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Experimental Investigation of Aloe Vera Gel as a Self-Curing Agent in Concrete Production

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Experimental Investigation of Aloe Vera Gel as a Self-Curing Agent in Concrete Production

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Declaration

I verified that this thesis titled **"Experimental Investigation of Aloe Vera Gel as a Self-Curing Agent in Concrete Production"** is originally executed by me with the guidance of my advisor. The study has not been submitted and presented for a degree or professional qualifications in any other university. When content from other sources has been used, it has been properly cited and acknowledged.

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Abstract

Nature-based admixtures are emerging as eco-friendly alternatives to synthetic additives, promoting sustainable practices in construction by replacing depletable resources. Aloe Vera gel is easily accessible and low-cost plant extract that has the potential to be used as a bio-admixture in concrete, improving workability and enhancing compressive strength. Due to the viscose nature of the plant, it is desired to examine the self-curing effect of aloe vera gel in concrete.

The research examined the effects of using Aloe Vera gel as a self-curing agent for the concentration of 0%, 1%, 2%, and 3% by weight of cement. The investigation started with selecting the appropriate concrete making ingredients such as cement, fine aggregate and coarse aggregate. The important physical tests, parameters useful for categorizing the ingredients and helpful for designing concrete, have been conducted in a laboratory. ACI mix design method was the procedure followed for designing C-30 grade concrete.

Workability, split tensile strength, flexural strength, water absorption, drying shrinkage, and compressive strength tests were conducted on concrete samples at specified time intervals. Additionally, mortar samples were cured under two conditions—water-cured and sealed-cured—and their compressive strength was evaluated. The study also analyzed the effect of Aloe Vera gel on the consistency and setting time of cement paste.

The addition of Aloe Vera gel improved workability and strength, with 1% gel showing optimal mortar compressive strength, and 2% gel yielding the best overall performance in concrete. On the long term, this natural additive has had an increasing drying shrinkage with the increase in dosage, however the change in length was marginal laid within the allowable limit. Additionally, the natural additive has a retarding effect on the setting time of cement paste.

In conclusion, this study underscores the potential of Aloe Vera gel as a sustainable alternative to conventional additives, warranting further research on optimization and large-scale applications.

Key words: Admixture, Aloe Vera gel, Self-Curing, Mortar, Concrete, Strength.

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List of Abbreviations

AVG- Aloe Vera Gel
AVM- Aloe Vera Mucilage
SC- Self Curing
SCC- Self- Consolidating Concrete
AAiT- Addis Ababa Institute of Technology
ACI – American Concrete Institute
ASTM- American Society for Testing and Materials
ES- Ethiopian Standard
FA – Fine Aggregate
CA – Coarse Aggregate
FM- Fineness Modulus
OPC – Ordinary Portland Cement
UK- United Kingdom
OD - Oven dry Condition
SSD – Saturated Surface Dry Condition
W/W – Weight to Weight ratio
PEG - Polyethylene Glycol
IST – Initial Setting Time
FST – Final Setting Time
C-S-H - Calcium Silicate Hydrate
NRMCA - National Ready Mixed Concrete Association
LWA - Light Weight Aggregate
SAP – Super Absorbent Polymer
HPC – High Performance Concrete
SRA – Shrinkage Reducing Admixtures

1. Introduction

1.1 General

As reported by World Bank, presently more than half of the human population worldwide resides in cities [1]. The study predicted that six billion or more individuals would reside in urban globally by 2045. Due to rise in population, there is a need for infrastructure, reasonable housing, and essential services. To keep up with the demand, the building industry will therefore have to advance substantially. However, as the constructed surroundings and population increase, environmental problems are growing.

The construction industry is one that has a major negative influence on the environment [2]. It is now in the spotlight due to ecosystem damage and natural resource depletion kinds of environmental issues that are brought on by the sector [3]. The carbon footprint of concrete and the enormous use of natural resources are the primary environmental implications of the construction industry [4]. The production and use of concrete release a significant amount of carbon dioxide (CO_2) into the atmosphere. This CO_2 contributes to global warming and climate change. Because concrete is one of the most widely used materials in construction, its carbon emissions are a major environmental concern.

Admixtures comprise the smallest percentage of the materials used to build concrete when compared to the other components. Nonetheless, admixtures are crucial to achieving the appropriate characteristics for both fresh and hardened concrete. Furthermore, the unintended environmental effects of admixtures are mostly caused by the raw materials utilized and due to the production processes [4], [5]. As ecological concerns grow, scholar and industrial studies on admixture are focused on developing innovative, eco-friendly, and recyclable products derived from regenerative natural resources [6].

The current trend of making concrete constitutes cement, natural or crushed sand and coarse aggregate with or without the introduction of different role entitled admixtures. Properly produced, carefully stored, correctly proportioned, and mixed ingredients will eventually provide the intended grade of concrete. However, without compensating for water lost due to evaporation through regular curing, it is difficult to maintain the integrity of concrete structure.

The motivation for undertaking this research originates from both professional and personal perspectives. The curing process in concrete production is vital to achieving optimal strength and durability; however, conventional curing methods often involve high resource consumption and environmental concerns. In pursuit of sustainable and cost-effective alternatives, this study explores the use of aloe vera gel as a natural self-curing agent.

My personal experience with aloe vera, primarily through its use in cosmetic applications, has revealed its remarkable water-retaining properties. This characteristic inspired the hypothesis that aloe vera gel could serve as an effective curing agent by maintaining the necessary moisture within concrete, thereby enhancing its curing process. The prospect of utilizing an abundant, renewable, and environmentally friendly material in construction aligns with the global movement toward sustainable building practices.

This research aims to provide an experimental evaluation of aloe vera gel's efficacy in concrete curing, contributing to the advancement of eco-friendly construction technologies. Additionally, this study offers an opportunity to develop technical expertise and enrich knowledge within the field of civil engineering materials.

1.2 Statement of the problem

Curing is the process of keeping concrete at a certain temperature and moisture content for a given period of time after putting and finishing it thereby the appropriate qualities can form [8]. Concrete curing can be achieved by water ponding or wet covering of horizontal structural parts, by immersing pre-casted concrete members in curing tank, and by spraying or fogging vertical structural members [9].

Water curing primarily affects only the outer 30 to 50 mm of a concrete element. This indicates that enhancing a structure's compressive strength is not the primary objective of water curing. However, it has a significant impact on surface hardness and permeability, which means that it regulates structural parts potential lifespan, especially for those exposed to harsh environments [10], [11], [12].

In comparison to the basic concrete, self-curing chemicals are thought to enhance the water reserving capability of concrete irrespective of the water lost due to evaporation. Self-curing concrete helps to moderate the effects of inadequate curing due to various causes such as lack of water in arid places, human neglect, struggle in accessing structures in rough territory, and areas where fluoride contamination of water negatively affects the properties of concrete.

Reduced permeability, autogenous shrinkage and cracking, along with improved strength development, durability, and hydration, are the main benefits of internal curing. In order to allow for retaining some water within the hardening concrete, a special material must be utilized [13]. The mechanism is that the retained water will gradually flow into the concrete after the poured concrete hardens.

1.3 Significance of the study

The study is thought to contribute a new area of knowledge towards the effect of employing Aloe Vera gel as a self-curing agent particularly in Ethiopia. It also carries out its role in alleviating the growing practice of chemical admixtures in concrete production and serve as an alternative curing agent. Furthermore, it presents its contribution for further studies in the sustainable use of this natural agent.

1.4 Research objective

Generally, the study aims to assess the self-curing effect of Aloe Vera gel on the production of concrete.

The specific objectives are listed below

- To investigate the effect of Aloe Vera gel on the properties of fresh concrete & cement paste.
- To assess the ability of Aloe Vera gel to improve the properties of hardened concrete in the test samples.
- To compare and contrast the effect of two curing conditions on the mechanical properties of Aloe Vera gel containing mortar specimens.
- To explore the impact of using Aloe Vera gel as a natural polymer-based alternative admixture on the durability of concrete.

1.5 Scope of the research

The study in this particular experiment was conducted by using the Aloe Vera gel of Aloe Barbadensis Miller Species.

The research examines the mechanical characteristics of mortar, cement paste, and concrete mixes with the addition of Aloe Vera gel as a self-curing admixture. The study is limited on concrete grade C-30 and mortar with water, cement and sand ratio of 1:2:2. In addition because of the lack of access to a calorimeter apparatus, the test for heat of hydration test was not conducted to observe the effect for the plant extract.

The selection of C-30 concrete for this experimental study was guided by several technical and practical considerations. As a starting point, employing a moderate-strength mix allows for the evaluation of self-curing performance under standard conditions without the complexity associated with higher-strength concretes. Moreover, the comparative nature of the study—where all other mix design parameters are held constant—ensures that variations in performance can be attributed primarily to the presence and dosage of the Aloe Vera gel, irrespective of the concrete grade. Additionally, the use of higher-grade concrete would have necessitated increased cement content, more stringent quality control, and enhanced testing procedures, all of which would have escalated the overall project cost. Therefore, C-30 was selected as a technically sound and economically viable option that facilitates meaningful analysis while maintaining resource efficiency.

2. Literature review

2.1 Introduction

This chapter is based on an examination of relevant studies that have been carried out in the field of making concrete from aloe vera plant. Additionally, an overview of the suitable literature is included to further reinforce the research study's contribution to knowledge. This part presents an overview of the research challenge through references to prior ideas, concepts, and researches related to this particular topic of study.

Maintaining a proper moisture content, temperature, and curing time are essential for giving concrete the strength, hardness, and durability it desires. The concrete strength, durability, and capacity to resist cracking are all improved by proper curing. Common techniques for curing concrete include curing chemicals, steam-curing, membrane-curing, and water-curing.

Water-curing is the conventional method of moisturizing concrete, which entails keeping it moist by ponding, immersing, spraying, or covering it with wet sand, burlap, or other materials. Traditional methods of curing concrete address only a certain depth. This limitation, coupled with the growing use of mixtures with a water-to-cement ratio of less than 0.4, increases the risk of self-desiccation [14]. While external water supply is necessary to get the maximum benefits of this mixture at the outside, it won't assist beyond a certain depth below the surface. In this situation, adopting internal curing methods might be taken into consideration.

Self-curing concrete is a modern type of concrete that retains moisture and prevents surface moisture evaporation. This kind of concrete is achieved by the introduction of a chemical admixture namely polyethylene glycol (PEG). However, in spite its prevalent advantage, it has not been practiced as such due to the products inflated buying price.

Although the production of natural polymer as an admixture has not started yet, there are a number of researches being done on the physical and mechanical behavior of concrete prepared with the addition of Aloe Vera gel.

2.2 Concrete making materials

Concrete is a widely used construction material valued for its strength, durability, and versatility. It is primarily composed of cement, water, fine and coarse aggregates, and may include admixtures to improve performance. Through hydration, the mix hardens and gains strength over time.

2.2.1 Cement

Cement is referred to us a component which is employed to join together several building parts. A mixture made of water and sand is used to bind sand or crushed gravel together. It is a necessary component of concrete and mortar mixture due to its quality regarding adhesion and cohesion. Cement and water are combined to form a paste that holds aggregates like sand or broken rocks together. The ingredients that make up cement include aluminum, iron, calcium, and finely ground silica [15].

The quality of cement blend utilized in a number of construction site is distinguished by its physical characteristics.

a. **Consistency**: is the ability of cement paste to viscose or to flow. It is measured by Vicat apparatus and the quantity of the standard specimen is operated by the percent by mass of the dry cement [16]. Ethiopia Standard ES.C. D8.490 outlines the process for calculating the amounts of the ingredient.

b. **Setting time:** is the total time it takes for concrete blend to transition from liquid to plastic state, then to a solid state. Conventionally, the concrete's setting time can be used to determine how thoroughly it has been hydrated [17]. Two setting times can be measured;

   - ✓ ***Initial setting time* -** is the duration of time needed for the cement paste to become sufficiently hard to endure a certain amount of pressure and starts to lose its flexibility.
   - ✓ ***Final setting time* -** is the time needed for the cement paste to fully solidify and harden.

   Same with consistence testing, initial and final setting times of a cement paste also measured with the Vicat device.

c. **Heat of hydration:** is the heat produced as water mixes with cementing particles. Appropriate proportioning of the raw ingredients is crucial for producing clinker with the right constitution when making Portland cement. The raw components should undergo a chemical examination in order to precisely determine the proportions.

   The current tendency in Portland Cement manufacturing is to use more lime—more than 65%. Lower lime content cement hardens more slowly; however, the maximum lime concentration should be kept to a minimum to prevent free lime from occurring in the cement, as this could lead to volume instability in the hardened cement paste [19].

   Table 2.1 shows the chemical analysis results that are expressed with respect to oxides of the main comprising elements utilized in the manufacture of Portland cement [18].

Table 2.1 Range of oxide composition in raw materials used for cement production [20]

Oxide		Content (weight in %)
Lime	CaO	60 - 67
Silica	S_1O_2	17 - 25
Alumina	Al_2O_3	3 - 8
Iron Oxide	Fe_2O_3	0.5 - 0.6
Magnesia	MgO	0.1 - 5.5
Sulphur trioxide	SO_3	1 - 3
Alkalis		
Soda	Na_2O	0.5 - 1.3
Potassa	K_2O	
Titanium Oxide	TiO_2	0.1 - 04
Phosphorous Pentoxide	P_2O_5	0.1 - 02
Carbon dioxide	CO_2	1 - 3
Manganese Oxide	Ma_2O_3	0 -0.1

The lower percentage limit of alumina and iron oxide can be explained by their function as a flux to lower the burning temperature of the clinker. On the other hand, the requirement to regulate the cement's rate of setting establishes the maximum limit for these oxides. Cement gets its grey tone from iron oxide [20].

Mechanism of setting time and hydration

Compared to lime or gypsum plastering, Portland cement requires significantly more complicated hydration, setting, and subsequent hardening. This intricacy is caused due to the nature of the compounds' hydration outputs as well as the existence of multiple distinct compounds that all undergo hydration in somewhat autonomous manner [18].

The heat liberation process is shown as follows:

a) The degree of heat evolution is seen to rise quickly due to the exothermic character of the process. This heat of immediate hydration can reach up to 14 mega Watt per gram, dependent upon the cement's precise composition as shown in Figure 2.1.[21].

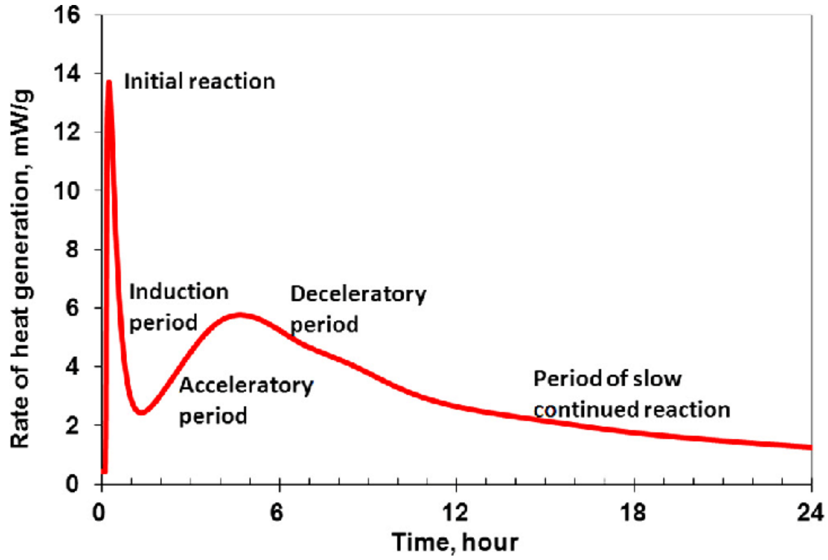


Figure 2.1 Heat liberation of a setting cement [21]

b) Following the development of dense layers, the paste experiences 30- to 120-minute-long, comparatively inactive or very slow reaction period during then it stays plastic and workable.

c) A new increase in the rate of heat liberation, or a second phase of comparatively quick chemical reactions that typically lasts fewer than eight hours, occurs after the dormant period.

d) After then the last phase, in which there is a progressive drop in the heat of hydration (coming down to less than one calorie per gram per hour within 24hours and even lower rates beyond that), will take place. Showing that the solid hydration products are causing hydration to occur at a slow pace through diffusion.

2.2.2 Admixtures

In order to analyze the possible replacement of bio-based admixtures, it is important to review the conventional admixtures that are contemporarily applicable. These conventional additives are substances added to concrete either before or during concrete mixing in addition to aggregate, water, and cement to alter its properties such as color, workability, setting time, and curing-temperature. A concrete mixture excluding an additive is uncommon these days. In order to achieve a particular adjustment to the ordinary characteristics of concrete, a chemical product admixture is included into the mix during mixing or during an additional mixing operation before concrete is casted in amounts not greater than 5% by mass of cement [22].

When it comes to the production of concrete, additives have the potential to provide significant financial and practical advantages. It has long been known that the use of admixtures saves associated costs, such as labor costs for achieving compaction and increasing durability without the need for additional precautions [22].

Admixtures do not take the place of sound concreting techniques. Admixtures should only be utilized following a thorough assessment of their potential impact on the intended usage of the concrete. To get reliable data on the properties of concrete containing admixtures, studies on typical trials of the product for a given work under simulated work environments are frequently required [7, 15].

As per ASTM C494-92, based on their function admixtures are classified as follows [23].

i. **Plasticizers/Water Reducers –** these are employed to lower the volume of water needed to mix concrete to attain a specific slump, lower the cement content, lower the water-to-cement ratio, or raise the slump.

   Admixtures can be added to concrete in amounts between 0.5% and 10% of the mass of cement, depending on how the concrete is used. Admixtures are added with a composition between 0.02% and 0.5% when compared to the mass of all constituents and the overall composition of concrete. Water content is often reduced by 5% to 10% using standard water reducers [24].

   Water-reducing admixtures usually result a rise in concrete strength when the water-to-cement ratio decreases. The 28-day strength of a water-reducer added concrete resulted 10% to 25% higher outcomes as from the respective conventional concrete while maintaining comparable slump, air-content and cement-content. However, because of its negative impact on the inevitable rise in creep and shrinkage, care must be given while using this admixture.

ii. **Super-plasticizers/ High water reducers**- these are added to concrete to make it stronger or to cast concrete that compacts on its own. In highly reinforced and unreachable regions, super-plasticized, high-strength concretes can be used.

   Super-plasticizers allow for a 30% or greater reduction in water content, while plasticizers chemical compounds allow for a 15% reduction in water content in concrete. A few weight percent is the amount at which these additives are used. Concrete's setting and hardening process are further delayed by plasticizers and superplasticizers [25].

   These additives have the power to significantly lower the water content of regular Portland cement concrete or significantly improve its workability. The dosage demands vary based on the type of admixture used, from 0.5 to 3 percent by weight of cement.

   Superplasticizers are not cost-effective for use in regular concrete since their cost is significantly higher than that of regular water-reducers. When it comes to applications requiring flowing concretes at extremely low water-to-cement ratios, they are perfect [26].

iii. **Accelerators –** they can be applied to speed up concrete stiffening or setting, or to speed up hardening and early strength acquisition to enable formwork striking and demolding earlier. Instead of completing both of these tasks, most accelerators only accomplish one.

   Accelerating admixtures improve the overall rate of hydration by altering the rates of reactions between cement and water. As a result, adding accelerators to concrete can speed up the initial development of strength and/or reduce the setting-time. On average, the range is between 0.5 and 2.5% by weight of cement; however, with the manufacturer's approval, greater dosages can be used employed.

The optimal operating temperature for accelerators is low. It should be noted that accelerators are not anti-freeze; rather, they are used to minimize the chance of damage from freezing during the cold weather concrete production and to enable the early removal of formwork [27].

iv. **Retarders –**these are added to freshly mixed concrete for delaying the chemical setting or hardening process for a maximum of 60 minutes. Usually used in hot weather, it slows down the rate at which the temperature hardens, giving more time to mix, transfer, and pour.
For the purpose of mitigating the increasing impression of hot weather on concrete setting, the concrete setting rate has to be slowed down. Placing and finishing become more challenging due to the accelerated hardening rate that high temperatures usually cause.

The primary disadvantage of using retarding admixtures is the potential for quick stiffening, which can make it challenging to place, consolidate, and finish concrete due to rapid slump loss.

When most retarding admixtures are significantly overdosed, the set time is rapidly extended into days, and in severe situations, the cement may never fully hydrate and gain strength.

v. **Self-curing admixtures –** Polyethylene glycol (PEG) group is commonly used chemical admixture frequently included into concrete mixture as a self-curing or shrinkage-reducing agent. Polyethylene glycol being a base subatomic concentration can prevent reinforcement bar corrosion by enhancing the viscosity of the pore-solution. The primary cause of the degradation of reinforced concrete is the corrosion of rebar caused on by chloride-ions [28].

When the cement begins to hydrate, the utilization of PEG competently disclosed the matter of water scarcity [25]. The amount of self-curing agent demanded in concrete mixture ranges approximately from 0.1 to 5% mass of cement [25, 26, 27].

Self-curing additives like water-soluble polyethylene glycol (PEG) have been shown to enhance the permeability, water absorption, and retention of concrete [29]. Furthermore, adequate water and appropriate spatial distribution are provided via internal curing, ensuring that the paste's interior components remain saturated and autogenously stress-free. By using this additive, the concrete would be able to maintain its desired qualities through continued hydration. Nevertheless, because of the inflated purchase price of the product, it has not been used as such despite its widespread benefit [30].

2.3 Self-curing concrete

In this topic, self-curing concrete will be defined, its working mechanism explained, and various methods used to achieve internal curing will be discussed. Self-curing (or internally curing) concrete is a type of concrete that retains moisture within the mix, promoting continuous hydration without the need for external water curing.

Engineering properties of concrete have been enhanced by rapid technological advancement. The improvement includes the development of high-performance and high-strength concrete, that have been used to build high-rise structures, tunnels, passageways, and others [26]. Concrete that is produced with a low water to cement proportioning and meets specific requirements for durability and performance is called HPC or HSC concrete. Complete hydration of cement in HPC is possible in the w/c range between 0.29 and 0.37 [31, 32].

Usually for water to cement ratio less than 0.5, there is hardly enough water available to thoroughly hydrate the concrete mix. Since the conventional water curing process has problems, such as curing vertical sections, certain inaccessible building locations, and poor craftsmanship, a paradigm shift in curing technology is also required. Concrete can now be cured more effectively with self-curing technology (SCT), sometimes referred to as internal curing. This innovative technique is gaining popularity among researchers and practitioners. Concrete that can hold onto more water throughout the curing process is referred to as a self-curing concrete. It is a technology where moisture is contained by tiny inclusions that are dispersed throughout the mixture, and the inclusions hold water until the setting period, then loosen the retained moisture when the cement hydrates. Self-curing is a potential technique that can assure the liberation of additional water into the concrete matrix for less self-desiccation and more effective cement hydration [31]. Figure 2.2 illustrated thee effect of internal and external curing inside a concrete matrix.

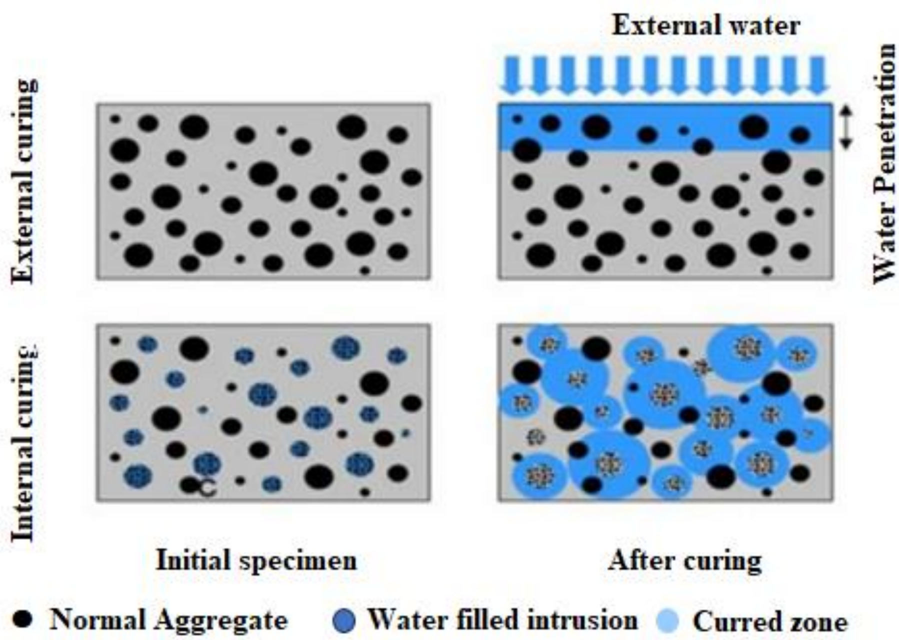


Figure 2.2 Self- curing and external-curing comparison [31]

In the construction industry, there are various methods for achieving internal curing. These include addition of wood powder, shrinkage-reducing admixtures, polyethylene glycol (PEG), superabsorbent polymers, and light weight aggregate.

Examples of light weight aggregates include expanded shale that is both natural and manufactured, 17% water-absorbing lightweight sand, and 20% water-absorbing 19mm lightweight aggregate. Superabsorbent polymers, that are also hydrophilic substances, include poly-acrylic acid, polyvalent, polyethylene glycol (PEG), glycerin, urethanes, hyaluronic acid, Xylitol, polyoxymethylene (POE), and phytosterols. The two main approaches that are most effective in establishing internal cure are the superabsorbent polymers and saturated light-weight aggregate [32].

The major benefits of an internal curing techniques are achieving higher durability, improved hydration and strength, decreased cracking and autogenous shrinkage and lowered permeability. Thus, an effective curing method that begins and ends with concrete mixing will be a workable substitute for conventional curing procedures.

2.3.1 Historical background

Among the earliest approaches to internal curing, the use of lightweight aggregate has played a significant role, with a rich historical background that highlights its development and application over time. Initially, lightweight aggregate was used to lower the weight of the concrete, which resulted in an inadvertent internal curing. The Pantheon in Rome is one of the most notable examples of light-weight concrete made by means of ordinary light-weight aggregate that goes back to the days of Roman era. Lightweight concrete with natural vesicular aggregates was used to build the Pantheon's dome; as the concrete's height inside the dome climbed, its density decreased [33]. The Pantheon in Rome is shown in Figure 2.3 below.

