Investigation of Durability, Microstructural and Mechanical Characteristics of Polyethylene Glycol-400-Based Self-Curing Concrete

Ansif Dabi Ourga

A Thesis Submitted to Department of Civil Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirements of Masters of Science in Civil Engineering (Specialization in Construction Engineering and Management)

Office of Graduate Studies

Adama Science and Technology University

Jan, 2024

Adama, Ethiopia

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Declaration and Recommendation

I hereby declare that this Master Thesis entitled "**Investigation of Durability, Microstructural and Mechanical Characteristics of Polyethylene Glycol-400-Based Self-Curing Concrete"** is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation. It is being submitted for the partial fulfillment for the award of the degree of Master of Science in Civil Engineering (Specialization in Construction Engineering and Management) at Adama Science and Technology University School of Civil Engineering and Architecture.

Ansif Dabi ______________________ ________________

Signature Date

I/we hereby certify that I/we have read and evaluated this thesis entitled " **Investigation of Durability, Microstructural and Mechanical Characteristics of Polyethylene Glycol-400-Based Self-Curing Concrete"** prepared under my guidance by Ansif Dabi submitted in partial fulfillment of the requirements for the degree of Mater's of Science in in Civil Engineering (Specialization in Construction Engineering and Management). Therefore, I/we recommend that the candidate has fulfilled the requirements and hence he/she can submit the thesis to the department.

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Major Advisor Signature Date

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Co-advisor Signature Date

Approval Sheet

I/we hereby certify that all the correction and recommendation suggested by the board of examiners are incorporated into the final thesis entitled "**Investigation of Durability, Microstructural and Mechanical Characteristics of Polyethylene Glycol-400-Based Self-Curing Concrete**'' by Ansif Dabi.

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Co-advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis open defense by Heran Bogale have read and evaluated his thesis entitled "**Investigation of Durability, Microstructural and Mechanical Characteristics of Polyethylene Glycol-400-Based Self-Curing Concrete**'' and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the degree of Master of Science in Civil Engineering (Specialization in Construction Engineering and Management).

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ABSTRACT

Proper curing of concrete is crucial to ensure adequate moisture content and the development of desired strength. Inadequate curing can significantly affect the strength and durability of concrete, often leading to early cracks in buildings and subsequent strength reduction. Self-curing concrete falls into the special concrete category, serving as a solution to address insufficient curing issues. various researchers have investigated the mechanical and durability properties of polyethylene glycol-based self-curing concrete in several ways. However, there was no relevant study on the polyethylene glycol- 400 self-curing concrete's cost-effectiveness and durability properties. In this regard this study aims to investigate the effects of incorporating polyethylene glycol-400 in self-curing concrete production. Factors such as workability, compressive strength, water absorption, sulfate attack, and microstructure, along with cost implications, were analysed. To develop the concrete mix for C-30 concrete grade, the American Concrete Institute's mix design method was employed. The study consisted of producing two mixes: a control mix made up of cement, water, fine and coarse aggregate, and involved varying the percentage of polyethylene glycol -400 (1%, 1.5%, 2%, 2.5%, and 3%) by the weight of cement added to the mixing water. As the polyethylene glycol -400 content increased in the concrete mix, the workability of the concrete increases due to the incensement of fluidity of the mix. However, the compressive strength at 28 days of curing saw a 20.39% improvement for the 2% mix compared to the control mix. The cause of the increase in the compressive strength of the concrete was due to the creation of more Calcium Silicate Hydrate gel. Therefore, a 2% mix showed the best results in terms of compressive strength. Moreover, the pores inside the concrete matrix were filled due to Calcium Silicate Hydrate (C-S-H) gel formation, leading to lower water absorption in the concrete with a 2% mix. Furthermore, adding polyethylene glycol-400 to concrete mix was improved the sulfate attack resistance of the self-curing concrete. The self-curing concrete was analysed microstructurally and compared to the control mix. The study found that the mix with a 2% had more calcium silicate hydrate gels. The study concluded that by utilizing polyethylene glycol-400 up to 2%, the compressive strength of self-curing concrete can be improved while also lowering the cost of the curing procedure of concrete.

Keywords: *Compressive strength, polyethylene glycol, self-Curing Concrete, Workability*

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LIST OF ACRONYMS

Acronyms	Full Names
ACI	American Concrete Institute
ASTM	American Society for Testing Materials
ASG	Apparent specific gravity
BSG	Bulk specific gravity
CA	Coarse Aggregate
CCC	Conventional Cured Concrete
FA	Fine Aggregate
LWA	Light Weight Aggregate
OPC	Ordinary Portland Cement
PEA	Poly Ethylene Alcohol
PEG	Poly Ethylene Glycol
PEA	Poly Ethylene Alcohol
XRD	X-Ray Diffraction
SAP	Super Absorbent Polymer
SCC	Self-Curing Concrete
SEM	Scanning Electron Microscope
SRA	Shrinkage Reducing Admixture

LIST OF CHEMICAL FORMULAS

Formulas	Name of Chemical Compounds
$H(OCH_2CH_2)NOH$	Ethylene Oxide
C-S-H	Calcium Silicate Hydrate
H_2O	Water
$Ca(OH)_2$	Calcium Hydroxide
C_3A	Tricalcium Aluminate
C-C-S-H	Calcium Carbonate Silicate Hydrate
CH	Calcium Hydroxide
$CaCO_3$	Calcium Carbonate
MS	Magnesium Sulphate
MH	Magnesium Hydroxide (bruite)
NH	Sodium Hydroxide
$[Ca_3Al(OH)_6 \cdot 12H_2O]_2(SO4) \cdot 32H_2O$:	Ettringite
$[Ca_2Al(OH)_6 \cdot 2H_2O]_2(SO_4) \cdot 2H_2O$:	Monosulfate
NS	Sodium Sulphate

1. INTRODUCTION

1.1 Background of the Study

Concrete is the most widely used construction material, and is a preferred building material because of its properties including strength, durability, affordability, and simplicity of on-site manufacturing (Kalaivani et al., 2020). Concrete is a mixture of cement, fine aggregate, coarse aggregate, and water. In some situations, in addition to the three main ingredients, concrete may contain admixtures and additives (Kumar et al., 2012).One of the concrete ingredients in the creation of concrete is water. Water is an essential component of concrete and is widely used during construction work. Water is needed when mixing new concrete and even after the concrete has been placed since the concrete must carry its strength and produce hydration reactions. It is a matter of fact that when concrete is exposed to the atmosphere, the hydration process is greatly affected by water evaporation, which results in shrinkage cracks and a lack of strength development (Aregawi, 2014; Saffar et al., 2019). To prevent such circumstances, "curing" is required.

Curing is the process of keeping the concrete at the right temperature and moisture content during its formation phase to create the appropriate type of structural concrete. To achieve the required performance and durability, the curing procedure must be properly carried out (Kumar et al., 2020; Rajasekaran & Claver, 2020). Conventional curing needs the external application of water curing after the concrete is mixed, set, and finished. It is a well-known fact that curing frequently presents a challenge in a quickly planned construction and that it is challenging to carry out the process to maintain the moisture in the concrete due to its immense water consumption (Chavan, 2020; Hu et al., 2018; Selvendiran et al., 2020; Soni et al., 2022). Innovations are being made to replace the time-consuming process of curing with a far better, more time-saving, and cost-effective replacement since modern construction demands modern approaches (Lokeshwari et al., 2021; Memon et al., 2018). Nowadays, a new technique is known as "self-curing".

Self-curing concrete is the most efficient technology of the twenty-first century, which has proven to be a long-term answer to the demand for modern construction. By reducing early-age cracks and producing extremely resistant concrete, it increases the durability of concrete structures. Internal curing would be a beneficial strategy for enhancing the sustainability of a nation's infrastructure because the usable service life of concrete is a crucial component for providing sustainable infrastructure (Joseph, 2016). It is one of the special concretes for mitigating inadequate curing caused by human error, a lack of water in dry regions, the inaccessibility of structures, and locations where the presence of fluorides in the water will negatively affect the properties of concrete (Evangeline, 2014). Self-curing concrete reduces both the amount of time required for building as well as the amount of field labor required for curing (Sudharson et al., 2021). self-curing, sometimes referred to as Internal curing, permits curing from the inside to the outside through the internal reservoirs formed (Thrinath & Kuma, 2017). The materials that can provide internal water reservoirs include lightweight aggregate (natural and synthetic, expanded shale), polyethylene glycol, and super-absorbent polymers. In this study, the internal curing agent is polyethylene glycol.

Polyethylene glycol has the standard formula $H(OCH_2CH_2)nOH$, where n is the average number of repeating oxyethylene groups, which ranges from 4 to roughly 180 on average (Sharafat et al., 2019). The acronym (PEG) is followed by a numerical suffix that describes the average molecular weight. The fact that PEG is water-soluble seems to be one shared characteristic (Reddy & Kumar, 2020). Numerous medicinal products use polyethylene glycol, which is non-toxic, odorless, neutral, lubricating, non-volatile, and non-irritating, and is used in numerous medicinal products (Memon et al., 2018). Polyethylene glycol is a chemical agent, which reduces the loss of water from concrete; it also attracts moisture from the atmosphere. PEG has been utilized as a concrete admixture, where it is added to concrete mixtures to modify their properties. The use of PEG in concrete can help in controlling the setting time, reducing water content, and improving workability.(Kalaivani et al., 2020). PEG has been investigated for its potential in reducing the permeability of concrete. By incorporating PEG into the concrete mix, researchers aim to create a denser structure that is less susceptible to water penetration, which can be particularly beneficial in construction projects where durability is a key concern. Some research has explored the use of PEG in self-healing concrete. Microcapsules containing PEG and other healing agents can be incorporated into concrete. When cracks form, these capsules rupture, releasing PEG, which then fills and seals the cracks, contributing to the self-healing properties of the concrete. In cold weather construction, PEG has been investigated as an anti-freeze agent for concrete. It helps prevent the water in the concrete mix from freezing at lower temperatures, reducing the risk of frost damage during construction in cold climates (Comun et al., 2020). PEG can be part of polymer-modified concrete formulations. Polymer-modified concrete often exhibits improved strength, durability, and flexibility. PEG may be one of the components contributing to the desired properties in these formulations. PEG can be added to grout and mortar formulations to improve their workability and adhesion properties. This is particularly useful in construction applications where precise placement and strong adhesion are crucial (Mechtcherine et al., 2021). PEG has been studied as a curing agent for concrete. It helps maintain adequate moisture levels during the curing process, promoting proper hydration of cement and enhancing the overall strength and durability of the concrete. Previously, many studies were conducted on the mechanical and durability properties of different Polyethylene glycols as curing agents in self-curing concrete. However, there is no relevant study conducted on the durability properties of PEG 400-based self-curing concrete.

Researchers are working on formulations that incorporate PEG to improve the durability of concrete. By reducing permeability and increasing resistance to environmental factors, such as freeze-thaw cycles and chemical exposure, PEG-enhanced materials can have a longer lifespan in construction applications. One area of significant improvement involves the development of self-healing concrete using PEG. Microencapsulation of PEG within the concrete allows for the release of the polymer when cracks occur. This process contributes to the automatic repair of small cracks, improving the overall integrity and longevity of the structure. Advancements in materials science are leading to the development of "smart" construction materials. PEG may be integrated into these smart materials that can respond to environmental conditions, such as changes in temperature or humidity, to optimize performance and durability. Researchers are focusing on optimizing PEG-based admixtures to improve concrete properties. This includes refining the dosage, particle size, and chemical compatibility of PEG with other components in the concrete mix to achieve the desired performance characteristics. PEG has been explored for its potential as an anti-corrosion agent in construction materials, particularly in reinforcing steel. By inhibiting the corrosion of steel within concrete structures, PEG can contribute to the longevity and structural integrity of buildings and infrastructure. PEG is used to modify the workability of concrete by reducing water content without compromising its flow ability. This can lead to improved compaction, reduced porosity, and increased strength in the final cured product. There is a growing emphasis on incorporating environmentally friendly practices in construction. PEG's biodegradability and low toxicity make it an attractive option for sustainable construction materials, aligning with the industry's increasing focus on green building technologies. Ongoing research explores novel applications of PEG in construction engineering, such as its use in 3D printing of concrete structures. By understanding and optimizing PEG's interactions with other materials, researchers aim to expand its role in emerging construction technologies.

Polyethylene glycol 400 is added to concrete to introduce self-curing properties due to its hydrophilic nature and water-locking abilities (Mandiwal & Jamle, 2018). Polyethylene glycol cannot produce fully self-curing features and outcomes without altering the general properties of freshly laid and hardened concrete. For the research, the properties of fresh and hardened concrete at concentrations of 0%–3% PEG–400 will be studied, along with a comparison to conventional concrete. In addition, the cost-effectiveness of using PEG-400 was examined.

1.2 Statement of the Problem

Concrete resistance to abrasion, strength, and durability are affected by improper curing. Improper curing can be caused by a variety of factors, including a lack of knowledge about curing techniques and their benefits, inaccessible structural components like the exteriors of high-rise buildings and complex structural designs, and, in some situations, a lack of water in construction sites (Kebede, 2020). Concrete that has not been adequately cured develops plastic shrinkage cracks, thermal cracks, and a considerable reduction in surface layer strength (Selvendiran et al., 2020). The evaporation from the exposed horizontal surface of the concrete causes plastic shrinkage cracks and a weak, dusty surface if the surface is not kept moist for the first 24 hours after casting (Hamzah et al., 2022). An alternative method to remove obstacles to uniform concrete curing, achieve uniform curing, and reduce the risks related to water curing is investigated. Numerous studies support the use of internal curing to overcome problems brought on by insufficient curing (Rizzuto et al., 2020).

Self - curing utilized to provide moisture to concrete for improved cement hydration and reduced self-desiccation. It improved durability, reduced autogenous and drying shrinkage, reduced cracks, reduces labor costs on site, and is Suitable for areas where water is scarce (Sudharson et al., 2021). Curing agents, which have Shrinkage Reducing characteristics, are widely used in the construction of self-curing concrete. The most commonly used materials that can offer interior water storage internal- curing includes: Lightweight aggregate (natural and synthetic, expanded shale), super-absorbent polymers, and polyethylene glycol (Khan et al., 2022).Researchers have investigated the mechanical and durability properties of polyethylene glycol-based self-curing concrete in several ways. However, there was no relevant study on the PEG 400 self-curing concrete's cost-effectiveness and durability properties. In the current study, the workability, compressive and flexural strength, microstructural analysis, cost analysis, sulfate attack, and water absorption of conventional concrete and self-curing concrete based on PEG 400 were all investigated.

1.3 Objectives of the Study

1.3.1 General Objective

The main objective of this study was to investigate the durability, micro-structural and mechanical characteristics of polyethylene glycol-400-based self-curing concrete.

1.3.2 Specific Objectives

- To characterize materials in polyethylene glycol-400 based self-curing concrete.
- To investigate the fresh properties of self-curing concrete in comparison to conventional concrete.
- To investigate the mechanical properties, durability properties, and microstructure of self-curing concrete.
- To compare the cost use of self-curing concrete over conventionally cured concrete.

1.4 Significance of the Study

The construction industry in Ethiopia will benefit from this study in a variety of ways, including by enhancing the toughness and longevity of concrete structures. The use of various alternatives to cutting-edge concrete technologies is beneficial to the building industry. This study concentrates on the characteristics of self-curing concrete made with polyethylene glycol 400, which is typically used in areas with difficult-to- reach structural components and uncertainties brought on by people during the curing process. Therefore, self-curing concrete is better suited to reduce damages, cracks, low strength, and low durability, which could occur on concrete structures as a result of insufficient curing systems. This study is a stronger basis for introducing and using self-curing concrete in the appropriate areas.

1.5 Scope of the Study

The purpose of the research was to examine the characteristics of fine and coarse aggregates as well as the effects of polyethylene 400 on the waterless drying of concrete. Workability, compressive strength, water absorption, water penetration, and sulfate attack were all investigated along with the characterization of conventional concrete and self-curing products by varying the amount of PEG-400 in the cement (from 0% to 3% by weight) for concrete of the C-30 grade. The research also looked at the cost implications of self-curing concrete-based polyethylene 400. As self-curing concrete is primarily targeted to high-performance concrete and high-strength concrete by which massive mega structures like tall skyscrapers, Tunnels, Bridge, high-rise buildings, and the roadway are needed to be constructed to prevent unstable slopes, the study used C-30 because it is a minimum requirement for commercial projects like roadways, bridges, high-rise buildings, etc.

1.6 Organization of the Document

The research was organized into five chapters. The background, problem statement, goals, and study scope are all introduced in the first chapter. The study's topic was primarily discussed in the second chapter's literature analysis. The definition of self-curing concrete, factors affecting its effectiveness, the mechanical, physical, and microstructural properties of self-curing concrete, cost-effectiveness, and study gaps are all covered in this part. The materials, techniques, and experimental methods used to carry out various experiments; characteristics of materials like cement, sand, and coarse aggregate were discussed in the third chapter. It was done to proportion the mix for compressive and flexural strength following the procedures to assess the material's properties, such as gradation, workability, and silt content. The presentation, analysis, and interpretation of the findings were key components of the fourth chapter. The results of the experimental investigation were all presented in this chapter, including the gradation curve, silt content, workability status, compressive and flexural strengths, sulfate attack, water absorption, and water penetration analyses along with a discussion of them. Finally, the self-curing effectiveness was determined, including concrete characterization to determine the morphology. Finally, the fifth chapter is concerned with a conclusion and recommendations.

