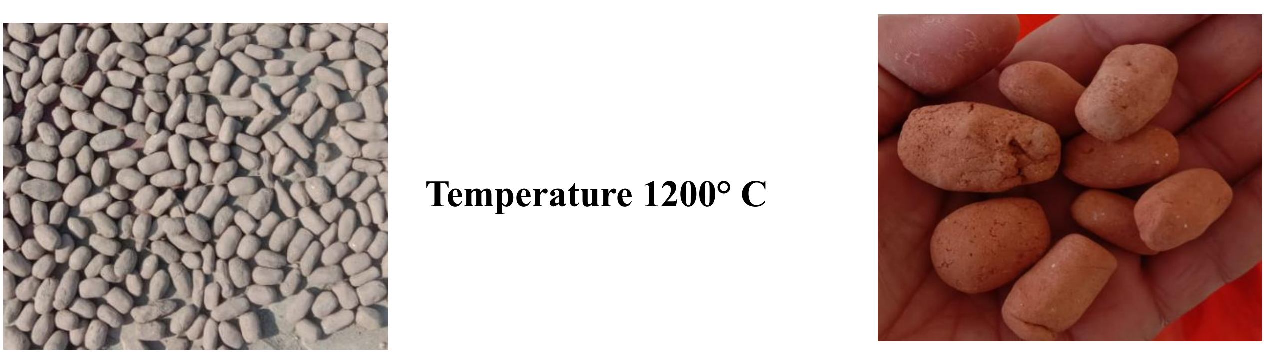


Fig 3.3 Formation mechanism of Expanded Clay

### 3.1.2 Cement

For all the concrete mixes ordinary Portland cement was used, which belongs to Type 1 and the specified grade is 53. This cement was in accordance with ASTM C150-04 and the manufacturer was best way cement limited.

### 3.1.3 Sand

Fine aggregate used in all the mixes, was in compliance with ASTM C778-13. It was discovered that the density was be 2600 kg/m3 and the fineness modulus 2.67.

## 3.2 Materials procurement-development of autoclave aeriated concrete

Materials conforming to the following specification were utilized from the development of autoclaved aeriated concrete.

### 3.2.1 Fly Ash

The fly ash of class C in accordance with the ACI PRC-232.2-18 was used in the development of autoclaved aeriated concrete. It was precured from the Port Qasim Coal Power Plant.

Fig 3.4 Fly Ash

### 3.2.2 Aluminum Powder

As per ASTM C1386, the production of a cellular structure by the incorporation of aluminum powder into the mixture either during the liquid or the plastic phase. The main function of aluminum powder is to produce aeriated effect in the matrix. The aluminum powder used in our case contains 90% free aluminum.

### 3.2.3 Lime

According to ASTM C1693, lime is a kind of inorganic mineral that is mostly composed of carbonates, oxides, and hydroxides. Lime also contains calcium. To use the word lime in its most literal meaning, it refers to calcium oxide or calcium hydroxide. Additionally, it is the name of the naturally occurring mineral that occurs as a consequence as a result of fires in coal seams and xenoliths found in modified limestone that are produced by volcanic ejection. The chemical formula for this mineral is CaO. Lime should be of the fast variety. The quick lime that was accessible in the area was utilized.

### 3.2.4 Gypsum

According to ASTM C22/C22M, the amount of setting that occurs in an aerated concrete mixture is controlled by the sulphates that are present in the mixture. The release of hydrogen from the mass of cast aerated concrete occurs at a more gradual pace, and the microstructure of the concrete is improved. Tobermorite crystals take on a bigger and more planar appearance when exposed to sulphates because of this impact. The Mianwali district of Pakistan provided the precured gypsum for this project.

### 3.2.5 Wood Waste

Wood waste is an organic material that is generated as a consequence of sawing, grinding, drilling, scraping, or otherwise generally pounding wood using a saw or any other cutting instrument that is used in sawmills, industries, or in the activities that take place in the home. It emerges in a variety of forms and sizes, each of which is determined by the dimensions of the instrument that was used to treat the wood. The present study studies the waste wood of a kind of hardwood tree called deodar, which is a member of the genus Cedrus Deodara and is indigenous to the northern parts of Pakistan. The sawdust sample shown in Figure 1(a) was procured from a nearby wooden manufacturer and used in its unprocessed, unaltered state without undergoing any kind of preliminary treatment.

Fig 3. 5 Wood waste

### 3.2.6 Super-plasticizer

To achieve required workability in AAC mixes super-plasticizers (SP) was used. 2% of MasterGelenium51 was used for the purpose in the statement.

Table 3.1 Chemical properties of different light weight aggregates by XRF

| **Oxides** | **Expanded Shale %** | **Expanded Slate %** | **Expanded Clay %** | **Fly Ash %** |
|---|---|---|---|---|
| $SiO_2$ | 51.68 | 50.42 | 54.24 | 55 |
| $Fe_2O_3$ | 41.2 | 42.48 | 14.17 | 7 |
| $Al_2O_3$ | 2.82 | 2.82 | 9.65 | 26 |
| $TiO_2$ | 1.37 | 1.33 | 0.05 | - |
| CaO | 1.24 | 1.29 | 8.94 | 9 |
| $K_2O$ | 1.1 | 1.2 | 1.10 | - |
| MnO | 0.17 | 0.22 | - | - |

Table 3.2 Physical properties of different light weight aggregates

| **Aggregate Type** | **Crushing Value %** | **Density (Kg/m^3)** | **Bloated Temp. (ºC)** | **Average Size (mm)** |
|---|---|---|---|---|
| Expanded Shale | 33 | 826 | 1000-1200 | 25 |

| | | | | |
|---|---|---|---|---|
| Expanded Slate | 31 | 800 | 1000-1200 | 25 |
| Expanded Clay | 24 | 680 | 1000-1200 | 27 |

**3.3 Development of light weight aggregate concretes (LWAC)**

Three mixes were designed to carry out in depth investigation for the purpose in statement. Table 3.1 shows the formulation names with required percentage of materials accordingly. NWAC shows the normal weight concrete, LWAC-SH shows the expanded shale light weight concrete, LWAC-SL shows the expanded slate light weight concrete and LWAC-EC shows the expanded clay light weight concrete. The mixing ratios were kept same in all formulation only the aggregate type is being changed. The water cement ratio for all mixes were kept same at 0.45.

Table 3.3 Percentage Mix proportion for lightweight concrete of varying stoichiometries

| | **water** | **Fly Ash** | **Saw Dust** | **Lime** | **Cement** | **Gypsum** | **Sand** | **NWA** | **LWA** | **Aluminum Powder** | **Superplasticizer** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **NWAC** | 0.45 | - | - | - | 21.27 | - | 33.33 | 45.4 | - | - | - |
| **LWAC-SH** | 0.45 | - | - | - | 21.27 | - | 33.33 | - | 45.4 | - | - |
| **LWAC-SL** | 0.45 | - | - | - | 21.27 | - | 33.33 | - | 45.4 | - | - |
| **LWAC-EC** | 0.45 | - | - | - | 21.27 | - | 33.33 | - | 45.4 | - | - |
| **AAC** | 0.45 | 70 | - | 6 | 20 | 4 | - | - | - | 0.05 | 0.02 |
| **AAC-SD10** | 0.45 | 60 | 10 | 6 | 20 | 4 | - | - | - | 0.05 | 0.02 |
| **AAC-SD15** | 0.45 | 55 | 15 | 6 | 20 | 4 | - | - | - | 0.05 | 0.02 |
| **AAC-SD20** | 0.45 | 50 | 20 | 6 | 20 | 4 | - | - | - | 0.05 | 0.02 |
| **AAC-SD25** | 0.45 | 45 | 25 | 6 | 20 | 4 | - | - | - | 0.05 | 0.02 |

### 3.4 Development of Autoclaved Aeriated Concrete (AAC)

AAC was casted to carry out the detail investigation for the purpose in statement. Table 3.1 shows the formulation of AAC with the required proportion of materials accordingly. The AAC was prepared using simple curing rather than aeriated curing. The fly ash was replaced with wood waste in 10, 15, 20 and 25% by weight.