Figure 2.3 Pantheon in Rome (2000 years ago) [33]

Stephen J. Hayde, who was granted recognition in 1918 by a remarkable method to create light-weight aggregates using shale, clay, and metamorphic rocks, is accredited for the invention and acceptance of artificial light-weight aggregates (LWAs). In order to produce lightweight aggregates for concrete ships during World War I, Hayde permitted the US government to practice his invention without any cost. Many of the concrete ships that were produced during World War II are still in existence today [34]. The typically great endurance of lightweight concrete is demonstrated by these ships and several bridge structures that have over 50 years of experience in operation. However, it wasn't until many years later that any interior curing contributed to this performance [35].

Article by Paul K. (1957) stated that " During mixing, light-weight aggregates absorb a significant amount of water, which may then be transferred to the mix through hydration process." It was possibly the first to acknowledge the internal-curing capability of light-weight aggregates [36] . The phrase "high strength concrete" was fittingly included in the title of Klieger's paper because renowned concrete technologist Philleo R. (1991) wrote these prescient phrases in response to the need for appropriate curing and the inhibition of self-desiccation in high-performance concrete. Philleo R. (1991) quoted “Either the fundamental properties of Portland cement should be altered to minimize self-desiccation, or a method for introducing curing water through the inner workings of structural components with high strength has to be discovered. The second alternative is feasible over the utilization of saturated light-weight aggregate. Nevertheless, individuals who are striving for high strengths do not want to use lightweight aggregate. A potential remedy could be to partial substitute saturated lightweight particles for fine aggregate [36].”

Several research teams in Israel, Netherlands, and Germany had actively explored internal-curing by the application of pre-socked saturated light-weight aggregates in the mid-1990s, carrying out Philleo's idea [37], [38], [39]. Other materials, like superabsorbent polymers (SAP) and pre-wetted wood fibers, that might serve as internal water reservoirs were also studied in 2001 [40], [41].

Due to its ease of usage and cost-effectiveness, internal curing is being used in a growing number of projects in 2012. In Europe, a team of researchers began purposefully researching the practice of LWAs for the purpose of internal-curing [42]. These developments stimulated the quantity and spatial distribution of saturated light-weight aggregate that were intended to add in the concrete mix. Nonetheless, the concrete's internal curing optimization to minimize change in volume was greatly affected by the kind of cement used. Consequently, instead of creating suitable ambient circumstances, typical curing could not necessarily prevent self-desiccation in the thick of the dense concrete part [43].

2.3.2 Self-curing agent and its mechanism in cementitious materials

Numerous scholars have examined the configuration of self-curing concrete by employing various supplies as curing agents, including porous aggregates like lightweight aggregate (LWA), chemical curing agents such polyethylene glycol and superabsorbent polymers, and natural fibers.

a) **Pre-wetted light weight aggregate-** apart from other decisive factors, concrete that contains porous aggregate has usually produced lower graded concrete. However, the aggregate can have positive impacts on the concrete when utilized in a wet situation because the water it absorbs is gradually discharged within the settled cement paste, extending the cement hydration. For this reason, concrete will have better qualities, exhibiting less shrinkage and more strength. The gradient in humidity amongst the cement paste aggregate and the aggregate is what drives the passage of water. Figure 2.4 shows schematic diagram of the self-curing concrete mechanism.

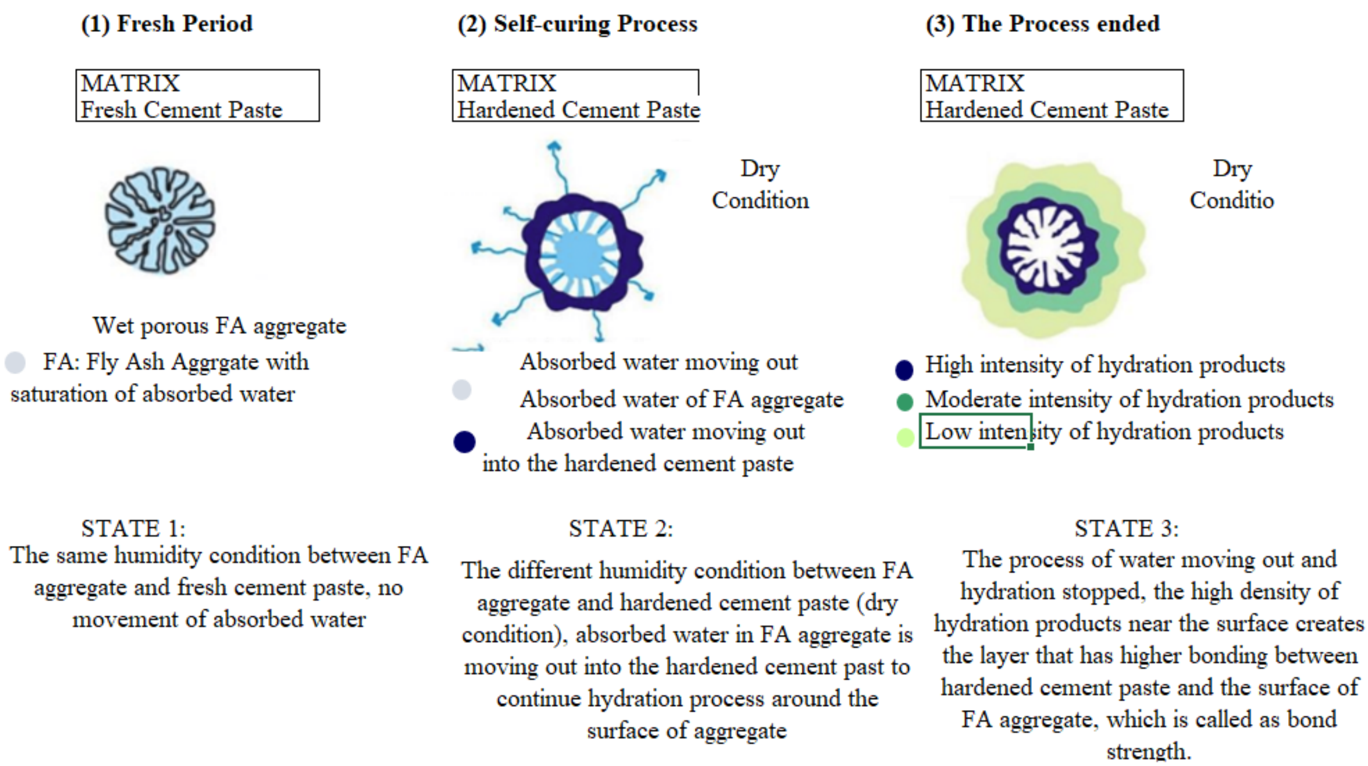


Figure 2.4 Self-curing concrete mechanism [44]

By adding pre-soaked element as an internal-curing factor, internal-curing makes it possible for curing to take place from within. The curing agent serves as a store for internal-water and gradually would be evenly distributed across the concrete matrix. Prior to the condition of moisture gradient during the primary hydration stage, the water included within the curing agent has not been engaged in the chemical process. The thrust of gas dispersion, capillary compression and suction transfer water out of curing agent towards the unhydrated cement particles in order to maintain continuous hydration. This leads to a significant reduction in self-desiccation and change in volume due to by low water to binder ratio. It was demonstrated on the study that the self-curing procedure takes place as seen in Figure 2.5 [45].

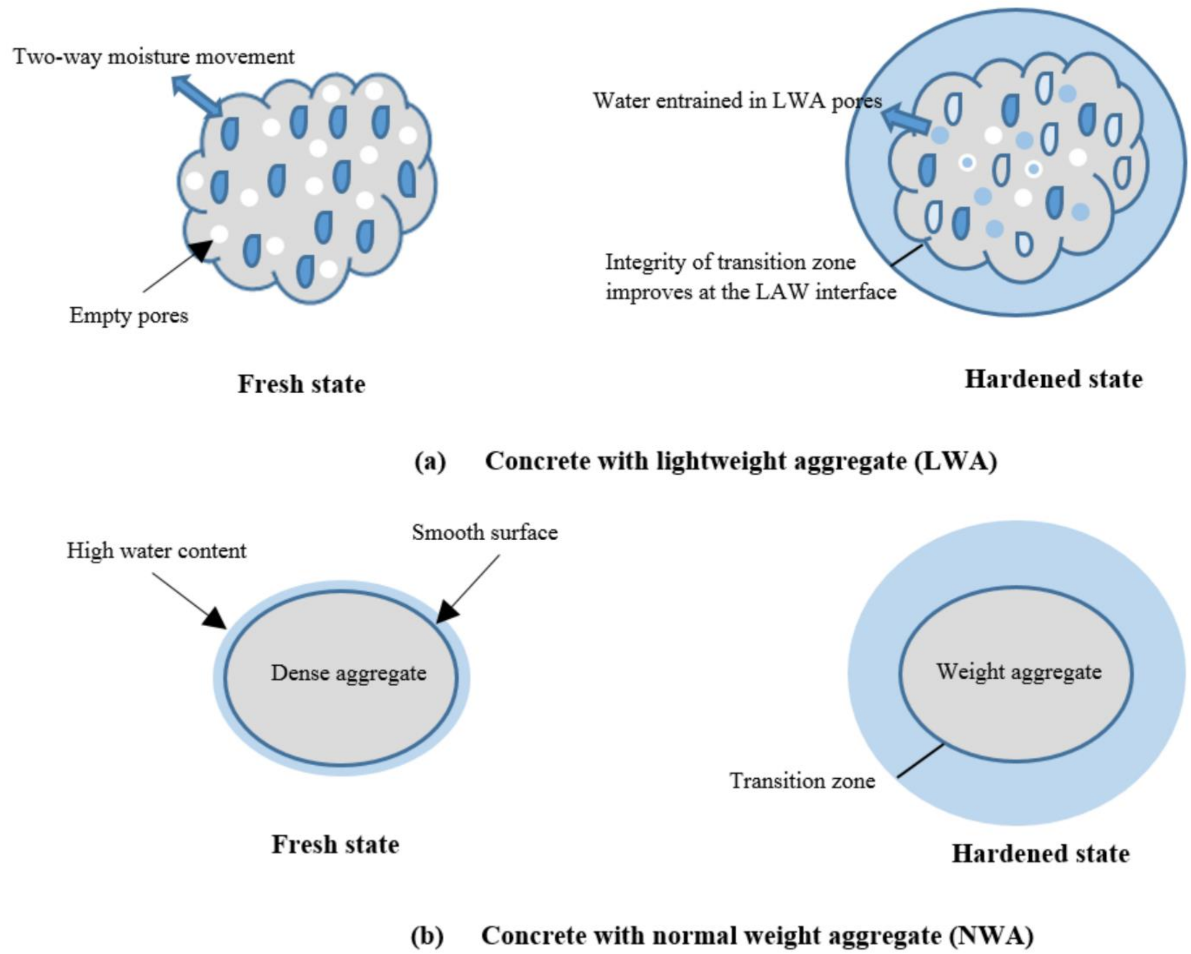


Figure 2.5 The comparison between internal-curing and normal-curing [45]

b) **Super-absorbent polymers (SAP)-** They were first formed in the 1980s and, because of its capacity to expand and hold water, have since been extensively utilized in health supply, agriculture, forestry, and other industries. SAP's capacity to reduce shrinkage by self-curing has been employed to improve durability contrary to freeze-thaw weakening [46], [47].

Superabsorbent polymers (SAP) are composed of a tri-dimensional interconnected system assembly that, due to osmotic pressure, can enlarge as to create an unsolvable gel and consume a huge amount of moisture relative to their size [48]. SAP is reported to swell or shrink owing to a chemical reaction that arises whenever it encounters an aqueous solution [38].

Osmotic pressure drives SAP absorption prior to the development of gap amongst the interconnected system. A gradient in movable ions concentration amongst the mixture and the gel is the source of osmotic pressure. The swelling SAPs then respond by acting as concrete water reservoirs. However, the water that has been absorbed is retracted towards the capillary pores of the cement paste when the humidity in the concrete falls. For this reason, the SAPs eventually leave the holes and release the water that they have absorbed [49], [50]. Figure 2.6 demonstrates the absorption mechanism of the polymer.

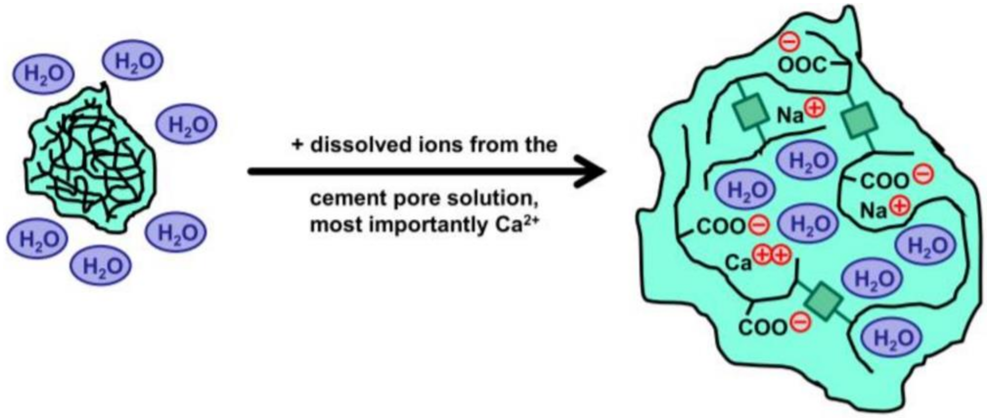


Figure 2.6 Process of water uptake to SAO [49]

c) **Polyethylene glycol (PEG) -**In accordance with Raoult's Law, when the pure state vapor pressure of the solvent is greater than the pure state vapor pressure of the solute adding PEG should theoretically lower the water's vapor pressure, thus lowering the degree of evaporation above the surface of concrete, [44], [51]. In order to retain water and improve the hydration process, reports indicated that using PEG as self-curing agent in concrete is both successful and productive [52]. Furthermore, hydrophilic units assembled in order to form the polymeric chains which utilized water particles to produce hydrogen bonds. A fragile connection formed within the area of hydrogen and other particles that are strongly electronegative is called hydrogen bond. Figure 2.7 depicts the electro-statical attraction of a positive charge at the hydrogen atom. With the purpose of reducing the effect of self-desiccation of concrete, solvable polymer containing hydroxyl has been practiced as a self-curing chemical [53].

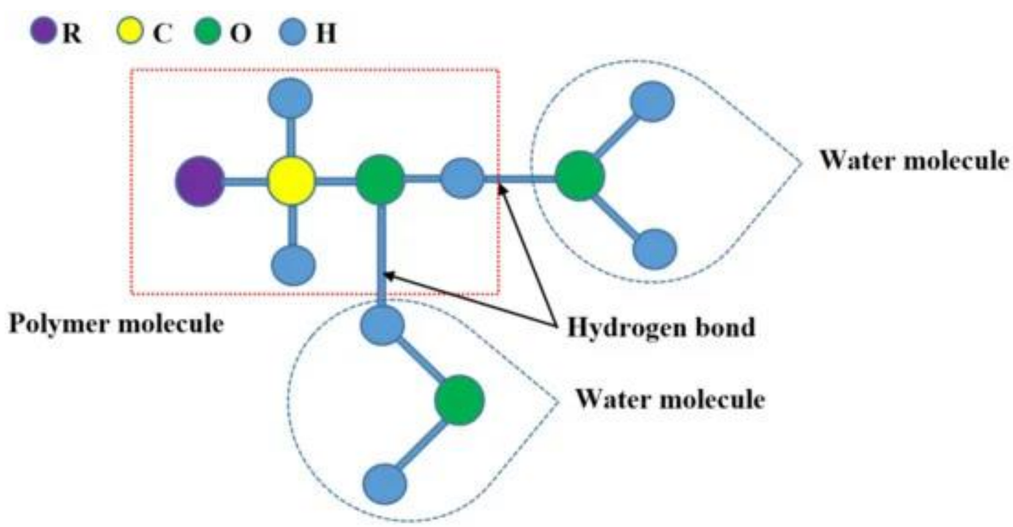


Figure 2.7 Hydrogen bonds among water and -OH group [53]

d) **Shrinkage reducing admixtures (SRA)-** They are employed to lessen concrete's shrinkage caused by drying or self-desiccation. They are employed in rather considerable concentrations as opposed to other concrete admixtures. When high number of shrinkage joints is undesirable for technical or financial reasons, or when shrinkage cracking could result in durability issues, shrinkage-reducing admixtures can be utilized.

Pore solution's (the alkaline solution found in the pores of hardened concrete) surface tension is lowered by SRA. Reduced shrinkage results from the pore solution's decreased surface tension, which also preserves a better interior comparative dampness and prevents formation of capillary stresses [54], [55].

e) **Wood powder-** Previous studies examined on the possibility of using threads resulting from wood and powder as self-moisturizing means for cement consuming materials because of its capacity to both consume and hold moisture while also releasing absorbed water gradually. Wood-derived fibers such as cellulose, kenaf, and eucalyptus pulp are good examples of the kind of fibers utilized in concrete as self-curing agents. Fibers made of wood are hygroscopic materials. Osmotic pressure and the concentration gradient caused by capillary enticement allow water to pass through the pulps. According to explanations, Elsaid et al. (2011), Wolfenden et al. (1991), and Jongvisuttisun et al. (2018) wood-derived threads are made up with 2 types of holes: bigger pores (called lumens) that contain free moisture and smaller pores as shown in Figure 2.8 [56], [57], [58].

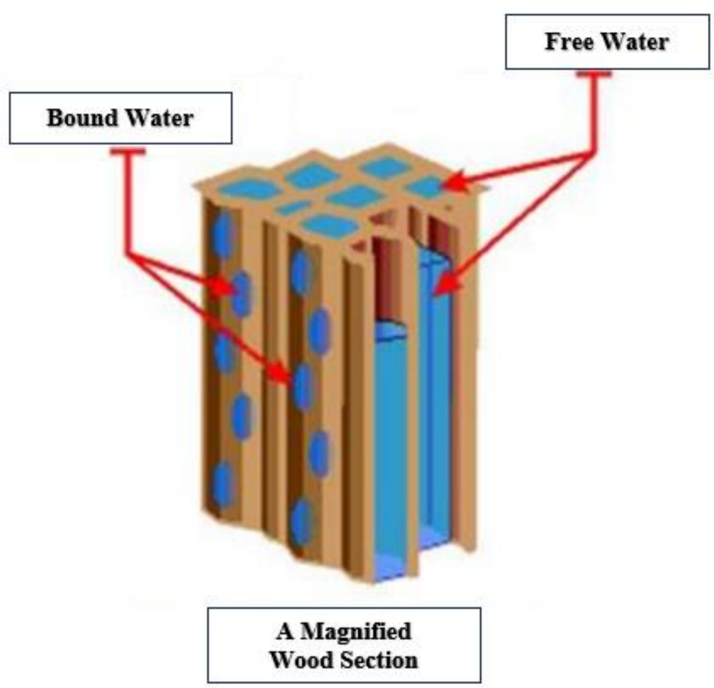


Figure 2.8 Free and retained water in wood [56]

When it comes to moving dampness through the wood pulp towards the adjacent reacting cement, both pores are essential. Additionally, because the pore solution in cement consuming materials is high pH, the water transport is impacted by the way wood pulp swells or shrinks and changes the useful area of the porous area [59], [60], [61].

2.3.3 The change in properties of concrete due to self-curing agents

Depending on the parameter in question, the use of self-curing chemicals might change the physical characteristics of mortar or concrete for the better or worse. The following section discusses how self-curing chemicals affect certain concrete or mortar properties:

1. **Compressive strength-** Researchers have shown that adding more porous aggregate to high-performance concrete does not boost its strength; instead, the strength of the concrete remains lower [62], [63], [64]. According to findings from other researchers [65], [66], [67], the low strength of the porous aggregate itself is the cause of the drop in concrete strength. By keeping the porous aggregate smaller and more evenly distributed, the negative effects it has on the strength of concrete can be minimized. In regard to compressive strength of concrete during early stage and subsequent duration, it has often showed to improve whenever the standard composition was achieved, which is typically between 20% and 40% replacement of normal aggregate. Nonetheless, a number of studies found that, as Figure 2.9 illustrates, concrete's compressive strength decreased if porous aggregate substitution exceeds 50%.

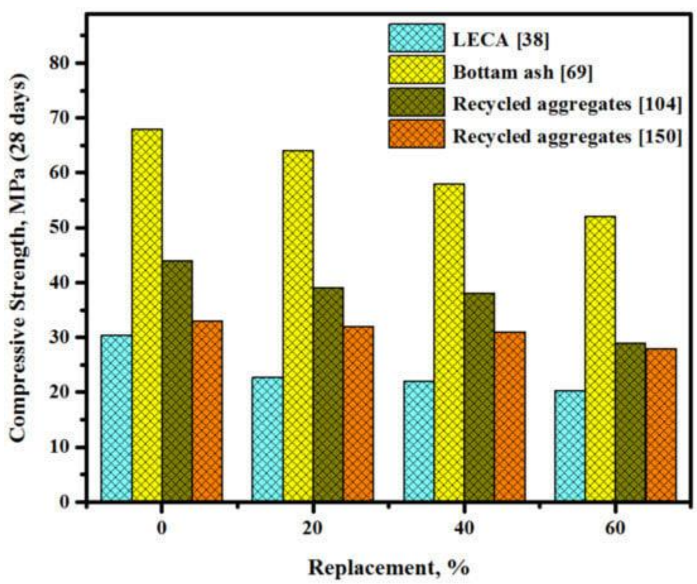


Figure 2.9 Compression strength comparison between porous aggregate and percent substitution of normal aggregate [68]

An enhanced level of reaction is induced through the additional water that the prewetted porous aggregate provides. Through the mechanism of filling the voids by reacted compounds, the compressive strength of the concrete improved. It has been found that right towards the conjunction point of cement paste and aggregates, the density of C-S-H increased while the prevalence of CH decreased [68], [69], [70], [71].

According to Liu et al. (2017), Memon et al. (2020) and Al Saffar et al. (2019) SAP increased high-performance concrete's compressive strength [72], [73], [74]. Studies on the influence of SAP on compressive strength of concrete revealed that SAP causes the concrete's strength to decrease [75], [76]. As shown in Figure 2.10, SAP inflated after collecting water, turning into hydrogels and functioning as pores in the cementitious resources [77], [78], [79]. The findings also showed that the concrete specimen had a more noticeable ratio of early-age strength decline as a result of SAP addition than the SAP-free concrete specimen. However, the specimen's SAP dosage determined the ratio of the later-age strength. Strength development was enhanced by SAP's self-curing, that improved the specimens' levels of hydration. These findings align with findings from two other researches [80], [81].

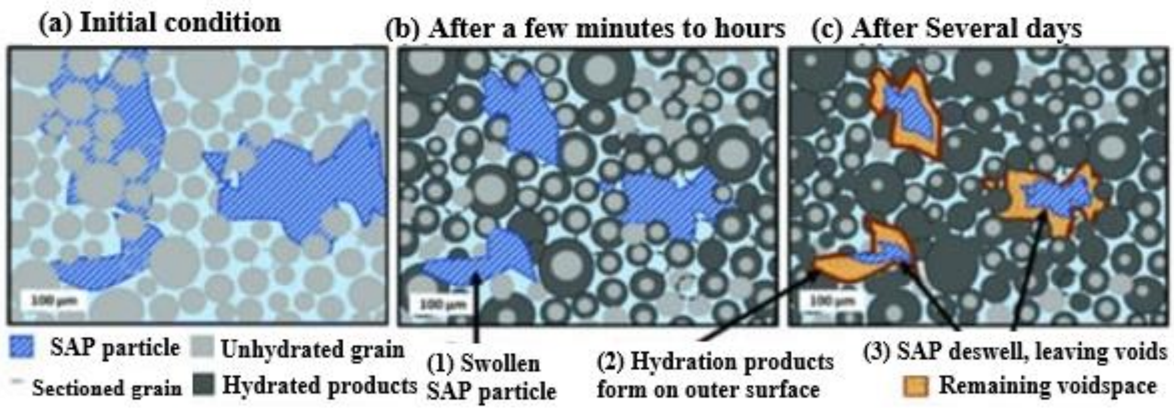


Figure 2.10 SAP'S mechanism [78]
((a) Saturated SAPs in cement; (b) SAPs slowly release the captured water; (c) SAPs de-swell and leave voids.)

According to a study by Rizzuto et al. (2020), Mousa et al. (2015) and Vaisakh et al. (2018), the utilization of PEG, solvable polymer self-curing media, greatly increased the cementitious material's 28th day compressive strength when compared to specimens without PEG [82], [83], [82], [84]. Mixes with and without PEG were examined, and they were made and cured at 25 °C in laboratory air. They discovered that, at the age of 28 days, 2% agent added samples had exhibited 32.5% increase in compressive strength over samples without the agent. This pronounced increment in the strength could be caused by the reason that the samples were sealed-cured. Furthermore, 5.41% increase in compressive strength was seen in sealed-cured mixes containing a PEG in comparison to water-cured normal mixes [83], [84].

2. **Workability -** The impact of porous aggregate on the workability of concrete is rarely investigated. One possible explanation is that before setting, saturated-porous aggregate neither consume nor expel water. Therefore, its workability is not influenced. Nevertheless, the absorption rate will be slower when the unsaturated aggregate is inserted into the

concrete mixture, which would cause segregation and further bleeding. Therefore, it is also advised to pre-mix porous aggregate and water for a few minutes [85], [86], [87].

Research has additionally demonstrated the inclusion of SAP reduced workability and prolonged setting-time of concrete. However, as SAP size increased, the prewetted SAP led to a growing slump. It demonstrates how the pre-absorbed SAP spherical particles can operate as a greasing agent within the concrete matrix, lowering friction between aggregate and paste [88], [89].