1.7 Summary

In this chapter, the background and statement of the problem have been presented. Further, the study aim, associated objectives, scope of the study, significance of the study, and the organization of the thesis to achieve these objectives have been briefly presented. The literature review and the areas of previous research that need to be filled have been described in the following chapter.

2. LITERATURE REVIEW

2.1 Introduction

To develop a better understanding of the research objective, a comprehensive literature review has been conducted to identify the introduction and advancement of the self-curing abilities of concrete as part of the study process. The second chapter provides a literature review on the aspects of self-curing agents that minimize the evaporation of water from concrete, thereby increasing the retention of water by the concrete compared to conventional concrete types. Effective inquiryinto how these self-curing agents affect properties of concrete like strength, workability, and durability-both indulgently and drastically. Hence, the structure of the literature review consists of the examination of the effect of polyethylene glycol 400 (PEG-400) on the self-curing properties of concrete; as well as its strength and workability, starting from the definition of curing and discussing the significance, methods, and requirements of curing as well as the properties of concrete influenced by curing and other issues related to curing from various literature.

2.2 Concepts Regarding Concrete and Its Ingredients

2.2. 1. Concrete

Concrete is the most commonly used building material because of its high compressive strength and durability, which make it a crucial component in many different types of construction, including buildings, infrastructure, and structures that serve as barriers against the elements and other developments (Selvendiran et al., 2020). Concrete of high quality and adequate weight is ensured by proper cement hydration. Fresh concrete must be put in an environment that promotesproper hydration, and after casting, concrete must be cured (Reddy & Kumar, 2020). Concrete is made up of a carefully selected mixture of fine and coarse aggregates, water, admixtures, and a binding substance like lime or cement. Essentially, high-quality concrete is a homogeneous mixture of cement, coarse and fine aggregates, and water that hardens into a mass as a result of a chemical reaction between the cement and water (Aregawi, 2014).

Around the world, concrete is anticipated to be used over 11 billion metric tons annually. This is due to both the extraordinary technical and financial merits of concrete. One of the key reasons is its water resistance, which makes it a great building material for controlling, transferring, and carrying water. The second reason for its versatility is that it can fit into a variety of shapes and sizes. This is mostly because the material has a plastic consistency, which enables it to flow into predetermined shapes. The third consideration would be the material's abundance and costs (Ayele, 2021).

2.2.1.1 Cement

Cement is the most important material for the construction industry, especially in infrastructure and housing projects. When combined with water in the hydration process, it creates cement paste, which is a temporary plastic that can be molded or deformed. The paste makes sure that the components of the concrete are correctly bonded. Cement is made by combining calcium, silica, aluminum, iron, and other elements in a carefully controlled chemical reaction (Kebede, 2020). The most expensive component utilized to manufacture concrete is cement. It is advised to utilize many aggregates as a particular amount of paste will bind together due to this and the fact that aggregates serve as reasonably inexpensive filler. The aggregates reduce volume fluctuations brought on by the setting and hardening process as well as changes in paste moisture in addition to being a comparatively inexpensive filler (Saffar et al., 2019).

i. Normal Consistency of Cement

A normal consistency of cement paste is defined as a percentage of water by the weight of cement that allows a standard plunger of 10 mm diameter to penetrate up to a depth of 5 to 7 mm above the bottom of Vicat's mold. According to (ASTM C187.), normal consistency is expressed as a percentage of dry cement weight and ranges from 22 to 30.

2.2.1.2. Fine and Coarse Aggregates

The most essential elements of concrete are the aggregates, which make up about 75% of the total volume. The massive amount of aggregates in concrete highlights their significance. To produce concrete, fine aggregates (less than 4.75 mm) and coarse aggregates (more than 4.75 mm) must be graded (Kebede, 2020;Tafa, 2017).

i. Fineness Modulus of Fine and Coarse Aggregates

Aggregate grading is the term used to describe the particle size distribution of an aggregate. Grading is the process of filling in the spaces left by larger particles. Since, it is made with appropriately, graded aggregate, dense concrete requires less fine aggregate and cement. Aggregate is graded using the percentage of weight retained on a set of specified sieves. To grade fine aggregate, sieves with (4.75 mm, 2.36 mm, 1.18 mm, 0.60 mm, 0.30 mm, and 0.15 mm, andapan) are used for grading fine aggregate Table 2.1.

Table2. 1 Fine Aggregate Grading Limit of ASTM C136

Sieve size	Percentage passing by mass ASTM C136
4.75 mm (No. 4)	98 to 100
2.36 mm (No. 8)	80 to 100
1.18 mm (No.16)	50 to 85
0.6 mm (No.30)	25 to 60
0.3 mm (No.50)	5 to 30
0.15 mm (No.100)	0 to 10
Pan	--

In addition, sieves with mesh sizes of (20 mm, 19 mm, 12.5 mm, 9.5 mm, and 4.75 mm, and pan) are used for grading course aggregate Table 2.2.

Table2. 2.Course Aggregate Grading Limit of ASTM C136

Sieve size	Percentage passing by mass ASTM C136
20 mm	100
19 mm	95 to 100
12.5mm	40 to 80
9.5 mm	20 to 55
4.75 mm	0 to 10
Pan	--

ii. Specific Gravity and Water Absorption of Fine and Coarse Aggregates

The weight of a substance concerning a volume of water with a similar volume is known as the specific gravity of that substance. The effects of both types of pores (permeable and impermeable) on the water absorption, specific gravity, and permeability of aggregates (Dinku, 2002). The absorption method is accurate enough for common tasks like adjusting batch quantities of concrete ingredients (ASTM C-566, 1997). It is used to calculate the amount of solid aggregate in a concrete mix (Ukala, 2019).

iii. Unit Weight of Fine and Coarse Aggregates

A specific volume of graded aggregate is equal to one unit of weight for aggregate. The term "bulk density" refers to the density measurement. The unit weight accurately calculates the volume of graded aggregate that will fill the concrete and accounts for both solid aggregate particles and spaces between them

iv. Sieve Analysis for Fine and Coarse Aggregates

A variety of gradations of hard and inert material particles make up aggregate for concrete. The aggregate must be solid, durable, long-lasting, and of a consistent quality. They should be free of dangerous materials like alkali, oil, coal, humus, or other organic waste as well as soft, brittle, thin, or laminated fragments. The 75mm to 4.75mm range of coarse aggregates is considered to be the Ethiopian standard (Dinku, 2002). Using a progression of square or round meshes, starting with the largest; sieve analysis is a method for determining the particle size distribution of aggregates. It is used to grade aggregates and calculate their fineness modulus, which measures their fineness, coarseness, and uniformity. This test method is primarily used to categorize materials that are being used as aggregates or that are suggested for use as aggregates (ASTM C-136, 2005).

v. Silt Content of Fine Aggregate

In comparison to other fine aggregates, silt is less durable. They may take in water and alter its characteristics. Silt will inhibit aggregates in concrete from bonding to cement. The silt in the air spaces of hardened concrete may shrink or swell when it comes into touch with water, increasinginternal pressure or creating larger voids, weakening the concrete (Malathy et al., 2023). However, depending on the amount of silt/clay remaining in the concrete, which should not be more than 4%, it can cause unsightly hairlines or significant cracks (Comun et al., 2020).

More than a certain amount of silt or clay in fine aggregates necessitates the use of more cement to **c**oat other concrete elements.

2.2.1.3. Water

Water is a crucial component of concrete because it hydrates when combined with a cementitiousingredient to make cement paste. The cement paste binds the aggregate together, fills any gaps, and promotes greater flow. In comparison to more water in the cement, which results in a freer-flowing, slumpier concrete, less water in the cement paste produces stronger and more lasting concrete (Mechtcherine et al., 2021). However, the concrete structure is also impacted by the quality of the water. When concrete is produced, using dirty water might lead to problems with setting or early structure failure. When mixing concrete, using contaminated water samples might reduce the material's strength, particularly its compressive strength (Afifi, 2016). Workability, compressive strengths, permeability, water tightness, durability, weathering, drying shrinkage, and cracking potential in both fresh and hardened concrete are all influenced by the amount of water added to the concrete mix. Conventionally, only potable water was assumed to be necessary for mixing and curing concrete (Soni et al., 2022).

2.2.1.4. Admixture

Chemical admixtures are added to concrete during mixing, substantially altering the concrete's hardened, or fresh states for economic or physical advantage. Even though they are commonly categorized as being added at rates of less than 5% by weight of the cement, the normal range for the majority of types is only 0.3-1.5%. It is sometimes offered as an aqueous solution of the chemical to make it simpler to administer and distribute the ingredient throughoutthe concrete while mixing. Admixtures have grown dramatically in popularity and applications in recent years. According to estimates for the UK, an admixture was used in around 12% of all concrete produced in 1975, 50% of it by 1991, and currently well over 75%. The percentage is significantly greater in various regions, most notably in portions of Europe, North America, Australia, and Japan (Sastry & Kumar, 2018).

Admixture is a substance used as an ingredient in concrete or mortar that is added to the batch right before or during mixing and includes water, aggregates, hydraulic cement, and fiber reinforcement. (ACI 116R, 2000). As a result, the phrase encompasses a wide range of products and materials, some of which are widely used and others of which have specific uses. ACI 211.1-91 limits the effects of air-entraining admixtures, chemical admixtures, fly ashes, natural Pozzolana, and ground granulated blast-furnace slags (GGBF slag) on concrete proportioning (ACI 211.1-91, 2002).

Chemical admixtures conforming to ASTM C 494, types A through G, are of many formulations, and their purposes for use in concrete are: Type A reduces water, Type B slows it down, and Type C accelerate it. Water-Reducing and Retarding Type D, Water Reducing and Accelerating Type E, High-Range, and Water-Reducing Types F and G are water-reducing, high-range, and retarding types, respectively.

i. Shrinkage-Reducing Admixtures

Admixtures that reduce or compensate for shrinkage encourage concrete expansion at a volume that is roughly equal to the amount that natural drying shrinkage is contracting it. The cured concrete's overall length should not alter much if at all, to avoid shrinkage fractures. Usually, calcium sulfoaluminate, calcium aluminate, and calcium oxide are employed as shrinkage-compensating ingredients in concrete. These shrinkage admixtures are used during batching to reduce early age and long-term shrinkages. This is accomplished by treating the underlying causeof capillary and cement paste pore drying and shrinkage (Lokeshwari et al., 2021).

This is carried out because the characteristics of concrete are lost when anti-shrinkage chemicalsare added. Using HRWRs, which offer good workability and permit water content reduction, reduces the effects of such agents on the strength of concrete while allowing outstanding workability. When these ant-shrinking agents are used, certain property losses are common. The use of HRWRs, which offer great workability while enabling the lowering of the water content, minimizes any negative impact on strength (Memon et al., 2018).

In slabs, bridge decks, structures, and repair work where cracking can result in corrosion issues with steel reinforcement, these admixtures can be very beneficial. However, maintaining effective air entrainment for resistance to freezing and thawing damage with shrinkage-reducing admixtures can be challenging. Depending on batch designs and water content, usage rates fluctuate but typically range from 8 to 25% (Nandhini et al., 2021). ACI

223 (Standard Practice for the Use of Shrinkage Compensating Concrete) outlines the optimal procedures for the utilization of this additive (ACI 223-98, 1998).

2.1.2. Concrete Mix Design

The right proportions of cement, fine aggregate, and coarse aggregate must be produced for concrete to have the appropriate strength. Concrete mix design refers to the economically efficient proportioning of concrete components for improved strength and durability based on the construction site (Selvamony et al., 2010).

Nominal concrete mix and designed concrete mix are the two sorts of concrete mix designs. In comparison to the nominal concrete mix, which may contain more cement, the intended mix may require less cement to achieve the same quality of concrete for a particular site (Babu.T et al., 2017). Utilizing ingredients that are readily available locally, a concrete mix design is produced. Before creatinga concrete mix, the three most crucial attributes to specify are strength, durability, and workability. The water-to-cement ratio and the aggregate-to-cement ratio are the two most important factors that affect the characteristics of concrete (Dahyabhai & Pitroda, 2014). Mix design is, therefore, the process of figuring out the proper ratios of cement, fine aggregate, coarse aggregate, water, and admixture (if any) in concrete.

2.1.3. Fresh Concrete Properties

Fresh concrete, often known as plastic concrete, is a substance that has just been mixed and is moldable into any shape. The qualities of concrete are controlled by the relative amounts of cement, aggregates, and water (Suthandradevi & Nivasini, 2019). Water, cement, aggregate, and additives (ifany) make up fresh concrete. Following mixing, fresh concrete can have a significant impact on the qualities of hardened concrete by being transported, placed, compacted, and finished. For the concrete mass to be fully compacted and the constituent ingredients to be evenly distributed throughout the mass's handling, both are crucial. When one or both of these requirements are not met, the qualities of the resulting hardened concrete, such as strength and durability, are negatively impacted (Verma & Nigam, 2007).

2.1.3.1. Workability of Concrete

Workability is defined as "the property of freshly mixed concrete or mortar that determines the ease with which it can be mixed, placed, consolidated, and finished to a homogenous condition" by the American Concrete Institute (ACI) 116R (ACI 116R, 2000). One of the most important criteria for assessing the uniformity of new concrete is workability. The most well-known and often-used test method to assess the workability of fresh concrete is the slump test. It is used to assess the freshly mixed concrete's workability, as well as how easily it can be placed, carried, and flowed (Hu et al., 2018).

2.1.4. Hardened Concrete Properties

The features of freshly laid concrete are only important during the first few hours of its existence. However, the features of hardened concrete acquire relevance and are preserved for the duration of the concrete's life. Strength and durability are essential characteristics of hardenedconcrete. Strength is generally regarded as the most important characteristic, and the strength of concrete is frequently used to determine its quality. There are certain exceptions, but generally speaking, an increase in strength leads to the development of other concrete qualities. Forinstance, adding more cement to a mix increases strength but also causes more shrinkage, which in some situations might negatively affect durability (Younis et al., 2022).

2.1.4.1. Strength of Concrete

Strength is generally regarded as the most important characteristic, and the strength of concrete is frequently used to determine its quality. There are certain exceptions, but generally speaking, an increase in strength leads to the development of other concrete qualities. Forinstance, adding more cement to a mix increases strength but also causes more shrinkage, which in some situations might negatively affect durability (Afifi, 2016). Concrete strength is determined by three parameters: flexural strength, compressive strength, and split tensile strength. Compressive strength measures the failure of cubes under compression, whereas flexural strength and tensile strength upon separation measure the tensile strength of concrete. Concrete has a high compressive strength but a relatively lower tensile and flexural strength (Rizzuto et al., 2020).

Compression strength is a widely used measure to evaluate how well a concrete mixture performs and is often used as a method for calculating the strength of concrete. It evaluates how well the concrete will withstand pressures that will cause it to shrink in volume (Joseph, 2016). The compressive strength of concrete is taken as the maximum compressive load it can carry per unit area. The compressive strength clearly shows whether a particular mix is suitable to meet the requirements of a certain project. Concrete is especially resistant to compressive loads (Chavan, 2020). For this reason, it can be used to construct foundations, dams, tunnel linings, arches, and columns. Concrete's compressive strength is strongly influenced by the quantity of cement and the quality of the aggregates used. In addition, the amount of water added to the cement, the appropriate mixing, and the pouring all have an impact (Tafa, 2017).

Flexural strength is used as a qualitative measure for other properties of hardened concrete. This is another indirect tensile strength measurement. It is known as the ability of an unreinforced concrete slab or beam to resist failure in bending. Alternatively, to put it another way, the concrete can withstand bending and normally ranges between 10 and 15 percent of compressive strength, depending on the reliable concrete mixture (Sharafat et al., 2019). Flexural tests are extremely sensitive to the handling, curing, and preparation of concrete to ensure that the concrete satisfies the quality specification (Santosh & Nagarjuna, 2022).

2.1.4.2. Durability of Concrete

Concrete durability is defined as its capacity to withstand weathering, chemical attacks, abrasions, and other deteriorating processes. Its essential feature is the capacity to sustain excellent performance for the duration of the service life required for the intended application. Permeability is the term used to describe a concrete's capacity to let fluids flow as a result of a pressure head difference. By inhibiting the entry of moisture, which may contain harmful compounds, as well as the flow of water during heating and freezing, this attribute of concrete increases concrete's longevity (Hamzah et al., 2022). Sulfate attack is one of the durability tests, and it measures the resistance of concrete cubes by measuring the mass loss of the cubes after exposure to a sulfate solution. The test method is applicable to concrete made with any type of cement and is not intended to be used to evaluate the performance of concrete in the field (Bashandy, 2016).

2.1.4.3. Microstructural properties of concrete

The microstructural study is a unique technique to find out the morphological characteristics of concrete. SEM and X-Ray Diffraction Analysis (XRD) are the two main techniques used to observe the microstructural behavior of concrete during the hydration process. These modern techniques enable the visualization of the particular properties of the concrete (Reddy & Kumar, 2020)**.** The mineral information obtained from the microstructural analysis can help in understanding the special characteristics of concrete and the presence of minor compounds in the hardened cement paste. The hydration process in concrete will lead to the formation of C-S-H gel, Ca (OH) 2 crystals, and other mineral compounds, which influence the individual properties of concrete (Memon et al., 2018).