Fig 3.6 AAC Preparation

### 3.5 Test Methods

#### 3.5.1 Compression Test

To determine the mechanical properties, compressive strength test was performed. For compression test specimens of (100 x 100 x100) mm were casted and tested at the age of 7 and 28 days in accordance with ASTM C39. The recommended loading rate of 0.6Mpa/s was considered for all the specimens. The compressive strength was taken as the average of three specimens and the maximum deviation from the average value was found to be 0.9 N/mm2. Furthermore, the Model No., sensitivity and maximum test load of the compressive machine used were MCC-08, 0.1kN and 5000kN respectively. Mechanical testing phase is presented in Figure

#### 3.5.2 Split Tensile Strength

Cylinders of size 100mm x 200mm were casted for Mix 1, Mix 3, and Mix 5; cured for a period of 28 days and tested in UTM for their split tensile strength using the split tensile assembly. The test was performed according to ASTM standard C496. The failure load was determined for the cylinder and strength calculated with the following formula:

$$T = 2F / \Pi Di\ Le$$

Where F = Applied load

Di = Diameter of the cylinder

Le = Length of cylinder

**3.5.3 Bulk Density**

The cylindrical measuring jar is filled with newly mixed concrete, and then it is compressed using a tamping rod, in order to estimate the density of all different kinds of fresh concrete in accordance with ASTM C-29/C-29M. The layers of 50 millimeters are stacked and crushed with at least 60 strokes until the measuring device is full. Taps of moderate force should be applied to the surface of the outside of the cylinder ten to fifteen times, or until the surface of the compacted layer does not display any big air bubbles. After the concrete has been allowed to fully consolidate, the top surface must be struck off and completed smoothly with a flat cover plate, taking special care to ensure that the measure is left just level full. After that, any concrete that was placed in excess must be removed from the outside. The weight of the filled measuring jar is determined (W). The density of concrete, denoted by the symbol "W1," is defined as the amount of weight that must be packed into one cubic meter of concrete. This value must be determined by the process of dividing the total weight of thoroughly compacted concrete in the cylindrical measure by the total volume of the measure expressed in kilograms per cubic centimeter.

**3.5.4 Thermal Conductivity**

The usual procedure was used for the purpose of determining the thermal conductivity. This technique involves measuring the differential in temperature that exists in the space between two of a specimen's surfaces while simultaneously heating one of those surfaces. The readings on the thermometers were used to determine the temperatures. The measurements of thermal conductivity were carried out in the same direction as the loading. For temperature measurement Microcomputer Thermometer, Model ST-7001, SOLEX, Taiwan, was used.

**3.5.5 Energy efficiency and $CO_2$ emissions**

To determine the energy efficiency and $CO_2$ emissions the AutoCAD Ecotect 2011 was used. Considering the climatic condition of Karachi Pakistan and analyzing on the basis of heat extraction capacity of heat ventilation and air conditioning (HVAC) system. A typical room with following dimensions was selected and different types of concrete were applied on wall and slab to evaluate $CO_2$ emissions caused by respective concrete.

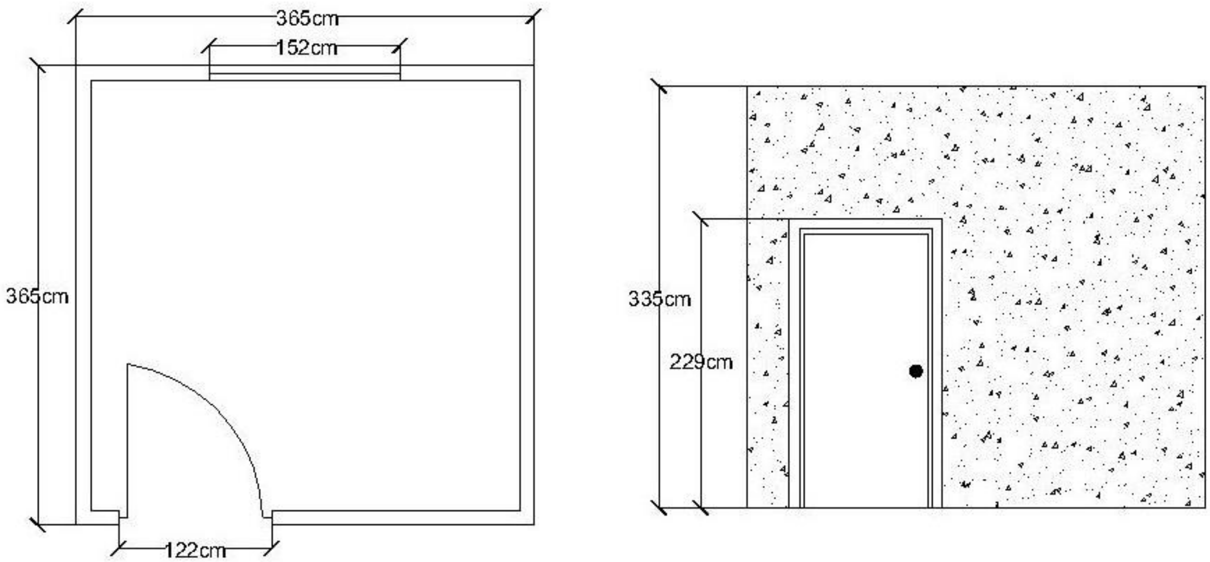


Fig 3.7 Architecture plan of single room being used for $CO_2$ emission calculation

### 3.5.6 Validation of LWAC through GEP

The population evolutionary theorem is the foundation of GEP, which was developed as a variant of GP and was suggested by Ferreira (2006). It runs into both the straightforward linear chromosomes of a predetermined length (GA) and parse trees (GP). The parameters that need to be discovered are quite similar to the ones that were found in the GP. These parameters include the terminal set, the function set, the fitness function, the control parameters, and the terminal conditions. During the execution of the computer programme, this method takes into account a character string that has a predetermined length, in contrast to the parse tree that is used in the GP, which has a variable length. Expression trees, also known as expression trees (ETs), are branching structures that represent chromosomes [33]. Individuals are initially recorded as linear strings of a constant size (genome), but they are subsequently expressed as nonlinear entities of varying sizes and forms. It is the same as saying that the genotype is differentiated from the phenotype in GEP, and that the programming may take use of all of the benefits that have evolved as a result of evolution [34]. Because all of the changes are implemented in a straightforward linear structure, one of the most remarkable aspects of the GEP modification is that only the genome is passed on to the following generation. Additionally, it is not necessary to replicate and mutate the overall structure because all of the changes take place in a linear format. One further distinguishing characteristic is that each person is generated by a single chromosome that contains many genes and is then subdivided into a head and a tail [33]. Each gene in the GEP has a variable with a predetermined length, constants in the form of terminal sets, and arithmetic operations in the form of sets of functions. There is a direct correlation between the symbol of the chromosome and the appropriate terminal or function in the genetic code operator. This connection may be thought of as a one-to-one correspondence. The genetic mechanism that operates at the level of individual chromosomes makes the process of the development of genetic diversity in the GEP a very straightforward one [35]. There is information that must be encoded into the chromosomes in order to build empirical relationships, and a new language called Karva has been devised in order to infer this information. Karva expression, also known as Kexpression, is a method that enables one to deduce the precise phenotype of an organism based on the sequencing of its corresponding gene [33]. The transition from Karva to the ET begins at the spot that is now in the leading position in the ET and continues all the way through the string. Recording the nodes from the root layer all the way through to the deepest layer is required in order to convert ET into the K-expression [36]. Because of how the GEP method works, the size of the ETs might vary, which leads to the creation of a certain number of redundant elements that are not used for the mapping of the genome. As a result, the length of the GEP gene and the K-expression may be the same or they could be different. The several phases that make up the GEP algorithm are shown in Figure 1. The procedure starts with the generation of chromosomes of a consistent length by random chance for each person. After that, the chromosomes are expressed in the form of the ETs, and the fitness of each person is analyzed. Individuals who are considered to be the greatest possible candidates for the reproduction process are selected. Iteration is continued with new individuals for a number of generations until the optimum solution is discovered. In the initial step of conversion, genetic procedures such as mutation, cross breeding, and reproduction are performed.