3. **Autogenous shrinkage and drying shrinkage -** concrete with saturated porous aggregate can effectively exhibit lower autogenous shrinkage when compared to oven-dry porous aggregate. This results from the dry porous aggregate's incapacity to take in enough water from the concrete while it is in the fresh stage [90]. Nearly the same strength values as prewetted porous aggregate can be achieved with dry porous aggregate if it can consume the essential amount of additional water within the concrete mix [91]. The period of duration that interior RH stays 100% was prolonged by the progressive release of internal curing water by prewetted porous aggregate. This lessens autogenous shrinkage, which enhances pore assembly and hydration process. Furthermore, the efficiency of light weight aggregate could differ based on its category. Autogenous shrinkage is lessened by prewetted porous aggregate that possesses a reduced strength and greater moisture absorption rate. In other hand, with a dry environment, porous aggregate having more strength with a reduced moisture absorption can show a relatively improved performance. At 28 days, porous aggregate often reduces the overall shrinkage, but it also increases drying shrinkage.

   When comparing the specimen of a grounded pumice stone with the control having the standard quality, 34% raise in drying-shrinkage was noted [92]. An elevated w/c ratio and a reduced elastic-modulus associated with this higher in drying shrinkage phenomenon [93], [94]. By adding SAP, the rate at which high-performance concrete develops autogenous shrinkage can be reduced. As a result, cracking may take longer to appear. The SAP's type, dosage, particle size, and water-saturated condition all have an impact on how well self-curing works. As the volume of water utilized in internal-curing supplied from SAP increase, the autogenous-shrinkage of self-cured concrete would also reduce [95]. Despite the fact that the degree of autogenous-shrinkage of the entirely mixes were strikingly comparable on the 28th day, the rate of autogenous shrinkage decreased as the concrete aged. The extra water that SAP supplies during self-curing at different doses may have an impact on autogenous shrinkage.

While it has barely adjust the initial w/c proportion, the moisture within SAP functions in the capacity of a water container through voids during batching [96], [97]. It is accessible to help with internal curing. Driving force results from a drop in internal relative humidity brought on by reduction in water through self-desiccation at the time of reaction [98]. As a result, SAP releases the water it holds toward the cementing mixture, assisting in continuous hydration. When autogenous shrinkage is decreased, a larger dosage of SAP shows the release of more water. According to reports by Hansen and Jensen [99], Kongs et al. [100], Reinhardt and Assmann [101], and Mai et al. [102], drying shrinkage also lessened whenever SAP concentration increased. On other hand, cracking occurs when the moisture inside SAP element swiftly vaporized in arid environment.

Early age shrinkage cracks have also been shown to be lessened through utilizing synthetics curing-agent as in PEG [103]. Using polyethylene glycol, Amin et al. [104] reviewed the engineering features of SC concrete. In comparison with reference concrete, the analysis showed that PEG included concrete mix has carried out the SC effect and assisted in reducing drying shrinkage. Nevertheless, while including PEG in concrete as SC agent, the drying and autogenous shrinkage has not been thoroughly studied by researchers.

2.4 Aloe Vera plant

Aloe Vera is relatively a perpetual shrub that is instinctive to torrid, arid places and belongs to the Liliacee family of lilies. It is prickly and succulent. It needs little and thrives best in direct sunlight. It is grown practically everywhere in the world, both for its commercial uses and as a houseplant, and is widely grown indoors [105]

Aloes are evergreen plants that include shrubs, trees, and herbs. Their robustly cuticularized, fleshy leaves—which typically have spiky edges—identify them. With the exception of a few species that exist on small islands in the insular Africa and the Arabian Peninsula, they are native to the continent of Africa south of the Sahara [106], [107].

Aloes may grow in a number of climates and ecosystems, including grassland, desert, coastal, and even alpine regions, despite the common misconception that they can only be found in hot, dry climates. The genus can be found in a variety of environments, including scrub lands and dry forests. Aloe massawana that are adaptive to zero meter into Aloe juvenna innate to an altitude above 2300 m, the plant can endure in a broad variety of altitudes. Aloes are most prevalent (32%) between 100 and 1500 meters above sea level. There have been reports of certain Ethiopian species reaching higher altitudes (A. ankoberansis, for example). Aloe polyphylla grows as high as 3,500 meters above sea level on Lesotho's Drakensberg Mountain. Aloes hardly grow among trees or shrubs; instead, they often thrive in the open. Their succulent nature also helps them adapt to arid environments [107].

Though Aloe Vera comes in over 650 variations, the most widely recognized kind is Aloe barbadensis Miller. It has prickly blooms and lance-shaped leaves that split open to reveal a colorless gel badensis. Although most examples of Aloe Vera barbadensis are between 300 and 600 mm tall, the plant can reach up to 1000 mm in height. It forms rosette-shaped leaves that are thick. The leaf has a lot of pulp within the parenchyma tissue. The succulent leaves, featuring sharp edges, emerge towards the middle point, then expand to approximately 300 – 500 mm in length, 100 mm in breadth in the bottom. Rhizome cuttings or root suckers planted in the main field are the two common methods used to reproduce Aloe Vera. The fact that the Aloe Vera plant takes two to three years to reach maturity, makes it ideal for mass production.[108].

Aloes are successful because they have made a number of significant environmental adaptations. They reduce water loss that would result from regular photosynthesis in hot areas by using a unique kind of photosynthesis known as CAM (Crassulacean Acid Metabolism) [109]. Aloes have another adaptation in that their leaves can hold a significant amount of water, which they can use during dry spells [110]. Aloes' waxy coating reduces water loss through the stomata and minimizes water evaporation from the leaf cells' surface. This helps the plant retain moisture in the foliage. Additionally, too much light may be reflected off the plant by the wax.

Ethiopia is home to 46 different species of aloe, of which roughly 66% are native to the nation. They are dispersed throughout the nation's floristic areas, which include Bale, Gamo Gofa, Wollo, Gojam, Afar, Shewa, Sidamo, Tigray, Arsi, Welega, Gonder, Hararghe, and Keffa. Consequently, the Sidamo floristic zone contains the majority of Aloe species (14 species), followed by the floristic regions of Hararghe, Bale, Shewa, Tigray, and Wollo (10, 8, 8, 7, and 7 species, respectively). Afar and Welega floristic regions only have one species of Aloe Vera each as shown in Figure 2.11 [111].

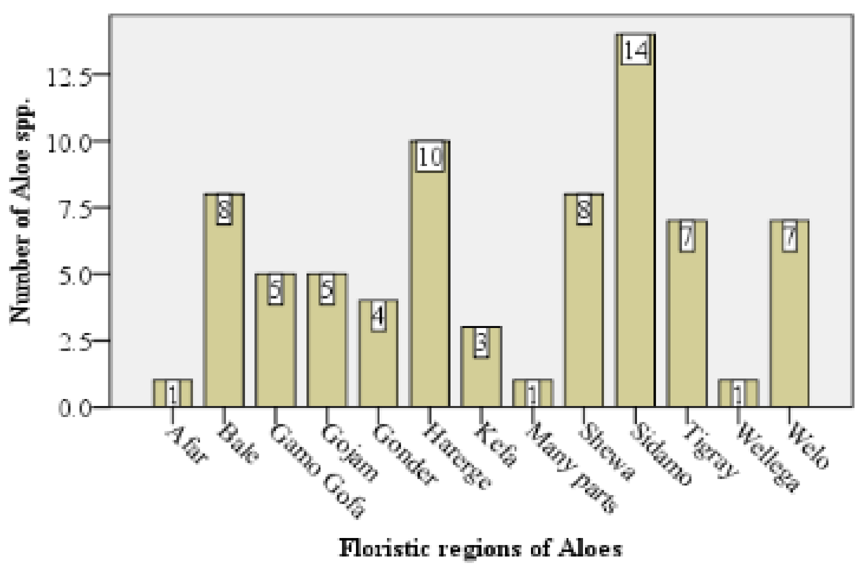


Figure 2.11 Aloes distribution over Ethiopia's floristic areas [111]

Aloes grow throughout Ethiopia in a range of vegetation types at different elevations. Thus, in the intermediate altitude region, the majority of aloes (about 48%) are found in height ranges of 1500–2500 m. A portion of aloe species (about 34%) can be found in semi-arid climates between 500 and 1500 meters, while other aloe species (around 14%) may reside in high altitude regions between 2500 and 3200 meters [105]. A small percentage of aloe species (about 2%) do, however, thrive in alpine regions at elevation ranges beyond 3200 m, while other aloe species (about 2%) may survive in desert climates at altitudes below 500 m as shown in Table 2.2. [111], [112].

Table 2.2 Ethiopia's Aloe Vera plant habitat elevations [112]

Altitude range	Frequency	Percentage
>3200m	1	2.0
2500-3200m	7	14.0
1500-2500m	24	48.0
500-1500m	17	34.0
<500m	1	2.0
Total	**50**	**100**

2.5 Aloe Vera gel

The major portion of the leaf include the uncolored inner parenchyma which comprises the AVG and the external green husk together with the vascular-bundles. Sometimes it might be difficult to understand descriptions of the inner, central portion of an aloe leaf since several words are used interchangeably. In technical terms, the mucilage or gel denotes the sticky, pure fluid found inside the parenchyma tissue. The parenchyma cells or pulp denotes the complete plumpy innermost section within the leaf, containing the tissue organelles and enclose [113].

The viscous liquid inside the cells, the degenerated organelles, and the cell walls make up those 3 basic elements of the pulp. Figure 2.12 illustrates the 3 elements of the pulp contrasting with each other [114].

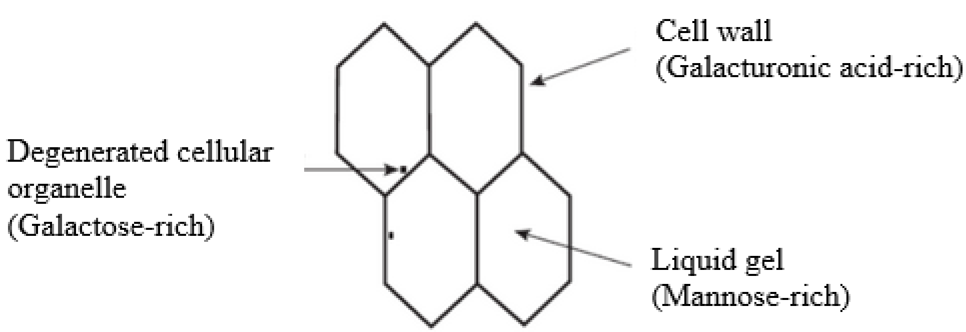


Figure 2.12 Illustrating the leaf-pulp structure of the plant [114]

2.5.1 Mechanical and physical properties

It is necessary to understand the qualities of the AVG extract for the reason that the material is added into the concrete matrix.

a. **Moisture content -** Aloe vera gel is composed of approximately 99.5% water by weight, marginally exceeding the 98.5% water content of the raw pulp. [10, [115].

b. **Specific gravity –** It is a measurement of materials in relation to water density. Aloe Vera gel's specific gravity ranges from 0.91 to 1.02, mostly based on anatomical structure. The specific-gravity of the parenchyma tissue of Aloe Vera is better from that of the viscous liquid [116], [117].

c. **Average weight –** Six-month-old freshly harvested barbadensis Aloe Vera leaves were analyzed and averaged in Texas, USA. Table 2.3 illustrates the fact that, as the leaves gets thicker and longer, the transparent fleshy part of the leaves becomes optically less dense.

Table 2.3 Features of newly harvested Aloe Vera leaves [117]

Grower	Weight (g)	Leaf length (cm)	Width (cm)	Optical density (abs)
1	478	53	9.7	1.095
2	611	56	11.4	1.356
3	704	60	11.5	1.020
4	387	48	8.9	1.437

d. **Viscosity** – The state of being thick, sticky, and semi-fluid in consistency as a result of internal friction is called viscosity. With time, the viscosity diminishes. The gel turns into water after a while when its viscosity approaches that of water. According to a report, the viscous pseudoplastic nature of AVG, that was mostly due to the occurrence of a material named polysaccharides constructed from the mixture of glucomannans, vanish immediately subsequent to extracting the gel by virtue of enzymatic degradation. The viscoelastic behavior of gel is associated to certain biological functions, as demonstrated by Channe G. et al. (1979) [118].

e. **Age of Aloe Vera -** The Aloe Vera leaf's bottom portions provide a gel that is roughly 60% larger than the top regions. As per Ravindra N. et al. (2020) and Vallabh C. et al. (2013) when leaves develop, the gel's specific gravity rises as well, increasing the proportion of gel content near the base of the leaves [119] [120]

2.5.2 Chemical properties

Joshi, (1998) has specified the molecular entities of the plant species named barbadensis Aloe Vera plant. The plant encompasses between 99 and 99.5% water. Minerals, vitamins, amino acids, sugar, enzymes, sterols, salicylic acid, saponins, and phenolic compounds are among the more than 75 components found in the residual solid material [121], [122]. Table 2.4 outlined the ranges of the molecular entities.

Table 2.4 The Aloe Vera leaf's analytical profile [121]

Tests	Units	Minimum	Maximum	Average
Solids	%	0.75	1.50	0.92
Water	%	98.5	99.25	99.1
PH	No.	4.47	4.54	4.51
Glucose	mg/dl	28.0	103.0	77.8
Purine	mg/dl	0.1	5.6	0.8
Sodium	meg/l	4.0	13.0	8.7
Pottassium	meg/l	10.0	22.5	13.4
Chloride	meg/l	1.0	11.0	3.0
CO_2	meg/l	1.0	7.0	1.7
Calcium	mg/dl	19.4	48.5	30.0
Cal. Calcium	mg/dl	23.3	52.3	33.8
Magnesium	mg/dl	3.2	4.7	3.9
Zinc	mg/dl	14.0	77.0	31.0
Phosphorus	mg/dl	0.6	1.3	1.0
Total Protein	gm/dl	0.1	0.4	0.2

2.5.3 Extraction process of Aloe Vera gel

Beginning from the harvesting stage, carful procedure should be adopted to prevent the gel from contamination. Different procedures can be used to extract Aloe Vera gel. A few of these are described here.

1. **Traditional hand filleted aloe** - This procedure involves using a sharp knife to cut off the lower area that connects the leaf with the huge flower stem of the shrub. The slashed part has to include the narrowing part of the leaf uppermost (50–100 mm) together with the small, pointy spine that are situated lengthwise the leaf borders. A knife is also used to remove the top rind and the layer of mucilage below the green husk, leaving the vascular-bundles. The same manner, the lower rind is cut off.

   A lot of work goes into the hand filleting procedure. This has led to the development of machines that imitate hand filleting techniques [105].

2. **Whole leaf aloe process -** In this procedure, the leaf is divided in separate segments then after discarding the upper and bottommost part, the segments undergo pulverizing process until particle emulsion achieved. After applying chemicals to the material, the fillet's hexagonal structure is broken down, releasing its constituents. The husk wastes are then expelled, and the fluid that has been produced run into a number of filtering columns to eliminate any unwanted laxatives. This process can also be done by passing the material through a juice press. When done correctly, this method can yield a juice that is rich in constituents and, ideally, has three times as many constituents as hand-filtered juice. It also should almost completely eliminate laxative anthraquinones [105].

3. **Total process aloe –** this process constitutes the whole leaf processing along with manual filleting. Aloe leaves are manually filleted using the traditional hand filleted technique in this operation. Subsequently, the mucilage pulp and the green rinds undergo separate processing. Total Process Aloe is the result of combining the products made from these two processes. With significantly higher amounts of calcium, magnesium, and malic acid—and almost no unfavorable laxative anthraquinones—the total process aloe method yields exceptionally higher concentration of total solids. For certification the IASC advises utilizing the total process method, that keeps a significant amount of the beneficial components [121].
4. **ALOECORP process -** ALOECORP had proposed its patented technique regarding for manufacturing the Aloe Vera leaves. Using the technique, each plant has three of its outermost adult leaves removed. After being collected in boxes, the leaves are quickly delivered to the production plant. The collected leaves are first given a manual wash before being sent to a mechanical leaf washer via stainless-steel conveyer. After being chopped, the leaves go through the devices that expel gel. Even when being not in use, the production facility is maintained in an extremely hygienic condition. Each time they enter the room; employees must go through a sanitization procedure. Every production cycle is followed by a thorough cleaning of the entire facility. After the gel separates from the leaves, a de-pulping machine is used to pump it through. The uncontaminated gel is subsequently passed into a cooling mechanism that lowers the gel's temperature to 2.5–3°C -. In preparation for being propelled through a conveyance container and delivered to the manufacturing site, the cooled fluid is kept within a preserved bucket [122][105].
5. **American quality Aloe Vera processing –** the plants leaf processing was recommended by the AQAC using its typical techniques. To prevent biological contamination and leaf deterioration, the approach entails gathering ripe the plants leave and further handling the production in under an hour. A unique solution that is a sterilizing mixture (Waller et al., 2004) is used to repeatedly scour and rinse the mature leaves [123]. The leaves are crushed, filtered to get rid of the big pieces, and then filtered by activated carbon filtration to get rid of the chlorophyll. In order to avoid deterioration due to cold and slacked heat stabilization practice, aloe liquid is pushed through limited period elevated heat interchange apparatus in order to attain speedy freezing and sterilization [105].
6. **Steam distillation -** this method involved removing the mature plant's leaves' tough outer layer, which is made up of the epidermis, cuticle, and mesophyll. Each component—the green outer section, the stalk, or the slice of the leave located on the surface are discarded subsequently the leaves were cut, the colorless inner part together with the fiber undergoes steam-distillation independently. As long as the condensate had a distinct smell, the distillation was permitted to continue; it takes around five hours to complete. After being saturated with sodium chloride, the steam distillation condensate was extracted using dried

anhydrous sodium sulfate, diethyl ether and the ether's volume exhibited a decrease with a stream of nitrogen [105].

A comparison between different processing techniques and their effects in content of aloin, overall solids, and constituent size dispersal is shown in Table 2.5. The whole leaf approach proved to yield AVG with a very acceptable low content of aloin and higher total solid and retained molecular weight of polysaccharides.

Table 2.5 The Aloe Vera gel's chemical properties [105]

Method of preparation	PH	Aloin (ppm)	H_2O (%)	Totla Solids (%)
Hand-filletin	4.27	6	99.25	0.48
Roller	4.30	32	99.61	0.39
Leaf Splitter	4.24	18	99.61	0.42
Whole Leaf	4.09	1	99.62	1.38

2.6 Previous works related with Aloe Vera gel in concrete

In this section a thorough presentation of recent data on the mechanical and physical properties of concrete including aloe vera plants has been given. It contains a variety of experimental investigations carried out globally, together with their characteristics and conclusions. The data and conclusions in the literature suggest that in order to reduce the negative environmental effects of synthetic materials, new eco-materials must be developed. Furthermore, it provides insight into the current research and uses related to the application of aloe vera plants to produce green concrete.

Using AVG and marble surplus residue into limited cement substitute, Oggu et al. (2022) carried out research regarding characteristics of porous concrete[124]. Research was done to investigate the tensile strength, permeability and compressive strength tests on hardened concrete. The report showed that the addition of Aloe Vera and marble waste improved the compressive strength of porous concrete as far as 30%. However, for all mixes, the tensile strength characteristics and coefficient of permeability are essentially the same. However, since the mix combines two materials—marble waste and Aloe Vera gel—it is difficult to determine which component is primarily responsible for the improvement in compressive strength.

In 2019, Manonmani et al. investigated research about the impact of fly-ash and Aloe Vera fiber on the tensile-strengths and the elastic-modulus for mortar with epoxy and polyester matrix composites [125]. According to their results, the tensile strength of the polyester matrix-composite's split-tensile strength showed a marginal decline while the strength for epoxy matrix-composite remained unchanged with the addition of plant threads. Elastic-modulus of together epoxy and polyester matrix composites were raised with introduction of the fiber.

Mateo-Santiago et al. (2022) studied the effects of Aloe Vera dosage over crystallization as well as energy reduction using cement-sand mortar [126]. With the Aloe Vera extract dosed, they made cement-sand mixes in a ratio of 1:4, then assessed the mixtures' mechanical capability to compaction, also illustrated the effect onto exterior configuration. According to the study, adding this component results in the production of polydentate nuclei and raises the compressive strength. With the help of these findings, it can be observed that altering the crystallization process improves resistance, which may enable mixtures to use less cement and use less energy in the process of making it.

Ahmed and Memon (2022) have carried out an experimental investigation on AVG in the role of a water-reducing additive within concrete [127]. In order to examine Aloe Vera Gel's stimulating effects on the strength and workability of concrete following 7^{th}, 28^{th}, and 90^{th} days, the study applied it to concrete at the proportions of 0%, 0.5%, 1%, 1.5%, 2%, and 2.5%. The AVG added mixture has caused the workability of the mix to be improved by 57% and 10% increment in compressive strength when added to water at a percentage of 2.5%.

An experimental investigation on the impacts of Aloe Vera mucilage in a place of superplasticizer on the performance of limestone-calcined-clay (LC_3) for self-consolidating concrete types was presented by Onderi et al. (2023). By applying varying doses of Aloe Vera mucilage up to 10%, they were able to ascertain the impact of the material on self-consolidating concrete made from blended (which is composed of limestone (15%), clinker (50%), gypsum (5%), and calcined waste clay (30%)) and ordinary Portland cement. [128]

Assessment of Musa x paradisiaca and Aloe barbadensis Miller as internal curing agents in concrete has also been evaluated by Malathy et al. (2023) [129]. In their investigation, the self-curing properties of bio admixtures such Musa x paradisiaca and Aloe barbadensis miller were compared to PEG's performance. It was stated that these bio admixtures' functional groups matched PEG's. According to their findings, M30 concrete with this bio admixtures has improved fresh and hardened qualities than both conventionally cured concrete and concrete that has PEG added to it.

A qualitative study reviewing on progresses in environmental-friendly additives for the use of concrete was also conducted by Bedada et al (2023) [130]. They have come to the conclusion that although bio-based admixtures for concrete show a lot of promise as an alternative to traditional chemical admixtures, more multidisciplinary cooperation and research are required to get over the obstacles found and reach their full potential. The evaluation recommends that research be done with an emphasis on refining the processes involved in the manufacture and use of bio-based admixtures as well as creating standardized protocols for quality assurance and testing [131].

Using electrochemical techniques (electrochemical impedance spectroscopy, zero-intensity chronopotentiometry and Tafel lines), Bodian et al. (2024) studied AVG acting as green-corrosion-inhibitor in concrete rebar within NaCl medium [124]. The study specifically examined how those with AVG affected the corrosion hindrance of a 12 mm-diameter concrete rebar submerged within the mixture of 0.5M NaCl. At an ideal concentration of 20% addition on concrete reinforcing bar, Aloe Vera extracts were found to possess on typical corrosion-hindering efficiency about 86%.

2.8 Literature review summary

This chapter has presented a comprehensive review of recent studies on the physical and mechanical properties of concrete incorporating Aloe Vera gel. It highlights various experimental investigations conducted globally, detailing their findings and observed benefits. The reviewed literature emphasizes the growing need for eco-friendly materials to reduce the environmental impact of conventional synthetic additives. Based on the insights gained from the literature, the following conclusions can be drawn:

- Using various extraction techniques, researchers have conducted investigations on the addition of natural polymers as an additive to a concrete mixture. Bio-based admixtures are now being widely used instead of conventional chemical admixtures, since these materials are eco-friendly materials that improve the environmental health [131], [132].
- By virtue of its special attributes, for instance greater water retention capacity and viscosity, Aloe Vera gel has been studied for its potential as a bio-additive in concrete. Studies indicate that adding Aloe Vera gel to concrete mixtures can increase workability and lower water requirements, which will improve the concrete's hydration and strength development. Polysaccharides and other organic chemicals found in Aloe Vera gel can also improve the overall performance of concrete [132].
- It is currently attracting growing interest the demand for environmentally friendly additives in the manufacturing of concrete. Natural additives have the ability to improve some concrete qualities while lessening their negative effects on the environment [133] . As per Patil et al. (2019) AVG has the ability to partially substitute cement in concrete mixtures. The addition of this natural ingredient could potentially increase concrete's durability and workability [134].
- Adding natural additives to concrete can change its mechanical characteristics. To comprehend how these additives influence the durability, workability, strength, and additional functional features of concrete, a proper evaluation of the additives is required [135].
- Using natural additives in concrete supports the more general objective of environmental sustainability in the building industry. Concrete production can be made more ecologically friendly by using renewable resources and lower dependency on the existing cementitious materials [136].

To date, no research has been published in Ethiopia on the application of Aloe Vera as a self-curing agent in concrete. Accordingly, this study aims to explore the potential benefits of incorporating Aloe Vera gel as a natural self-curing admixture. The experimental investigation focuses on evaluating key concrete properties—such as workability, compressive strength, split tensile strength, flexural strength, absorption capacity, and drying shrinkage—at varying dosage levels of Aloe Vera gel.

2.9 Literature gap statement

The literature review makes it evident that researchers have tested the mechanical properties for varying Aloe Vera percentiles and comes up with a positive result. However, the fact that the majority studied the effect of AVG with the addition of other natural ingredients, has narrowed an exclusive understanding on its impact.

In all of the experiments covered above, a limited number of research studies are provided concerning the performance of Aloe Vera gel to be used as a self-curing agent. Regarding the study areas, only mechanical properties of concrete were being examined. Furthermore, particularly in Ethiopia, it was quite difficult to locate a single study that make use of the Aloe Vera plant to produce concrete. Thus, based on the stated gap, this study is aimed to investigate the feasibility and impact of employing AVG as a self-curing agent in concrete through different percent additions.

3. Methodology

3.1 Introduction

Physical characteristics of the materials used to build concrete must be tested before any concrete experiments are conducted in order to provide acceptable quality. The topic provides a detailed description of the materials used in this study, the respective physical examination results obtained by performing different tests, the mix-design and proportioning, as well as the concrete making procedure. AAiT, School of Civil and Environment Engineering, Material Laboratory is where all experimental studies on the materials were conducted.

3.2 Materials

The materials used in this study were tested, and the results are presented below along with a detailed explanation of each test outcome.

3.2.1 Cement

Dangote Ordinary Portland Cement, that is accessible at the local market, was employed in this particular study. The type of cement used was Grade 42.5 N. The availability and consistent quality of Dangote cement make it a practical choice for the study. Additionally, since the purchased sand was coarser, a relatively finer cement grade was selected to ensure that the concrete mix achieves the desired strength and workability required for the intended grade.

3.2.2 Aggregates

A. ***Fine Aggregates*** - around 250 kg of local river sand, that was originally collected from Awash-basin, Metehara river and purchased from Henok Lema Sand Supplier.