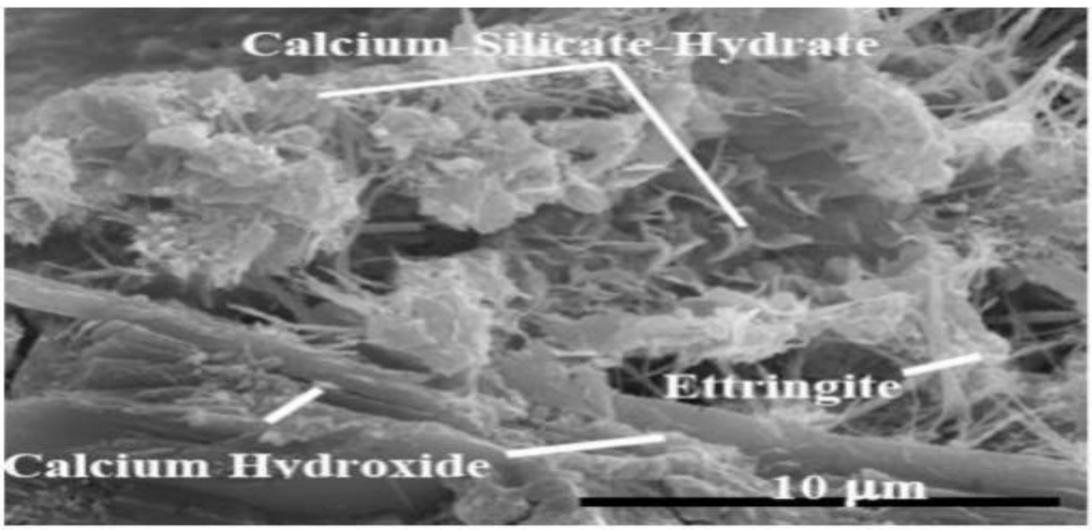

Figure2. 1 Electron microscopic images of hardened cement paste after hydration adopted from (Hamzah et al., 2022)

2.1.5. Concrete Casting and Curing

According to (ACI 308R-01, 2004), curing is a process in which hydraulic cement concrete acquires hardened qualities as a result of the cement's hydration in the presence of water and heat. For the concrete to develop its appropriate mechanical and durability properties, hydration must take place during curing. Cement paste that has hardened reacts by forming a porous matrix that binds aggregates. The inter-particle porosity reduces, and the inter-particle bonding strength grows as hydration progresses. The availability of water affects the rate and extent of hydration (Karthiga et al., 2019).

Curing is the process of maintaining a satisfactory moisture content and favorable temperature in concrete during the period immediately following placement, allowing the hydration of cement to continue until the desired properties are sufficiently developed to meet the requirement of service (Chavan, 2020). Curing can be defined as keeping the concrete moist and warm enough to facilitate the cement's continued hydration. Concrete quality will suffer a kind of permanent damage if curing is neglected during the initial stage of hydration. Adequate curing in the early period of hydration can be associated with good and healthy feeding given to a newborn baby (Kale & Sawant, 2022).

The concrete is kept in a suitable temperature range and protected from moisture loss during curing. Concrete produced through this method gains more strength but loses more permeability. Curing is particularly important for fracture mitigation because cracks can negatively affect durability (Ayele, 2021). To make sure that enough water is accessible for cement hydration to take place, curing can be done in several different ways. In contrast to conventional concrete, self-curing agents are designed to decrease the amount of water that evaporates from concrete, increasing the concrete's ability to retain water (Sudharson et al., 2021).

2.1.5.1. Types of Curing

Concrete can be cured in a variety of ways, but exterior and internal curing is currently more popular. Both internal and external curing are possible. Ponding, wet coating, fogging, sprinkling, etc. are adopted for exterior curing. By including admixtures in the concrete, internal curing or self-curing can be accomplished (Wakkad et al., 2019).

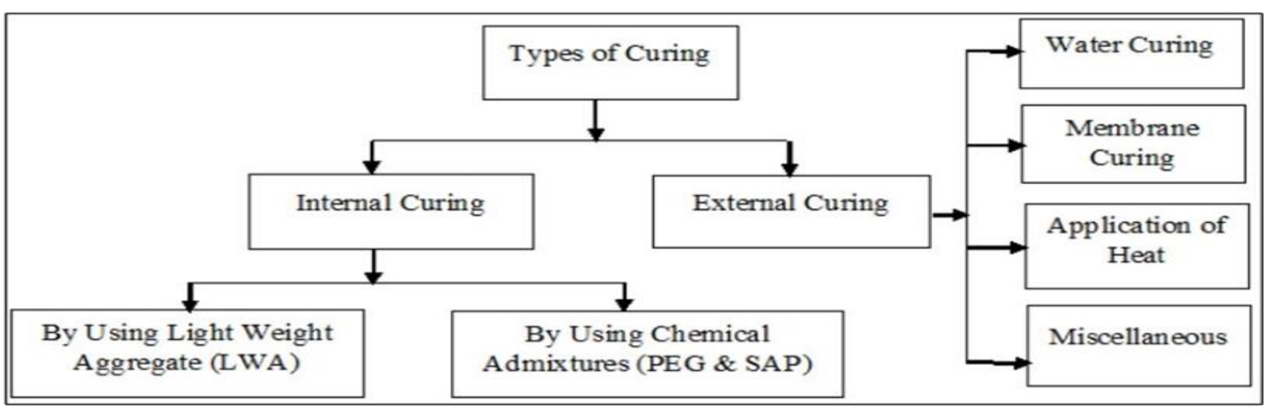

Figure2. 2. Types of Curing Methods Adopted from (Wakkad et al., 2019)

2.1.6. Challenges in Concrete Curing

Essential characteristics that have a direct impact on the lifespan of concrete are strength and durability. Curing significantly affects the qualities of hardened concrete, including strength, permeability, abrasion resistance, volume stability, resistance to freezing and thawing, and deciding chemicals (ACI 308R-01, 2004). Improper curing is one of the factors that have shortened the service life of many structures and has forced extensive repairs, with substantial economic costs. Some degree of weathering should be expected, but improper concreting procedures can have caused the deterioration to be earlier than expected. The long-term performance of concrete structures can be significantly changed bydecay (Anil & Bhikshma, 2020).

Due to increased permeability, improper curing of concrete reduces its compressive and flexural strength and durability. It also causes cracks owing to drying shrinkage, plastic shrinkage, and heat impacts. In addition, makes concrete less resistant to weather and frost. However, in many circumstances, proper treatment is not always feasible. The neglect of appropriate curing at construction sites has long been a source of debate. Consequently, the requirement to create self-curing concrete attracted many researchers (Chandrakasu et al., 2022).

2.2. Self-Curing Concrete

2.2.1. Meaning of Self-Curing Concrete

The concept of self-curing concrete emerged in the United States by Paul Klieger in 1957. Self-curing concrete falls under the category of specialty concrete that reduces the effects of inadequate curing brought on by human negligence, a lack of water in dry areas, the inaccessibility of certain structures, and locations where the presence of fluorides in the water will significantly affect the properties of concrete (Kale & Sawant, 2022).

Concrete that cures on its own eliminates the need for external curing after placement or even theneed to add water. These concrete characteristics are at least comparable with or even better than those of conventionally cured concrete. A water-soluble polymer is added to the concrete mixture in the "internal curing" process known as "self-curing" (Comun et al., 2020).

Self-curing is an extraordinary concrete gaining significance due to inherent advantages. This type of concrete does not need curing; some chemicals are added during the mixing of concrete, and these are responsible for the continuous hydration of cement even if there is no external application of water (Kumar et al., 2012). When concrete is self-curing, it means that no curingis required for it, or even any externally supplied water is not needed after placing.

2.2.2. Mechanism of Self-Curing Concrete

Cement undergoes chemical shrinkage during hydration, which results in the formation of empty pores and a reduction in relative humidity. Capillary pores and micro-cracks, which are the weak areas in the matrix, are produced as a result of self-desiccation and a lack of moisture in the cement paste. To maintain the relative humidity and prevent self-desiccation, self-curing is used (Khan & Gupta, 2020).

External methods are used for conventional curing, which keeps concrete warm and moist so that cement hydration continues until full strength development. To prevent self-desiccation throughout the concrete, self-curing was first suggested. Proper long-term curing is impossible because improper curing often occurs in areas with issues with water scarcity or incline construction (Thrinath & Kuma, 2017). Small inclusions spread throughout the concrete self-cure by holding the water throughout mixing and up until setting time and releasing it during cement hydration. Concrete must always have a moisture-containing environment because when relative humidity falls below 80%. If not enough water is available for curing in concrete, it will result in stopping cement hydration and do not achieve desirable properties (Hamzah et al., 2022).

Self-curing concrete is a new approach that was recently developed to keep concrete warm and moist for better strength and durability. Cement, mixing water, coarse aggregates, fine aggregates, and self-curing agents are the main ingredients of self-curing concrete. The idea behind self-curing concrete is that it uses porous aggregates or polymers, which can absorb significant amounts of water during mixing, to provide water from an internal source. Additionally, it has the idea of increasing concrete's water storage capacity and decreasing water evaporation from concrete in comparison to conventional concrete (Hu et al., 2018; Memon et al., 2018). After placing the concrete, it starts the hardening process, in which the cement paste begins to starve and dry out pores, which generates capillary stress.

This show that the water desorption process starts at an early age. Self-curing not only provides water for curing the concrete but also increases the degree of reaction of the cement with other constituents. As compared with coarse aggregates lightweight fine aggregates have greater dispersion property that's why it is commonly used for internal curing and lightweight aggregate approximately moves 1.8 mm from absorbent material into the paste surrounding the aggregates particles (Sathanandham et al., 2013).

The performance of self-curing concrete systems is strongly related to the content and properties of the self-curing agents, such as water absorption, pore structure, and grain size distribution, as well as mechanical properties. A large number of naturally occurring or artificial materials are used as internal reservoirs for self-curing because of their porosity (Rizzuto et al., 2020).

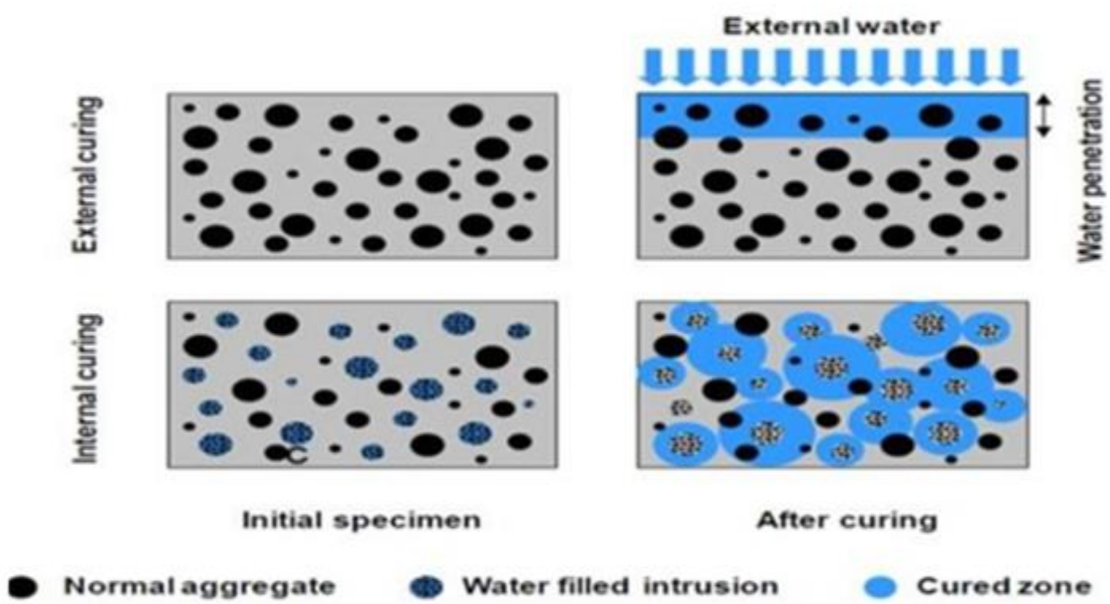

Figure2. 3. Mechanism of Self-curing adopted from (Hamzah et al., 2022)

2.2.3. Advantages of Self-Curing Concrete

Self-curing concrete is an alternative for construction in dry locations where there is a serious lack of water. It provides water to maintain highrelative humidity, preventing self-desiccation, eliminating most autogenous shrinkage, reducing autogenous cracking, somewhat increasing the strength of concrete, lowering permeability, and protecting reinforcement steel (Sudharson et al., 2021). Additionally, it increases early-age strength, improves rheology, and offers excellent durability. Additionally, it reduces the ability of mortar and concrete to maintain strength over an extended period, which increases the likelihood of internal and external cracking (Khan & Gupta, 2020).

2.2.4. The Disadvantage of Self-Curing Concrete

While adding a self-curing agent, proper and exact supervision is required. Concrete strength may be reduced if self-curing chemicals are added in excess. The dosage of the self-curing ingredient has only been determined thus far through trial and error. Choosing the best dosage of the self-curing ingredient may take some time because there are not any established guidelines for doing so right now (Sarathschandra et al., 2017).

2.3. Self-curing Agents

During the mixing of the concrete, a few specialized water-soluble ingredients are added tocreate self-curing concrete, which reduces the amount of water that evaporates from the set concrete. The ability of chemicals must reduce the dehydration of the solution and improve water retention in the ordinary Portland cement matrix (Kumar et al., 2012; Mandiwal & Jamle, 2018).

Concrete can be successfully cured by using self-curing chemicals. The following substances may have hydrophilic qualities that are used for self-curing: Expanded shale (natural and manufactured), lightweight aggregate, super-absorbent polymers (SAP), Polyethylene glycol-type propylene glycol SRA (Shrinkage Reducing Admixture) (Evangeline, 2014).

2.3.1. Polyethylene Glycol

The standard formula for polyethylene glycol is $H(OCH_2CH_2)$ nOH, where n is the average number of repeated oxyethylene groups, commonly ranging from 4 to about 180. Polyethylene glycol is a condensation polymer of ethylene oxide and water. A numerical suffix is used in combination with the acronym (PEG) to denote the average molecular weights (Santosh & Nagarjuna, 2022). Polyethylene glycol is a polyether compound that is extensively used in both industrial manufacturing and medicine. PEG is frequently referred to as polyoxyethylene (POE) or polyethylene oxide (PEO), depending on its molecular weight (Mechtcherine et al., 2021).

The family of water-soluble linear polymers known as polyethylene glycols (PEGs) is created when ethylene oxide (EO) reacts further with monoethylene glycols (MEGs) or diethylene glycol. The average number of repeated ethylene oxide groups in the generalized formula for polyethylene glycol is $H(OCH_2CH_2)$ n OH, N. PEGs are classified into a variety of grades according to their average molecular weight. For instance, PEG 400 is composed of a variety of polymers with average molecular weights of 400 (Kalaivani et al., 2020).

PEG 400 (polyethylene glycol 400) is a low-molecular-weight grade of polyethylene glycol. It is a clear, colorless, viscous liquid. Due in part to its low toxicity, PEG 400 is widely used in a variety of pharmaceutical formulations. In addition to being somewhat soluble in aliphatic hydrocarbons, it is soluble in water, acetone, benzene, glycols, glycerin, and these other substances. PEG 400 Strongly hydrophilic and PEG-400 chemical formula is $2nH_{4n}+_2O_{n+1}$ (Kebede, 2020).

2.3.1.2. The Properties of PEG in Concrete

When water is added to dry concrete, the cement begins to react with it, creating heat of hydration and exothermal heat in the process. This causes early shrinkage cracks. Simultaneously, the evaporation of water takes place, and that is why cracks develop (Rajasekaran & Claver, 2020). When PEG is introduced to concrete, it surrounds water molecules with a shell, trapping the water inside these shells. Every water molecule in the concrete has these shells built into it. Water is neveravailable at the time when the heat of hydration is occurring since it cannot evaporate from concrete due to the construction of this shell, which lowers the rate of evaporation. As a result, early-age shrinkage cracks won't appear. Water is eventually conserved because evaporation is prevented, and there is no need for curing for a particular period (Dahyabhai & Pitroda, 2014; Selvamony et al., 2010, 2010; Suthandradevi & Nivasini, 2019)

2.4. Previous Studies on Properties of PEG-Based Self-Curing Concrete

Explains research done on the effect which materials used as self-curing agents have had on being compared to improve concrete performance. The references, test experiment details, amount of admixtures, materials, and test result comparison between conventional and self-cured concrete are listed in table 2 below.

Table 2. 3. A summary of the various research works published on internal curing concrete.