The LWAC data in this database was gathered from over 40 peer-reviewed, multinational research. The total database contains 77 strength results. The database includes information regarding ten parameters age, water-to-cement ratio (*w/c*), quantity of water, quantity of cement, quantity of fine aggregates, aggregate type, quantity of NWA, quantity of LWA, maximum size of aggregate and unit weight of LWA. The distribution of a model affects its performance[36]. It is recommended to utilize the offered formulations for this data range in order to generate accurate estimates of mechanical characteristics. In the end testing results of LWAC are being validated through GEP model results.

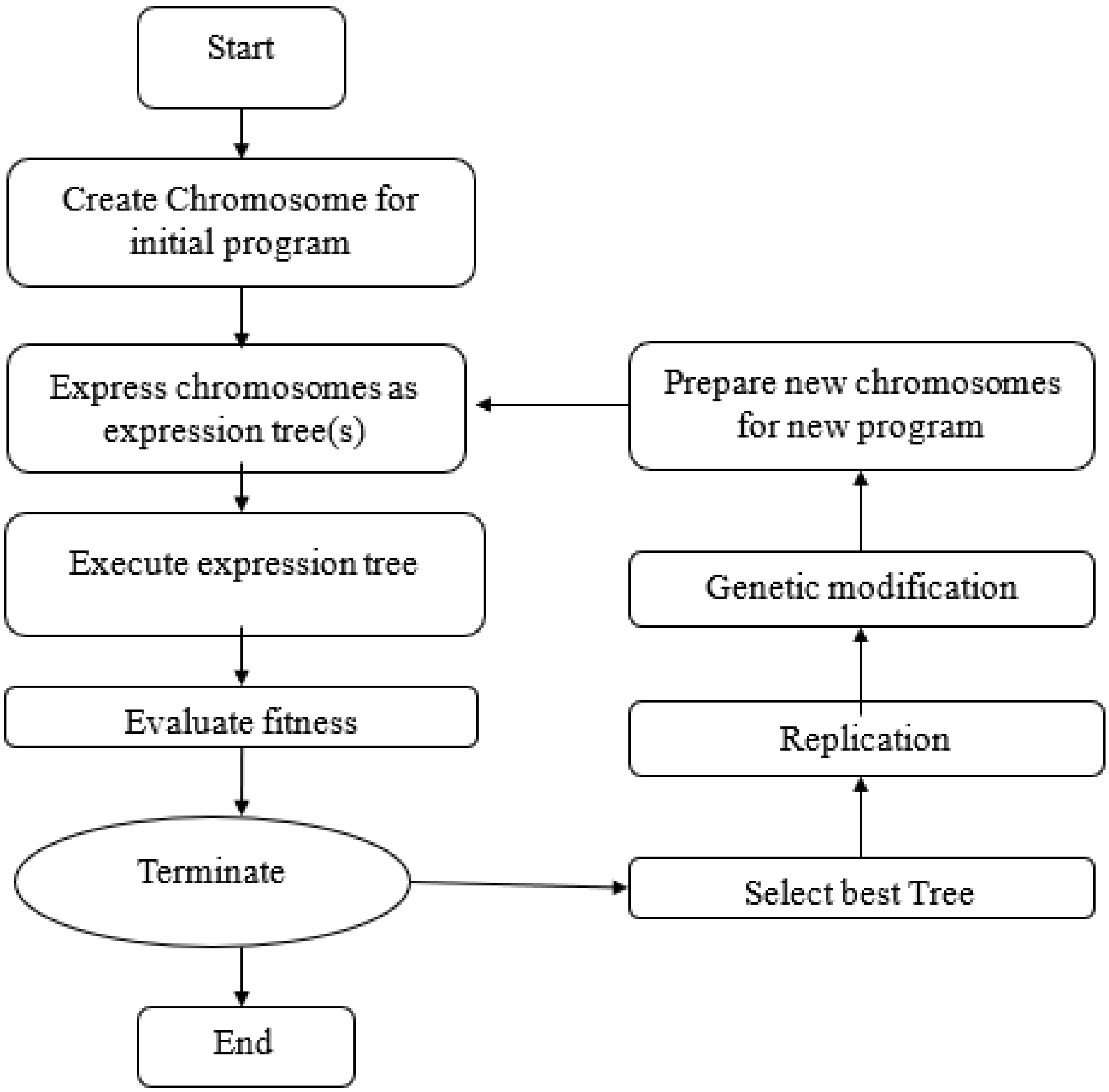


Fig 3.8 Schematic representation of steps involved in GEP algorithm.

Chapter 4

# RESULTS AND DISCUSSION

This chapter will comprise of results and discussion done for current study to evaluate the required objectives. The results of different experiments are shown and their respective discussion is mentioned.

## 4.1 Hardened Density

The hardened density of mixtures containing NWA, LWA1, LWA2, LWA3, AAC and AAC with different percentage of wood waste are shown in fig 4.1. The mean density of NWAC was recorded as 2358 kg/m$^3$. The mean density of mixtures containing different types of light weight aggregate ranges from 1894 to 1586 kg/m$^3$. Similarly, the mean density of AAC mixtures were recorded 986 kg/m$^3$. Whereas, the mean density of AAC-SD25 was recorded as low as 890 kg/m$^3$. It was obvious that with the addition of light weight aggregate the density would decrease and similarly in case of AAC and AAC with wood waste the density would go down as recorded. According to ACI 213 the density of light weight concrete normally ranges from 1920 to 320 kg/m$^3$. The results showed that the densities of all the light weight concrete lies in between that range. The trend of variation in the densities of different kind of concrete is shown in fig and is compared with normal weight concrete. The trend indicates that with the introduction of lighter aggregate density decreases and similarly in case of AAC and AAC with wood waste which is lighter shown by their densities. The purpose of this research was to produce a lighter and sustainable concrete both for structure and non-structure elements. Decrease in density can significantly improve the performance of structures in both structure and non-structure components. When lighter materials are employed here. It is possible that the total weight of the structure will decrease; as a result, there will be fewer forces acting on the structure; this will make it easier to lower the cross-section of the elements and the amount of reinforcement steel that is required. As a result, the total cost of building reduced. By replacing the NWA with LWA more sustainable and alternative solution can be found. The LWAC-SH can be used for structural units and similarly AAC-SD25 can be utilized for items in the building business that are not structural.