It was roughly examined to see if fine clay materials were present during the selection process. The silt and clay particles, which are considerably finer than the actual sand, were eliminated by thorough washing. The washed sand was sieved once it had completely dried, and any particles that were retained on 4.75mm sieve were discarded.

Finally, physical characteristics of sand such as moisture and silt content (ASTM C566), fineness-modulus (ASTM C136), absorption capacity and specific gravity (ASTM C128), were examined as per the respective ASTM standards.

B. ***Coarse Aggregates*** - 300 kg of basaltic crushed rock was collected from i.e. Ethio-Keradion Construction, crushing plant, located around Tulu-Dimtu quarry.

In order to clear the exterior part of the aggregation particles off dust, the coarse aggregate was also given thorough washing. The coarse aggregate particles were left to fully dry out, sieved by sieve size 25 mm, and the retained particles were discarded. This process was intended to ensure the particles' nominal maximum aggregate size to be 19 mm.

Similar to sand, the coarse aggregate sample's physical characteristics has also been determined, including its fineness modulus, moisture content, specific gravity, and absorption capacity following ASTM C136, and ASTM C128.

3.2.3 Water

For the purpose of cleaning and washing aggregates, binding concrete making ingredients together, as well as watering those test samples, tap water at the AAiT supplied by Addis Ababa City Municipal was used as a source of water.

3.2.4 Aloe Vera gel

A ripened freshly harvested Aloe Vera leaf was purchased from the suppliers at an area in Addis Ababa commonly called 02 Kotebe. The extraction process adopted was the traditional hand filleting method. The green rind's vascular bundle was gently cut away with a knife as shown in Figure 3.1. The residual colorless inner parenchyma that contains the Aloe Vera gel was used for this study.

Figure 3.1 Traditional hand filleting method

The moisture content of the Aloe Vera pulp was investigated with the help of Addis Ababa University Science Faculty, chemistry department. The moisture content analysis by using the pulp of the plant was carried out with the eight flasked Lyphophilizer (Freeze drier) Thermo-scientific apparatus. In order to analyze the moisture concentration of the sampled Aloe Vera plant, the entire whole-body mass of the pulp was needed to feed it to the 8 flasked Lyphophilizer (Freeze drier) Thermo-scientific apparatus. The Lyphophilizer apparatus is shown in Figure 3.2.

Figure 3.2 Freeze drier apparatus

- However, in order to achieve its juicy state, the pulp of the plant was grounded using a standard household grinding machine as shown in Figure 3.3.

Figure 3.3 Aloe Vera gel preparation using grinding machine

According to Dabhi et al. the portion of a matured Aloe Vera gel and the specific gravity increases with its age [105]. Therefore, for this study three matured Aloe Vera leaves were selected and the average weight, length, and width were computed.

In addition, samples of aloe vera gel were taken to the Ethiopian Conformity Assessment Enterprise in order to examine the chemical composition of the gel. The available metal related testes in the enterprise's laboratory together with solid and water content were assessed.

3.3 Experimental program

To ensure their suitability, all of the component materials used to produce the concrete samples were selected and their individual physical characteristics were assessed. The ACI mix design method was utilized to determine the proportions of constituent ingredients for C-30 normal grade concrete (the ACI mix design method was selected over the other methods primarily due to its greater flexibility, comprehensive guidelines, and suitability for research-based applications). The mixed samples were placed into the respective cast, demolded, cured by using ponding, and finally inspected at the designated age. The examinations performed includes the spilt-tensile, compressive, and flexural strength together with absorption capacity and drying shrinkage testing.

3.3.1 Testing constituent materials

All physical tests conducted on coarse aggregates, sand, cement, and Aloe Vera gel are all reviewed in subsequent section.

I. Tests for cement

Physical tests of cement that assess the physical properties of cement conducted in the laboratory were setting time and consistency tests.

1. ***Consistency test*** - is the ability of cement paste to viscose or to flow. It is estimated with Vicat device and the quantity of the standard specimen is operated by using the percent by weight of dried cement [7].

   The right amount of water must be used to create clean pastes with acceptable workability to examine cement for setting time and consistency. For the reason that the w/c percentage influence the setting time and degree of reaction, it is also necessary to determine the appropriate amount of water.

   As per ASTM C187, two trials were conducted in order to investigate the percentage of water essential to produce the ideal normal consistency of the paste. The trials outcomes are presented in Table 3.1. Since the penetration laid between 5 - 7 mm from the base point of the mould, 30% by weight of dry cement was selected as the ideal percentage of water.

Table 3.1 Consistency test results of cement paste

S.N	Consistency (P)	Weight Cement (g)	Weight of Water	W/C ratio	Pentration (mm)	Remark
1	30%	400	120	0.3	7mm	accepted
2	28%	400	112	0.28	5mm	accepted

2. ***Setting time*** - as per ASTM C125, the rigidity of cementitious products develops progressively and continuously. The setting time is the duration of time recorded starting

from adding water into cement powder to the point where the mixture reaches at a given degree of rigidity as determined by a particular procedure.

- ✓ ***Initial setting-time***- the interval between the time elapsed beginning from mixing the cement and water component until the required penetration attained was recorded for all percent additions.
- ✓ ***Final setting-time***- the time that passes from when water is added to cement and the needle is unable to leave an impression on the test block's surface, was also recorded for all percent additions.

II. Tests for fine aggregate

Physical characteristics of sand such as fineness modulus (ASTM C136), absorption capacity and specific gravity (ASTM C128), bulk density and silt and moisture content (ASTM C566) were briefly examined and presented as follows;

1) ***Silt content***- The initial silt percentage of the sand used in the experiment was found to be 9%, which exceeded the maximum allowable limit set by Ethiopian standards. As a result, the sand was thoroughly washed and cleaned before being used in any further experiments. Using the sample from the cleaned sand, the silt content test was re-examined by sedimentation method using a measuring cylinder. The result is displayed in Table 3.2.

Table 3.2 Silt content test result

Volume of deposited silt (ml)	Volume of sand (ml)	Silt content (%)
5	295	1.7

Similarly, ASTM standard states that when the fine aggregate incorporates more than 6% silt content, the material shall be washed or rejected. As the silt percentage in the washed sand used in this study is now well below 6%, it was deemed good for using for the experimental study.

2) ***Sieve analysis*** – The ASTM standard defines fine aggregates as particles sized between 9.50 mm and 150 µm. In order to comply with the gradation criteria outlined in this standard for the grading of fine aggregates, representative materials had been taken for further examinations of particle size dispersal. Particularly, sand from Metehara river with 4.75 mm maximum size was collected. This fine aggregate sample's fineness modulus was determined to be 3%. According to conducted tests, the sand sample used in this particular study had a dispersion that fell among the acceptable boundary specified by the American standard for fine aggregate classification. It thereby fulfills both gradation requirements.

The gradation graph for sand samples employed in the study is displayed in Figure 3.4, along with a comparison to the standard's upper and lower limits by making use of various sieve sizes.

Sieve Size	9.50 mm	4.75 mm	2.36 mm	1.18 mm	600 μm	300 μm	150 μm
Upper Limit	100	100	100	85	60	30	10
Lower Limit	100	95	80	50	25	10	2
Result	100	100	97	64	24	11	3

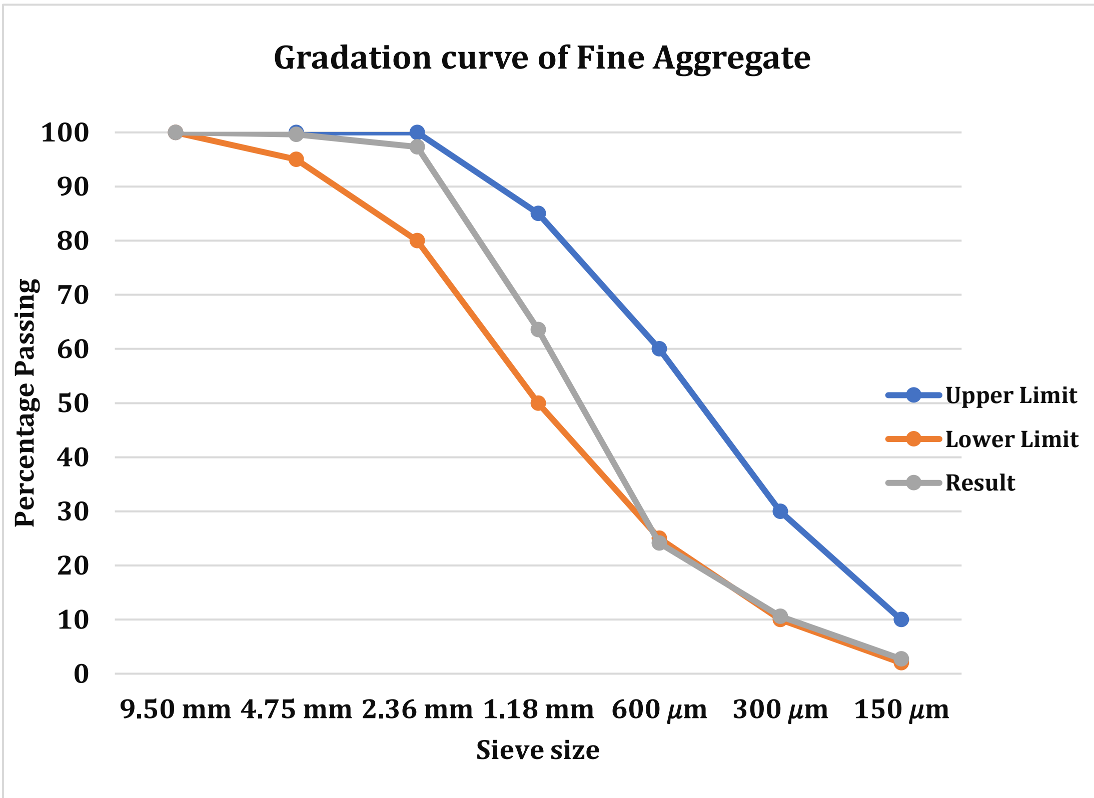


Figure 3.4 Particle size distribution of fine-aggregate

Appendix A(A1) of this article presents an extensive overview of the fine aggregate gradation results obtained using limits of percent passing through each sieve opening with the criteria stated in the American method for classifying of sand (ASTM C33).

3) ***Specific gravity and absorption capacity*** – refers to the proportion of the weight of a given material with the respective weight of water. The water absorbed inside attempts to occupy the porous voids of a permeable dense figure over a process called absorption.

A sample separator was used to distinct representative sand weighted over 500g out of the available mass. As per ASTM C128 guidelines, procedures were followed and sample tests were prepared. The outputs of the absorption capacity, bulk specific gravity (SSD), apparent specific gravity, and bulk specific gravity of the sand are summarized in Table 3.3.

Table 3.3 Absorption capacity and specific gravity and of the fine aggregate sample

Bulk Specific Gravity	Bulk Specific Gravity (SSD basis)	Apparent Specific Gravity	Absorption Capacity
2.4	2.5	2.6	4%

4) ***Bulk density*** –encompasses both solid particles and the spaces between them, efficiently measuring the volume that is occupied by the well-graded aggregate. Within the ASTM grading limitations, fine and coarse aggregate s typically fall between 1450 and 1750 kg/m^3. The dry rodded bulk density computation of the sand utilized in this investigation is shown in Table 3.4.

Table 3.4 Bulk density calculation of fine aggregate

Weight of Metal Cylinder (Kg)	Weight of measured sample (Kg)	Internal Diameter of metal cylinder (m)	Internal Height of metal cylinder (m)	Volume of metal cylinder (m^3)	Rodded Bulk density of Fine Aggregate (kg/m^3)
4.845	26.355	0.255	0.275	0.014044392	1,531.57

5) ***Moisture content*** – The amount of moisture within the material could fluctuate rapidly with respect to the way they are stored and surroundings condition.

Determining the amount of surface (free) moisture, absorbed moisture, and total moisture in the stored fine aggregate is crucial, even if the materials have dried thoroughly. ASTM C566 utilized to calculate the moisture concentration of the sand. Table 3.5 presents the measured weight of the fine aggregate on different conditions and the resulting moisture content.

Table 3.5 Moisture content results of fine aggregate

weight of original sample (g)	weight of oven-dry sample in air (g)	Moisture Content (%)
500	489	0.81

III. Tests for coarse aggregate

Physical characteristics of coarse aggregate such as moisture content (ASTM C566), Bulk density, fineness modulus (ASTM C136), absorption capacity and specific gravity (ASTM C128) were examined and presented as follows;

1. ***Sieve analysis*** – the major characteristics of aggregates that affects the important features of concrete is the distribution or gradation of aggregate grain size.

   To comply with the ASTM C136 gradation criterion within the limits indicated in the Specification for classifying coarse aggregates, samples were produced for particle size distribution by blending crushed basaltic aggregate with nominal maximum size of 19 mm.

   The gradation curve for the coarse aggregate is depicted in Figure 3.5, along with the specified lower and upper limits of coarse aggregate on every set of sieves that are prescribed in ASTM C136. Appendix A(A2) of this work contains a comprehensive gradation test computations for the coarse aggregate.

Sieve size (mm)	37.5	25	19	12.5	9.5	4.75
Upper Limit	100	100	100	78	55	10
Lower Limit	100	100	95	60	25	0
Result	100	100	98	66	34	0

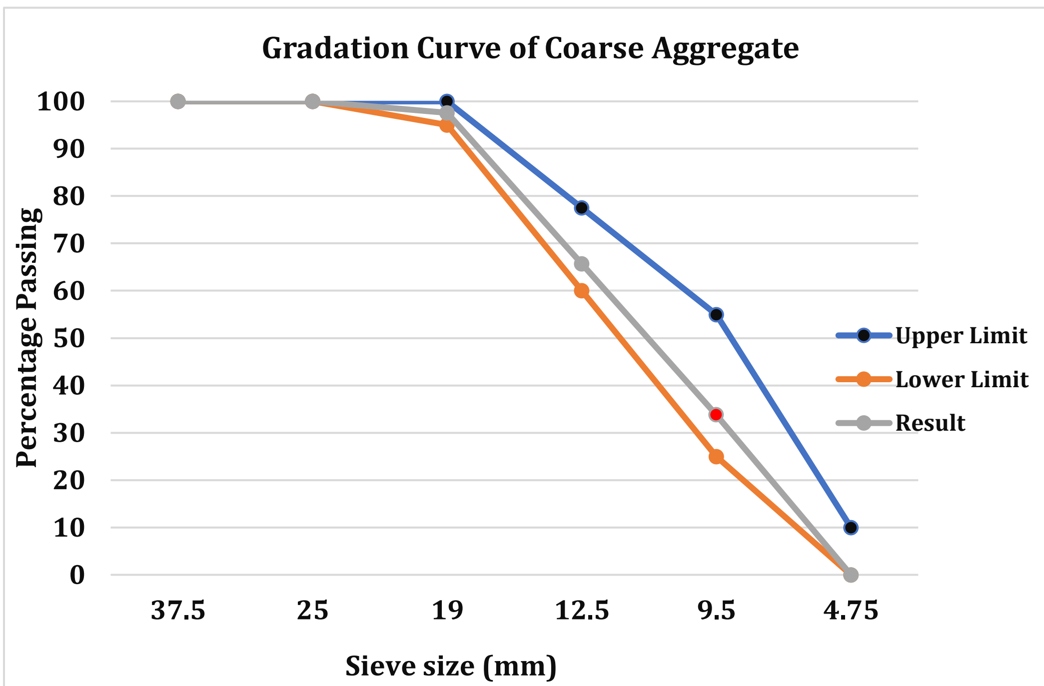


Figure 3.5 Particle size distribution of coarse aggregate

2. ***Absorption capacity and specific gravity*** –aims to ascertain the coarse aggregate apparent specific gravity, absorption capacity, and bulk specific gravity at SSD. In compliance with ASTM C127, sample tests were conducted. Similarly, for the purpose of designing concreting materials the bulk specific gravity (SSD) is the one employed. The results of absorption capacity, apparent specific gravity, bulk specific gravity, and bulk specific gravity (SSD) are summarized in Table 3.6.

Table 3.6 Absorption capacity and specific gravity and of the coarse aggregate sample

Bulk Specific Gravity	Bulk Specific Gravity (SSD basis)	Apparent Specific Gravity	Absorption Capacity
2.44	2.49	2.57	2%

Bulk density – As per ASTM C29 the bulk density was determined for coarse aggregate. The dry rodded density of the coarse aggregate utilized in this investigation is calculated as shown in Table 3.7.

Table 3.7 Bulk density calculations of coarse aggregate

Weight of Metal Cylinder (Kg)	Weight of measured sample (Kg)	Internal Diameter of metal cylinder (m)	Internal Height of metal cylinder (m)	Volume of metal cylinder (m^3)	Bulk density of Coarse Aggregate (kg/m^3)
4.845	27.42	0.255	0.275	0.014044392	1,607.40

3. ***Moisture content*** – As part of the process, a pre-weighed quantity of aggregate must be heated in order to eliminate moisture. After weighing the dried sample, the corresponding moisture percentage was ascertained.

   The ASTM C566 method was used to calculate the moisture concentration of the aggregate sample. Table 3.8 presents the measured weight of the coarse aggregate on different conditions and the resulting moisture content.

Table 3.8 Moisture content of coarse aggregate

weight of original sample (g)	weight of oven-dry sample in air (g)	Moisture Content (%)
2,000	1,989.4	0.61

Likewise, before any tests were performed, the coarse aggregate was washed and allowed to fully air dry for about 4 days due to continues rainfall on the area.

IV. Tests for Aloe Vera

Measurements were taken of the average width, weight, thickness, and length of three ripped Aloe Vera leaves in order to determine their average age. This approach is helpful in order to select the appropriate specific gravity within the range i.e. 0.91 - 1.02 [119]. Table 3.9 presents the measured average quantities of all parameters.

Table 3.9 Measurements of the Aloe Vera leaves used for the experiment

Test Results	Weight (g)	Average Length (cm)	Average Width (cm)	Average Thickness (cm)
Sample 1	565	52	10.1	2.1
Sample 2	585	57	10.4	2.2
Sample 3	595	59	10.4	1.8
Average	**582**	**56**	**10.3**	**2.0**

By using the traditional hand filleting techniques of preparing Aloe Vera leaf, as shown in Figure 3.6. a portion of ungrounded aloe pulp sample was prepared out of three aloe vera leaves.

Figure 3.6 Aloe Vera plant leaves used for the experiment

1. ***Moisture content*** – as it was mentioned on the previous section, the test for moisture concentration of the pulp of aloe leaf was carried out by using Lyphophilizer (Freeze drier) Thermo-scientific apparatus. Table 3.10 presents the measured weight of the Aloe Vera.

Table 3.10 Moisture content of Aloe Vera plant sample

Weight of empty flask (g)	Weight of sample in air (g)	Weight of sample inside the flask after freeze drying (g)	Moisture Content (%)
144	188	120	93

2. ***Chemical Compositions*** – this test was conducted by the laboratory in Ethiopian Conformity Assessment Enterprise. The detail of the studied composition is attached on Annex Section. The result is expressed in Table 3.11 below.

Table 3.11 Chemical Compositions of Aloe Vera gel

It.	Characteristics tested	Unit	Test Results
1	Water Content	%	95.04
2	Solid Content	%	3.96
3	P^H Value	P^H meter	5
4	Sodium	mg/kg	5.82
5	Calcium	% by mass	0.13

3.3.2 Proportioning and mixing

a. Proportioning and mixing of cement paste

The water requirement for paste preparation has been obtained by conducting a normal consistency test for the normal combination. On the basis of percent acquired from the consistency test, the weight of water needed to measure the setting times was computed. In testing cement, P refers the required water proportion to achieve standard consistency. For this test the standard consistency selected was 30%. According to ASTM C187, the required weight of cement and water were analyzed. The required quantities of Aloe Vera gel for the different percentiles and mixes are indicated in Table 3.12.

Table 3.12 Proportioning cement paste ingredients for inspecting consistency

No.	Consistency (P)	Weight Cement (g)	Weight of Water	W/C ratio	Penetration (mm)	Remark
1	30%	400	120	0.3	7mm	accepted

In order to check the consistency of the cement paste, 400gm of cement sample and 30% of water by weight of cement were mixed manually for about 3 to 5 minutes. By using Vicat apparatus, the depth of penetration value quickly after placing the mould on the apparatus was recorded.

Regarding initial and final setting time measuring samples, 0.85P values from consistency percentage was used to determine the required weight of water. Table 3.13 illustrated the results for the quantities of cement paste ingredients.

Table 3.13 Proportioning cement paste ingredients for inspecting setting times

No.	Mix code	Consistency (P)	Weight Cement (g)	Weight Water ($0.85P*W_{cement}$)	Aloe gel (ml)
1	Co	30%	400	102	0
2	C1			98	4
3	C2			94	8
4	C3			90	12

b. Proportioning and mixing of mortar

The method of the study was adding this plant extract to three distinct proportions. A total of 48 cube samples were casted for the purpose of inspecting the SC impact of AVG in mortar mix. In designing the proportion of the ingredients, cement to sand proportion of 1:2 has been selected due to its application on structural works. Therefore, from the recommended range (0.4 – 0.6), w/c proportion valued 0.5 has been chosen for the study. Appendix B (B1) of this paper displayed the mix design of the proportional ingredients. Table 3.14 listed the weights of the materials needed for producing 48 mortar cubes containing—0%, 1%, 2%, and 3% AVG by weight of cement.

Table 3.14 Measures of ingredient materials for mortar

Test	Mix Code	Percent added by weight of cement	Cement (Kg)	Water (Kg)	Fine Aggregate (Kg)	AVG ml
Water-Cured	M0-wc	Control	1.413	0.706	3.00	-
	M1-wc	1%	1.413	0.692	3.00	14.05
	M2-wc	2%	1.413	0.678	3.00	28.10
	M3-wc	3%	1.413	0.664	3.00	42.15
		Sub total	**5.650**	**2.741**	**12.02**	**84.30**
Sealed-cured	M0-sc	Control	1.413	0.706	3.00	-
	M1-sc	1%	1.413	0.692	3.00	14.05
	M2-sc	2%	1.413	0.678	3.00	28.10
	M3-sc	3%	1.413	0.664	3.00	42.15
		Sub total	**5.650**	**2.741**	**12.02**	**84.30**
		Total Summary	**11.301**	**5.481**	**24.04**	**168.60**

From specific gravity and percent by weight of cement, the mass and volume of AVG samples were calculated. Appendix B(B1) of this research also includes a comprehensive volume computation for each percent addition of the Aloe Vera gel.

As per ASTM C270 standard condition for mixing mortar, cement and sand were blended for about a minute in a dry state to create the desired cement mortar. Then, using a shovel, water was added gradually for mixing the materials. Finally, the mortar mixing bucket was put in place in order to proceed with machine mixing. Every minute, the machine mixing was being assisted manually to ensure that the bottom may not have any dry mortar mix left. The mixing process continued for around 4 minutes until a uniform and workable consistency was achieved.

Allocating the mortar mix into 75 mm sided cubic moulds was followed by compacting the mix with a table vibrator. Finally, the molds were vibrated for two minutes at a predetermined rate of 12,000–14,000 vibrations per minute. Figure 3.7 and Figure 3.8 show the water cured and air-cured mortar samples.

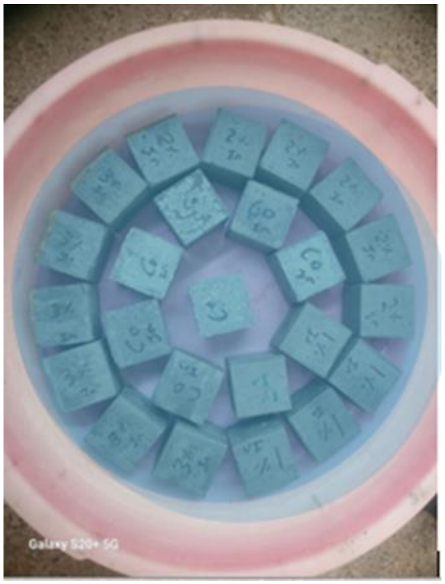


Figure 3.7 Water-cured samples

Figure 3.8 Sealed sealed-cured samples

For the purpose of determining compressive strength, 70mm cube samples were casted. Totally 48 cubes were cured in two different manners, half of which were submerged in water and the other half wrapped in plastic for the third, fourteenth-, and twenty-eighth-day's compressive strength testing. Two 70mm cubic specimens have been utilized for each percent addition of AVG (0%, 1%, 2%, and 3%).

The sealed-cured mortar cubes were wrapped in plastic film after demolded and it was placed away from direct sunlight upon the table shelf. The test cubes for water-cured specimens were taken out of the damp storage 24 hours before the compressive strength testing.

c. Proportioning and mixing of concrete

This particular experiment used the American Concrete Institute's (ACI) mix design approach to establish the proportions of cement, water, sand, coarse aggregate, and Aloe Vera gel in a self-curing concrete mix design for C30 concrete grade. Appendix B(B2) of this paper illustrated the completed design by making use of ACI technique. The wet density of one cubic meter of concrete was estimated to be 2,355 kg/m^3 by using ACI method.

The weights of the components needed to produce each sample of concrete are displayed in the Table 3.15 for every percent addition of Aloe Vera gel (0%, 1%, 2%, and 3%).

Table 3.15 Quantities of ingredient materials designed for concrete mix

Mix Code	Water (Kg/m³)	Cement (Kg/m³)	Fine Aggregate (Kg/m³)	Coarse Aggregate (Kg/m³)	AVG (% added by weight of cement)
M0	44.68	84.09	189.65	242.55	0
M1	43.81	84.09	189.65	242.55	1
M2	42.95	84.09	189.65	242.55	2
M3	42.08	84.09	189.65	242.55	3
Total	**173.52**	**336.36**	**758.60**	**970.20**	

Similarly, the quantities of Aloe Vera gel required for the preparation of the various concrete samples were analyzed independently. The completed calculation of each percent addition of the gel is described in Appendix B(B2).

For every percent addition of AVG by weight of cement (0%, 1%, 2%, and 3%), 150 x 150 x 150 mm cubic concrete specimens, 100 mm diameter and 200 mm height cylindrical sample, and 100 * 100 * 500 mm beam samples were casted for examining compressive, split tensile & flexural strength respectively. The casted concrete was arranged in such a way as shown in Figure 3.9.