No	Experiments Conducted	Materials and Quantity Of Admixtures	Strength Of Normal Concrete			Strength of Self-Curing Concrete			% Increase In Strength	Result and Discussion	Reference
1	By adding the additive polyethylene glycol PEG-4000 to concrete, you can compare traditionally cured concrete to self-curing concrete.	PPC-53, FA, CA, Fly Ash, Super Plasticizer,and PEG-4000(1%)	28.9	-	-	34.2	-	-	18.5%	Self-cured concrete's compressive strength is around 18% higher than water-cured concrete's.	(Kalaivani et al., 2020)
2	Utilizing wood powder, examine the mechanical properties of self-curing concrete.	PPC-53, FA, CA20mm and (2%,4%,6%) wood powder	33.0			26.6 30.2 4.7			5%	When compared to normal concrete cubes, wood powdered concrete cubes have a higher compressive strength of 6%.	
3	By adjusting the PEG % for both M20 and M40, you can investigate the mechanical properties of concrete.	PPC-53, FA, CA20mm and (0.5%-2%) PEG-400,PAM	26.6	1.8	3.5	28.5 47.2	2.0 2.5	3.8 4.8	7.1%, 11.6%, 8.5% 2.8%	Slump value increases with an increase in PEG percentage (1% is optimal for M20, 0.5% is optimal for M40).	(Bashandy et al., 2017; Rizzuto et al., 2020)
4	Utilizing waste granite as a self-curing agent and water-soluble polyethylene glycol to study the strength and durability characteristics of concrete.	PPC-53, FA, CA20mm, (0%-2%) PEG400 and10% granite	22.6	2.8		42.6 38.4	3.4 7.6	3.6 3.1	97.9% 11.4%	The optimum dosage of PEG400 for maximum Compressive strength was found to be 0.2% for grades of concrete.	(Dahyabhai & Pitroda, 2014)

5	investigate how polyethylene glycol (PEG600 and PEG1500) affects the self-curing concrete's strength properties.	PPC-53, FA, CA20mm, 0.0-2%(PEG - 600) and PEG-1500	24.9			34.2 33.3			37.5 33.9	For M25 to achieve its highest compressive strengths, the ideal dosage is % of PEG600 or PEG1500.	(Dahyabhai & Pitroda, 2014)
6	Examining how polyethylene glycol (PEG) affects the self-curing concrete's strength properties.	PPC-53, FA, CA20mm, and 0%-1.5% (PEG-400)	22.0	2.2	4.5	36.5	2.5	5.1	30.4%, 13.6%, 13.3 %	Maximum strengths (compressive, tensile, and rupture modulus) were found to be best achieved with a PEG400 dosage of 1%.	(Joseph, 2016)
7	This study's objective is to assess the effectiveness of PVA's water-soluble polymeric glycol self-curing agents.	0.0% 0.03% 0.06% 0.12% 0.24% 0.48%PVA	18.9	3.6	5.9	18.6 18.2	6.0	7.0	1.5%, 62.8% 19.6%	0.24% of PVA results in a nice self-curing concrete that combines good workability and excessive compressive strength.	(Chandrak et al.,2022)
8	Investigate how polyethylene glycol (PEG-200) affects the self-curing concrete's strength qualities.	PPC-53, FA, CA20mm, 1% PEG200 , 1%PEA	36.2	2.7		35.7 30.3	2.3 2.1		1.5%, 16.2% 15.6%, 23.5%	When compared to standard concrete, both PEG and PEA showed a 1% increase in compressive strength for M25.	(Kumar & Babu,2019)

2.5. Research Gaps and Summary

By compiling a broad range of research articles, an extensive report was produced. The addition of self-curing natural and chemical admixtures to concrete has led to extensive experimentation on the fundamental properties of the material, according to a thorough literature review that has been conducted. Despite extensive research on the mechanical characteristics of self-curing concrete using molds, no relevant studies on the durability of a comparative study on the cost use of self-curing concrete over conventionally cured concrete. It is vital to examine the behavior of the concrete in terms of durability before using self-curing concrete. The experimental analysis of PEG 400 characteristics and its impact on workability, compressive strength, water absorption, microstructure, and cost aspects of concrete was investigated.

In this chapter, various research works carried out across the world using natural and chemical self-curing agents were reviewed to identify the research gaps that enabled setting the objective for this research. The next chapter discusses the research methodology adopted to achieve the objectives of the study.

3 MATERIALS AND METHODS

3.1 Introduction

Various historical studies and research gaps concerning self-curing procedures were covered in the literature review in the preceding chapter. Chapter one described the goals for the study which are based on the found research gaps. This chapter addressed the research materials used, the methodology employed to achieve the study's objectives, and the experimental process for all tests carried out.

3.2 Materials Used

The materials utilized in this experiment were examined to ensure that their physical, mechanical, and microstructural qualities met the requirements set out by the standard. Materials and chemicals used in the experimental examination of polyethylene 400-based self-curing concrete were discussed in this part, along with their properties. such materials were: cement, fine and coarse aggregates, water and poly ethylene glycol.

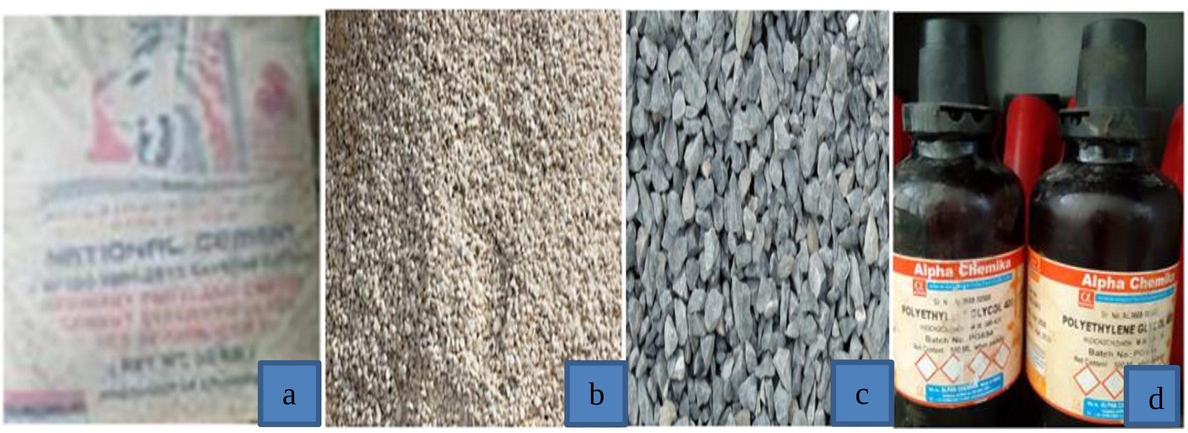

Figure3. 1 Materials used; a) National OPC cement, b) Fine Aggregate, c) Coarse Aggregate and d) Polyethyleneglycol-400

3.2.1 Cement

The selection of National OPC cement was deliberate to align with the concrete requirements specified in Figure 3.1(a). This cement was procured from a supplier in Adama, Ethiopia, who adhered to the ASTM C150 (2016) regulations. To preserve its quality during the entire experimental duration, the cement was appropriately stored in a dry area, keeping it away from moisture.

3.2.2. Fine Aggregate

According to ASTM specifications, the water absorption of fine aggregate should not exceed 5%. For this study, river sand, which had undergone sieving with a 4.75 mm sieve and was retained at 150 microns according to ASTM C33 (as illustrated in Figure 3.1(b)), was utilized. It was imperative that the sand be free from silt, clay, or any organic contaminants.

3.2.3. Coarse Aggregate

Crushed gravel served as the coarse aggregate in the concrete samples examined in this research. The gravel was sourced from a local quarry and met the standards outlined in ASTM C33. Specifically, the chosen coarse aggregate for the experiment needed to be robust, enduring, devoid of vegetable matter, possess water absorption of less than 5%, and exhibit a non-sharp and non-angular structure, in accordance with ASTM C33, as indicated in fig. 3.1(c).

3.2.4 Water

Concrete quality is significantly influenced by water impurities and water content. As a result, the concrete water ought to be free of contaminants and toxins. Although it is generally safe to use potable water, concrete can be made with water that is unfit for consumption. For this experimental laboratory work, potable water from the ASTU university lab that complies with the ASTM C1602 standard was used for mixing and curing purposes.

3.2.5. Polyethylene Glycol-400

The PEG-400 utilized in this investigation possesses distinct characteristics. The substance demonstrates a hydroxyl value within the range of 265 to 295. Notably, it has a specific gravity of 1.126 and presents itself as a clear liquid with water-soluble attributes. The product is endowed with a shelf life of 5 years and maintains a pH value between 5 and 7 at 10g/L at 23°C. Additionally, its density is documented at 1.125 g/cm^3 indicated in Figure 3.1(d).

3.3. Research Method

Experimental Program to achieve the goal of the study, an experimental approach was used; the main purpose of the test method was to investigate the effect of polyethylene 400-based self-curing concrete over conventional concrete. Various laboratory tests were carried out following various established methods to accomplish the current study's objective. The methodology carried out was described in the flow chart given in fig 3.2 below.

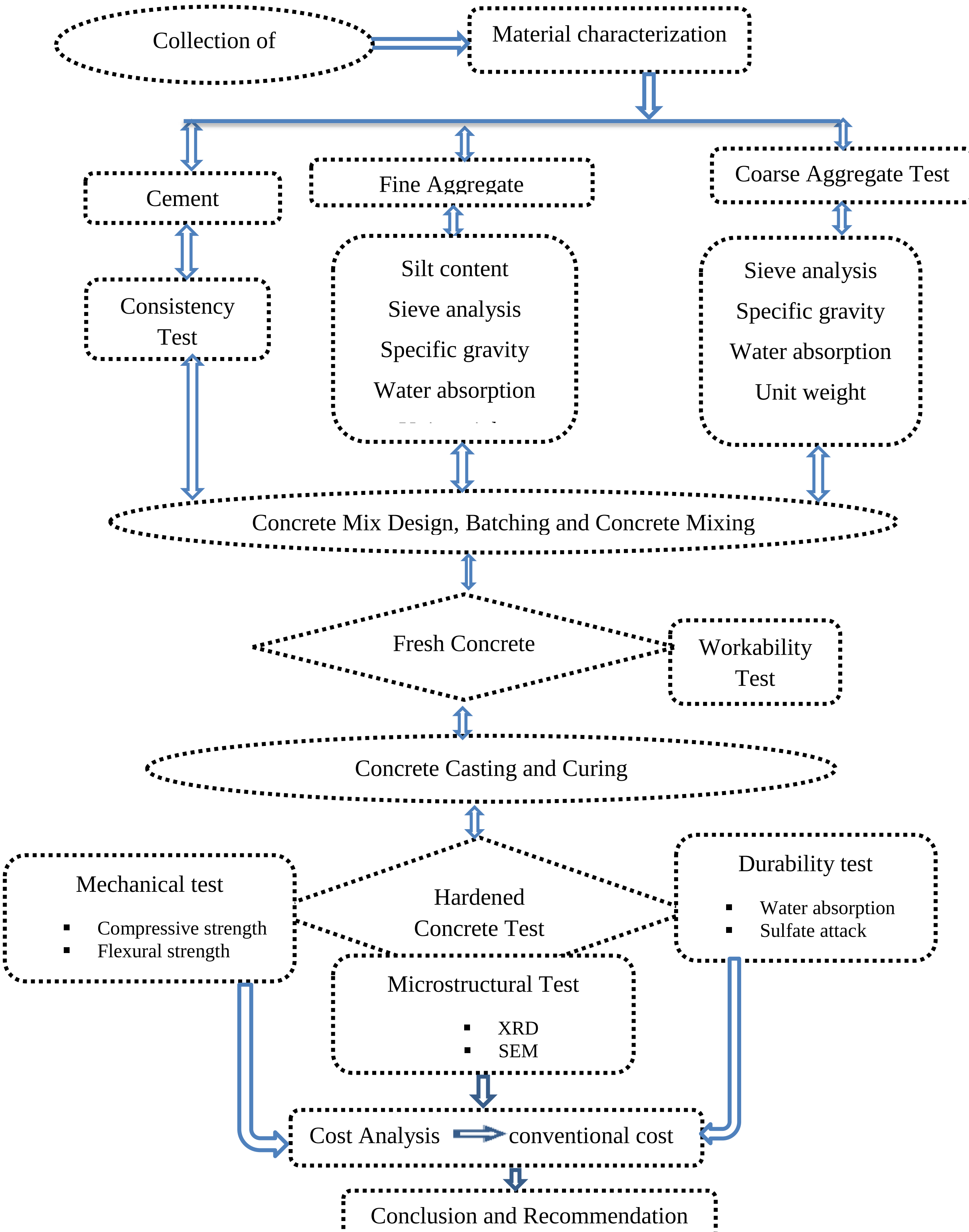

Figure3. 2 Methodological framework of the Research

3.3.1. Tests on Cement

3. 3.1.1. Normal Consistency Test for Cement

The test was conducted in a laboratory or on the construction site and has a straightforward method. Based on how deeply the plunger of the Vicat device penetrated the cement mixture, the test findings were analysed. The test was conducted per the guidelines in (ASTM C 187).

Apparatus: Vicat Apparatus, Graduated Cylinder, Mixing Dish, Trowel, Weighs, And Weighing Apparatus

Test Procedures for Consistency

i. 400 grams of cement were measured.
ii. Water amounting to a percentage of cement (22-30%) was added to cement and mixed.
iii. Within 3-5 minutes, properly combine the paste; gauging time wes the time it took to got cement paste after adding water.
iv. Filled the paste in the Vicat mold appropriately, level the paste and lower the plunger gently removed any surplus paste with a trowel.
v. Then, set the Vicat mold on the glass plate, making sure the plunger lightly touches the surface of the Vicat mold.
vi. Allow the plunger to sunk into the test mold after it had released.
vii. Took note of the plunger's penetration from the bottom of the mold as indicated on the scale.
viii. Repeat the experiment with varied percentages of water until the Vicat apparatus scale reading became between 5-7 mm.
ix. The water added was right and the penetration was between 5 mm and 7 mm

The amount of water required for normal consistency then expressed as a percentage weight of the dry cement.

Water $= \frac{\text{weight of water in gm}}{\text{weight of cement in gm}}$ x 100% ---------------------------- Equation 3.1

Figure3. 3 Vicat Apparatus(A) and Normal Consistency Test (B)

3.3.2. Properties of Fine and Coarse Aggregates

3.3.2.1. Silt Content of Fine Aggregate

Finding out how much silt was in the sand was the main objective of this test. The test was conducted under the guidelines in (ASTM C 117).

Apparatus: sample sand, clean water, a graduated jar, a spoon, a dish for taking a sand sample, and a funnel

Procedure for the Silt Content Test

- **i.** The researcher used a graduated cylinder with a 1000-ml capacity.
- ii. 300 ml of sand was added to the cylinder.
- iii. The jar was filled with water to approximately 3/4 of its capacity.
- iv. For almost a minute, the jar was shaken vigorously.
- v. Leaving the jar unattended for an hour allowed the silt to accumulate on the layer of
- vi. The amount of fine that separated into a layer on top was measured.
- vii. The silt content was computed using Equation 3.2 below.

$$\text{Silt content} = \frac{A}{B} \times 100\% \text{ ----------------------------- Equation 3.2}$$

Where: A = Amount of Silt Deposited above B = Amount of Clean Sand

Figure3. 4 Silt Content Test

3.3.2.2. Specific Gravity and Water Absorption Capacity of Coarse and Fine Aggregate

The researcher determined specific gravity and water absorption capacity based on the (ASTM C127) standard.

Procedure for Specific Gravity and Water Absorption of Fine and Coarse Aggregate

i. A 500 g weight was assigned to the S.S.D sample.
ii. Place 500 g of saturated, surface-dry aggregates into the Pycnometer after partially filling it with water.
iii. After that, they added more water to the Pycnometer until it was 90% full.
iv. To get rid of any air bubbles, the Pycnometer was rolled and turned upside down.
v. Immersed the Pycnometer for an hour in a 23 °C water bath.
vi. Raised the water level in the Pycnometer to the appropriate level for calibration.
vii. The combined weight of the Pycnometer, sample, and water was then determined.
viii. The fine aggregate was taken out of the Pycnometer, dried to a constant weight at 105 °C, dried in ambient air for one hour, and then
ix. The weight of the Pycnometer filled with water was determined at 23°C, based on the equations below.

Specific Gravity and Water Absorption of Fine and Coarse Aggregate

$$\text{Bulk Specific Gravity (Oven Dry Basis} = \frac{A}{(B+500-C)} \text{---------------Equation.3.3}$$

$$\text{Apparent Specific Gravity} = \frac{A}{(B+A-C)} \text{--------------------------------Equation.3.4}$$

$$\text{Absorption Capacity (\%)} = (500 - A) * \frac{100}{A} \text{----------------------Equation.3.5}$$

Where: A = Weight of Oven-Dry Sample in Air, [gm.]

B = Weight of Pycnometer Filled with Water, [gm.]

C = Weight of Pycnometer with Sample and Water to Calibration Mark, [gm.]

3.3.2.3. Unit Weight of Fine and Coarse Aggregates

The unit weight of aggregate ranges from 1200 to 1750 kg/m^3 (ASTM C29).

Procedure for Specific Gravity and Water Absorption of Fine Aggregate

i. With the tamping rod distributed equally throughout the surface, tamp the aggregate layer with 25 strokes. Fill the measure to its halfway point, level, and rod as usual. Finally, fill the measuring cup with the rod as described above.
ii. Level the aggregate's surface such that any tiny protrusions of the large pieces of coarse aggregate roughly equal the surface's larger voids below the top of the measure.
iii. The second and third layers of rodding exert only enough force for the taping rod to penetrate the previous layers of aggregate.
iv. The fine aggregate was weighed, and the data were recorded as the equation 3.6.

$$\text{UWFA} = \frac{A-C}{V} \text{---Equation.3.6}$$

Where A=Fine(Coarse) aggregate plus cylinder weight.