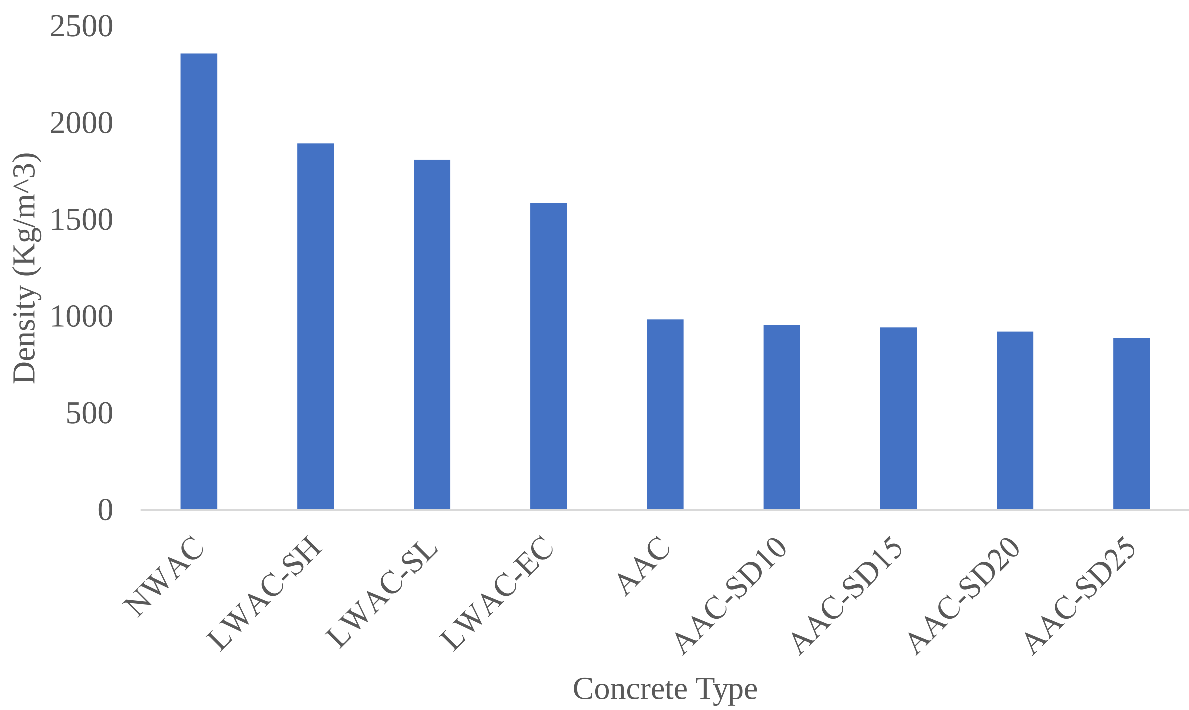


Fig 4.1 Hardened Density at 28 days (ASTM C642-21)

### 4.2 Compressive Strength

The compressive strengths of concrete produced is given in fig 4,2. The mean compressive strength of NWA comes out to be 23.6 MPa. The mean compressive strength of mixtures containing different types of light weight aggregates ranges from 17.6 to 15 MPa. Similarly, the mean compressive strength of AAC was recorded as 11.2 MPa and the in case of AAC with wood waste, mean compressive strength for AAC-SD25 comes out to be 4.23 MPa. According to ACI 318 for structure concrete, the minimum compressive strength requirement is 17.5 MPa. The light weight concrete produced from LWAC-SH can be used as a structure concrete as it meets the minimum strength requirement of strength. The light weight concrete produced from expanded slate (LWA-SL) and expanded clay (LWACL) cannot be used as structure concrete as it does not meet the requirement of strength for structure concrete. While, in case of AAC and AAC with wood waste strength is more compromised duo can be used as non-structure concrete. The strength and density of AAC with wood waste is less as compare to AAC but the strength of AAC with wood waste is on low side as compare to AAC. According to ACI 530 the minimum requirement for strength in non-structure concrete is 3.52 MPa which meets in case of AAC and all proportion of AAC with wood waste.

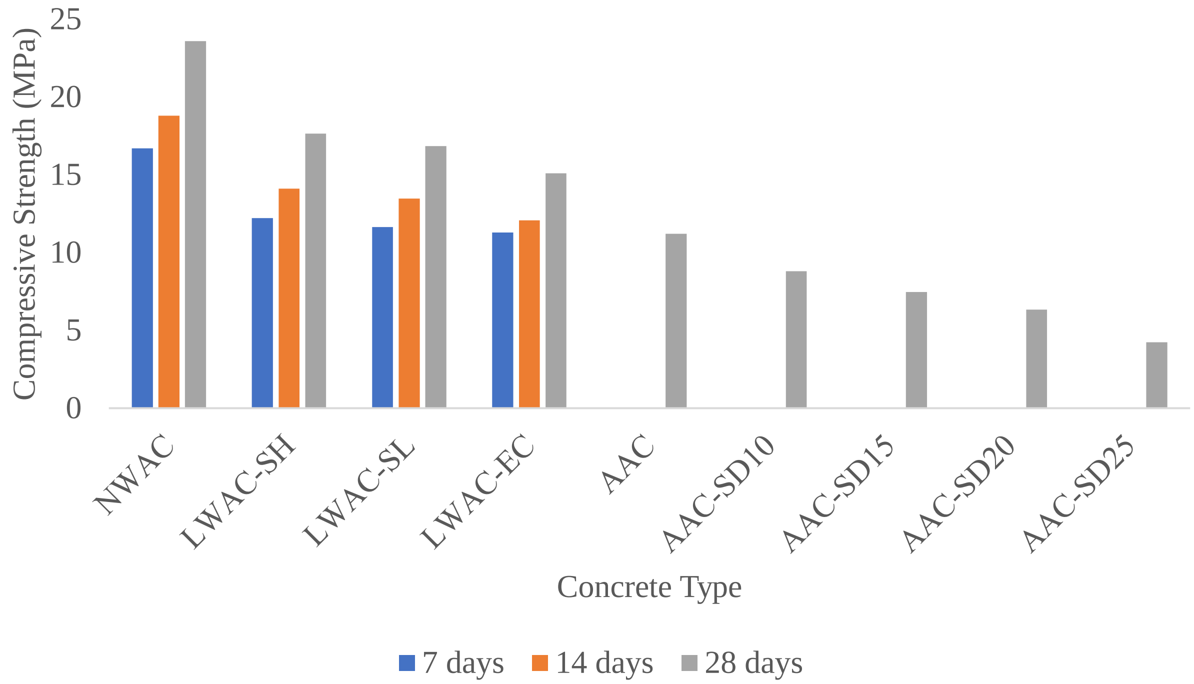


Fig 4.2 Compressive strength at 7,14 and 28 days (ASTM C39)