Figure 3.9 Cube, cylinder and beam casted samples

For every percent addition of AVG (0%, 1%, 2%, and 3%), cylinder samples having 100 mm diameter and 200 mm height and beam samples with size 80 * 80 * 300 mm were also casted for examining absorption capacity and drying shrinkage. The samples casted for absorption capacity and drying shrinkage tests were arranged as shown in Figure 3.10.

Figure 3.10 Beam and cylinder casted samples for absorption and shrinkage testing

The constituents of the concrete mixture were appropriately dry-mixed in prior so that fresh concrete with a homogenous mix is ultimately produced. Afterwards, the designed quantity of water was gradually added to the dry mix. Pan type mixer was used to mix the ingredient materials. Finally, the concrete molds were vibrated on a table vibrator for two minutes at a programmed rate of 12,000–14,000 vibrations per minute.

3.3.3 Curing of the specimens

The moulds of the casted specimen were dismantled exactly 24 hours from the time of placing. With the exception of twenty-four mortar cubes, all the other mortar and concrete specimens were cured with water ponding according to ASTM C192/C192M until respective testing dates arrived. Those remaining mortars was wrapped in plastic film and placed in a shelf. The environmental temperature of the laboratory was on average between 18-22℃.

3.3.4 Experimental testing

With the intention of identifying the actual effect of the plant extracts, different tests were adopted. Regarding mortar, at the 3rd, 14th and 28th days the compressive strength of both the casted batches, immersed in water and placed outside (wrapped in a thin plastic film and placed in an ordinary temperature), were conducted and recorded for comparisons. Concerning concrete, consistency and setting times of cement, slump value of fresh concrete, compressive strength at the 3rd, 14th and 28th day, split tensile strength and flexural strength of hardened concrete at the 14th and 28th day, absorption capacity at the 28th day and 32nd day, and drying shrinkage of hardened concrete at the 2nd, 28th, 60th, 90th and 180th day were conducted and recorded.

One day prior to the testing date, all of the cast and cured specimens were taken out from the water pond. The tests performed are briefly discussed in the following sections:

i. Setting time of cement paste

To compare the setting times of cement paste samples having different proportions of Aloe Vera gel, physical tests on both initial & final setting times have been carried out based on the standard from ASTM C125. The initial-setting-times were determined by measuring the penetration's depth to 7 mm. The final-setting-times were analyzed by recording the duration of time beginning from mixing the ingredient together up to the occurrence of the phenomenon by which the ring on the apparatus failed to lay a spot on the specimen.

ii. Concrete slump test

This test is performed in order to check the workability or consistency of concrete mixes formed within a workshop. Batch-by-batch concrete slump testing was carried out to make sure the concrete was consistently high-quality. The test has followed the standard specifications listed on ASTM C181 guidelines.

Measuring scale, a non-porous base plate, a 60-cm rounded metal rod, and 30-cm frustum slump cone was used to conduct the test. As briefly described concrete mixing section, there were twelve mixes each categories having three slightly different quantities of concrete making materials. For this reason, the slump figures are the results of the average slump values of each individual mixes. The slump test was conducted as shown in Figure 3.11. below.

Figure 3.11 Slump test of concrete

iii. Compressive strength test

The compressive strength test of mortar sample was performed according to ASTM C109 while the test for concrete cubes was executed as per ASTM C109 guideline. The mechanical characteristics of every sample has been checked with a Universal Testing Machine by using mortar cube samples size 70 mm and concrete cube samples size 150 mm with a rate of loading 35 N/mm^2/min and 0.28 MPa/s respectively. The measured crushing load was employed to assess the average strength of the individual group and reported to nearest 0.5 N/mm2. Three concrete cube samples (n=3) for each test point were used on the third, fourteenth-, and twenty-eighth-day. Two 70 mm mortar cube specimens (n=2) on each test point have been examined for each individual percent addition of AVG. Forty-eight cubic specimens of mortar and thirty-six cubic specimens of C30 class concrete were produced in total. The compression tests were conducted on water-cured mortars, sealed-cured mortars and concrete cubes at the for 3rd, 14th and 28th days.

The experiment was conducted in order to evaluate and compare the attainment of target strength at the 3rd ,14th and 28th dates of the control and AVG containing samples. As seen in Figure 3.12, an electronic compressive strength measurement instrument was utilized for overloading the concrete and mortar specimen to collapse. The point of failure was further measured.

Figure 3.12 Cube sample in compression testing machine

iv. Split tensile strength test

The test on cylinder sample is one technique to examine the tensile strength in concrete. Because of the brittle feature of concrete, it is not meant to endure direct tension and is hence particularly weak in tension. Tensile stresses cause cracks to emerge in the surface of concrete. Consequently, it is fundamental to ascertain the load at which member of concrete may fracture for calculating the tensile strength. In compliance with ASTM C496 prescribed protocols, three cylindrical specimens (n=3) of diameter 100 mm and height 200 mm have been assessed for split tensile strength on each test point, fourteen- or twenty-eight-days following curing. Up until the specimen failed, the load was exerted progressively with a degree of 0.28 MPa/s.

v. Flexural strength test

Another index for estimating the tensile strength is flexural strength. It measures either the strain or the stress thereto a slab or beam can sustain before bending and failing. The section of concrete withstanding the exerted load experiences interior pressures such as shear, tensile, and compression during pure winding. To produce the pure bending moment, two loadings are applied to the beam at equal distances from the center, continuing until the outermost part of the tensioned beam specimen reaches its maximum tensile stress. When a member is simply supported at both ends and a winding force is exerted downward, upper and lower sections of the neutral axis basically endure compressive and tensile strains, respectively. The part of a prism that lays above the neutral-point, or its upper half, is compressed, and the part that is below is under tension. In this stress and support system, shear stresses are somewhat greater than tensile stresses in regions of the element near the supports.

Conventional testing protocols such as ASTM C293 (Mid-point loading) and ASTM C78 (3^{rd} point loading) can both be employed for evaluating flexural strength, which is represented as the modulus of rupture in MPa. In this particular study, two beam samples (n=2) of 500 * 100 * 100 mm have been tasted at the 14^{th} and 28^{th} days after water curing by using ASTM C78 standard test procedures. Up until the specimen failed, the load was exerted progressively with a loading rate of 0.015 MPa/s.

vi. Absorption capacity test

As stated in ASTM C642, the absorption capacity of a solidified cylinder concrete was examined. The test is shown as the proportion of water absorbed by the control and aloe added concrete for the 28 days of water curing time. The change in weight of the cubes following the curing days indicate the concrete's water absorption capacity.

The concrete specimens have been taken out of the ponding tanker after being emersed about 28 days. Two cylindrical specimens of diameter 100 mm and height 200 mm have been used for examining the absorption capacity. By using a towel, the surface moisture was dried out. The weight of the surface dried cylindrical sample was measured (W1). Finally, the samples were taken into a drier to loss all the moist with a temperature of 50±2ºC for around 72hours. The mass would be subjected to multiple weighing until the constant value maintained. This constant measured weight was recorded as the dried weight (W2) of the specimen. The absorption capacity of the different percent added specimen is given subtracting the maintained constant weight from the weight of surface dried specimen and dividing the result with the maintained constant weight.

$$W_{ABS} = \frac{W1 - W2}{W2} \quad \text{……Eq.01}$$

vii. Drying shrinkage test

It is a change in volume of a solidified concrete due to the reduction in moisture content by evaporation. Drying shrinkage testing is executed to identify the change in length of a hardened concrete due to loss of moisture.

As per ASTM C157/C157 M, molded beam specimens measuring 300 * 80 * 80 mm have been formed from a concrete mixture. Two concrete beams representing similarly percent additions were used to examine the drying shrinkage test. One at a time, the beams were dismantled from the molds not later than 24-hour period, and the first comparator reading was recorded by taring the comparator and setting the specimen on the devise using the gate studs maintaining the same reading orientation for all specimens. Gently spined the specimen to stabilized the comparator and recorded the length value for each specimen. It was tried to complete the recordings as quickly as possible to limit drying of the specimens. For every set of length measurement, record the reference bar (i.e. 28cm) to track environmental changes in the laboratory. The initial difference of the comparator reading and reference bar reading is the 1^{st} reading taken after mold removal.

Following the first measurement, the beams had been kept within the pond at a relative temperature of 22°+/-1°C for around twenty-eight days until the second comparator reading was taken. The samples were tested as shown in Figure 3.13.

Figure 3.13 Sample beams for drying shrinkage testing

The specimen was stored in a workshop which had an average temperature of 23°C and relative humidity 50%. A comparator was used to track the change in beam length over time, measuring it at 28^{th}, 60^{th}, 90^{th} and 180^{th} day after it was removed from the pond. Length change estimated as of ASTM C157 stated that the prescribed boundary laid within the range of 0.050 to 0.075 percent at 28-days of drying.

3.4 Cost Analysis Approach

The availability of the self-curing admixture such as Polyethylene glycol was checked from the well-known suppliers around Addis Ababa however it was easy to learn that the additive has not been introduced in our country regarding concrete works. Therefore, the purchasing price of a related admixture available on the local market was gathered and checked with that of aloe vera plant of same volume.

4. Results and discussions

The section presents the examination outcomes and elaborations for the physical and mechanical characteristics of AVG containing fresh and dried concrete, cement paste and mortar. The results of all the six distinctive examinations were presented in graphical figures to make the clarification easy to understand.

4.1 Setting time of cement

In accordance with the results, introducing AVG to this specific type of cement can increase the initial setting time by up to 24% and 60% for percent additions of 1% and 2% AVG by weigh of cement, and up to 112% for percent additions of 3%, when compared to reference cement paste. Likewise, the result indicated an increase in the final-setting-time. In contrast to the control cement paste, the increment ranges from 1%, 8% and 14% for the 1%, 2%, and 3% AVG, respectively. The initial and final setting times are presented in Table 4.1.

Table 4.1 Initial and final setting time of AVG cement past

S.N	Mix Code	Initial Setting Time (min)	Final Setting Time (min)
1	M-0	78	678
2	M-1	97	687
3	M-2	125	738
4	M-3	165	774

According to Ethiopian standards, the initial-setting-time of cement shall not take below forty-five minutes, whereas the final-setting-time shall not be more than six-hundred minutes. The outcomes for the hardening time indicate the fact that the introduction of AVG hindered the normal hardening point; however, the observed inhibition was inside the boundary as detailed in the Ethiopian criterion. The setting time showed an increasing trend as the AVG content increased. The cause of the prolonged setting times might occur as a consequence of the water-storing nature of the AVG plant.

4.2 Fresh concrete

Amongst the newly casted concrete characteristics, slump examination has been inspected for each concrete mixes including 0%, 1%, 2% and 3% addition of AVG by weight of cement. Table 4.2 shows an average slump figures of all the unique mixes.

Table 4.2 Slump values of fresh concrete

S. N	Mix code	Class	Average Slump (mm)
1	Co	C-30	50
2	1%	C-30	62
3	2%	C-30	75
4	3%	C-30	85

Slump results for mixes 1%, 2% and 3% in the table above were increased by 24%, 50% and 70% respectively contrasted to the conventional sample. As presented in the table 4.3 workability enhances as the AVG dosage rises. AVG is predominantly made with water and contains highly qualified viscous ingredients, which accounts for the increase in workability. It was found that the concrete mixture became noticeably adhesive as the AVG dosage increased.

4.3 Compressive strength

a. Mortar samples

In comparison to the control, the water-cured mean compressive strength of AVG containing mortar cubes with 1%, 2%, and 3% addition of AVG by mass of cement exhibited an increase of 15.5%, 14.6%, and 11.9%, respectively. Regarding In comparison to the control mortar, the water-cured mean compressive strength of mortar cubes with 1%, 2%, and 3% addition of Aloe Vera gel by weight of cement exhibited an increase of 15.5%, 14.6%, and 11.9%, respectively. The comprehensive findings of the compressive strength test on mortar samples conducted on the third, fourteenth, and twenty-eighth days are provided in Appendix C(C1). As seen in Figures 4.1, the mean compressive strength results are contrasted on several concentrations of AVG for sealed-cured and water-cured specimens at the third, fourteenth and twenty-eight days.

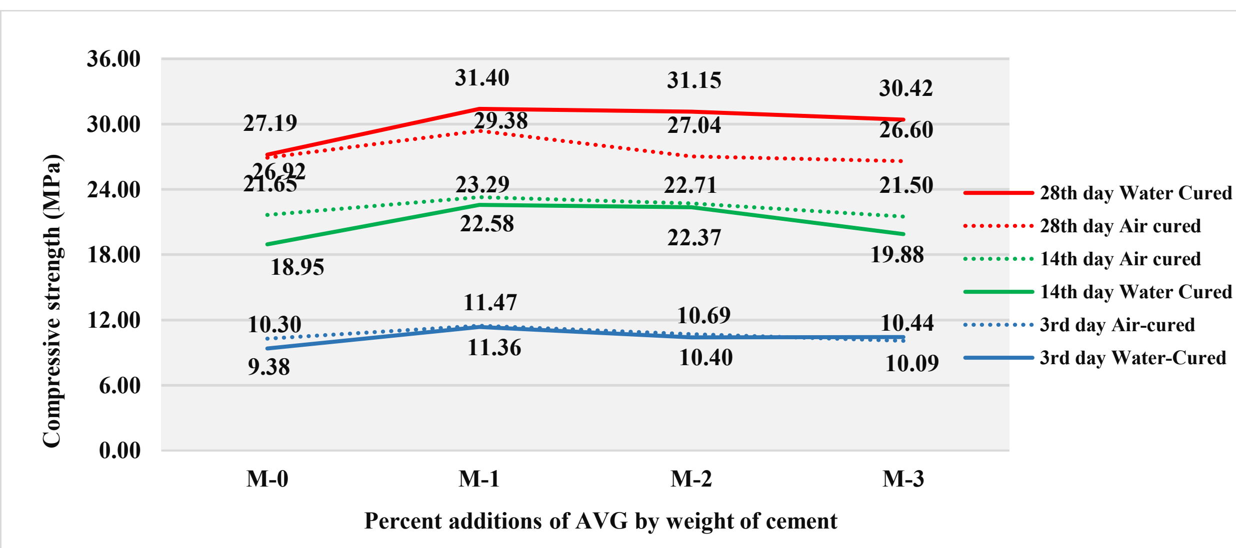


Figure 4.1 Compressive strength of sealed mortars and water-cured

The outcomes of the compressive strength conducted at the third and fourteenth days revealed the fact that the introduction of 1% AVG was the ideal proportion for both water-cured and sealed samples. In contrast to samples placed in ponds, the compressive strength figures of the sealed-cured samples were greater at the same date. One possible explanation for this could be that the mortar matrix has sufficient moisture to keep the reaction going. Alternatively, as discussed below, the situation has changed in the long effect.

The 28th day mortar strength for both sealed-cured and water-cured cubes exhibited an increase in strength at 1% addition of AVG by weight of cement. on other hand, 2% and 3% additions of AVG, shows a decline in compressive strength indicating the fact that gel was in surplus amount within the body of the mortar. The basic purpose of preparing the sealed-cured sample was to investigate how much the AVG assist on curing the mortar cubes internally.

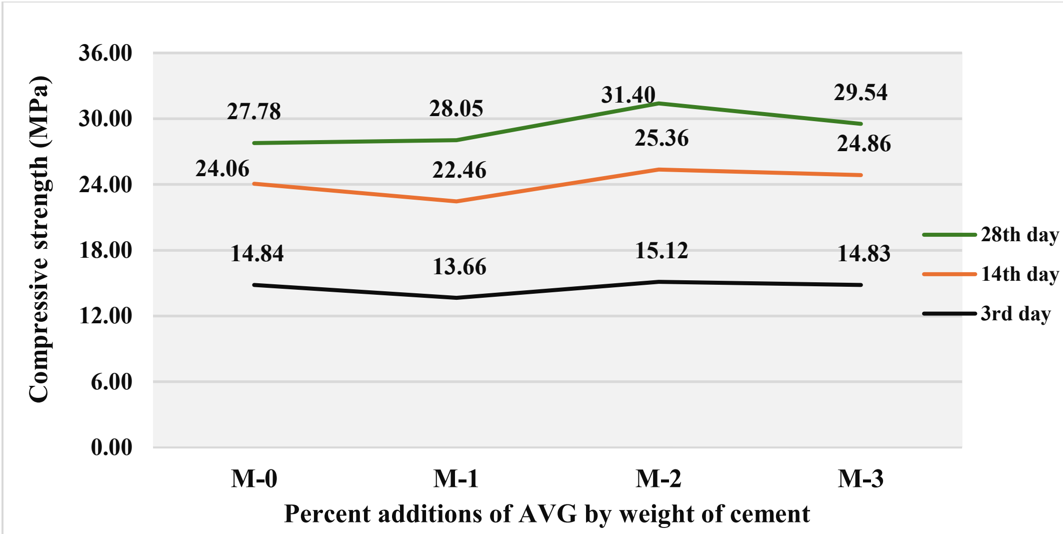
Thus, the results show that the water-cured samples with 0% and 1% addition of AVG have displayed an increase in strength by 1% (0.27 MPa) and 6% (2.02 MPa) respectively compared with the sealed-cured samples. In addition, the water-cured samples with 2% and 3% addition of AVG shows an increment in strength by 13% (4.11 MPa) and 12% (3.82 MPa) correspondingly when contrasted with the sealed-cured specimens.

These outcomes shows that the Aloe Vera gel has assisted the mortar cubes to undergo self-curing especially to 1% addition of AVG. As the percentage of the Aloe Vera gel enhanced the compressive strength of the mortar cubes lowered, indicating the gel prevails in excess amount. In contrast to the 3rd and 14th day results, the 28th day compressive strength test result, which examined into the gel's relative long-term effect, showed that the sealed-cured samples could not achieve the same level of strength as the water-cured samples.

b. Concrete samples

Three cubic samples, each size 150 * 150 * 150 mm, were tested to each percentage of AVG. The experiment on compressive strength of each specimen was measured and recorded at 3, 14, and 28 days. The cubes were removed from water curing tank one day prior to testing. The detailed test results for the compressive strength of AVG containing specimens at 3rd, 14th, and 28th days are presented in Appendix C (C2).

The 28th day mean compressive strength of the samples with 1% Aloe Vera gel showed 1% (0.27 MPa) increase compared with the control sample. Concrete with 2% Aloe Vera gel exhibited 13% (3.62 MPa) rise in strength from the control. The compressive strength for the last percent addition i.e. 3% demonstrated 6% (1.76 MPa) increase from the control. The failure load of the control sample compared with 1%, 2%, and 3% Aloe Vera gel samples also showed an increment in strength by 1%, 13%, and 6%, accordingly. Figures 4.2 compare the results of the tests implemented on the third, fourteenth, and twenty-eighth day for different ratios AVG by weight of cement, including the control concrete.



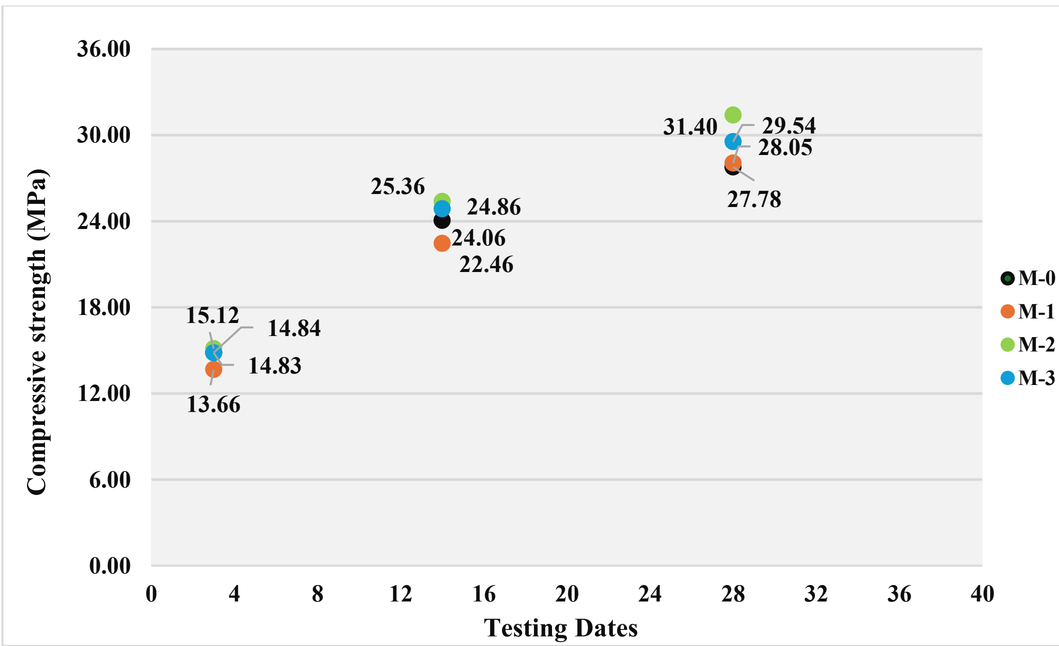


Figure 4.2 Compressive strength of concrete cubes

The compressive strength of concrete cubes demonstrates an increase in performance at 2% addition of AVG by weight of cement. Out of these three percentiles, the recommended percentage with the addition of AVG for mortar and concrete cubes were 1% and 2% respectively. This inconsistency in desirable percentage could come as a result of the occurrence of coarse aggregate, that potentially captivate a significant volume of water, inside the concrete matrix.

4.4 Split tensile strength

The 28th day mean split-tensile strength of 1% AVG containing samples in comparison to the control sample has increased by 4% (0.08 MPa), whereas 2% of AVG samples exhibited 24% (0.51 MPa) increase in split tensile strength. On the other hand, concrete containing 3% Aloe Vera gel also demonstrated a 16% (0.33 MPa) improvement in tensile strength. In comparison with the load of fracture of the control concrete, the average failure loads with 1%, 2%, and 3% Aloe Vera gel were likewise higher by 4%, 24%, and 16%, respectively. Appendix C(C3) shows comprehensive test results and stress estimates of split tensile strength for concrete specimen during 14th and 28th days. Figure 4.3 illustrates the comparison of the 14th and 28th day average tensile strength experimental results including the control concrete for different ratios of AVG by weight of cement.

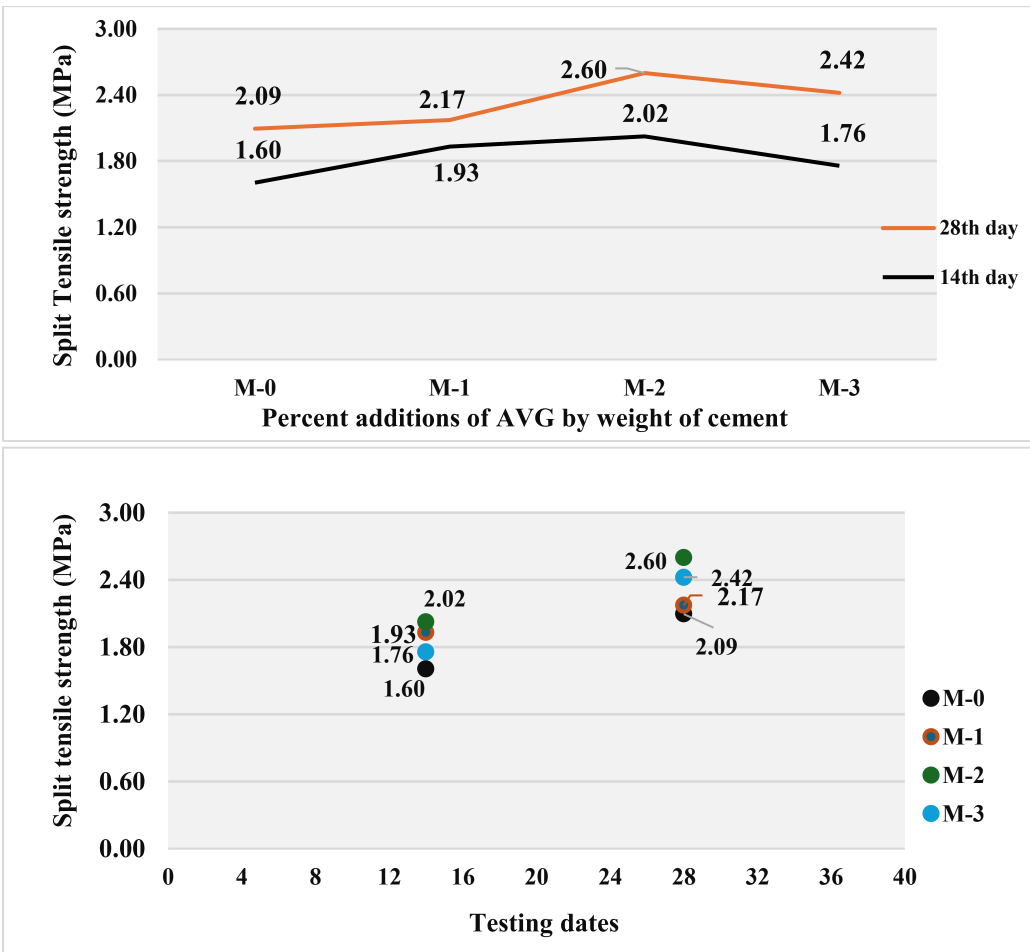


Figure 4.3 Split tensile strength of concrete samples

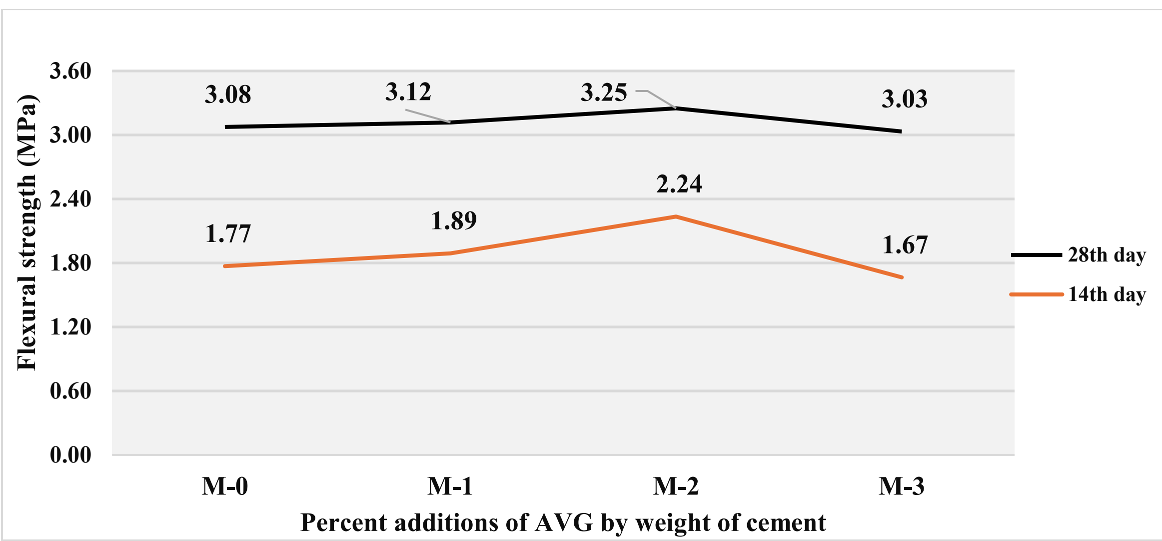
The tensile performance of concrete cylinders illustrated a greater improvement in strength at a percentage of 2% addition of AVG. The maximum strength was attained on 2% addition while the 3% added samples has reduced by 7% at the 28th day testing. Regarding the 14th day tests, the maximum performance was also obtained at 2% addition of AVG then it showed a reduction by 13% on the 3% addition of AVG.