C= Weight of empty cylinder

V=Cylinder volume

3.3.2.4. Sieve Analysis for Fine and Coarse Aggregates

i. Sieve Analysis of Fine Aggregate

With 500 g of fine aggregate, a series of IS sieves with sizes ranging from 4.75 mm to 2.36 mm, 1.18 mm to 0.6 mm, and 0.3 mm to 0.15 mm, respectively, a balance, a sieve shaker, a shovel, and a sieve brush, the purpose of this test was to ascertain the fineness modulus of fine aggregate. The testing process followed ASTM C136 guidelines. The fineness modulus ranges from 2.3 to 3.1 (ASTM).

Procedure for Grading Fine Aggregate

i. A 2 kg sample of fine aggregates was weighed.
ii. The sample underwent a quartering process.
iii. From the quartered sample, a 500 g portion was weighed.
iv. The empty sieves were weighed, and the data was accurately recorded.
v. The pan was positioned at the bottom, and subsequent sieves, arranged by increasing opening sizes, were placed on top of the pan.
vi. The 500 g sample was deposited on the uppermost sieve with the largest opening size.
vii. The sample was subjected to sieving for approximately 10 minutes using a sieve shaker.
viii. Each sieve, along with the aggregate retained on it, was weighed, and the weight retained on each sieve was calculated.
ix. The gradation chart was completed, and the fineness modulus was computed.

Fineness modulus = $\sum_{n=1}^{7}(\text{Cumulative retained by mass} / 100)$------------Equation 3.7

Figure3. 5 Sieve Analysis of Fine Aggregate Test

ii. Sieve Analysis of Course Aggregate

The purpose of this test is to ascertain the fineness modulus of coarse aggregate. To do so, a variety of equipment was used, including 2,000 g of coarse aggregate, a balance, sieve shaker, shovel, and sieve brush, as well as a series of IS sieves with the following sizes: 20 mm, 19 mm, 12.5 mm, 9.5 mm, 4.75 mm, and pan. The test protocol that was used complied with ASTM C136.

Sieve Analysis for Coarse Aggregate

i. Weighed 20 kg of coarse aggregates.
ii. A representative sample was obtained through quartering.
iii. Extracted 2 kg from the quartered sample.
iv. The empty sieves were weighed, and the data was accurately recorded.
v. Positioned the 2 kg sample on the top sieves, which featured larger opening sizes.
vi. Subjected the sample to sieving for approximately 10 minutes using a sieve shaker.
vii. Each sieve, along with the retained aggregate, was measured, and the weight retained on each sieve was calculated.
viii. Completed the gradation chart and computed the fineness modulus using Eqn. 3.8.

$$\text{Fineness modulus} = \frac{\%\text{cum.retained}}{100} \quad \text{-------------------Equation.3.8}$$

3.3.4. Mix Proportions

The C-30 concrete grade was designed as a result of the fact that self-curing concrete is mostly used in the construction of bridges and all asphalt concrete, both of which frequently develop fractures as a result of high loads and frequent maintenance required. C-30 concrete grade is used for building roads and bridges. Since it is difficult to cure these huge structures much better to use this curing method, the following processes were used to proportion the materials for concrete per ACI's 211.1 methods of mixing: The following processes were used to proportion the materials for concrete following ACI's 211.1 methods of mixing: Details on the mix amounts, necessary calculations, and mixing technique were included in the Annex.

1st Step: The required mean compressive strength calculated based on characteristic strength of 30 MPa which gave; fck = f'ck +8.5 = 30 + 8.5 = 38.5 MPa from Appendix A1

2nd step: The minimum cement content was determined

Minimum cement content was determined, and according to durability considerations, the cement content of concrete should not be less than 300 kg/m3. According to IS 456 (2000), increased cement content was advised for conditions of exposure to harsh weathering agents in concrete.

3rd step: A Slump Value was selected

A 2–10 cm concrete slump recommended for C-30; from ACI concrete mix design from Appendix A2.

4th Step: The maximum possible aggregate size determined.

A smaller aggregate with a lower maximum size was used for higher compressive strength. In this instance, the aggregate's maximum size was 20 and its nominal size was 19 mm from Appendix A3.

5th Step: The amount of water and air in the mixture was mixed.

The aggregate grading, amount of entrained air, and maximum aggregate size all affect how much water is needed per unit volume of concrete to achieve the desired slump value.

40	0.42	
38.5	x	By interpolation, (40-38.5) /(0.42-X) = (38.5-335)/(X-0.47)
35	0.47	

By solving the above equation, x = 0.44

Hence, the minimum water cement ratio is 0.44

6th Step: The cement content of the mix was computed using eqn.3.12

$$\text{cement content } = \frac{water\ content}{water\ cement\ ratio} \text{ --------------------Eqn3.9}$$

$$\text{cement content} = \frac{185}{0.44} \quad = 425.29\text{kg/m}^3$$

Since the mix's cement content exceeds the required minimum cement use, a mix design of 425.29 kg/m^3 was used for this study.

7th Step: The Bulk Concrete Volume per Unit Volume was computed using AnnexA5 Depended on the aggregate's maximum size of 20 mm and the fineness modulus, which was 2.78.

2.6	0.66	
2.78	x	By interpolation, (26-2.78) / (0.66-x) = (2.78-2.8)/(X-0.62)
2.8	0.62	

By solving the above equation, x = 0.62

Hence, the dry volume of aggregate per volume of concrete is 0.62

8th Step: The WCA (Weight of Coarse Aggregate) Per Cubic Meter of Concrete determined**.**

WCA= bulk volume x bulk density of coarse aggregate

WCA = 0.624 x 1631.64

= 1,018.14 kg/m^3

9th Step: The Coarse Aggregate Solid Volume was calculated.

$$\text{Solid Volume of Coarse Aggregate==} \frac{\text{WCA}}{\text{Specific Gravity}} \text{ --------------Eqn3.10}$$

10th Step: The Solid Volumes of Air, Water, and Cement was determined

$$\text{Volume of cement (VC)} = \frac{\text{weight of cement}}{\text{Specific gravity of cement}} \text{ -------------Eqn3.11}$$

$$= \frac{425.29}{3.15} = \quad 135.01\text{kg/m}^3$$

Volume of water (VW) = 185 kg/m3 Volume of air (VA) = 2% or 20 kg/m3

11th Step: Solid Volume of Sand was calculated

Solid volume of sand = 1000 - (VCA + VC + VW + VA)

1000 - (379.9 + 135.01 + 185 + 20)

1000 - 719.91 = 280.09 kg/m^3

Solid weight of sand = dry volume of sand x specific gravity

280.09 kg/m^3 x 2.75

= 770.25 kg/m^3

12th Step: Aggregate Moisture Content was adjusted

Fine aggregate adsorption = 3.7% Coarse aggregate absorption = 1.67%

Water absorbed by coarse aggregate = 1,018.14 kg/m3 x 0.0167

= 17 kg/m3

Water supplied by fine aggregate = 770.25 kg/m3 x 0.037

= 28.5 kg/m3

Amount of water needed = 185 kg/m3 + 17 kg/m3 - 28.5 kg/m3

= 173.5 kg/m3

Cement = 425.29 kg/m3

Fine aggregate = 770.25 kg/m3 + 28.5 kg/m3

= 798.75 kg/m3

Coarse aggregate = 1,018.14 kg/m3 - 18.05kg/m3 = 1001 kg/m3

Hence, the estimated batch weight for 1 cube of concrete is given in Table 3.1.

Table3. 1.Calculated Batch for 1 m^3 of Concrete

Water	173.5 kg/m^3
Cement	425.29 kg/m^3
Fine aggregate	798.75 kg/m^3
Coarse aggregate	1001 kg/m3

The above result in the mix design ratio can be expressed in Table 3.2 below.

Table3. 2 Mix Ratio for C-30 Concrete Grade

Ingredients	Cement	Fine aggregate	Coarse aggregate
Amount / m^3	425.29/425.29	798.75 /425.29	1001 /425.29
Ratio	1	1.88	2.35

Based on the mix proportion given above, the quantity of each concrete ingredient can be calculated for one cube standard mold.

Wet volume for 1 mold = length x width height

= 0.15 x 0.15 x 0.15

= 0.00375 m^3

Dry volume = wet volume x 1.55

= 0.00375 m3 x 1.55

= 0.0058125 m^3

$$\text{weight of CA} = \frac{2.35}{\text{sum of ratio}} \text{ x dry volume x unit weight of CA}$$

$$\text{weight of CA} = \frac{2.35}{5.23} \text{ x } 0.0058125 \text{ x } 1{,}631.64$$

$$= 4.26 \text{ kg}$$

$$\text{Weight of water} = \text{amount of water needed} * \text{ dry volume}$$

$$= 173.5 \text{ x } 0.0058125$$

$$= 1.01 \text{ kg (L)}$$

Table3. 3 Summary of mix design for the production of one cubic meter of concrete

No.	Mix code (%)	PEG content (kg/m^3)	Cement content (kg/m^3)	Fine aggregate content (kg/m^3)	Coarse aggregate content (kg/m^3)	Water content (kg/m^3)	Water to cement ratio
1	PEG0	-	425.29	829.97	978.6	172	0.435
2	PEG1	4.25	425.29	829.97	978.6	172	0.435
3	PEG1.5	6.38	425.29	829.97	978.6	172	0.435
4	PEG2	8.5	425.29	829.97	978.6	172	0.435
5	PEG2.5	10.6	425.29	829.97	978.6	172	0.435
6	PEG3	12.8	425.29	829.97	978.6	172	0.435

3.3.5. Batching and Mixing

3.3.5.1. Batching

In this research, the weight batching technique was utilized, and National Ordinary Portland cement was adding by different percentages of PEG-400 by cement weight. Additionally, a control test was conducted. The dry mix involved blending the aggregate and cement before the wet mix phase. Subsequently, water was incorporated into the mixture and mixed with mixer.

3.3.5.2. Concrete Mixing

The solution was mixed with coarse aggregate, fine aggregate, water and PEG-400 in a machine. Once the solution was added to the dry mixture, additional water was incorporated in the mix with constant water-cement ratios.

3.4. Fresh Concrete Test

3.4.1. Slump Cone Test for Workability of Concrete

As per ASTM C143 (2010) specifications, the test was carried out using specific equipment. The tools employed included a tamper rod measuring 16 mm in diameter and 600 mm in length, a ruler, a flat pan, and a test slump cone shaped like a frustum of a cone. The slump cone had dimensions of a base diameter of 200 mm, top diameter of 100 mm, and a height of 300 mm.

Procedure for a slump test

i. The slump cone was first set down on a flat metal plate.
ii. Three layers of freshly mixed concrete were applied to the slump cone.
iii. A metal rod with a diameter of 16 mm and a length of 600 mm was used to tap each layer of concrete mix 25 times.
iv. Extra concrete was removed from the cone's top following the last layer of filling.
v. With two hands, quickly lift the drooping cone upward. The concrete was then unhindered and can fall.

The height that remains after free fall were measured and was called a slump (it was the height difference between the mold and the vertical axis)

3.5. Casting of Concrete Specimens and Curing

3.5.1. Concrete Casting

After casting a concrete cube with dimensions of 150 x 150 x 150 mm, the compressive strength of the concrete was investigated. Cement, fine aggregate, coarse aggregate, water, and polyethylene glycol 400 concentrations varying from 0% to 3% by weight of cement were used to make concrete specimens for the experiment. The researcher mixed, poured, and compacted the concrete in various layers as per the study (Comun et al., 2020; Memon et al., 2018; Sarathschandra et al., 2017), then de-molded the samples after 24 hours.

3.5.2. Curing of Concrete Specimens

After pouring a 150 x 150 x 150 mm concrete cube, the properties of hardened concrete were examined. By mixing the main components of concrete (cement, sand, coarse aggregate, and water) with various amounts of PEG-400, ranging from 0% to 3% by weight of cement, the experimenter created concrete specimens.

3.6. Hardened Concrete Test

One of the toughest and most durable building materials currently available is hardened concrete, which can support structural and service loads. Testing hardened concrete is one of its goals to make sure that it is strong and durable properly.

3.6.1. Compressive Strength Test

Hardened concrete's capacity to sustain axial stresses without cracking or deformation is known as its compressive strength. Determining the compressive strength of concrete with and without a self-curing substance was the objective of this test. The test was conducted using a balance, mold, tamping rod, compressive test equipment, trowel, shovel, and brush. For comparing the compressive strength of polyethylene 400-based concrete with conventional concrete, concrete cubes with sample sizes of 150 x 150 x 150 mm were cast. At Adama Science and Technology University's Construction Material Laboratory, the researcher used an automatic compressive strength test device in line with (ASTM C39) to evaluate the compressive strength after 7, 14, and 28 days of curing.

For the compressive strength test, the cast cubes of conventional concrete were removed from the curing water after 7, 14, and 28 curing periods and the excess water was wiped off the surface; for self-curing concrete, the cast cubes that had only been treated with curing agent were put after the same intervals. The test apparatus was then cleaned, the sample was placed inside, and a load of 3000 KN was applied at a rate of 14 N/mm^2/minute. The highest load was noted when the specimens failed, and then the compressive strength was computed.

Compressive strength = Load / Cross-sectional Area of the sample .... Eqn. 3.12

Results from the test were compared with the desired mean and characterizing strengths. By creating the concrete mix under the code, the desired mean strength is ascertained.

3.6.2. Flexural Strength test

Flexural force, also known as bend strength, fracture force, or modulus of rupture, was a mechanical characteristic for brittle materials that describes a material's ability to resist deformation under load. To determine flexural strength, beams of the dimensions 10cm*10cm*50cm were cast. The test was conducted on the beams at the age of 7, 14, and 28 days, and the specimen was placed in the machine following ASTMC78 The load was applied at an increasing rate of 108KN/min, and the load at which the specimen fails was recorded.

The beam specimens were put through a two-point loading test on flexural testing equipment to create pure bending. The specimen's surface should be free of any unnecessary debris, such as sand, on the bearing surface of the flexural testing equipment. The applied two-point bending load was raised progressively and steadily until the specimen could no longer resist it. The maximum load placed on the specimen was recorded. The modulus of rupture was given by the equation.

Rupture (R) = $(3Wa) / (bd^2)$ --Equation 3.13

W = load at failure L = specimen's length b = specimen width d = specimen depth.

3.6.3 Durability Test

3.6.3.1. Water Absorption Test

This research examined the water absorption of conventional and self-curing concrete at curing periods of 28 days to determine the water tightness of concrete. The water absorption test procedure followed was: after 28 daysof curing, the samples were taken out of the curing water for conventional and from the surface for self-curing and dried at a temperature of 105°C for 24 hours, weighed, then immersed in curing water for 24 hours, weighed again, based on (ASTM, C1585), and the highest water absorption limit is 10%. The increase in weight as a percentage of the original weight is expressed as water absorption. The water absorption and percent reduction can be computed based on the formula:

Water absorption % = $\frac{S-H}{H}$*100% ----------------------Equation 3.14

Reduction % = $\frac{H-S}{H} * 100\%$------------------------Equation 3.15

Where, S= Submerged sample H= Oven Dry sample

3.6.3.2. Sulphate Attack

The test method is applicable to concretes that are to be exposed to sulfate –rich environments and not applicable to concretes that are to be exposed to environments that are highly acidic or alkaline. The sulfate attack index should not exceed 0.5% and concrete cubes with a sulfate attack index greater than 0.5% are considered to be suspected to be sulfate attack. The test was conducted as per ASTM C1260-22

Apparatus: Balance, Mold, Stirrer, Container, Graduated Cylinder

Procedure for the Sulfate Attack

i. The concrete cubes prepared in accordance with the requirements of ASTM C1260 standard.
ii. The sulfate solution prepared by dissolving50g of sodium sulfate (NA2SO4) in 1000ml of water.
iii. Immerse the concrete cubes in the sulfate solution so that all six sides were exposed to the solution.
iv. The concrete exposed cubes to the sulfate solution for a period of 14 days.
v. Removed the concrete cubes from the sulfate solution and weigh them.
vi. Calculated the mass loss of the concrete cubes by subtracting the weight of the dry concrete cubes from the weighted of the wet concrete cubes.
vii. Calculated the sulfate attack index by dividing the mass loss of the concrete cubes by the original mass of the concrete cubes.

Loss in Kg = W_1-W_2----------------------Equation 3.16

% of Loss= $\frac{W1-W2}{W1} * 100\%$----------- Equation 3.17

Where, W1= weight of the concrete before exposure to sulfate solution

W2 = weight of the concrete after exposure to the sulfate solution

3.6.4. Characterization of Concrete via XRD and SEM

Finding out the morphological properties of the concrete was done using a procedure called concrete microstructural analysis. Examinations under a microscope and X-ray microanalysis were extremely helpful in the research of concrete microstructure. Techniques like SEM and XRD were created for photos with a sub-micrometer resolution of the intricate microstructure of concrete.

SEM - the SEM scans the specimen with a concentrated electron beam and records any signals created by the beams interactions with the sample. Topography photos are used to examine a surface's size, form, surface roughness, and fracture. To undertake an SEM study of the concrete, samples from the control mix and 2% self-curing were taken after 28 days of curing. At first, the samples were made by taking a piece of the cured specimen and taking it down to size.