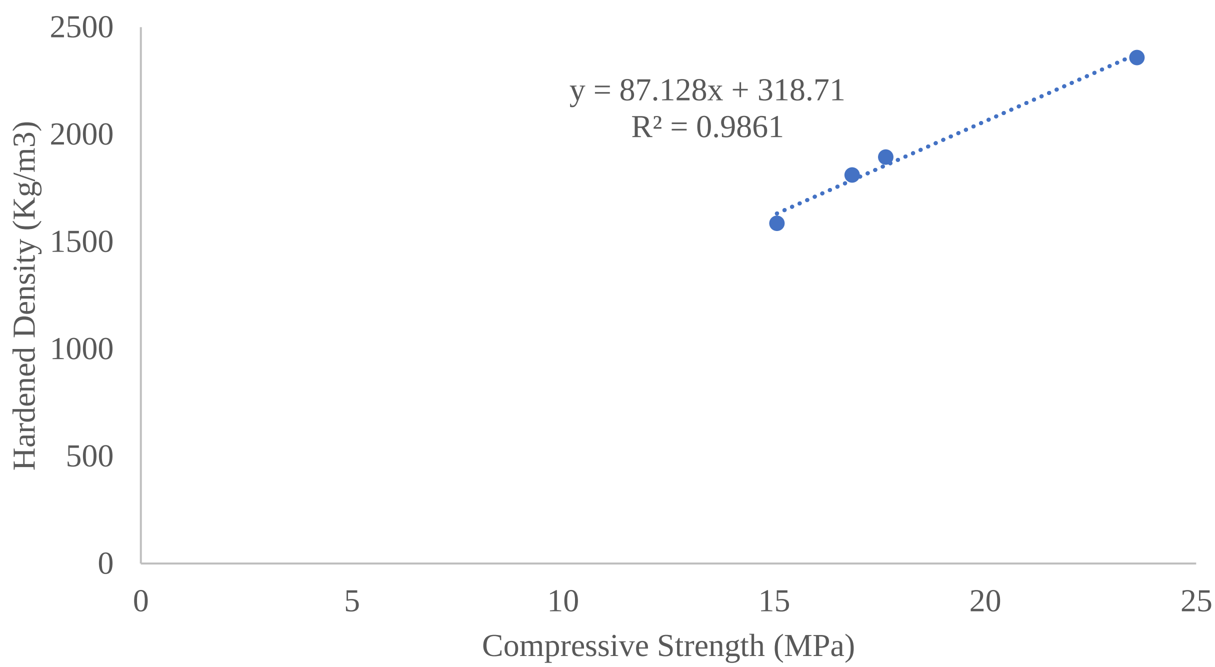


Fig 4.3: Relationship between density and compressive strength of NWAC & LWAC

A relationship between hardened density and 28 days compressive strength is developed as shown in Fig 4.3, which indicates a direct relation between these two perimeters. According to the data shown in Figure, the compressive strength of various LWAC and NWAC dropped as their densities were more hardened. When the compressive strengths of concretes that comprise various types of concrete are compared, the results are as follows. The relationship is based on testing results of different types of concrete and a strong relation ($R^2$ = 0.986) is developed as given below

$$Y = 87.128X + 318.71$$

Where Y is hardened density and X is the 28 days compressive strength. Such strong relation was obtained even only one type of light weight aggregate was taken into account [11]. But, in our case it’s the result of all types of concrete being selected.

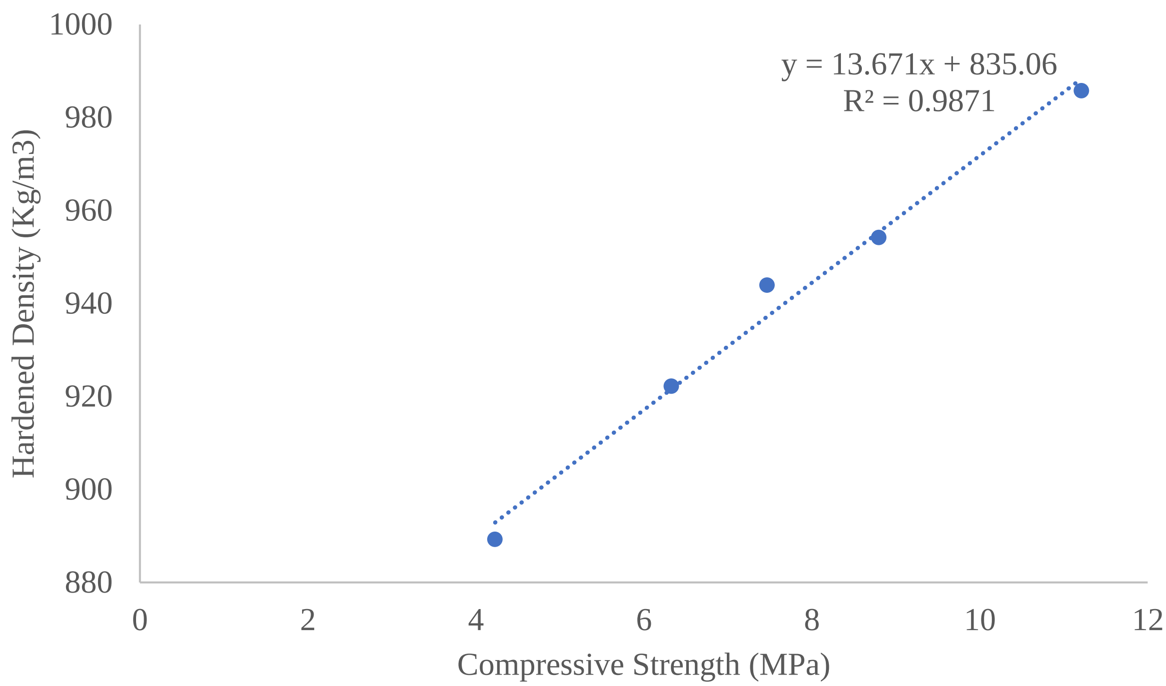


Fig 4.4: Relationship between density and compressive strength of AAC & AAC-SD

Similarly, a relationship between hardened density and characteristic compressive strength for AAC and AAC with different proportion of wood waste developed as shown in Fig 4.4, which indicates a direct relation between these two perimeters. As presented in Fig the compressive strength decreased with the hardened density of different wood waste replacement in AAC compare to simple AAC. When compressive strengths of the concretes containing different types of AAC and AAC with wood waste are compared. The relationship is based on testing results of different types of concrete and a strong relation ($R^2 = 0.987$) is developed as given below

$$Y = 13.671X + 835.06$$

Lightweight concretes may be categorized differently depending on their hardened density as well as their compressive strength, as stated in ACI 213. According to the findings of the test, enlarged shale has the potential to be used in the production of lightweight structural concretes. However, because of the large decrease in strength, expanded polystyrene beads can only be used for insulation reasons, while autoclaved aeriated concrete may be used as a non-structure light weight concrete material. Both of the concretes that were chosen provide an alternative and environmentally friendly answer to our building sector.

### 4.3 Split Tensile Strength

The split tensile strengths of concrete produced is given in fig 4,5. The mean tensile strength of NWA comes out to be 2.72 MPa. The mean tensile strength of mixtures containing different types of light weight aggregates ranges from 3.6 to 3.12 MPa. The results of tensile strength for the mixes are plotted in fig 4.5. It is seen in fig 4.5 that LWAC-SH, LWAC-SL and LWAC-EC had higher tensile strength at 28 days as compared to NWAC. This behavior of LWAC mixes confirms good bond of LWAs with hydrated cement which can be explained based on different factors. Firstly, penetration of cement paste into the pores of LWAs takes place due to porous surfaces of these aggregates which increases their bond with hydrated cement. Secondly, the moduli of elasticity of LWAs and hardened cement paste are similar which reduces the chances of differential stresses development between the two materials. Thirdly, the water absorbed by LWAs during mixing remains available for hydration of cement. As a result, additional hydration occurs which benefits the bond between aggregates and hydrated cement. Similarly, the mean tensile strength of AAC was recorded as 0.8 MPa and the in case of AAC with wood waste, mean tensile strength for AAC-SD25 comes out to be 0.75 MPa.