From these outcomes it is apparent that the introduction of Aloe Vera gel has likely showed a water retaining capability and enabled the concrete cylinder achieve an improved split tensile strength.

4.5 Flexural strength

In order to examine prismatic samples for each percent additions of AVG by weight of cement: 0%, 1%, 2%, and 3%, 3rd-point loading was used in compliance with ASTM C78 specification. Appendix C(C4), at the end of this study, has a thorough computation to determine the modulus of elasticity and all other outcomes for the flexural strength of the sample beams on the 14th and 28th days.

Compared with the control beam, the 28th day mean flexural strength of the specimen with 1% addition of Aloe Vera gel by weight of cement exhibited an increase of 1% (0.04 MPa). Concrete with 2% Aloe Vera gel demonstrated 6% (0.17 MPa) increase in flexural strength while the concrete sample with 3% Aloe Vera gel has showed a 1% (0.05 MPa) decrease in flexural strength. With regard to the load of fracture on the control beam, the average failure loads having 1% and 2% Aloe Vera gel were also higher by 4% and 24%, respectively. However, contrasted with the control sample, the mean failure load of the 3% Aloe Vera gel was 1% lower. Figure 4.4 compares the results of the twenty-eight-day average flexural performance assessment for different proportions of AVG by weight of cement with a control specimen.



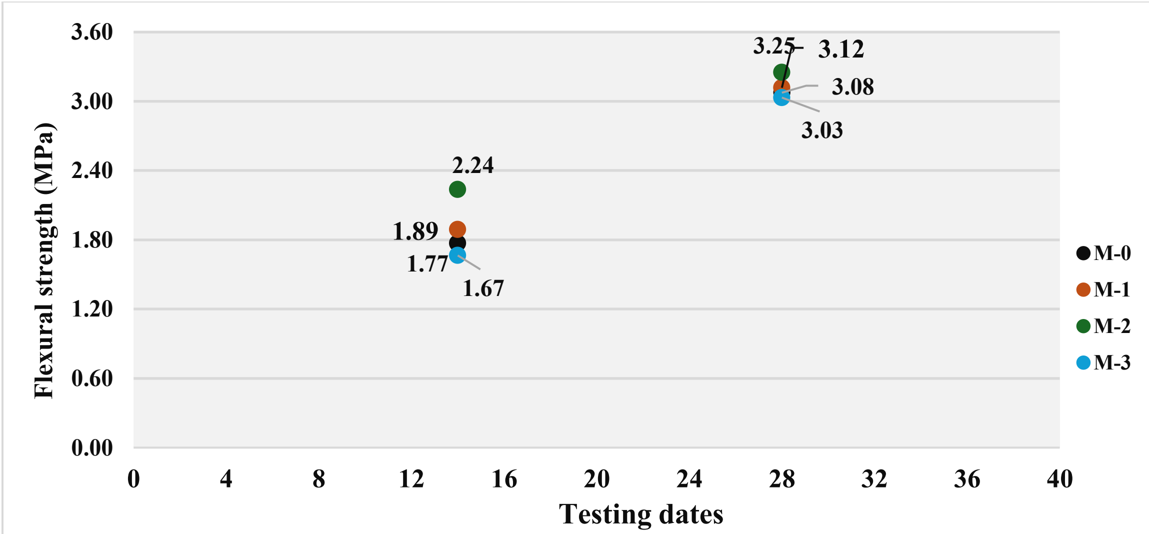


Figure 4.4 Flexural strength of concrete samples

The flexural strength of concrete beams also shows an increment in strength at the proportion of 2% addition of AVG by weight of cement. After attaining the improved performance at 2%, for the addition of 3% AVG, the flexural strength also reduced by 7% compared with the optimum percentile. On the 14th day, the maximum strength was also obtained at 2% addition of AVG then it was lowered by 26% for the 3% addition of AVG.

From this observation it can be ascertained that the addition of Aloe Vera gel has possibly presented a water retaining ability and enabled the concrete beam attain an enhanced flexural strength.

4.6 Absorption capacity

For every concrete mixture containing 0%, 1%, 2%, and 3% addition of AVG by weight of cement, the absorption capacity procedure has been studied. Every concrete specimen was subjected to a 28-day water cure. After using a towel to dry the specimen's surface, the initial weight was measured. Afterward, the samples were placed within a drier configured with a temperature of 130°C for a duration of 72 hours. The final weight has also been recorded so as to compute the absorption capacity of the cylinder for each AVG percentiles.

The weight of the 28^{th} day and the weight after oven dry were recorded and presented in Table 4.3below for each kind of specimens. The absorption capacity for the concrete cylinder with all percent addition was calculated as per the formulation presented in section 3.3.4 of this paper. The conducted test results are described in Table 4.3.

Table 4.3 Absorption capacity of cylindrical samples

Mix Code	Percent added	Water-Cured Weight Kg	Oven- dried Weight Kg	Weigth of Absorbed water Kg	Absoption Capacity %
N0	Control	3.765	3.628	0.138	**3.79%**
N1	1% AVG	3.780	3.673	0.108	**2.93%**
N2	2% AVG	3.760	3.655	0.105	**2.87%**
N3	3% AVG	3.715	3.613	0.102	**2.82%**

As shown in the Figure 4.5 below, among the results of the absorption capacity, 3% addition of AVG specimens absorbs less water during the course of 28 days compared with the other percentages. The control mix, 1% addition and 2% addition samples absorb 35%, 5% and 3% as much water than the 3% addition samples.

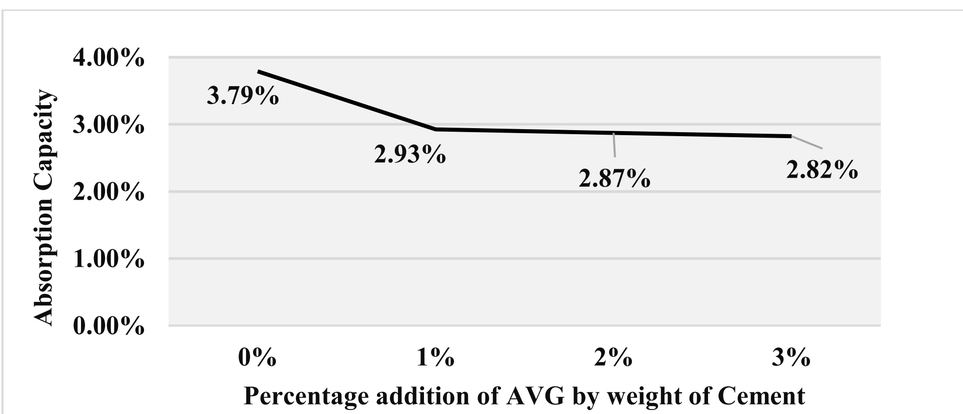


Figure 4.5 Absorption capacity of concrete

It is demonstrated that the presence of the gel has somehow inhibited the absorption of the surrounding water, particularly the 3% AVG has clearly exhibits the prevalence of a relatively excessive water within the concrete matrix.

4.7 Drying shrinkage

Length change is expressed as the percent of the initial specimen length, a positive number indicates expansion and a negative number indicates shrinkage. A length change at a given duration was identified with the variance between the reference bar and comparator reading, as well as the initial difference, deducting the initial difference value from the age difference value then divide by the gage length. It is not uncommon to see positive length changes during moist curing and negative length changes once specimens have been moved to air storage.

By using the reference rod to measure the stud length and by setting the dial gage zero, the length of each sample beam was recorded on the comparator reading. The length and drying shrinkage calculation for each specimen were presented in detail on Appendix C(C5).

As it is shown on Table 4.4 at the 28th day the samples exhibited an expansion due to the water curing process. On the other hand, the tests conducted on the second, third and sixth months resulted in negative results showing a shrinkage for the samples were sealed-cured.

Table 4.4 Drying shrinkage in percentage at different ages

Mix Code	AVG added	Drying Shrinkage			
		28th day	60th day	90th day	180th day
M-0	Co	0.01%	-0.02%	-0.04%	-0.05%
M-1	1%	0.02%	-0.03%	-0.05%	-0.06%
M-2	2%	0.02%	-0.04%	-0.06%	-0.07%
M-3	3%	0.03%	-0.04%	-0.06%	-0.09%

Throughout the recording ages, the average shrinkage percentages have shown an increasing pattern along with the percent addition of AVG. As presented in Figure 4.6, on the 28th day, the results revealed an increase in length because the samples were kept in a water pond, however after being placed outside, the specimens started to shrink. the change in length were not significant at the 60th day testing but it was persistently increasing along with time.

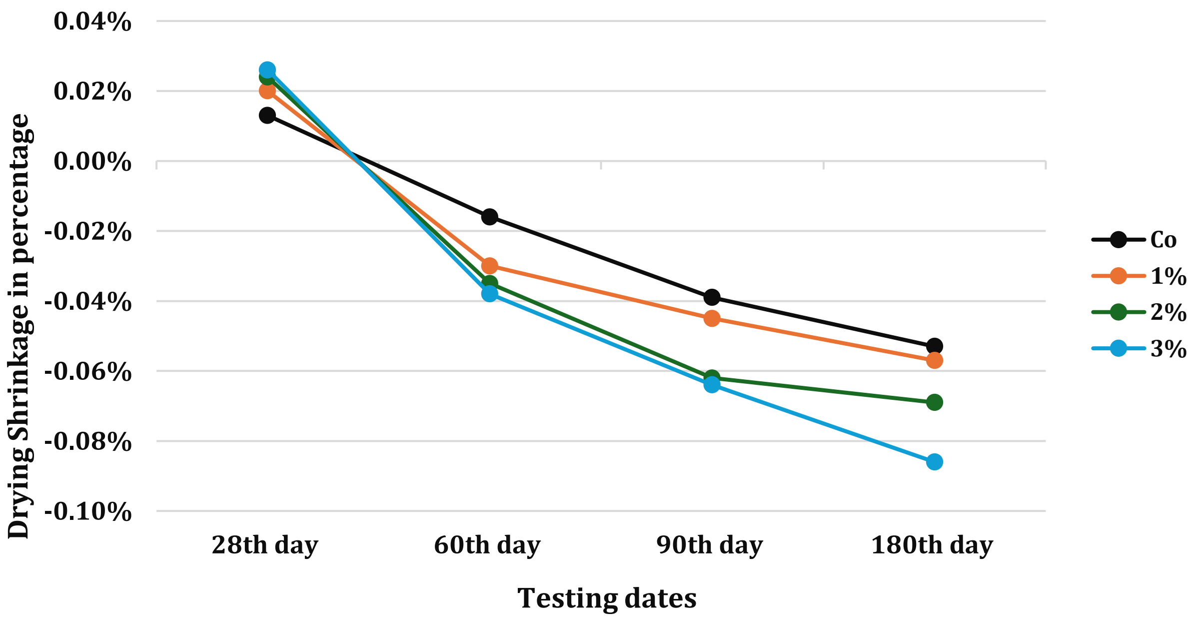


Figure 4.6 Comparison of drying shrinkage of the samples

It is evident that the addition of AVG in the concrete mix caused the samples to undergo a reduction in length. Particularly on the long term, the 3% AVG containing sample has a significant reduction compared with the original length. This situation could possibly occur due to the existence of the Aloe Vera mucilage, the fibrous section of the colorless inner parenchyma, inside the AVG or it could arise from the 3% addition of AVG being an over-dosed on the concrete mix. Compared with the original recorded data, samples containing 1% and 2% AVG have also showed a significant change in length. However, as per ASTM C157 the calculated shrinkage percentage for these percent additions were within the acceptable range i.e. 0.050 to 0.075.

4.8 Cost comparison

The cost comparison was analyzed among the whole sell price of aloe vera leaf and the buying price of the related admixture from sika distributer. The outcome is as shown in Table 4.5.

Table 4.5 Cost comparison

It.	Material	Lit	Price Birr	Comparison in %
1	Admixture	1	385	**95%**
2	Aloe Vera gel	1	20	**5%**

As it is evident in the table above the buying price of one liter aloe vera gel is only 5% from the purchasing value of the respective admixture. Therefore, it is economical to make use of this bio-admixture as a potential substitute after a relative researches and studies.

5. Conclusions and Recommendations

The study is intended to examine the change in characteristics of cement paste, mortar, fresh and harden concrete when Aloe Vera gel is added with different percentiles. The results of the control samples were analyzed by correlating to the different percent added sample outcomes.

According to the findings of this experiments, the following conclusion and recommendation are stated:

5.1 Conclusions

1. The workability of the Aloe Vera gel added concrete increased as the concentration of the natural additive rises. This is due to the viscose nature of the plant extract, which results in a more pasted concrete mix.
2. The setting time of the cement paste exhibited retardation along with the increase in the dosage of the Aloe Vera gel. All the recorded results showed a significant delay for both initial and final setting times. The increase in setting time with the percent addition is possibly caused by the presence of the gel.
3. The experiment indicates that for 0%, 1%, 2%, and 3% addition of Aloe Vera gel have resulted an improvement in split tensile strength, flexural strength and compressive strength of concrete. At 2% Aloe Vera gel the maximum results was attained. This is likely because of the water that was kept in the gel and was thought to have been eliminated once the concrete had dried.
4. Regarding mortars the study revealed that the proportion of Aloe Vera gel has to be minimized in order to maintain a maximum compressive strength. For both sealed-cured and water cured condition, the better percentile that achieved a better compressive strength was 1% AVG. Compared to the results of the concrete specimens, the deviation can possibly arise from the absence of coarse aggregates, which potentially divert the outcome of the mortar sample. It is observed in the examination that as the dosage increases beyond 1% the concrete samples show a reduction in compressive strength.
5. The experiment illustrates the long-term effect of the Aloe Vera gel with respect to drying shrinkage. It has actually showed a tolerable marginal change in length along with the percent addition of the gel. Therefore, it is possible to justify the fact that the addition of Aloe Vera gel has not significantly affect the volumetric change of concrete.
6. The cost analysis showed that the chemical admixture is way too expensive compared with the relative aloe vera gel.

The objectives set forth at the inception of this study have been accomplished. The primary aim was to conduct experimental investigations on the use of aloe vera gel as a self-curing agent in concrete production. Through rigorous laboratory testing, the research has demonstrated that aloe vera gel possesses notable water-retention capabilities, which contribute positively to the curing process. This effect has been evidenced by improvements in the compressive strength and durability of concrete specimens treated with aloe vera gel compared to control samples.

Nonetheless, while the immediate objectives have been met, it is acknowledged that further comprehensive studies are necessary to assess long-term performance, scalability, and behavior under diverse environmental conditions to validate the widespread application of aloe vera gel in the construction industry.

5.2 Recommendations

The experimental examination of this subject can be further explored in the following areas.

1. The effect of Aloe Vera gel in long term cement hydration process by using isothermal calorimeter apparatus.
2. A study on the influence of Aloe Vera gel on the durability of concrete.
3. The application of Aloe Vera gel to produce concrete with high-strength or high-performance concrete form.
4. An investigation to find the optimum proportion of Aloe Vera gel in concrete by using multiple & decimal percent additions.

5.3 Practical Interpretation and Future Industry Implications

The investigation of aloe vera gel as a self-curing agent in concrete production holds significant potential for transforming the construction industry toward more sustainable and cost-effective practices.

- From a practical standpoint, if AVG proves effective in maintaining moisture within concrete, it can reduce the reliance on traditional curing methods that consume large quantities of water and energy. This innovation could lead to lower operational costs on construction sites and minimize environmental impacts.
- Looking ahead, further research and development are crucial to fully optimize the use of AVG in concrete mixtures, including understanding its long-term effects on concrete strength, durability, and workability under various environmental conditions.
- Beyond academic research, there is a promising commercial opportunity to establish a company dedicated to the production and supply of aloe vera-based natural admixtures for the construction sector. This enterprise would address growing demand for eco-friendly building materials and cater to industry stakeholders seeking sustainable alternatives.
- Ultimately, the integration of aloe vera gel as a self-curing agent represents not only an innovation in construction materials but also a step toward greener, more sustainable infrastructure development. This aligns with global sustainability goals and offers competitive advantages in markets that increasingly value environmental responsibility.

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Appendix A: Tests for concrete-making materials

Standardizing aggregates is necessary because the mechanical, chemical, and physical characteristics of the parent ingredients utilized to make aggregates determine the strength and quality of the concrete. This session covered all of the physical examination that were done on both sand and coarse aggregates.

A1: Tests for fine aggregates

i. **Silt content**

Finding the finer silt and fine clay components inside the fine aggregate that are finer than No. 200 sieve is the goal of silt content testing.

Test Result:

A = 5ml **Where: A = quantity of dumped silt above the settled sand**

B = 295ml **B = quantity of pure sand**

Calculation:

$$\text{Silt Content (\%)} = \frac{A}{B} * 100, \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. 2}$$

$$= \frac{5}{295} * 100 \quad = 1.7\% < 6\ \% \ \ldots\ldots\ldots\ldots \quad \text{OK!}$$

As per the Ethiopian Specification, it is advised to either wash-down or discard sand that has a silt level greater than 6%. Since the silt percentage in the sand samples used in this particular study is currently significantly less than 6%, they were safe to use after washing.

ii. **Sieve analysis of fine aggregate**

The objective is to ascertain the fine aggregates material size dispersal. The particle size distribution for the grading of the sand according to the Ethiopian Standard is summarized in Table A.1 and Figure A.1.

Test Result:

Table A.1: Sieve analysis results for sand

Sieve Size (mm)	Weight of Sieve (gm)	Weight of Sieve & Retained (gm)	Weight of Retained (gm)	Percentage Retained (%)	Cumulative Coarser (%)	Cumulative Passing (%)
9.50	585.00	585.00	0.00	0.00	0.00	**100.00**
4.75	566.50	568.20	1.70	0.34	0.34	**99.66**
2.36	401.70	413.30	11.60	2.32	2.66	**97.34**
1.18	372.60	541.81	169.21	33.79	36.45	**63.55**
0.60	313.10	510.56	197.46	39.44	75.89	**24.11**
0.30	309.30	376.98	67.68	13.52	89.40	**10.60**
0.15	274.00	313.44	39.44	7.88	97.28	**2.72**
Pan	240.00	253.61	13.61	2.72		
Total			**500.70**	**100.00**	**300.02**	

$$\text{Fineness modulus F.M} = \frac{\sum \textit{Cummulative}\ \textbf{coarser}\ \%}{\mathbf{100}}$$

$$= \frac{300}{100} = 3$$

The Ethiopian Standard specifies that fine aggregate should be graded according to ranges of percentages that pass through each sieve, as shown in figure A.1.

Comment:

The acquired fine aggregate sample was examined to check if its particle size dispersal was inside the limits specified by the Ethiopian specification for fine aggregate classifying. It thereby fulfills the graduation requirement.

iii. Specific gravity and absorption capacity of fine aggregate

The proportion of a substances weight to that of an equivalent volume of water is called specific gravity. Water is captured within the particles and then inclines to occupy the porous voids of a permeable dense form over a process known as absorption capacity. The ASTM C128 guide has been implemented in the making of the test specimens and also the setup procedures. The test results are displayed as follows.

Test Results:

A = 485g
B = 495g
C = 795g
D = 505g

Where,

A = Weight of oven-dry sample in air
B = Weight of pycnometer filled with water
C = Weight of pycnometer with sample and water
D = Weight of Surface Saturated (SSD) Sample

Calculations:

Bulk Specific Gravity

Bulk sp gr: $= \frac{A}{B+S-C}$ ……………………………………………..……Eq. 3

Bulk sp gr: $= \frac{485}{495+505-795} = \mathbf{2.4}$

Bulk Specific Gravity (SSD Basic)

Bulk sp gr (SSD Basic) $= \frac{S}{B+S-C}$ ………………………………………Eq. 4

Bulk sp gr (SSD Basic) $= \frac{505}{495+505-795} = \mathbf{\mathit{2.5}}$

Apparent Specific Gravity

Apparent sp gr $= \frac{A}{B+A-C}$ ……………………………………………Eq. 5

Apparent sp gr $= \frac{485}{495+485-795} = \mathbf{\mathit{2.6}}$

Absorption Capacity

Absorption Capacity (%): $= \frac{S-A}{A} * 100$ …………………………………Eq. 6

Absorption Capacity (%): $= \frac{505-485}{485} * 100 = 4.0\%$

Comment: It is the Bulk Specific Gravity (SSD Basic) that is utilized for designing concrete making materials.

iv. Bulk density of fine aggregate

The bulk density, which accounts for both the dense particle and the spaces within, indicates the volume that the classified aggregate will take up in concrete. According to ASTM C29, an empty metal cylinder's weight was first determined. Subsequently, the metal cylinder has been loaded to one third of the container, and the aggregate was stroked with 25 blows by the packing metal rod. The cylinder was then filled two-thirds of the way, leveled, and rodded once more as before. Lastly, fill the cylinder to the brim and rod once more using the previously described method. By using fingertips or a straight edge, the surface of the aggregate was leveled.

Test Results:

Weight of the metal cylinder measures = 4,845g

Weight of the sand with the cylinder= 2,635.5g

Dimensions of the metal cylinder

Inside diameter = 0.255m

Inside height = 0.275m

Volume of the metal cylinder measure = $\frac{\pi D^2}{4} * h = \frac{\pi\, 0.2552}{4} * 0.275 = 0.014044392m^3$

Calculations:

$$\text{Bulk density of sand} = \frac{\text{Net weight of sand}}{\text{Volume of the metal cylinder}} \quad \text{……………………………….Eq. 7}$$

$$= \frac{26.355 - 4.845}{0.014044392}$$

$$\mathbf{= 1{,}531.57kg/m^3}$$

v. Moisture Content of sand

This procedure aims to ascertain the materials moisture content. The moisture content of the sand has been determined utilizing the formula given by ASTM C566.

Test Results:

A= 500g

B= 489g

Where:

A= Weight of original specimen (g)

B= Weight of oven-dry specimen in air (g)

Calculations:

Moisture Content: $= \frac{A-B}{B} * 100$ ……………………………………………Eq. 8

$$= \frac{500-496}{496} = 0.806\% \cong 0.81\%$$

Moisture Content (%): = **0.81%**

A2: Tests for coarse aggregates

a. Sieve analysis of coarse aggregate

The sieve experimental testing goal is to ascertain the coarse aggregate's size dispersal. The material size dispersal as per Ethiopian specification for coarse aggregate grading is summarized in table A.2 and figure A.2 below.

Test results:

Table A.2: Sieve analysis results for coarse Aggregate

Sieve Size (mm)	Weight of Sieve (gm)	Weight of Sieve & Retained (gm)	Weight of Retained (gm)	Percentage Retained (%)	Cumulative Coarser (%)	Cumulative Passing (%)
37.5mm	1,085.0	1,085.0	0.0	0.0	0.0	**100.0**
25mm	1,200.0	1,200.0	0.0	0.0	0.0	**100.0**
19mm	1,380.0	1,429.0	49.0	2.4	2.4	**97.6**
12.5mm	1,150.0	1,572.5	422.5	21.0	23.4	**76.6**
9.5mm	1,160.0	2,022.7	862.7	42.8	66.2	**33.8**
4.75mm	1,170.0	1,850.8	680.8	33.8	100.0	**0.0**
2.36	401.7	401.7	0.0	0.0	100.0	**0.0**
1.18	372.6	372.6	0.0	0.0	100.0	**0.0**
0.6	313.1	313.1	0.0	0.0	100.0	**0.0**
0.3	309.3	309.3	0.0	0.0	100.0	**0.0**
0.15	274.0	274.0	0.0	0.0	100.0	**0.0**
Pan	240.0	240.0	0.0	0.0		
Total			**2015.0**	**100**	**668.6**	

$$\text{Fineness modulus F.M} = \frac{\sum \textit{Cummulative}\ \textbf{coarser}\ \%}{\textbf{100}}$$

$$= \frac{669}{100} = 6.69$$

Comment:

For the purpose of maintaining the gradation requirement within the range, all of the coarse aggregate samples were blended.

b. Specific gravity and absorption capacity of coarse aggregate

Determining the apparent and bulk specific gravities as well as the absorption capacity is the aim of conducting this test.

The mass sample was quartered in order to obtain an approximate aggregate sample weight of 5 kg. All coarse aggregate particles that pass through the no. 4 sieve were discarded.

Test Results:

A = 2,035.0g
B = 2,075.0g
C = 1,242.4g

Where,

A = Weight of oven-dry sample in air
B = Weight of Surface Saturated (SSD) Sample in air
C = Weight of Saturated sample in water

Calculations:

Bulk Specific Gravity

$$\text{Bulk sp gr:} = \frac{A}{B-C}$$

$$\text{Bulk sp gr:} = \frac{2,035.0}{2,075.0-1,242.4} = \mathbf{2.44}$$

Bulk Specific Gravity (SSD Basic)

$$\text{Bulk sp gr (SSD Basic)} = \frac{B}{B-C}$$

$$\text{Bulk sp gr (SSD Basic)} = \frac{2,075.0}{2,075.0-1,242.4} = \mathbf{2.49}$$

Apparent Specific Gravity

$$\text{Apparent sp gr} = \frac{A}{A-C}$$

$$\text{Apparent sp gr} = \frac{2,035.0}{2,035.0-1,242.4} = \mathbf{2.57}$$

Absorption Capacity

Absorption Capacity (%): $= \frac{B-A}{A} * 100$

Absorption Capacity (%): $= \frac{2,075.0-2,035.0}{2,035.0} * 100 = 2.0\%$

Comment: It is the Bulk Specific Gravity (SSD) that is utilized for designing Concrete making materials.

c. Bulk density of coarse aggregate

Determining the bulk density of coarse aggregate is the aim of this test. As per the standard of construction material guide by Professor Abebe Dinku, the bulk density of the coarse aggregate was calculated as follows.