XRD - a piece of the concrete from the control was removed, and 2% self-curing specimens were cured for 28 days before being analyzed using XRD. The specimens' top, middle, and bottom halves were used to create the parts. The pieces were subsequently crushed to a powder and brought to the XRD lab. After examination, the peaks were produced using the Origin Software utilizing the gathered XRD data in terms of diffraction intensity and degree. After that, the peaks were analyzed with the help of the X'pert High Score plus programmed.

3.7. Analysis of Cost

To analyze cost for traditional concrete, the material cost and the curing procedure is necessary. For normal curing processes, extra time and money are required for labor to transport water through vehicles for road and bridge projects. However, there are no additional costs associated with the curing process for self-curing concrete. In order to analyse cost conventional cost analysis method such as material and curing process cost for 1 m^3 of concrete, for construction works performed and the price is provided in Ethiopian Birr.

3.8. Summary

In this chapter, the research methodology was discussed. After presenting the overall research methodology of the study, the methodology adopted for individual objectives was discussed. In this chapter, the materials and chemicals used in this experiment were examined to ensure that their physical and microstructural qualities met the requirements set out by the standard. Materials and chemicals used in the experimental examination of polyethylene 400-based self-curing concrete are discussed in this part, along with their properties. The results of various analyses and discussions using the research methodology for different research objectives are described in the next chapter.

4. RESULTS AND DISCUSSION

4.1. Introduction

The previous chapter discussed the research methodology adopted in this study. This chapter presents the test results of cement, Fine Aggregate, and Coarse Aggregate. as well as The characteristics of the materials employed in this investigation were discussed. Additionally, the concrete's workability, compressive strength, water absorption, sulfate attack, and microstructure were discussed. Finally, the economic use of poly ethylene glycol 400 based self-curing concrete was presented.

4.2. Material Characteristics

4.2.1. Tests on Cement

4.2.1.1. Normal Consistency of Cement

The results of the consistency test of cement are interpreted based on the depth of penetration of the Vicat apparatus plunger into the cement paste. The different types of consistency and their corresponding depth of penetration are Dry or stiff consistency: the depth of penetration is less than 5 mm; normal consistency: the depth of penetration is between 5 to 7 mm. soft consistency: the depth of penetration is between 7 to 10 mm; very soft consistency: the depth of penetration is between 10 to 15 mm; and fluid consistency: the depth of penetration is more than 15 mm. According to ASTM C 187, normal consistency, also known as standard consistency, is the ability of a 10 mm Vicat plunger to penetrate to a point between 5 and 7 mm above the bottom of the Vicat mold calculated. According to the test results, cement has a typical consistency. As the Vicat plunger immersed about 7 mm into the material, it penetrated 27%. This shows that 27% of the weight of cement is made up of water to create a cement paste.

4.2.2. Fine Aggregate

4.2.2.1. Silt Content

By using silt content analysis, the amount of silt that was deposited over the clean sand was calculated. After measuring the silt content, the fine aggregate was washed to remove silt, clay, mud, and other impurities for the mix's quality and a better outcome (ASTM C 117). Equation

3.2 was used to determine the silt content. According to ASTM C 33, Table 4.1 shows that the fine aggregate's silt content was 3.06%, which is within the acceptable range.

Table4. 1 Analysis of Silt Content

Items	Trial 1	Trial 2	Trial 3	Average
A	10	9	8.5	9.17
B	300	300	300	300
$Silt\ Content\ (\%) = \frac{A}{B} * 100\%$	3.33	3	2.83	3.06%

4.2.2.2. Specific Gravity and Water Absorption of Fine Aggregate

Using Equations 3.3, 3.5, and 3.6, respectively, the bulk specific gravity (Bsg), apparent specific gravity (ASG), and water absorption of fine aggregate were calculated in this work. Following the ASTM C33 range, the Bsg, Asg, and water absorption were 2.55, 2.69, and 3.31%, respectively as shown in the table 4.2 below.

Table4. 2 Specific Gravity and Water Absorption of Fine Aggregate

	Calculations		Result
Bulk-specific gravity (Bsg)	$Bsg = \frac{D}{(B+D-C)}$	$= \frac{500}{(1461+500-1765)}$	= 2.55
Apparent specific gravity (Asg)	$Asg = \frac{A}{(B+A-C)}$	$= \frac{484}{(1461+484-1765)}$	= 2.69
Water absorption (WA) in %	$Absorption = \frac{D-A}{A} *100\%$	$= \frac{500-484}{484} *100\%$	= 3.31

4.2.2.3. Unit Weight of Fine Aggregate

The unit weight of the fine aggregate represents the volume that it will occupy in the concrete. The unit weight of fine aggregate was determined using Equation 3.11, and the results showed that it was 1,418.82 kg/m^3 shown in table 4.3 below and the fine aggregate's computed unit weight was within the range per ASTM C29 specified.

Table 4. 3 Unit Weight of Fine Aggregate Calculation

Descriptions	Quantity	Calculation	AST range
A = Fine aggregate plus cylinder weight	6,684g	UWFA = $\frac{A-C}{V}$	1200-1720kg/m^3
C = Weight of empty cylinder	4,734 g	$= \frac{6,684-4,734}{0.001375}$	
V= Cylinder volume	0.001375 m^3	= 1,418.82 kg/m^3	

4.2.2.4. Sieve Analysis of Fine Aggregate

The distribution of a material's particle sizes is measured via sieve analysis. 4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.3 mm, 0.15 mm, and pan sieve sizes were used for this investigation. The fineness modulus of fine aggregate is illustrated in table 4.2. Using Equation 3.13, the fineness modulus of the fine aggregate was calculated.

Table4. 4.Sieve analysis results and standard for fine aggregate.

Sieve opening (mm)	Weight of container (g)	Weight of container+ FA retained(g)	Weight of FA retained (g)	Percent of FA retained (g)	Cumulative percent retained (%)	Percent finer (%)	Range of finer (%)
4.75	441	441	0	0	0	100	98-100
2.36	383	450	67	13.4	13.4	86.6	80-100
1.18	359	444	85	17	30.4	69.6	50-85
0.60	329	430	101	20.2	50.6	49.4	25-60
0.30	301	483	182	36.4	87	13	5-30
0.15	278	343	65	13	100	0	0-10
Pan	252	252	0	0	0	0	-
Total cumulative percentage retained by mass = 281.4							

$$\text{Fineness modules} = \frac{13.4+30.4+50.6+87+100}{100} = 2.8$$

The outcome showed that the fine aggregate's fineness modulus was 2.8 and that its percent finer fell within the range of (ASTM C33), which is between 2.3 and 3.1.

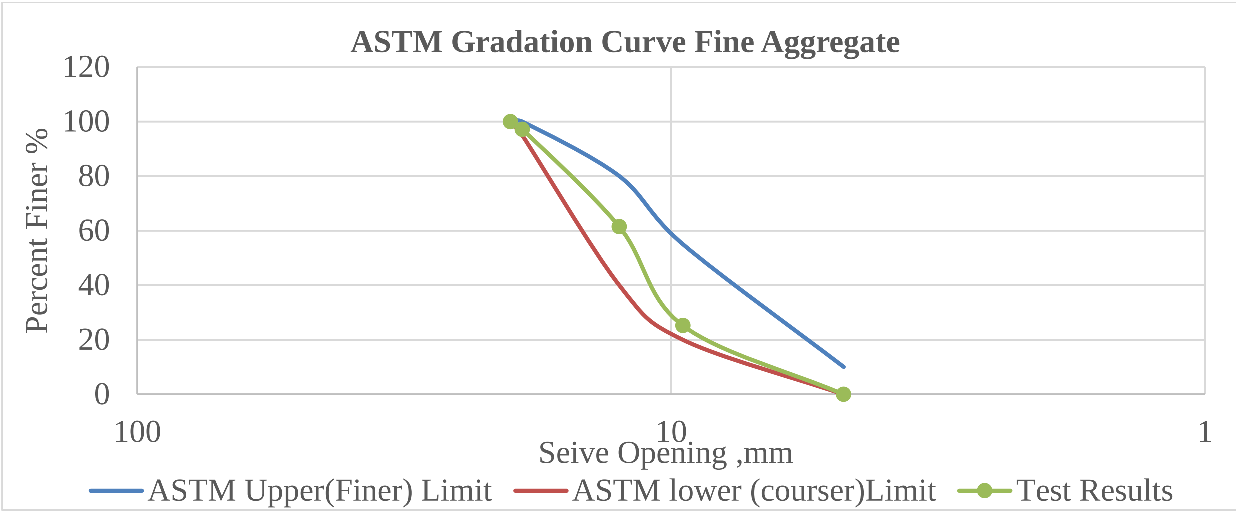

Figure4. 1. Fine Aggregate Gradation Curve

4.2.3. Coarse Aggregate

4.2.3.1. Specific Gravity and Water Absorption of Coarse Aggregate

The computation in Table 4.5 determined that the apparent and bulk-specific gravities of coarse aggregate were 2.62 and 2.68, respectively. Although the achieved water absorption of coarse aggregate is 1.33 percent, the outcome was within the range of the ASTM C128 limit (2.5 to 3.0) for coarse aggregate specific gravity. Additionally, the amount of water absorbed by coarse aggregate fell below the permitted maximum value (2%).

Table4. 5 Specific Gravity and Water Absorption Capacity of Coarse Aggregate

Descriptions	Quantity	Calculation
M= Weight of oven-dry specimen in air	2960g	Bsg $= \frac{3000}{3000-1855} = 2.62$
N = Weight of the saturated surface-dry specimen	3000 g	Asg $= \frac{2960}{2960-1855} = 2.68$
W= Weight of Pycnometer with specimen and Water to the calibration mark	1855g	Absorption $= \frac{3000-2960}{3000} * 100\% = 1.33\%$

4.2.3.2. Unit Weight of Coarse Aggregate

The volume of space that coarse aggregate will take in the concrete is measured by its unit weight. Equation 3.12 was used to calculate the UWCA, and Table 4.6 contains the results. The outcome reveals that coarse aggregate has a unit weight of 1,633.45 kg/m^3. The test outcome in this part complies per ASTM C29 standard.

Table4. 6. Unit Weight of Coarse Aggregate Calculation

Descriptions	Quantity	Calculation
B = Coarse aggregate plus cylinder weight	6,980	$UWCA = \frac{B-E}{F}$
E = Weight of empty cylinder	4,734 g	$= \frac{6{,}980-4{,}734}{0.001375}$
F= Cylinder volume	0.001375 m^3	= 1,633.45 kg/m^3

The outcome demonstrates that coarse aggregate was laid between the limits (1200 to 1750) kg/m^3 that ASTM C29 specified. Therefore, in terms of unit weight, the coarse aggregate employed for the current investigation met the requirements.

4.2.3.3. Sieve Analysis of Coarse Aggregate

The laboratory test was carried out to identify the physical properties of the coarse aggregate was meeting the grading requirement ASTM C136. The grain size distribution of the coarse aggregate and the grading requirement for coarse aggregate according to ASTM C136 (2006) is as shown in Table 4.7.

Table4. 7.Result of sieve analysis of coarse aggregate

Sieve opening (mm)	Weight of container (g)	Weight of container+ FA retained(g)	Weight of FA retained (g)	Percent of FA retained (g)	Cumulative percent retained (%)	Percent finer (%)	Range of finer (%)
20	1380	1380	0	0	0	100	100
19	430	486	56	2.8	2.8	97.2	95-100
12.5	440	1,155	715	35.75	38.55	61.45	40-80
9.5	442	1,167	725	36.25	74.8	25.2	20-55
4.75	443	956	514	25.7	100	0	0-10
Pan	252	252	0	0	0	0	-

The gradation curve of the employed coarse aggregate was within the ASTM lower and higher

The material test results of cement, fine aggregate, coarse aggregate, and water in the current study can be summarized in Table 4.8 below.

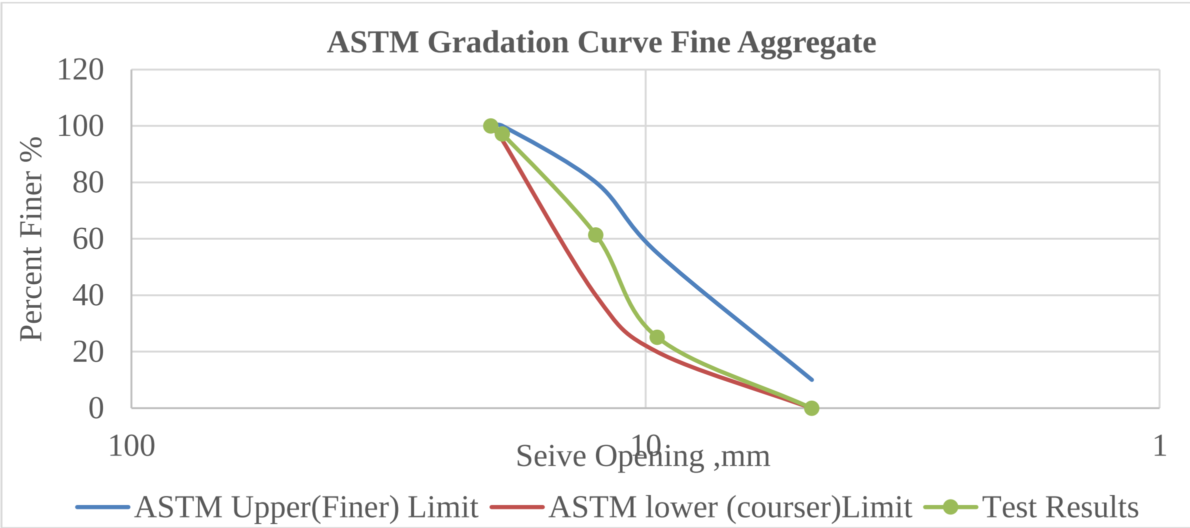

Figure4. 2 Gradation Curve of Coarse Aggregate

Table4. 8 Summary of Material Test Results

	Test Results		
Description	Cement	Fine aggregate	Coarse aggregate
Silt content (%)		3.05%	
Unit weight (kg/m3)		1,418.82kg/m^3	1,633.45kg/m^3
Water absorption (%)		3.31%	1.33%
Consistency	27%		
Fineness modulus		2.8	
Bsg		2.55	2.62
A sg		2.69	2.68

4.3. Test Result for Fresh Concrete Property

4.3.1. Workability of the Concrete

Following ASTM-C 143, the researcher determines the effect of polyethylene glycol 400 on the properties of fresh concrete. As the percentage of PEG rises, concrete becomes more workable. The obtained result suggested that increasing the amount of PEG 400 in concrete increases its workability, which is similar to the characteristics of other chemical additives covered in the literature. Table 4. 9 and Figure 4.3 below show the result of the slump value of self-curing and control concrete

Table4. 9.Fresh concretes mean slump value results

NO	Mix Code	Percent Added	Slump result in (mm)
1	PEG1	0	30
2	PEG1	1	40
3	PEG1.5	1.5	45
4	PEG2	2	50
5	PEG2.5	2.5	55
6	PEG3	3	60

Despite not being a component of the combination, the internal curing agent made the mixture more workable because the chemical was a liquid. This is because as the PEG dosage increases, the fluidity of the mix increases. The workability of fresh concrete was increased in the current investigation by adding polyethylene glycol to the concrete mixture, and comparable outcomes were reported by (Kale & Sawant, 2022; Mandiwal & Jamle, 2018; Sharafat et al., 2019). Fresh concrete was getting more workable, making it simpler to mix, pour, and compact as the slump value increased. This might be because polyethylene glycol, which is used in the concrete mix as a reducing agent, could enhance the fluidity of freshly mixed concrete (Verma & Nigam, 2007).

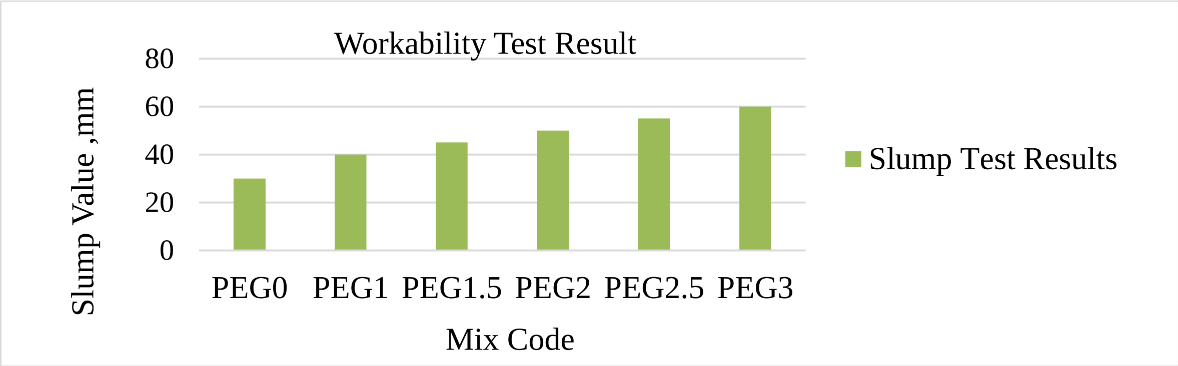

Figure4. 3 Self-Cured and Conventional Concrete

4.4. Test Result for Hardened Concrete Property

4.4.1. Compressive Strength

The compressive strength test is the most common test for hardened concrete. Concrete is easy to distinguish from other materials in various tests that rely on compressive strength. Cubes 150 x 150 x 150 mm in size were used to evaluate the compressive strength of concrete while they were under a 3000 KN compression machine. The compressive strength of the concrete for each mix code and curing day was calculated using the average values from three cube samples. The current research indicates that, in comparison to conventional concrete, all self-curing concrete samples had improved compressive strength. Table 4.10 provides a summary of the data about average compressive strength.