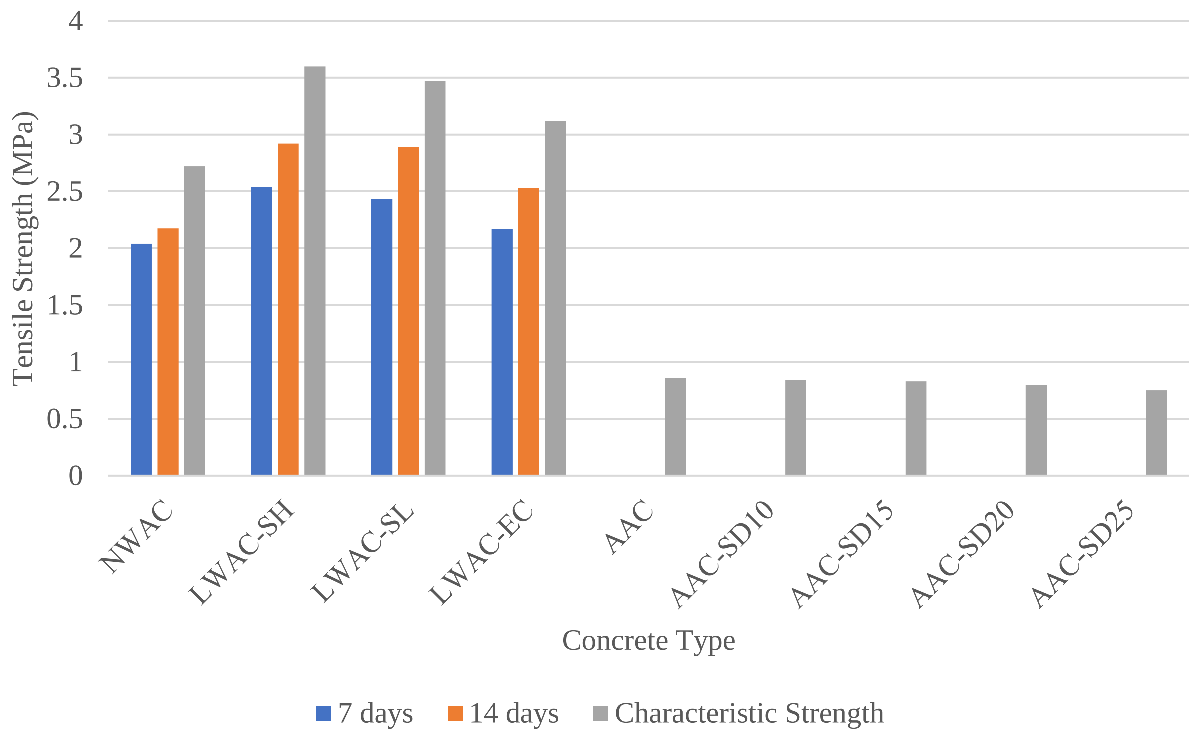


Fig 4.5 Split tensile strength at 7,14 and 28 days (ASTM C496)

### 4.4 Thermal conductivity

Thermal conductivity test results different types of concrete shown in Table 7. The mean thermal conductivity of NWAC comes out to be 1.176 W/m.k and for LWAC it ranges from 0.92 to 0.81 W/m.k . While in case of AAC it is as low as 0.2767 W/m.k and in case of AAC with wood waste at 25% replacement its value is 0.212 W/.k. It was obvious that as we move towards lighter concrete the value of thermal conductivity would decrease. NWAC contains traditional aggregate and less pours its thermal conductivity is on higher side as compare to LWAC, which contain lighter aggregate and a bit porous as compare to normal aggregates which cause to reduce thermal conductivity approximately 20%. In case of AAC and AAC with wood waste the samples are more porous and density is also reduced which cause to reduce thermal conductivity of AAC approximately 75% and in case of AAC-SD25 reduction is approximately 78% as compare to NWAC. According to the research that is currently accessible, it might also be linked to a phenomena referred to as convection, which is connected to the quantity and shape of pores created within the concrete matrix [37]. This is said to be the case because of the following: It is well knowledge that the addition of lightweight particles to concrete has the effect of lowering the material's density. This, in turn, produces a more porous structure, which in turn lowers the material's ability to transfer heat [38].

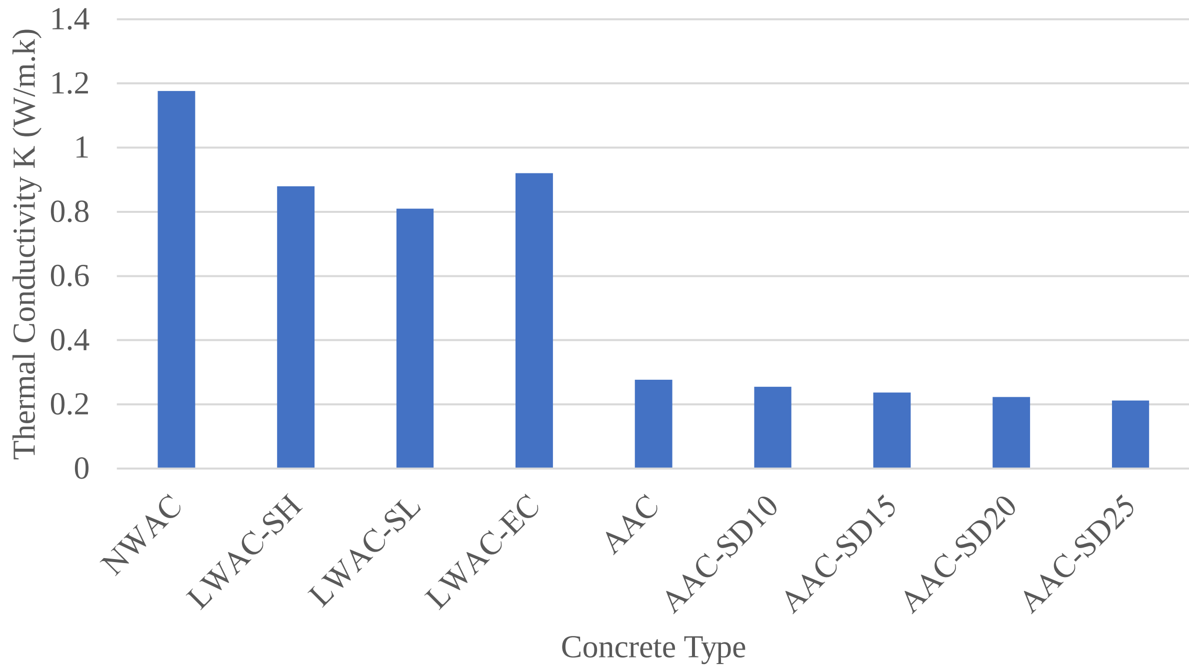


Fig 4.6: Thermal conductivity of different samples (ASTM C417-21)

**4.5 Energy Efficiency and CO2 Emissions**

A room was chosen for load calculation in order to examine the effect that various types of concrete have on the heating, ventilation, and air-conditioning (HVAC) systems of buildings including the heating and cooling loads of buildings. The results of this investigation are depicted in Figure 3. In order to do HVAC analysis, ECOTECT software was purchased. Figure 4 depicts the room's annual usage of heating, ventilation, and air conditioning. Calculations of carbon emission were performed in accordance with the recommendations provided by the IEA [39] in order to illustrate the energy efficiency and long-term viability of various kinds of concrete. The International Energy Agency (IEA) estimates that the CO2 emissions per kilowatt-hour produced by coal, natural gas, petroleum, and hydropower are 1000, 412.7, 966, and 18, respectively. We have a diversified generation of power here in Pakistan [40]. According to the information on energy production that was supplied by PEMRA, the figure of 363.5 gCO2-eq/kWh was chosen[41]. In case of LWAC the reduction in $CO_2$ emissions ranges from 69.9% to 68.8%, in AAC $CO_2$

emissions reduction is 66.2% and in AAC-SD25 reduction in $CO_2$ emissions is 70% in compare with the NWAC. It was observed that $CO_2$ emissions reduce drastically by replacing the normal weight concrete by other types of light weight concrete due to the highly dependance of thermal properties of selected concrete [42].