Test Results:

Weight of the metal cylinder measures = 4845g

Weight of the coarse aggregate with the metal cylinder= 2742.0g

Dimensions of the metal cylinder

Inside diameter = 0.255m

Inside height = 0.275m

Volume of the metal cylinder measure = $\frac{\pi D^2}{4} * h = \frac{\pi\, 0.2552}{4} * 0.275 = 0.014044392m^3$

Calculations:

$$\text{Bulk density of Coarse Aggregate} = \frac{\text{Net weight of coarse aggregate}}{\text{Volume of the metal cylinder}}$$

$$= \frac{27.42-4.845}{0.014044392}$$

$$= \mathbf{1,607.40 kg/m^3}$$

d. Moisture content of coarse aggregate

This test aims to investigate the coarse aggregate moisture content. Similarly, the moisture content of the aggregate was determined using the formula given by ASTM C566.

Test Results:

A= 2000g

B= 1989.4g

Where:

A= Weight of original specimen (g)

B= Weight of oven-dry specimen in air (g)

Calculations:

Moisture Content: $= \frac{A-B}{B} * 100$

$$= \frac{2000-1989.4}{1989.4} = 0.603\% \cong 0.61\%$$

***Moisture Content (%):* = 0.61%**

Same way, the coarse aggregate was also washed and air dried for almost 4 days prior to any test conducted.

Appendix B: Mix design and proportioning

Proportioning is the process of determining how much of each ingredient to use when making a batch of mixture. Achieving the right balance between cost and the need for strength, placeability, density, durability, and appearance is crucial when choosing the proportions for concrete. The proportions of w/c in the cement mix, the proportions of cement pastes to aggregate in the concrete mixture, the proportions of sand to coarse aggregate, and the use of building additives are the determinant factors to be chosen when using concrete-making materials with specific characteristics. Mix design's primary objective is to identify the most suitable constituents from the variety of resources accessible and develop the most economical method of integrating them to generate concrete that conforms to a minimal set quality criterion.

B1: Mix design for mortar

The mix design and proportioning of mortar is discussed as follows;

- ***Mix information***

  Cement to sand ratio = 1:2
  Water to cement ratio = 0.5
  Bulk density of cement = 1,440kg/m3 (from the suppliers)
  Bulk density of sand = 1,531.6kg/m3
  Mortar wastage = 10%
  Shrinkage Factor = 25%
  Total cube required = 48pcs
  1 cube dimension = 7cm*7cm*7cm
  Cube per mix = 3
  Total mix = 16 mixes (due to the capacity of the bucket)

- ***Mix Proportioning***

Total volume of the mixture = 48* 0.07* 0.07* 0.07 = 0.016464m^3 of mortar

Add 10% wastage = 1.1* 0.016464m^3 = 0.0181104m^3 of mortar

Shrinkage Factor = 1.25 * 0.0181104m^3 = 0.022638m^3 of mortar

- ✓ **Cement**, 1:2 ratio = $\frac{1}{3}$ part= 0.33333

  - total volume of cement with 4% wastage added = $\frac{1}{3}$ * 0.022638m^3 *1.04 =**0.00784784m^3** of cement.

  - weight of cement = 0.00784784m^3 * 1,440kg/m^3 = **11.30kg** cement required.

- ✓ **Sand**, 1:2 ratio = $\frac{2}{3}$ part= 0.666667

  - total volume of sand with 4% wastage added = $\frac{2}{3}$ * 0.022638m^3 *1.04 =**0.01569568m^3** of sand

  - weight of sand = 0.01569568m^3 * 1,531.6kg/m^3 = **24.04kg** of sand is required

- ✓ **Water**, = 0.5 part

  - weight of water = 0.5 * 11.30kg =**5.65kg = 5.65lit.** of water

- ✓ **AVG** – quantity for the gel extracted out of the Aloe Vera plant is calculated from the weight of cement per a single mix.

  - for the total mixes (48cubes or 0.016464m^3) 11.30kg of cement is required.

  - for a single mix (3 cubes, 0.001029m^3) = 11.30kg * (3 $cubes$)/ (48 $cubes$) = **0.706kg** of cement

  - Specific gravity of Aloe Vera i.e. 1.005 was used to find the volume from its respective weight. (taken from literature reviews).

  - the amount of 1%, 2% and 3% addition of AVG was deducted from the quantity of cement needed for the mixes.

Table B.1: Volume of Aloe Vera gel for a single mortar mix

Volume of Aloe Vera gel for compressive strength testing

Addition %	Weight of Aloe			Volume of Aloe m^3	Vol. of Aloe ml
	% by weight of cement		kg		
1% Aloe	1% by weight of cement	1% * 0.706kg	0.007	0.0000070	7
2% Aloe	2% by weight of cement	2% * 0.706kg	0.014	0.0000140	14
3% Aloe	3% by weight of cement	3% * 0.706kg	0.021	0.0000211	21

Twenty-four cubes were cured with water and the remaining 24 cubes were cured with air. Calculated quantities of all ingredients for each mix are tabulated as follows.

Table B.2: Quantities of ingredient materials for mortar

Mixes	Samlple % ages	Sample Size	Size in m^3	Cubes per mix	Volume per mix	Cement (Kg)	Water (Kg)	Fine Aggregate Kg	Aloe-Gel ml
Cubes water cured placed inside the pond									
Mix 1	Control	(70*70*70mm)	0.000343	3	0.001029	0.706	0.353	1.50	0
Mix 2	Control	(70*70*70mm)	0.000343	3	0.001029	0.706	0.353	1.50	0
Mix 3	1% Aloe	(70*70*70mm)	0.000343	3	0.001029	0.706	0.346	1.50	7
Mix 4	1% Aloe	(70*70*70mm)	0.000343	3	0.001029	0.706	0.346	1.50	7
Mix 5	2% Aloe	(70*70*70mm)	0.000343	3	0.001029	0.706	0.339	1.50	14
Mix 6	2% Aloe	(70*70*70mm)	0.000343	3	0.001029	0.706	0.339	1.50	14
Mix 7	3% Aloe	(70*70*70mm)	0.000343	3	0.001029	0.706	0.332	1.50	21
Mix 8	3% Aloe	(70*70*70mm)	0.000343	3	0.001029	0.706	0.332	1.50	21
Sub-total required Quantities				**24**		**5.65**	**2.74**	**12.02**	**84**
Cubes air cured wrapped in thin plastic film									
Mix 9	Control	(70*70*70mm)	0.000343	3	0.001029	0.706	0.353	1.50	0
Mix 10	Control	(70*70*70mm)	0.000343	3	0.001029	0.706	0.353	1.50	0
Mix 11	1% Aloe	(70*70*70mm)	0.000343	3	0.001029	0.706	0.346	1.50	7
Mix 12	1% Aloe	(70*70*70mm)	0.000343	3	0.001029	0.706	0.346	1.50	7
Mix 13	2% Aloe	(70*70*70mm)	0.000343	3	0.001029	0.706	0.339	1.50	14
Mix 14	2% Aloe	(70*70*70mm)	0.000343	3	0.001029	0.706	0.339	1.50	14
Mix 15	3% Aloe	(70*70*70mm)	0.000343	3	0.001029	0.706	0.332	1.50	21
Mix 16	3% Aloe	(70*70*70mm)	0.000343	3	0.001029	0.706	0.332	1.50	21
Sub -total required Quantities				**24**		**5.65**	**2.74**	**12.02**	**84**
Design Quantities per 0.016464m^3 (48cubes) of mortar						**11.30**	**5.65**	**24.04**	**169**

B2: Mix design for concrete

This particular study used the American Concrete Institute's (ACI) mix design approach to establish the proportions of cement, water, sand, and coarse aggregate in a self-curing concrete mix design for a C30 concrete grade.

Mix design –ACI method

A. Mix information

- Desired strength = 30MPa
- Expected Slump = 50mm
- Maximum aggregate size = 20mm
- Materials

Cement = Specific $Gravity_{cement}$ = 3.15

Aloe Vera gel = Specific $Gravity_{aloe\text{-}gel}$ = 1.005

Sand = Dry Bulk $density_{sand}$ = 1,531.57kg/m^3

Dry bulk specific gravity = 2.5

Absorption Capacity = 4%

Coarse Aggregate = Dry Bulk density = 1,607.4kg/m^3

Dry bulk specific gravity = 2.49

Absorption Capacity = 2%

Fineness Modulus = 3.00

B. Mix Proportioning

1. Using maximum aggregate size of 20mm and slump value of 50mm and, readings from table indicated under;

Water content = 185kg/m^3

Air content = 2% =20lit

Table A1.5.3.3- Approximate mixing water requirements for different slumps and maximum sizes of aggregates

	Water kg/m^3 of concrete for indicated maximum sizes of aggregate in mm							
Slump cm.	10	12.3	20	25	40	50$^+$	70$^+$	150$^+$
	Non-air entrained concrete							
3 to 5	205	200	185	180	160	155	145	125
8 to 10	225	215	200	195	175	170	160	140
15 to 18	240	230	210	205	185	180	170	-
Approximate amount of entrapped air in non-air entrained concrete percent	3	2.5	2	1.5	1	0.5	0.3	0.2
	Air entrained concrete							
3 to 5	180	175	165	160	145	140	135	120
8 to 10	200	190	180	175	160	155	150	135
15 to 18	215	205	190	185	170	165	160	-
Recommended Average total air content, percent	8	7	6	5	4.5	4	3.5	3

*These quantites of mixing water for use in computing cement factor, for trial batches. They are maxima for reasonably well-shaped angular coarse aggregates graded within limits of accepted specifications.

*The slump values for concrete containing aggregate larger than 40mm are based on slump tests after removal of particles larger than 40 mm by wet-screening.

2. As per the Ethiopian building code standard, for C-30 Concrete with maximum aggregate size 20mm, the minimum cement content is 290kg/m^3. Reading from table is shown as follow;

Water to cement ratio of the non-air-entrained concrete = 0.55

Cement content = (185kg/m^3)/0.55 = 336.36kg/m^3 > 290 kg/m^3 … OK!

Table A1.5.3.4(a) Relationship between water-cement ratio and compressive strength of concrete

Compressive strength at 28days, kgf/cm^2	Water cement ratio, by weight	
	Non-air-entrained concrete	Air-entrained concrete
450	0.38	-
400	0.43	-
350	0.48	0.4
300	0.55	0.46
250	0.62	0.53
200	0.70	0.61
150	0.80	0.71

3. From table using the maximum aggregate size 20mm and the fineness modulus of sand which is 3, the Bulk volume of coarse aggregate can be obtained.

Bulk volume of coarse aggregate = 0.6m^3 per m^3 of concrete

Weight of dry coarse aggregate=0.6m^3 * 1,607.40kg/m^3 =964.44kg

For its convenience, the volume batching is used.

The absolute volume is calculated by using this formula

$$V = Va + \frac{WW}{1000} + \frac{W_c}{1000Gc} + \frac{W_{fa}}{1000Gfa} + \frac{W_{ca}}{1000Gca} \quad \text{............Eq..9}$$

$$V = \frac{W}{1000(G)}$$

Where

	V	is the absolute volume in cu.m.
	W	is the weight of the material in kg
	G	is the specific gravity of the material
	1000	is the density or Bulk density of fresh water in kg per cu.m.

Table A1.5.3.6 - Volume of coarse aggregate per unit of volume of concrete

Maximum size of aggregate mm	Volume of dry rodded coarse aggregate per unit volume of concrete for different fineness modulus of sand			
	2.40	2.60	2.80	3.00
10	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
20	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
40	0.76	0.74	0.72	0.70
50	0.78	0.76	0.74	0.72
70	0.81	0.79	0.77	0.75
150	0.87	0.85	0.83	0.81

Calculations

- Absolute volume of air = 0.020 cu m.
- Absolute volume of water $= \frac{W_w}{1000} = \frac{185}{1000}$ = 0.185 cu m.
- Absolute volume of cement $= \frac{W_c}{1000\ Gc} = \frac{336.36}{1000 * 3.15}$ = 0.107 cu m.
- Absolute volume of c. aggregate $= \frac{W_{ca}}{1000\ Gca} = \frac{964.44}{1000 * 2.49}$ = 0.387 cu m.

Total Volume without Sand **= 0.699 cu m.**

- Absolute volume of sand = 1.000cu m – 0.699cu m = 0.301 cu m.

Weight of sand = 0.301m^3 * 2.5 * 1000kg/m^3 **= 752.5kg**

Table B. 3: Summary of ingredients quantity

	Absolute Volume	Weight
Absolute volume of air	0.02 m^3	
Absolute volume of water	0.185 m^3	185 kg
Absolute volume of cement	0.107 m^3	336.36 kg
Absolute volume of c. aggregate	0.387 m^3	964.44 kg
Absolute volume of f. aggregate	0.301 m^3	752.5 kg

Adjustment

Increase weight of water by an amount equivalent to the weight of water demanded to saturate the fine and coarse aggregate.

- Adjusted water = 185 + 964.44*0.02% +752.5*0.03%

  =185 + 0.1929+0.2258 = **185.45kg**

Increase the weight of sand and weight of coarse aggregates to consider the prevailing moisture content.

- Adjusted Sand = 752.5 + 752.5*0.81% = 752.5 + 6.1 = **758.6kg**
- Adjusted Coarse aggregate = 964.44 + 964.44 * 0.6% = 964.44 + 5.8 = **970.2kg**

Decrease the weight of water by the same amount the sand and aggregate increased.

- Adjusted water = 185.45 – 6.1 – 5.8 = **173.52kg**

Thus, the modified mass of constituent materials per cubic meter of concrete

Cement = 336.36kg
Sand = 758.6kg
Coarse Aggregate = 970.2kg
Water = 173.52kg

Aloe Vera gel (for concrete compressive, split tensile and compressive mixes) - in its juice form, weighted as a percent by mass of cement. There were two kinds of mixes; one mixes for 9 cubes and the other were for 6 tensile cylinder and flexural beam. Same procedure to mortar AVG calculation was followed for the concrete as well. All the major ingredients were subjected to the addition of 10% wastage. The amount of 1%, 2% and 3% was deducted from the quantity of cement needed for the mixes. Aloe Vera gel quantity used for the cube mixes and for the tensile and flexural samples is presented in Table B.4 below.

Aloe Vera gel (for cylinder for absorption and beam for shrinkage mixes) - there were only one kind of mix each comprising 2 cylinders for testing absorption and 2 beams for testing shrinkage. All the major ingredients were subjected to the addition of 8% wastage. The amount of 1%, 2% and 3% was deducted from the quantity of cement needed for the mixes. Aloe Vera gel quantity used for the cylinder and for the drying shrinkage samples is presented in Table B.4.

Table B.4: Volume of Aloe Vera gel needed for a single compressive, split tensile, flexural, absorption-cylinder and shrinkage -beam mix

Calculations of Aloe Vera gel volume

Volume of Aloe Vera gel for compressive strength testing

Addition	Weight of Aloe			Volume of Aloe	Vol. of Aloe
%	% by weight of cement		kg	m^3	ml
1%	1% by weight of cement	1% * 11.242kg	0.112	0.0001119	111.86
2%	2% by weight of cement	2% * 11.242kg	0.225	0.0002237	223.72
3%	3% by weight of cement	3% * 11.242kg	0.337	0.0003356	335.58

Volume of Aloe Vera gel for split tensile strength testing

Addition	Weight of Aloe			Volume of Aloe	Vol. of Aloe
%	% by weight of cement		kg	m^3	ml
1%	1% by weight of cement	1% * 3.498kg	0.035	0.0000348	34.81
2%	2% by weight of cement	2% * 3.498kg	0.070	0.0000696	69.61
3%	3% by weight of cement	3% * 3.498kg	0.105	0.0001044	104.42

Volume of Aloe Vera gel for flexural strength testing

Addition	Weight of Aloe			Volume of Aloe	Vol. of Aloe
%	% by weight of cement		kg	m^3	ml
1%	1% by weight of cement	1% * 7.403kg	0.074	0.0000737	73.66
2%	2% by weight of cement	2% * 7.403kg	0.148	0.0001473	147.32
3%	3% by weight of cement	3% * 7.403kg	0.222	0.0002210	220.99

Volume of Aloe Vera gel for absorption capacity testing

Addition	Weight of Aloe			Volume of Aloe	Vol. of Aloe
%	% by weight of cement		kg	m^3	ml
1%	1% by weight of cement	1% * 1.166kg	0.012	0.0000116	11.60
2%	2% by weight of cement	2% * 1.166kg	0.023	0.0000232	23.20
3%	3% by weight of cement	3% * 1.166kg	0.035	0.0000348	34.81

Volume of Aloe Vera gel for drying shrinkage testing

Addition	Weight of Aloe			Volume of Aloe	Vol. of Aloe
%	% by weight of cement		kg	m^3	ml
1%	1% by weight of cement	1% * 1.430kg	0.014	0.0000142	14.23
2%	2% by weight of cement	2% * 1.430kg	0.029	0.0000285	28.46
3%	3% by weight of cement	3% * 1.430kg	0.043	0.0000427	42.69

Proportioned quantities of all ingredients for each concrete mixes are tabulated as follows:

Table B.5: Quantities of ingredient materials for concrete mixes

Test	Mix Code	Percent added by weight of cement	Cement (Kg/m^3)	Water (Kg/m^3)	Fine Aggregate (Kg/m^3)	Coarse Aggregate (Kg/m^3)	AVG ml
Compressive Strength Test	M0-cu	Control	37.82	20.09	85.34	109.15	0.00
	M1-cu	1%	37.82	19.70	85.34	109.15	376.28
	M2-cu	2%	37.82	19.31	85.34	109.15	752.55
	M3-cu	3%	37.82	18.92	85.34	109.15	1128.83
		Sub total	151.26	78.03	341.38	436.60	2257.65
Split-Tensil Strength Test	M0-st	Control	11.77	6.24	26.47	33.89	0.00
	M1-st	1%	11.77	6.12	26.47	33.89	117.08
	M2-st	2%	11.77	6.00	26.47	33.89	234.16
	M3-st	3%	11.77	5.88	26.47	33.89	351.24
		Sub total	47.07	24.23	105.89	135.56	702.48
Flexural Strength Test	M0-ft	Control	24.90	13.24	56.21	71.89	0.00
	M1-ft	1%	24.90	12.98	56.21	71.89	247.78
	M2-ft	2%	24.90	12.73	56.21	71.89	495.56
	M3-ft	3%	24.90	12.47	56.21	71.89	743.35
		Sub total	99.61	51.43	224.82	287.56	1486.69
Absorption Capacity	M0-ac	Control	4.31	2.30	9.73	12.43	0.00
	M1-ac	1%	4.31	2.26	9.73	12.43	42.93
	M2-ac	2%	4.31	2.21	9.73	12.43	85.86
	M3-ac	3%	4.31	2.17	9.73	12.43	128.79
		Sub total	17.26	8.94	38.94	49.70	257.58
Drying Shrinkage Test	M0-ds	Control	5.29	2.80	11.89	15.20	0.00
	M1-ds	1%	5.29	2.75	11.89	15.20	52.65
	M2-ds	2%	5.29	2.70	11.89	15.20	105.30
	M3-ds	3%	5.29	2.64	11.89	15.20	157.95
		Sub total	21.16	10.89	47.57	60.79	315.89
		Total Summary	**336.36**	**173.52**	**758.60**	**970.20**	**5020.30**

Appendix C: Test results

C1: Compressive strength tests of mortar

Mix Code: Co (0% AVG)

Table C.1: 3rd, 14th and 28th day mortar compressive strength results for 0% addition

Test age (days)	No.	Dimension (cm)			Volume (cm^3)	Failure Load (kN)	Compressive strength (Mpa)
		L	W	D			
	Water-cured samples						
3	1	7	7	7	343	44.60	9.10
	2	7	7	7	343	47.30	9.66
	Average					**45.95**	**9.38**
	Air-cured samples						
	1	7	7	7	343	49.00	10.01
	2	7	7	7	343	51.80	10.58
	Average					**50.40**	**10.30**
	Water-cured samples						
14	1	7	7	7	343	98.80	20.17
	2	7	7	7	343	86.90	17.73
	Average					**92.85**	**18.95**
	Air-cured samples						
	1	7	7	7	343	101.90	20.80
	2	7	7	7	343	110.30	22.50
	Average					**106.10**	**21.65**
	Water-cured samples						
28	1	7	7	7	343	142.00	28.99
	2	7	7	7	343	124.40	25.39
	Average					**133.20**	**27.19**
	Air-cured samples						
	1	7	7	7	343	132.30	26.99
	2	7	7	7	343	131.60	26.85
	Average					**131.95**	**26.92**

Mix Code: 1% (1% AVG)

Table C.2: 3rd, 14th and 28th day mortar compressive strength results for 1% addition

Test age (days)	No.	Dimension (cm)			Volume (cm^3)	Failure Load (kN)	Compressive strength (Mpa)
		L	W	D			
	Water-cured samples						
3	1	7	7	7	343	57.90	11.81
	2	7	7	7	343	53.40	10.90
	Average					**55.65**	**11.36**
	Air-cured samples						
	1	7	7	7	343	55.20	11.26
	2	7	7	7	343	57.20	11.68
	Average					**56.20**	**11.47**
	Water-cured samples						
14	1	7	7	7	343	108.80	22.21
	2	7	7	7	343	112.40	22.94
	Average					**110.60**	**22.58**
	Air-cured samples						
	1	7	7	7	343	112.50	22.96
	2	7	7	7	343	115.70	23.61
	Average					**114.10**	**23.29**
	Water-cured samples						
28	1	7	7	7	343	160.60	32.78
	2	7	7	7	343	147.10	30.02
	Average					**153.85**	**31.40**
	Air-cured samples						
	1	7	7	7	343	143.20	29.23
	2	7	7	7	343	144.70	29.53
	Average					**143.95**	**29.38**

Mix Code: 2% (2% AVG)

Table C.3: 3rd, 14th and 28th day mortar compressive strength results for 2% addition

Test age (days)	No.	Dimension (cm)			Volume (cm^3)	Failure Load (kN)	Compressive strength (Mpa)
		L	W	D			
	Water-cured samples						
3	1	7	7	7	343	51.00	10.41
	2	7	7	7	343	50.80	10.38
	Average					**50.90**	**10.40**
	Air-cured samples						
	1	7	7	7		51.50	10.51
	2	7	7	7		53.30	10.87
	Average					**52.40**	**10.69**
	Water-cured samples						
14	1	7	7	7	343	109.30	22.32
	2	7	7	7	343	109.80	22.41
	Average					**109.55**	**22.37**
	Air-cured samples						
	1	7	7	7		110.60	22.56
	2	7	7	7		112.00	22.86
	Average					**111.30**	**22.71**
	Water-cured samples						
28	1	7	7	7	343	153.60	31.34
	2	7	7	7	343	151.70	30.96
	Average					**152.65**	**31.15**
	Air-cured samples						
	1	7	7	7		137.40	28.05
	2	7	7	7		127.50	26.02
	Average					**132.45**	**27.04**

Mix Code: 3% (3% AVG)

Table C.4: 3rd, 14th and 28th day mortar compressive strength results for 3% addition

Test age (days)	No.	Dimension (cm)			Volume (cm^3)	Failure Load (kN)	Compressive strength (Mpa)
		L	W	D			
	Water-cured samples						
3	1	7	7	7	343	50.40	10.28
	2	7	7	7	343	52.00	10.60
	Average					**51.20**	**10.44**
	Air-cured samples						
	1	7	7	7	343	53.40	10.91
	2	7	7	7	343	45.40	9.26
	Average					**49.40**	**10.09**
	Water-cured samples						
14	1	7	7	7	343	97.90	19.98
	2	7	7	7	343	96.90	19.78
	Average					**97.40**	**19.88**
	Air-cured samples						
	1	7	7	7	343	102.50	20.92
	2	7	7	7	343	108.20	22.08
	Average					**105.35**	**21.50**
	Water-cured samples						
28	1	7	7	7	343	147.20	30.04
	2	7	7	7	343	150.90	30.80
	Average					**149.05**	**30.42**
	Air-cured samples						
	1	7	7	7	343	138.30	28.23
	2	7	7	7	343	122.30	24.96
	Average					**130.30**	**26.60**

C2: Compressive strength tests of concrete

Mix Code: Co (0% AVG)

Table C.5: 3rd, 14th and 28th day compressive strength results for 0% addition

Test age (days)	No.	Dimension (cm)			Volume (cm^3)	Weight (kg)	Failure Load (kN)	Compressive strength (Mpa)
		L	W	D				
3	1	15	15	15	3375	7.860	324.60	14.43
	2	15	15	15	3375	7.976	343.20	15.25
	3	15	15	15	3375	7.918	333.90	14.84
	Average					**7.918**	**333.90**	**14.84**
14	1	15	15	15	3375	7.830	572.50	25.44
	2	15	15	15	3375	7.839	510.10	22.67
	3	15	15	15	3375	7.835	541.30	24.06
	Average					**7.835**	**541.30**	**24.06**
28	1	15	15	15	3375	7.900	644.80	28.65
	2	15	15	15	3375	7.865	616.50	27.40
	3	15	15	15	3375	7.863	613.80	27.28
	Average					**7.876**	**625.03**	**27.78**

Mix Code: 1 (1% AVG)