The data shown in Table 4.10 indicate that at 7 days, the compressive strength of the control PEG 400 mix was recorded as having the highest value (39.15N/mm^2). This is because, in comparison with conventional concrete, polyethylene-containing concrete achieves early strength due to the availability of water, which enables the hydration to continue and increase the setting. The PEG 2% mix's compressive strength was 36.14 N/mm^2 and 39.15 N/mm^2, respectively, at its greatest points for the corresponding curing days of 14 and 28 days. The current study's findings show that self-curing concrete made with polyethylene glycol 400 and peg 2% maintains its maximum compressive strength.

Using a chemical curing agent such as PEG was also reported to reduce early-age shrinkage cracks. The results revealed that adding PEG to the concrete mixes to perform the self-curing role contributes to reducing dry shrinkage compared with reference concrete. Hence, the application of the self-curing explained in this research increased the subsequent degree of hydration of cement and the chemical shrinkage, consequently effectively reducing early and late shrinkage.

Table4. 10.Average compressive strength of conventional and self-cured concrete at 7, 14, and 28 days of age.

		Average compressive strength result (N/mm2)			
No.	Mix code (%)	7th day	14th day	28th day	% increase
1	PEG0	21.84	28.06	32.52	
2	PEG1	23.21	30.49	35.25	8.39
3	PEG1.5	23.45	31.30	35.57	9.38
4	PEG2	28.86	36.14	39.15	20.39
5	PEG2.5	25.58	31.71	37.11	14.11
6	PEG3	24.28	30.96	36.16	11.19

Figure 4.4 shows that the compressive strength of concrete with 2% PEG improves by 20.39% when compared to the conventional one. The reason for the highest improvement is that the concrete matrix is less porous at an early age. It is also said that PEG-400 is the best water retention agent on concrete for the continuous hydration process to get fewer voids and pours in the concrete leading to an increase in concrete strength. PEG strengthened hydrogen bonds between water molecules, thus preventing water evaporation and enhancing C-S-H gel production required for concrete compressive strength.

Recently, applying Polyethylene Glycol-400 (PEG) as a chemical agent in self-curing concrete will help to reduce self-desiccation and improve mechanical characteristics. PEG-400 retains the internal water for proper hydration of cement in concrete as compared to conventional concrete (Kalaivani et al., 2020; Sharafat et al., 2019; Sudharson et al., 2021).

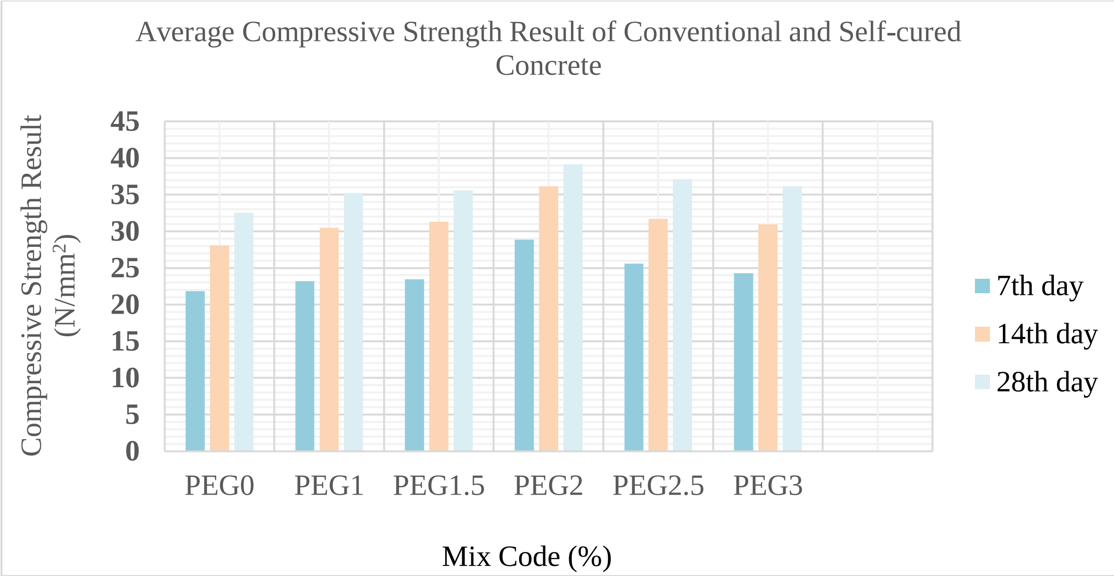

Figure4. 4 Average compressive strength of the concrete

The strength of the self-curing concrete is more when compared to the conventional curing evaporation minimizes and surface tension of water from concrete, consequently assembling the water maintenance limit of the concrete for the nonstop hydration reason. In general, introducing PEG-400 into concrete mixtures can improve compressive strength significantly.

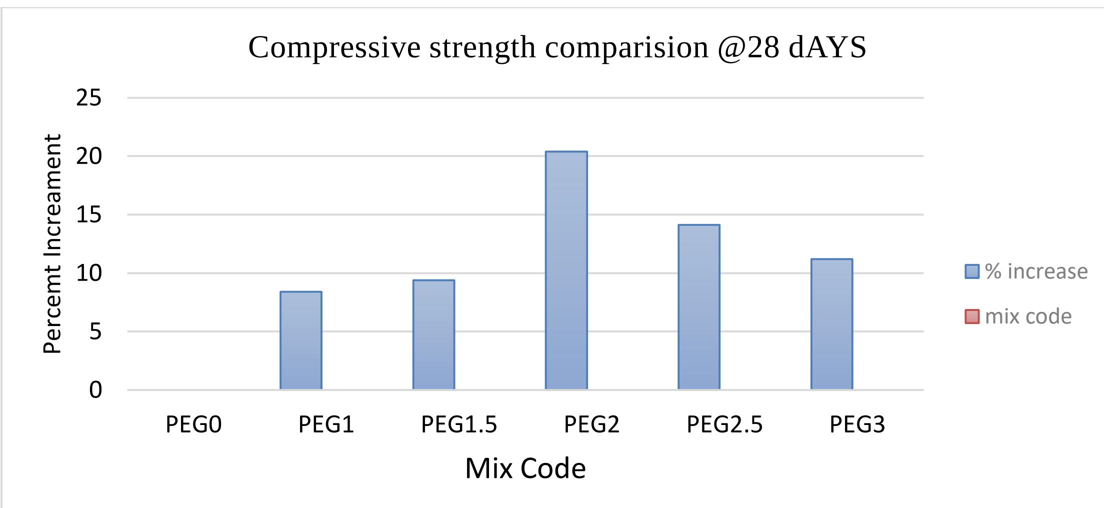

Figure4. 5 Compressive Strength Improvement at 28 days

4.4.2. Flexural Strength

The beam specimens were tested on the universal testing machine for two-point loading to create pure bending. The bearing surface of the machine was wiped off clean and sand or other material is removed from the surface of the specimen. The two-point bending load applied was increased continuously at a constant rate until the specimen breaks down and no longer can be sustained. The maximum load applied to the specimen was recorded.

Table4. 11.Result of Flexural Strength on Beams

	Average Flexural Strength Result (N/mm^{2})				
No.	Mix code (%)	7th day	14th day	28th day	% increase
1	PEG0	4.63	5.36	5.86	
2	PEG1	4.68	5.45	5.92	1.02
3	PEG1.5	4.7	5.52	6.02	2.73
4	PEG2	4.87	5.88	6.75	15.19
5	PEG2.5	4.75	5.58	6.44	6.78
6	PEG3	4.72	5.55	6.21	5.97

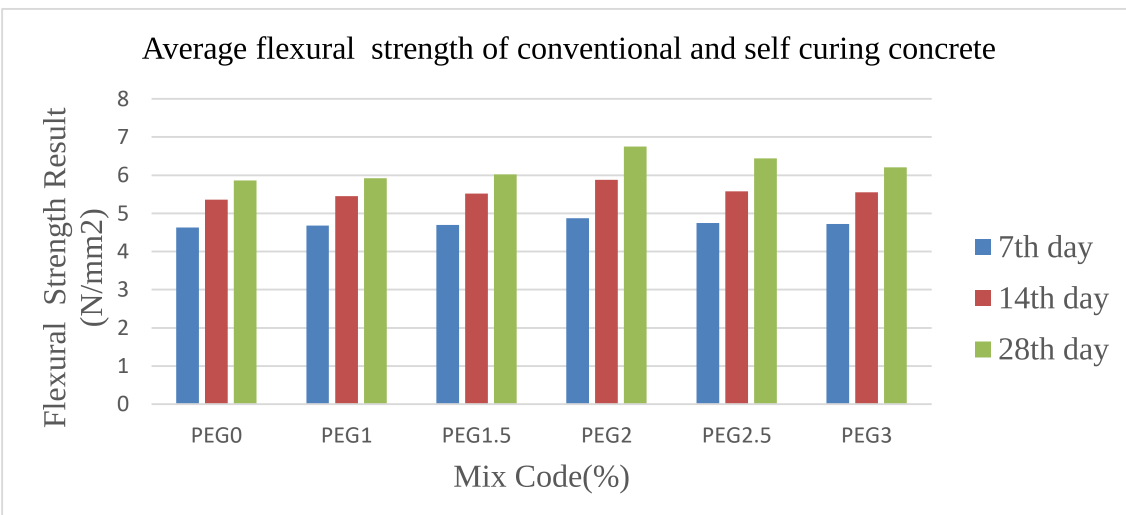

Figure4. 6 Average Flexural Strength of Self-Curing Concrete

Flexural strength was increased by introducing PEGs, which stopped water from evaporating and improved cement hydration results. PEG accelerates the curing process, which increases concrete's flexural strength while also eliminating concrete pores.

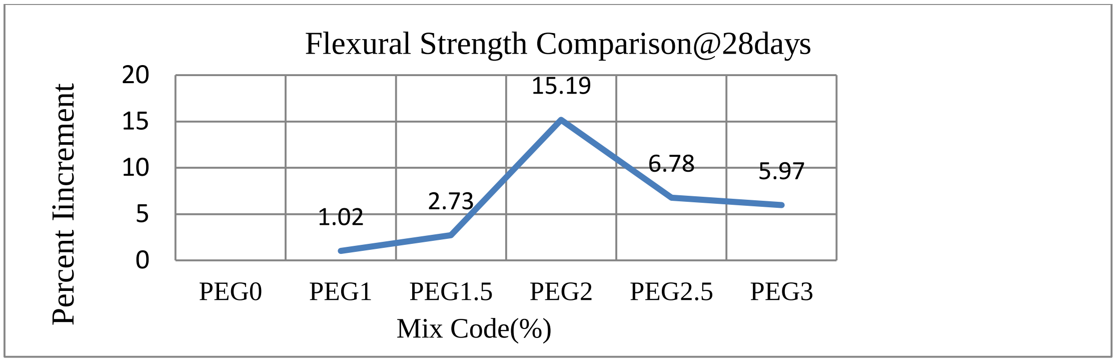

Figure4. 7 Flexural Strength Improvement at 28 days

4.4.4. Water Absorption of polyethylene glycol-based self-curing and conventional curing

To calculate the amount of water absorbed under particular circumstances, water absorption is utilized. The durability of the concrete was evaluated using a water absorption test. Compared to samples of traditional concrete, self-curing concrete had less water absorption (Karthiga et al., 2019, 2019; Seenu & Kaviya, 2017). Using Equations 3.15 and 3.16 were used, respectively, to calculate the water absorption and the percent reduction of the water absorption. Table 4.12 provides the average concrete water absorption and reduction percentage at 7 days and 28 days.

Table4. 12. Average water absorption and reduction in percentage.

No	Mix code	Average of water absorption and reduction percentage							
		At 7th day				At 28th day			
		S	O	% of water absorption @ 7 days	% age reduction	S	O	% of water absorption @ 28 days	% age reduction
1	PEG0	748	690	8.4		763	708	7.77	
2	PEG1	756	702	7.7	8.33	770	720	6. 94	10.68
3	PEG1.5	754	702	7.4	11.90	764	715	6.85	11.84
4	PEG3	764	712	7.3	13.09	754	707	6.65	14.41
5	PEG2.5	776	725	7.03	16.31	760	714	6.44	17.12
6	PEG2	788	740	6.49	22.74	788	748	5.34	31.27

The highest reduction in water absorption of PEG 400-based self-curing at 7 days and 28 days of curing was 22.74 % and at 28 days of curing was 31.27% respectively, for 2% of PEG 400 dosage compared to the conventional concrete (Figure 4.8 and Table 4.12). The results of the study showed that adding polyethylene glycol 400 to concrete at 7 and 28 days of curing reduced its ability to absorb water. When polyethylene glycol was added to the concrete paste, the pores were filled, which reduces water absorption and increases the durability of the concrete.

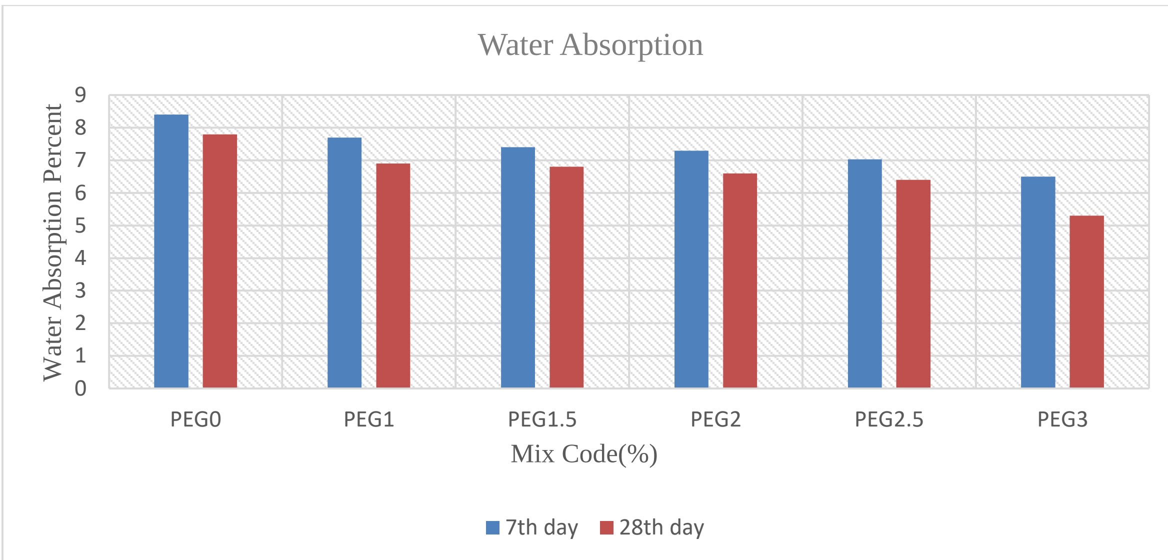

Figure4. 8. Water Absorption of Conventional and Self-Curing Concrete

4.4.5. Sulfate Attack of polyethylene glycol-based self-curing and conventional curing

To determine the weight loss of various types of concrete, tests were conducted in accordance with ASTM C1260 to determine the weight loss of various types of concrete. Results of the sulphate attack test are shown in Table 4.13. According to the results, weight loss on different percentages of self-curing concrete as compared to conventional concrete is reduced by 30 days of sulphate attack solution to the concrete.

Table4. 13 Average sulfate attack and loss in percentage

No	Mix Code	Average sulfate attack and loss in percentage at 28th day			
		W1(kg)	W2(kg)	Weight loss in kg @ 28 days	% of loss
1	PEG0	7.185	7.155	0.030	0.42
2	PEG1	7.334	7.310	0.024	0.327
3	PEG1.5	7.520	7.499	0.021	0.279
4	PEG2	7.355	7.337	0.018	0.245
5	PEG2.5	7.217	7.200	0.017	0.236
5	PEG3	7.612	7.596	0.016	0.21

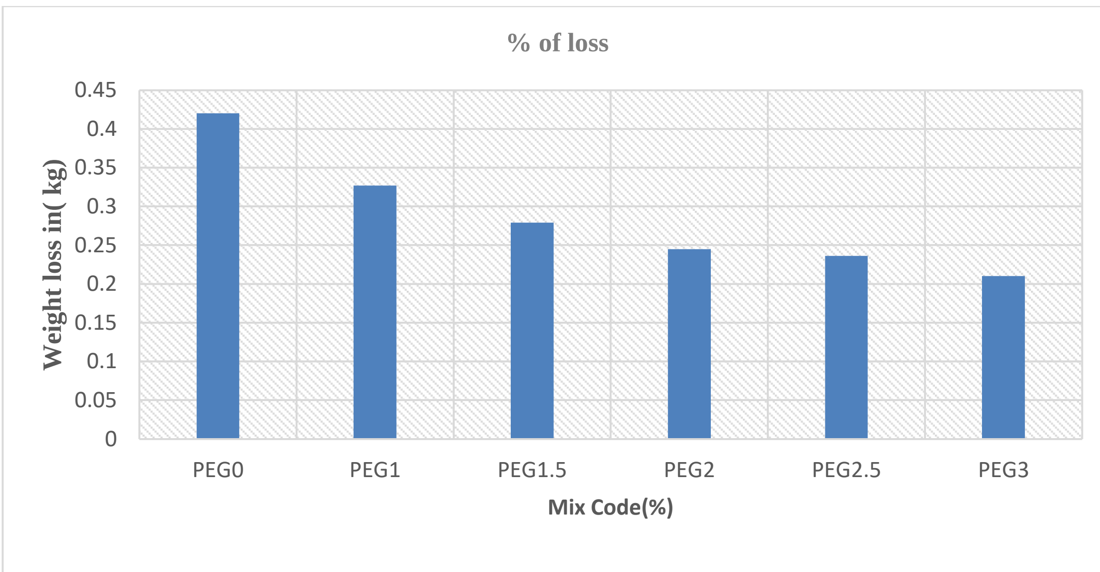

Figure4. 9. Sulfate attack Weight loss in kg @ 28 days

According to the information shown in Figure 4.8, Comparing self-curing concrete to conventional concrete, the weight loss from sulfate attack is lower. This result can be explained by the simultaneity of calcium hydroxide dissolution and C-S-H decalcification with sulfate diffusion in concrete, where the dissolution and decalcification dominated at early immersion times.