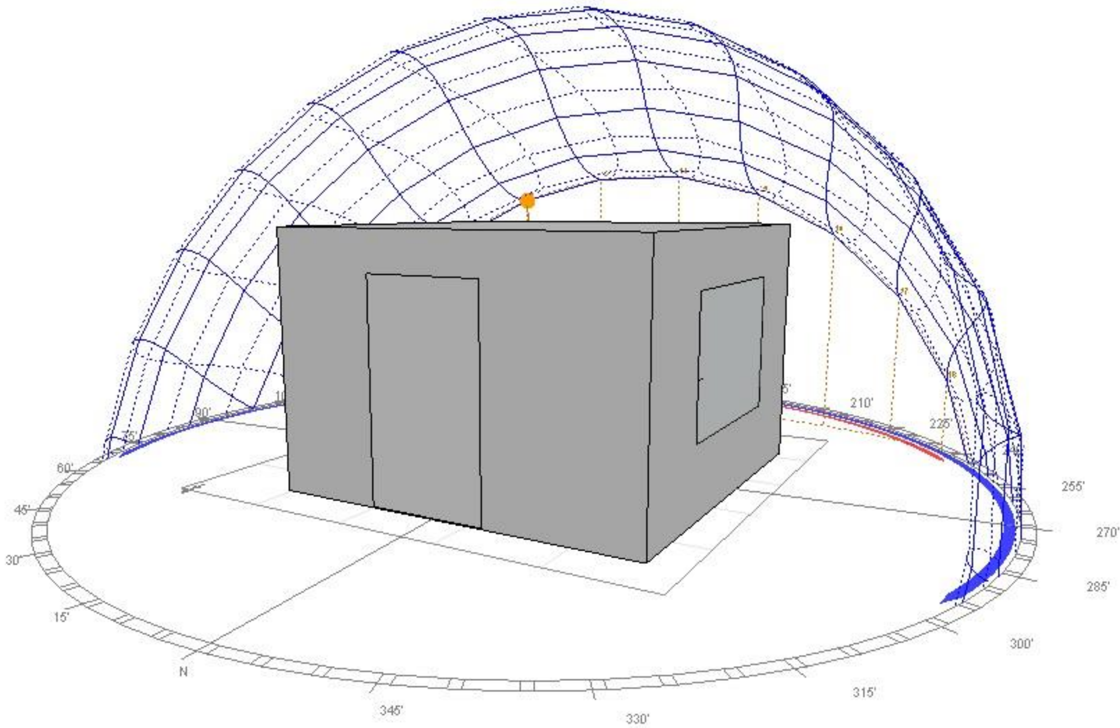


Fig 4.7: Average Annual sun path direction by AutoDesk Ecotect 2011

Table 4.1: Annual CO2 emissions using different kind of concretes

| Mixes | Annual CO2 Emission in Kg | | |
|---|---|---|---|
| | **Heating (kg)** | **Cooling (kg)** | **Total (kg)** |
| NWAC | 172125 | 17136 | 189261 |
| LWAC-SH | 45629 | 12939 | 58568 |
| LWAC-SL | 45579 | 12932 | 58511 |

| | | | |
|---|---|---|---|
| LWAC-EC | 46565 | 12899 | 59464 |
| AAC | 49919 | 13982 | 63901 |
| AAC-SD10 | 50082 | 12539 | 61621 |
| AAC-SD15 | 48372 | 12729 | 59101 |
| AAC-SD20 | 50040 | 13631 | 58371 |
| AAC-SD25 | 48102 | 12571 | 55473 |

### 4.6 Morphology using SEM

#### 4.6.1 Morphology of LWAC & NWAC

The technique of micrography known as scanning electron microscopy, or SEM, is used for the investigation of crystal structures. At 28 days, samples were collected taken from a variety of different concrete types, and then they were analyzed using SEM. SEM micrographs of a few different types of concrete are shown in fig 4.8.

The microstructure of LWAC is somewhat different from that of NWAC in a major way. The latter is an example of a three-phase system that consists of an aggregate, a matrix, and an interfacial transition zone (ITZ) surrounding the aggregate [43], [13]. In the LWAC, there is no ITZ even when the composition is done properly, in contrast to the NWAC.

This is as a result of three different processes.:

1. During the mixing process, the LWA is able to absorb water. In addition to the water used for mixing, some of the components of the binder make their way into the porous LWA. Because of this, the hydration products increase not only towards the outer surface of the LWA, but also, to a lesser degree, into the interior of the LWA. The increased particle strength that is produced as a consequence is linked to both an increase in bulk density and a reduction in the amount of binder component that is present in the matrix. Although there is a benefit to including binder components into the LWA, it is more cost-effective to retain such components inside the matrix.[23].

2. The surface of the LWA is rough and porous, which makes it possible for extremely effective mechanical interlocking. [44].
3. As was said before, the water that is absorbed by the lightweight aggregate is made accessible for the best possible internal post-treatment as the hydration process progresses. This feature is used to a certain extent in the production of high strength normal concretes.[45].

The lack of a well defined ITZ has an impact on the load-bearing capacity and structural integrity of LWAC.

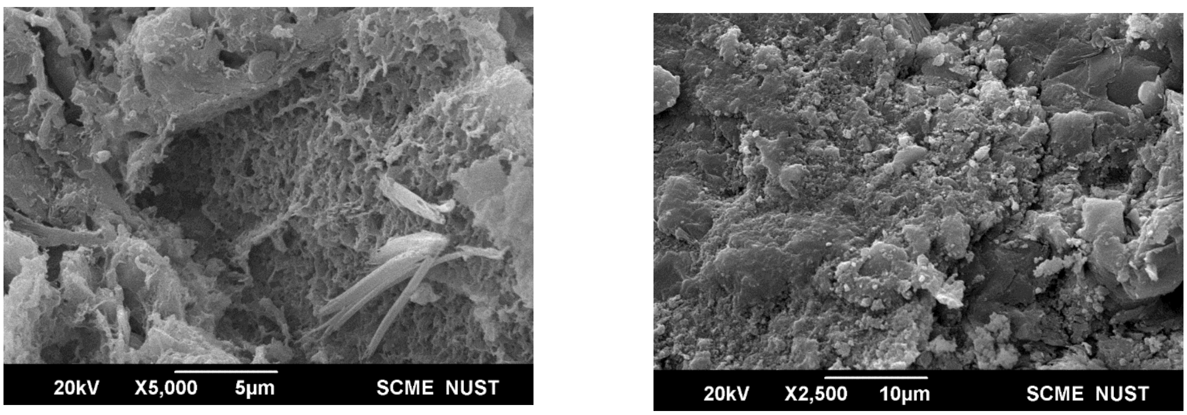


Fig 4.8 Morphology of NWAC and LWAC-SH

**4.6.2 SEM for Porous Concrete**

In the control mixture, SEM micrographs revealed the production of needle-like tobermorite crystals surrounded by hexagonal calcium hydroxide crystals (fig 4.9). These needle-like tobermorite crystals were later transformed into grass-like, fibrous but density interconnected tobermorite crystals, and the transformation of Ca(OH)2 into fibrous C-S-H gel was also observed. Energy Dispersive X-ray spectroscopy (EDX) was performed on identical scanning electron micrographs in order to determine the hydration phase in AAC. Calcium silica ratios (Ca/Si) were also analyzed and published in this study.

The literature makes it abundantly clear that the Ca/Si ratio of the starting materials has an effect on the crystal shape of tobermorite [46], [47]. The Ca/Si ratio is one of the most important factors in controlling the progression of the crystalline phase [48]. Tobermorite crystals are present when the Ca/Si ratio is between 0.7 and 1.4, as EDX makes abundantly obvious. These crystals may be found in the range. While a Ca/Si ratio that is more than 2 suggests the existence of C-S-H gel, which can be seen rather well from the corresponding EDX, According to previous research, the optimal range of Ca/Si ratio for the creation of tobermorite crystals falls between (0.7-1.4). [26] This information was gleaned from previous research. Tobermorite crystals were almost impossible to form from fibrous C-S-H when the Ca/Si ratio was less than 0.8. Their metamorphosis is not allowed, which contributes to the very low pace at which it occurs. While the CSH that has a grass-like structure and a Ca/Si ratio that is more than 2 is able to be quickly changed into tobermorite crystals due to the propensity to have short chained silica at early stages[49], the CSH that does not have this tendency will not produce crystals. In this study, the EDX of AAC demonstrated that the Ca/Si ratios of the crystalline phases were 1.18 and 3.8, which provided a favorable indicator of the densification of the microstructure brought about by the production of plate-like tobermorite via the consumption of calcium hydroxide crystals.