Table C.6: 3rd, 14th and 28th day compressive strength results for 1% addition

Test age (days)	No.	Dimension (cm)			Volume (cm^3)	Weight (kg)	Failure Load (kN)	Compressive strength (Mpa)
		L	W	D				
3	1	15	15	15	3375	7.988	302.50	13.44
	2	15	15	15	3375	8.055	312.00	13.87
	3	15	15	15	3375	8.022	307.25	13.66
	Average					**8.022**	**307.25**	**13.66**
14	1	15	15	15	3375	8.328	497.10	22.10
	2	15	15	15	3375	8.113	513.10	22.81
	3	15	15	15	3375	8.221	505.10	22.46
	Average					**8.221**	**505.10**	**22.46**
28	1	15	15	15	3375	8.230	613.10	27.25
	2	15	15	15	3375	8.073	674.40	29.97
	3	15	15	15	3375	8.287	605.80	26.92
	Average					**8.197**	**631.10**	**28.05**

Mix Code: 2 (2% AVG)

Table C.7: 3rd, 14th and 28th day compressive strength results for 2% addition

Test age (days)	No.	Dimension (cm)			Volume (cm^3)	Weight (kg)	Failure Load (kN)	Compressive strength (Mpa)
		L	W	D				
3	1	15	15	15	3375	8.010	339.40	15.09
	2	15	15	15	3375	8.068	340.60	15.14
	3	15	15	15	3375	8.039	340.00	15.12
	Average					**8.039**	**340.00**	**15.12**
14	1	15	15	15	3375	8.124	562.50	25.00
	2	15	15	15	3375	8.282	578.80	25.72
	3	15	15	15	3375	8.203	570.65	25.36
	Average					**8.203**	**570.65**	**25.36**
28	1	15	15	15	3375	8.211	698.80	31.06
	2	15	15	15	3375	8.142	723.60	32.16
	3	15	15	15	3375	8.304	696.80	30.97
	Average					**8.219**	**706.40**	**31.40**

Mix Code: 3% (3% AVG)

Table C.8: 3rd, 14th and 28th day compressive strength results for 3% addition

Test age (days)	No.	Dimension (cm)			Volume (cm^3)	Weight (kg)	Failure Load (kN)	Compressive strength (Mpa)
		L	W	D				
3	1	15	15	15	3375	8.171	333.80	14.84
	2	15	15	15	3375	8.073	333.60	14.82
	3	15	15	15	3375	8.122	333.70	14.83
	Average					**8.122**	**333.70**	**14.83**
14	1	15	15	15	3375	8.327	563.40	25.04
	2	15	15	15	3375	8.208	555.30	24.68
	3	15	15	15	3375	8.268	559.35	24.86
	Average					**8.268**	**559.35**	**24.86**
28	1	15	15	15	3375	7.999	686.20	30.50
	2	15	15	15	3375	8.192	649.60	28.87
	3	15	15	15	3375	8.180	658.00	29.24
	Average					**8.124**	**664.60**	**29.54**

C3: Split tensile strength tests of concrete

Mix Code: Co (0% AVG)

Table C.9: 14th and 28th day split tensile strength results for 0% addition

Test age (days)	No.	Dimension (cm)		Volume (cm^3)	Weight (kg)	Failure Load (kN)	Split Tensile strength (Mpa)
		Length	Diameter				
14	1	20	10	1,570.80	3.795	43.60	1.39
	2	20	10	1,570.80	3.80	50.40	1.60
	3	20	10	1,570.80	3.795	57.20	1.82
	Average				**3.795**	**50.40**	**1.60**
28	1	20	10	1,570.80	3.762	64.50	2.05
	2	20	10	1,570.80	3.78	65.80	2.09
	3	20	10	1,570.80	3.792	67.10	2.14
	Average				**3.777**	**65.80**	**2.09**

Mix Code: 1% (1% AVG)

Table C.10: 14th and 28th day split tensile strength results for 1% addition

Test age (days)	No.	Dimension (cm)		Volume (cm^3)	Weight (kg)	Failure Load (kN)	Split Tensile strength (Mpa)
		Length	Diameter				
14	1	20	10	1,570.80	3.786	78.20	2.12
	2	20	10	1,570.80	3.78	71.35	1.93
	3	20	10	1,570.80	3.774	64.50	1.75
	Average				**3.780**	**71.35**	**1.93**
28	1	20	10	1,570.80	3.760	71.50	2.28
	2	20	10	1,570.80	3.71	68.30	2.17
	3	20	10	1,570.80	3.669	65.10	2.07
	Average				**3.715**	**68.30**	**2.17**

Mix Code: 2% (2% AVG)

Table C.11: 14th and 28th day split tensile strength results for 2% addition

Test age (days)	No.	Dimension (cm)		Volume (cm^3)	Weight (kg)	Failure Load (kN)	Split Tensile strength (Mpa)
		Length	Diameter				
14	1	20	10	1,570.80	3.759	55.20	1.76
	2	20	10	1,570.80	3.74	63.60	2.02
	3	20	10	1,570.80	3.727	72.00	2.29
	Average				**3.743**	**63.60**	**2.02**
28	1	20	10	1,570.80	3.723	87.60	2.79
	2	20	10	1,570.80	3.74	81.65	2.60
	3	20	10	1,570.80	3.759	75.70	2.41
	Average				**3.741**	**81.65**	**2.60**

Mix Code: 3% (3% AVG)

Table C.12: 14th and 28th day split tensile strength results for 3% addition

Test age (days)	No.	Dimension (cm)		Volume (cm^3)	Weight (kg)	Failure Load (kN)	Split Tensile strength (Mpa)
		Length	Diameter				
14	1	20	10	1,570.80	3.773	43.30	1.38
	2	20	10	1,570.80	3.77	55.20	1.76
	3	20	10	1,570.80	3.766	67.10	2.14
	Average				**3.770**	**55.20**	**1.76**
28	1	20	10	1,570.80	3.785	77.20	2.46
	2	20	10	1,570.80	3.80	76.05	2.42
	3	20	10	1,570.80	3.810	74.90	2.38
	Average				**3.798**	**76.05**	**2.42**

C4: Flexural strength tests of concrete

Mix Code: Co (0% AVG)

Table C.13: 14th and 28th day flexural strength results for 0% addition

Test age (days)	No.	Dimension (cm)			Volume (cm^3)	Weight (kg)	Failure Load (kN)	Max. Moment (kNm)	Bending Strength (Mpa)
		L	B	D					
14	1	50	10	10	5,000.00	11.717	7.00	116.67	2.10
	2	50	10	10	5,000.00	11.417	4.80	80.00	1.44
	Average					**11.567**	**5.90**	**98.33**	**1.77**
28	1	50	10	10	5,000.00	11.576	5.70	95.00	2.85
	2	50	10	10	5,000.00	11.497	6.60	110.00	3.30
	Average					**11.537**	**6.15**	**102.50**	**3.08**

Mix Code: 1% (1% AVG)

Table C.14: 14th and 28th day flexural strength results for 1% addition

Test age (days)	No.	Dimension (cm)			Volume (cm^3)	Weight (kg)	Failure Load (kN)	Max. Moment (kNm)	Bending Strength (Mpa)
		L	B	D					
14	1	50	10	10	5,000.00	11.645	5.70	95.00	1.71
	2	50	10	10	5,000.00	12.697	6.90	115.00	2.07
	Average					**12.171**	**6.30**	**105.00**	**1.89**
28	1	50	10	10	5,000.00	12.625	6.00	100.00	2.29
	2	50	10	10	5,000.00	12.639	7.90	131.67	3.95
	Average					**12.632**	**6.95**	**115.83**	**3.12**

Mix Code: 2% (2% AVG)

Table C.15: 14th and 28th day flexural strength results for 2% addition

Test age (days)	No.	Dimension (cm)			Volume (cm^3)	Weight (kg)	Failure Load (kN)	Max. Moment (kNm)	Bending Strength (Mpa)
		L	B	D					
14	1	50	10	10	5,000.00	13.281	7.60	126.67	2.28
	2	50	10	10	5,000.00	12.644	7.30	121.67	2.19
	Average					**12.963**	**7.45**	**124.17**	**2.24**
28	1	50	10	10	5,000.00	13.376	6.70	111.67	3.35
	2	50	10	10	5,000.00	12.875	6.30	105.00	3.15
	Average					**13.126**	**6.50**	**108.33**	**3.25**

Mix Code: 3% (3% AVG)

Table C.16: 14th and 28th day flexural strength results for 3% addition

Test age (days)	No.	Dimension (cm)			Volume (cm^3)	Weight (kg)	Failure Load (kN)	Max. Moment (kNm)	Bending Strength (Mpa)
		L	B	D					
14	1	50	10	10	5,000.00	11.341	5.10	85.00	1.53
	2	50	10	10	5,000.00	13.370	6.00	100.00	1.80
	Average					**12.356**	**5.55**	**92.50**	**1.67**
28	1	50	10	10	5,000.00	12.787	6.40	106.67	2.52
	2	50	10	10	5,000.00	12.517	7.10	118.33	3.55
	Average					**12.652**	**6.75**	**112.50**	**3.03**

C5: Drying shrinkage testing of concrete

Table C. 17 Drying Shrinkage test results

Test Age	Test Age	Mix Code	Reference bar (mm)	Length (mm)	Difference (mm)	Shrinakge %	Average %
1-day	31-May-24	Co-1	0.200	6.165	5.965		
		Co-2		5.510	5.310		
		1%-1		5.125	4.925		
		1%-2		7.165	6.965		
		2%-1		6.670	6.470		
		2%-2		6.110	5.910		
		3%-1		7.105	6.905		
		3%-2		5.175	4.975		
28-day (wet)	28-Jun-24	Co-1	0.200	6.205	6.005	0.016%	0.01%
		Co-2		5.535	5.335	0.010%	
		1%-1		5.165	4.965	0.016%	0.02%
		1%-2		7.225	7.025	0.024%	
		2%-1		6.735	6.535	0.026%	0.02%
		2%-2		6.165	5.965	0.022%	
		3%-1		7.175	6.975	0.028%	0.03%
		3%-2		5.235	5.035	0.024%	
60-days (dry)	27-Aug-24	Co-1	0.200	6.110	5.910	-0.022%	-0.02%
		Co-2		5.485	5.285	-0.010%	
		1%-1		5.045	4.845	-0.032%	-0.03%
		1%-2		7.095	6.895	-0.028%	
		2%-1		6.505	6.305	-0.066%	-0.04%
		2%-2		6.100	5.900	-0.004%	
		3%-1		7.035	6.835	-0.028%	-0.04%
		3%-2		5.055	4.855	-0.048%	
90-days (dry)	26-Sep-24	Co-1	0.200	6.050	5.850	-0.046%	-0.04%
		Co-2		5.430	5.230	-0.032%	
		1%-1		5.010	4.810	-0.046%	-0.05%
		1%-2		7.055	6.855	-0.044%	
		2%-1		6.485	6.285	-0.074%	-0.06%
		2%-2		5.985	5.785	-0.050%	
		3%-1		7.005	6.805	-0.040%	-0.06%
		3%-2		4.955	4.755	-0.088%	
180-days (dry)	25-Dec-24	Co-1	0.200	5.985	5.785	-0.072%	-0.05%
		Co-2		5.425	5.225	-0.034%	
		1%-1		5.005	4.805	-0.048%	-0.06%
		1%-2		7.000	6.800	-0.066%	
		2%-1		6.465	6.265	-0.082%	-0.07%
		2%-2		5.970	5.770	-0.056%	
		3%-1		6.905	6.705	-0.080%	-0.09%
		3%-2		4.945	4.745	-0.092%	

Appendix D: Sample photo taken at the time of the study

D1: While preparing and testing ingredient

Photo: purchasing and washing sand and aggregate

Photo: silt content test after washing


Oven dry sample of sand

pycnometer filled with water


Pycnometer filled water and sample

Weight of Pycnometer only

Sample at SSD

Weighting Aggregate weighting sand weight of cylinder



Oven dry sample of coarse aggregate Aggregate at SSD state SSD aggregate in water

Volume of measuring cylinder weighting agg. sample

Aloe Vera gel grounded by the grinding machine

Remaining Aloe Vera pulp after water absorption takes place by freeze- drier

D2: While mixing the mortar and concrete

Casted mortar Cube

mortar cubes water-cured

mortar cubes sealed-cured

Casted concrete cube, cylinder and beam

cylinder – absorption and beam-shrinkage

Concrete cylinder for absorption capacity testing at the 28th day, oven dried for 72hrs.

50cm slump for control

62cm slump 1%

75cm slump 2%,

85cm slump 3%

Final Setting time Speciemen at the time of No Impression

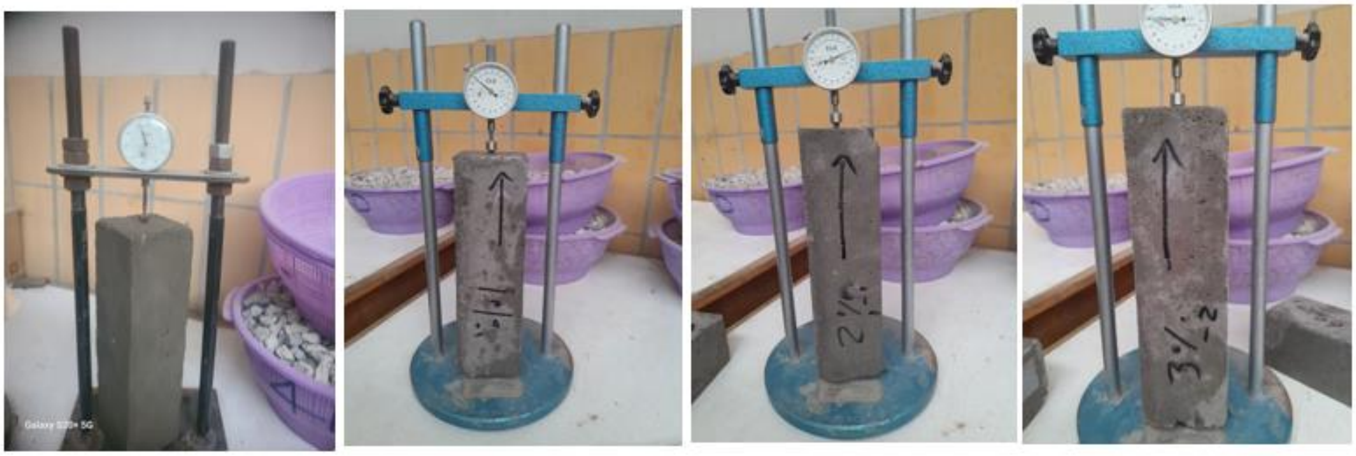
Samples for testing drying -shrinkage at the 28th day

OPC cement used

Testing Consistency of cement

Mechanical Mortar-Mixer

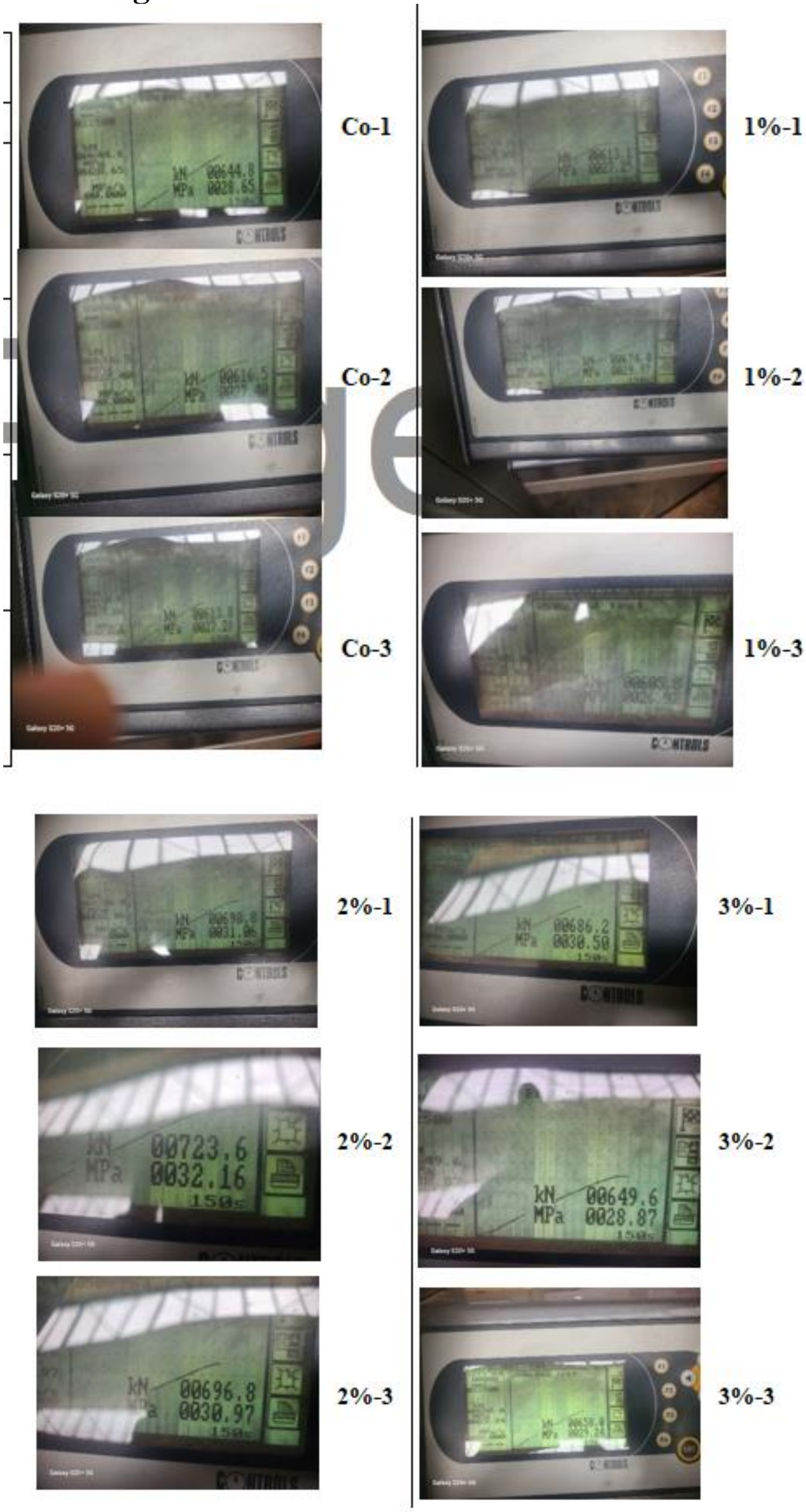
Mechanical Concrete-Mixer



Conducting Shrinkage Test

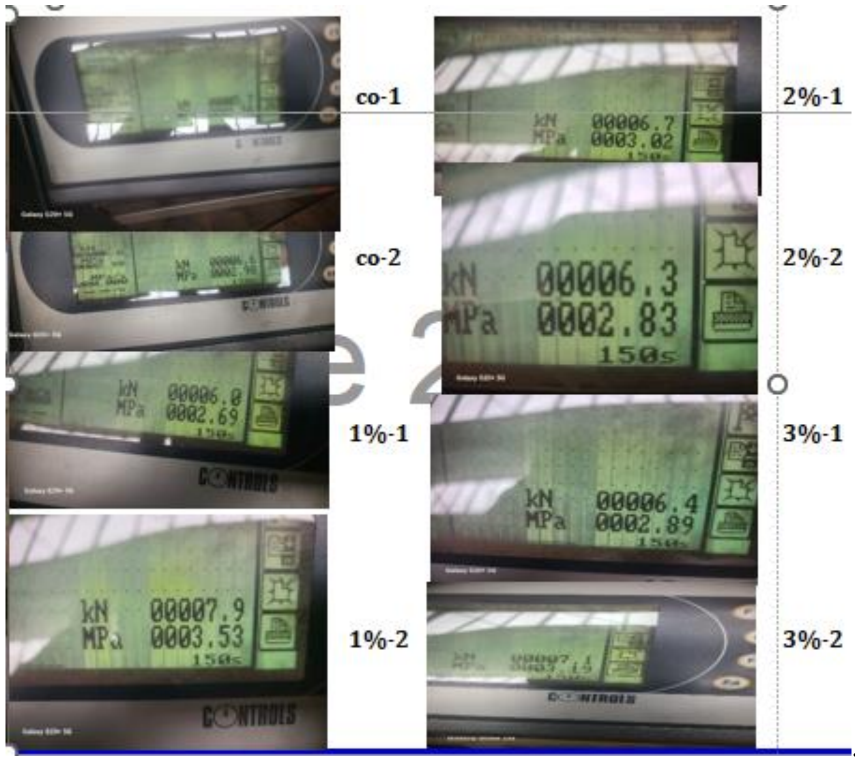
Mixing concret

D3: While conducting the tests

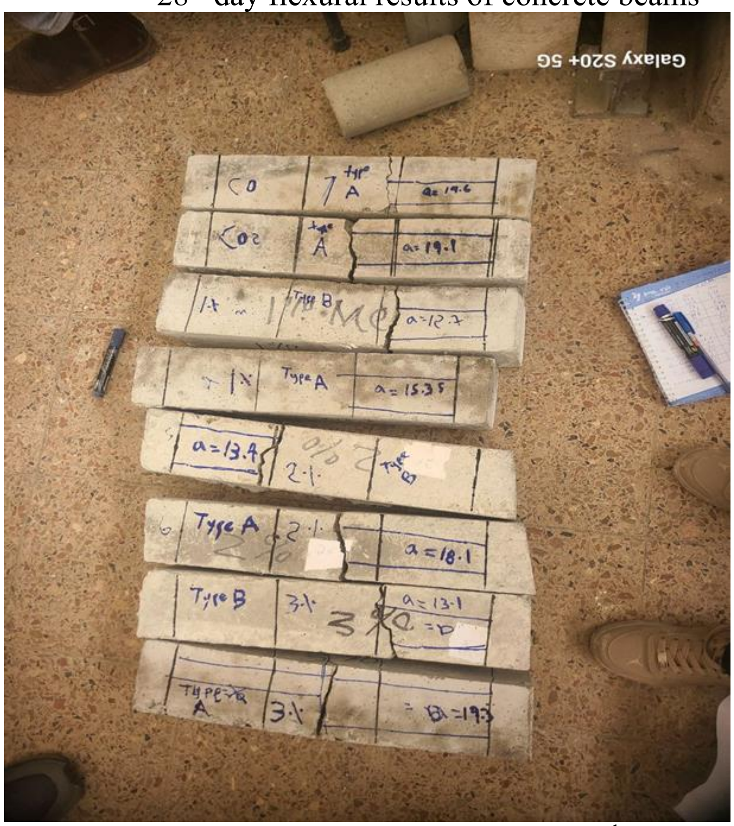


28th day compressive results of concrete cubes

28th day split tensile results of concrete cylinders



28th day flexural results of concrete beams



Measuring fracture distance at 28th day

Compressive Strength testing machine and mortar and concrete cube samples

Split Strength testing machine
cylinder sample

Flexural Strength testing machine a
beam sample

Annexes

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Ethiopia Conformity Assessment Enterprise

ቁጥር (No.) 2/18/106/414/17

ቀን (Date) ግንቦት 05 2017

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በኢትዮጵያ ፌዴራላዊ ዴሞክራሲያዊ ሪፐብሊክ
አዲስ አበባ ቴክኖሎጂ ቢዩልት ኢንቫይሮመንት ኮሌጅ
አዲስ አበባ

መጋቢት 24 ቀን 2017 ዓ.ም በቁጥር አአሣተቴ/1007/1722/17 በተፃፈ ደብዳቤ የ Aleo Vera leaf ናሙና እንዲፈተሽላችሁ መጠየቃችሁ ይታወሳል፡፡

ስለሆነም በጥያቄው መሠረት ፍተሻው ተካሂዶ 01 ገጽ የፍተሻ ውጤት በዚህ ደብዳቤ ሸኝነት የላክን መሆኑን እንገልፃለን፡፡

ከሠላምታ ጋር

አባሪ፡ 01 ገጽ የፍተሻ ውጤት ATR/1453/17
ግልባጭ፣

በኢትዮጵያ የተስማሚነት ምዘና ድርጅት

- ለደንበኞች አገልግሎት

አዲስ አበባ

ወደ ላቀ ብቃት የሚያደርስ!
Moving you forward!

ECAE	የኢትዮጵያ የተስማሚነት ምዘና ድርጅት Ethiopian Conformity Assessment Enterprise	Document No TLD/F7.08-1	
		Copy No -	Rev No 3
Title:	TEST REPORT የፍተሻ ሪፖርት	Page No 1 of 1	Effective Date 26 Oct 22

Name and address of client:	Addis Ababa University College of Technology and Built Environment (Meron Tadesse), Addis Ababa	Test Report No:	ATR/1453/17
Tel:	+251-937-01-22-34	Test Order No	---
Fax:	---	Reported date:	12/05/2025
E-mail:	---	Date of sampling:	Not specified
Date sample Received:	25/04/2025	Place of sampling:	Not specified
Client Sample code: (Brand)	---	Sampled and submitted by	Client
Type of sample:	Aleo vera leaf	Date tested:	05-06/05/2025
Lab Designated number:	17227041	Specification:	--

S/N	Characteristics tested	Specification/ Test Method	Standard Requirements			Test result	Comment
			Min	Nom	Max		
1.	Water content, % by mass	ES ISO1573:2012	-		-	96.04	-
2.	Solid content, % by mass	By calculation	-		-	3.96	-
3.	P^H value (10% aquas solution)	P^H meter	-		-	5.0	-
4.	Sodium (as Na), in mg/kg	BCTL/SOP/M051.01	-		-	5.82	-
5.	Calcium (as Ca), in % by mass	BCTL/SOP/M051.01	-		-	0.13	-

INVALID IF COPIED

Remark

1 This test report relates only to the specific sample product which has been tested by ECAE testing laboratory.

Test report authorized by, Name Biniyam Asmare Position Analyst IV Sign ____

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ISO/IEC 17025:2017 Accredited Testing Laboratory

✉ 11145 ☎ 011 6 46-05-69, Fax. 011 6 45-97-20, E-mail info-cs@eca-e.com Web site: www.eca-e.com

BOLE SUBCITY, WOREDA 6, ADDIS ABABA, ETHIOPIA

WATERPROOFING, CONSTRUCTION CHEMICALS & FINISHING CONTRACTOR

Date; 25/04/2025 G.C

Proforma invoice

To - GAG G.C

Item no	Item description	unit	Quantity	Unit price with vat	Total price with vat	Remark
1	Sikament NN 200L (superplasticizer high range water reducer)	Pcs	1	77,000	77,000	

Prepared by ....

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+251-904-02-10-10 abiywaterproofing@gmail.com