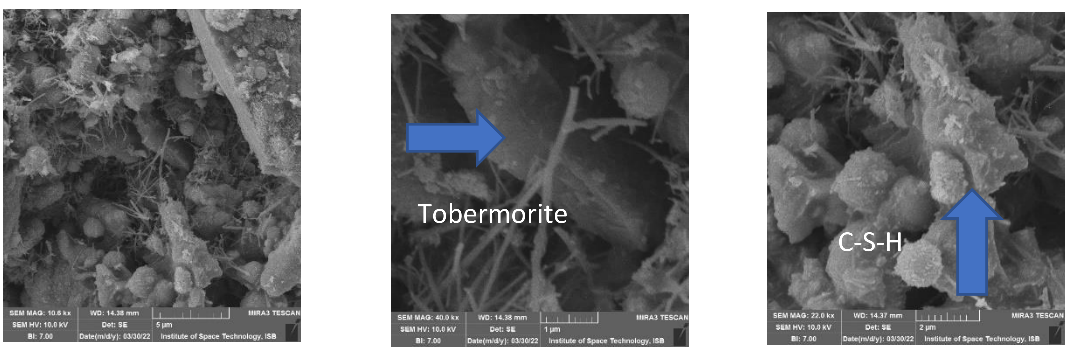


Fig 4.9 Morphology of AAC

**4.7 GEP Validation of LWAC**

Estimating the compressive strength of lightweight aggregate concrete with the use of gene expression programming is one approach that has been taken. In order to demonstrate how accurately the association holds, both the fit function, also known as Mean Squared Error as well as the correlation coefficient were used. An estimator is a mathematical function that maps a sample of data to a parameter of the population from which the sample was drawn, whereas a predictor is a mathematical function that maps arbitrary inputs to a sample of the values of a random variable[50]. The MSE evaluates the accuracy of both estimators and predictors. The average of the squares of the mistakes or deviations, which is the difference between the estimator and what is estimated, is measured by the mean squared error (MSE) or mean squared deviation (MSD) of an estimator. In statistics, these terms are abbreviated as "MSE" and "MSD," respectively[51]. The Eq. (2) is obtained for LWAC and this equation is derived from best expression tree as shown in Fig 4 obtained after iterations. The obtained expression tree is the combination of 4 sub trees and final equation is developed after adding them. In this equation the proposals are measured in kg/m3, whereas the compressive strength of the 28-day concrete sample is evaluated in MPa. In addition to that, the accuracy as well as the correlation coefficients are shown underneath the formula. In these equations $fc^{'}$, $d_0$, $d_1$, $d_2$, $d_3$, $d_4$, $d_5$, $d_6$, $d_7$, $d_8$ and $d_9$ are compressive strength, the, age, water cement ratio, quantity of water, quantity of sand, quantity of cement, aggregate type, NWA, LWA, mean size of aggregates and unit wight of LWA.

$f_c' = A+B+C+D$ Eq (2)

$A = d_1 + [\arctan (((-6.2/d_1) – (d_9 + d_6) + (d_7 + d_0)) + d_1]$

$B = \text{Min} ([\text{Min} (d_4, (d_9 \times d_8)) – \text{Min} ((d_7 – 5.8), (d_4/d_9))], (d_0)^{1/3})$

$C = \text{Avg} [(\text{Min} (d_0, d_2) – 86.8/d_5)^{1/3}, (\text{Max} (d_6, d_1) \times \text{Avg} (d_0, d_9))^{1/3}]$

$D = (d_8 \times d_2) \div 1 – [[\text{Avg} ((d_7 + d_0), \text{Min} (d_2, d_9))]/ (d_4 – d_0)]$

Fig shows the correlations between the actual compressive strength and the anticipated compressive strength using equations obtained from GEP. the actual compressive strength may be found in the table below. The projected equation is useful for achieving the appropriate compressive strength of light-weight aggregate concrete. It is based on the findings of past research [52]. The value of $R^2 = 0.93$ indicates that a strong relation exists between predicted and actual testing results of LWAC.

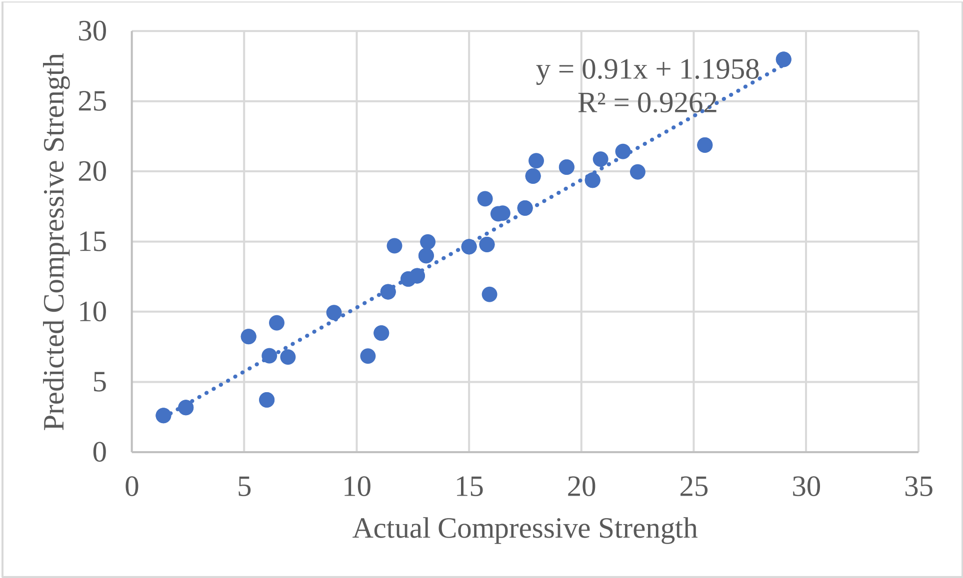


Fig 4.10 The relationship between actual and predicted compressive strength of LWAC

**Chapter 5**

# CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusions

On the basis of the findings and observations made during this experimental inquiry on the thermal, physical, and mechanical characteristics of conventional normal aggregate concrete (NWAC), lightweight aggregate concrete was developed (LWAC), autoclaved aerated concrete (AAC) and incorporation of wood waste in autoclaved aerated concrete the following conclusions are drawn:

- The LWAC produced using local shale and slate complies with ACI 318 requirements for structural concrete along with 23% low in weight and 66% thermally efficient than corresponding NWAC.
- The cellular concrete is successively developed using indigenous wood waste satisfying the non-structural concrete requirements laid by ACI 318.
- The AAC-SD25 reduced concrete weight 78% compare to NWC along with the added thermal performance and reduced $CO_2$ emissions.
- Machine learning model using GEP is developed for LWAC to efficiently predict compressive strength with least laboratory trials.

## 5.2 Recommendations

This research work investigated the possible impact of wood waste on thermal insulation properties, physical properties and mechanical strength of autoclaved aerated concrete (AAC). Although research findings revealed that sawdust possess the potential ability of improving thermal insulation, energy efficiency and shrinkage response of cement composites still it demands due attention in terms of mechanical strength especially compressive and flexural strength. Similarly expanded clay aggregates being used in current study can be further enhanced to use for structural purposes to address the issues of depiction in natural resources of normal weight aggregates. Following are key recommendations for future research work in this area

- The outcomes of this research showed that the presence of sawdust in autoclaved aerated concrete had a negative impact on the material's mechanical qualities (AAC). Nevertheless, the improvement of wood waste concrete's mechanical qualities may be accomplished with the use of appropriate admixtures.

- Echo efficiency and Electrical resistivity of concrete containing wood waste requires in-depth study.
- In addition, the research results showed that the presence of expanded clay aggregates in conventional concrete had an effect on the mechanical characteristics of lightweight aggregate concrete (LWAC). However, improved mechanical qualities of expanded lightweight aggregate concrete may be achieved with the use of an appropriate admixture.
- Echo efficiency and Electrical resistivity of concrete containing lightweight aggregates requires in-depth study.

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