4.4.6 Microstructural Analysis of polyethylene glycol-based and Conventional Concrete

4.4.6.1. SEM Analysis

In the present study, the microstructure of the concrete was analyzed using Scanning Electron Microscope (SEM) which practically helps to visualize the microstructure polyethylene glycol-based and Conventional Concrete Microstructural observations of control and 2% PEG 400 mixtures using SEM investigation can be seen in Figure 4.9 shows. Due to the greatest compressive strength, improved workability reported reduced water absorption, and less weight loss during sulfate attack at 2% PEG400 based self-curing concrete by cement weight compared to other percentages, the 2% PEG400 mix was studied using SEM.

The capture of SEM pictures follows a prolonged 28-day curing process. By its comparative brightness and hexagonal patterns in the concrete, calcium hydroxide can be identified. Figure 4.9 depicts the thin, brilliant structure that was seen in the control mixture and may have been CH. The microstructure of each blend was examined under (x1500) magnification and shows that water-immersed curing converts cement particles into CH and CSH after hydration and few places show the crystalline structure of Ettringite whereas PEG-based concrete microstructure shows Ettringite in the greatest quantity and small gaps or cracks that were clearly present in this case compared to the control mix. The formation of calcium hydroxide (CH) represents hydration initiation, however, the process still has to continue for the maximum duration. The curing of concrete microstructure takes 28 days, representing a transformation of the cement molecule into calcium silicate hydrate (CSH). Moisture is retained inside concrete specimens by a uniform blend of admixture. This prevents the evaporation of moisture and helps to cure to occur as soon as necessary after the required curing period.

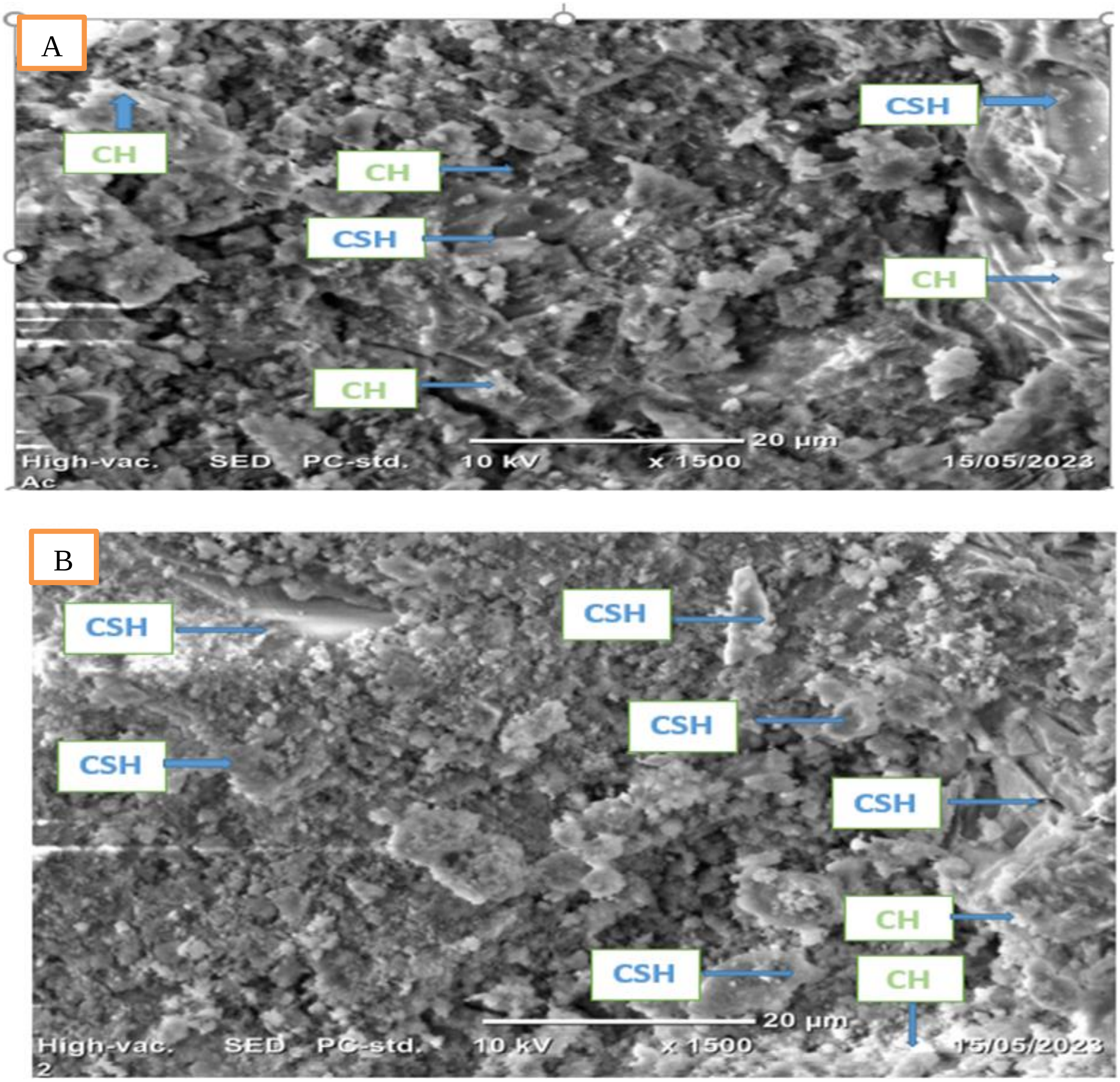

Figure4. 10 SEM images 28 days. at 1000 magnification (A) convention and (B) 2% PEG

4.4.6.2. XRD Analysis

Figure 4.10A illustrates the predominant hydration process of samples that started and form CSH gel. The diffraction angle 2θ with sharp peaks indicates the presence of ether and hydroxyl groups. A height of 2θ accelerates the presence of tricalcium silicate into calcium aluminum silicate hydrogen. A few places of the sample in the micro level indicate the incomplete hydration process through the availability of Ettringite—sample specimen core area of particles took a longer time to react with H_2O. The findings from XRD.

In Figure 4.10B, XRD represents the sample of chemical admixture in the self-curing process. Holding moisture around cement particles in concrete mixing plays a significant role in supporting the hydration process. Plot XRD indicates that the hydration process of concrete was completed, and the complex compound CSH and CH was formed.

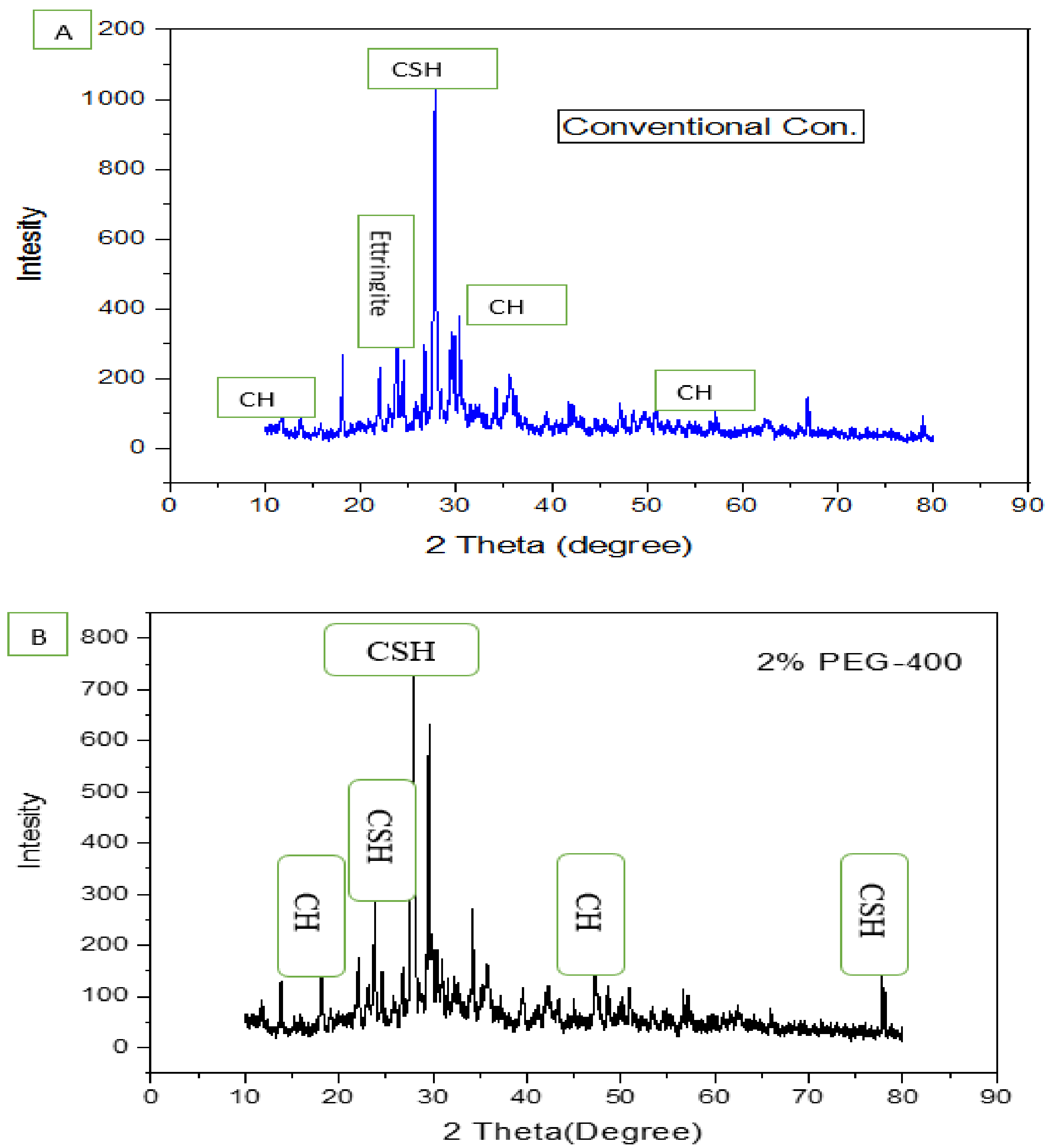

Figure4. 11 XRD analysis of (A)Conventional,(B) polyethylene lycol-400

4.4.7. Analysis of Cost of Self-Curing Concrete

4.4.7.1. The material cost of SCC and CC

Estimated material costs for the production of concrete with and without PEG-400 were used to evaluate the analysis of the economic consequences of utilizing PEG-400 as a self-curing concrete. The calculation of costs was based on the current market price of materials surveyed on March 16, 2023 Based on the current market prices for construction materials, one quintal of OPC National cement costs about 1,800 ETB. It was about 18 ETB per kilogram after conversion. The price of coarse aggregate is 1500 ETB per cubic meter, whereas the price of fine aggregate is 1600 ETB. In addition, water costs 25 ETB per cubic meter. The estimated total material cost to make one cubic meter of typical concrete was 8,705.30ETB, as shown in Table 4.14.

I) Material cost for producing one cubic meter of conventional concrete

Table4. 14.Material Cost Analysis of Traditional Concrete

Types of material	Unit	Quantity	Rate	Cost (ETB/m^3)
Cement	Kg	425	18	7650
Fine Aggregate	M^3	0.31	1600	496
Coarse Aggregate	M^3	0.37	1500	555
Water	M^3	0.172	25	4.3
Total				8,705.30

I) Material cost for producing one cubic meter of 2% PEG-400-based self-curing

The rate of PEG 400 per kg was 600 ETB based on the current market price on March 16, 2023. The material cost of 2% PEG 400-based self-curing concrete was higher than the rate of conventional concrete. As a result, the estimated total cost of one cubic meter of concrete with 2% PEG 400 increases by 1.58 ETB when compared to conventional concrete. PEG 400-based self-curing concrete has a higher material cost overall than ordinary concrete, but it is necessary to reduce open porosity on the surface of the concrete to produce safe and more durable concrete, extending the lifespan of the construction and lowering repair costs. Additionally, it contributed to water safety and mechanical strength greater than that of regular concrete. This advantage makes the higher material cost seem less effective.

Table4. 15.Material Cost Analysis of Peg 2% self-curing Concrete

Types of material	Unit	Quantity	Rate	Cost (ETB/m^3)
Cement	Kg	425	18	7650
Fine aggregate	M^3	0.31	1600	496
Coarse aggregate	M^3	0.37	1500	555
Water	M^3	0.172	25	4.3
PEG-400	Kg	8.5	600	5,100
Total				13,805.3

4.4.7.2. The Curing process cost of SCC and CC

For traditional concrete, the curing procedure was necessary. For normal curing processes, more time and money were required for workers to transport water through vehicles for road and bridge projects. However, there were no additional costs associated with the curing process for self-curing concrete (Hamzah et al., 2022; Lokeshwari et al., 2021; Memon et al., 2018). When compared to mixing in construction, curing used larger amounts of water. It was discovered that 3 m^3 of water is needed to cure 1 m^3 of concrete.

The estimation and cost-benefit analysis for curing concrete with self-curing polyethylene glycol (PEG-400) and conventional curing methods were displayed in Table 4.15. In Table 4.15, a comparison of the cost-benefit analyses of conventional and self-curing concretes was shown. Costs were calculated based on the materials' current market prices surveyed on March 16, 2022.

Table4. 16.Estimation for curing process of conventional and self-curing concrete

Type of Concrete	Water Required for Curing Process of 1 m^3 Concrete	Cost of Water Per Liter (ETB)	Labor Cost for Conventional Curing Process of 1 m3 (Number of Laborers × Labor Cost Per Day) Or Self-Curing Polyethylene Glycol (PEG-400) Concrete-(Number of Liters × Cost)	The Total Cost Required for 1 m3 of Concrete (ETB) X = (A × B) + (C)
Conventional Concrete	3000	1	3*200	3600
Self-curing Concrete	172	1	3.2*600	2092
	The Cost saved by using self-curing PEG 400 for 1 m^3 of concrete (ETB) = 1508			

Where: A = Liters of water B = Cost of water /L C = Labor cost/ Cost of PEG-400/L

It has been demonstrated that the self-curing method reduces the cost of the curing procedure by around 1,508 ETB for 1 m^3 of concrete. Consequently, this study suggested that for construction projects including bridges, railroads, distant sites, steep and mountainous areas, and water-scarce areas, self-curing concrete is preferred.

5. CONCLUSIONS AND RECOMMENDATIONS

The findings and suggestions of this study were based on the experiment's results and overall performance.

5.1 Conclusions

This study investigated the production of PEG-400 based self-curing concrete. The research showed that the workability of the PEG -400 based self- curing concrete was influenced by the of percentage of PEG-400 used in the mix, with an increase in PEG-400 leading to an increase in workability. Additionally, the compressive strength test results were obtained on the 7th, 14th, and 28th days of curing ages. The 28th-day compressive strength for all samples achieved the desired strength. The maximum compressive strength was recorded for 2% of polyethylene glycol-400, so 1% polyethylene glycol-400 is the optimum percentage. Self-cured concrete has better compressive strength results than conventionally cured concrete. According to various studies, studies have shown that the strength of self-curing concrete is greater than conventional concrete, and this research is consistent with previous studies.

By adding 2% PEG -400, the compressive strength of the concrete increased by 20.39% after 28 days of curing, compared to conventional concrete. This improvement is due to the formation of additional amorphous C-S-H. On the other hand, as the addition percentage rose up to 3%, the compressive strength of the concrete reduced. Furthermore, it was observed that the water absorption of self-curing concrete based on PEG-400 decreased for all concrete samples after 7 and 28 days of curing. Specifically, at the end of the 28-day curing period, the smallest amount of water absorption (2.64) was found in the sample containing 2% PEG-400, compared to conventional concrete and other PEG-400 samples. This decrease in water absorption may be attributed to the filling of pores in the concrete matrix as a result of the formation of CSH-gel. In addition, it was observed that after 30 days, all concrete specimens incorporating PEG-400 and exposed to sulfate solution exhibited less weight loss compared to their respective control specimens. Among the PEG-400 based self-curing concrete samples and control specimen, the specimens with 2% PEG-400 experienced the lowest weight loss in terms of mass. Furthermore, the microstructure analysis of the concrete containing 2% PEG revealed the presence of additional C-S-H gel on day 28, indicating further development.

5.2 Recommendations

PEG-400 based self-curing concrete offers a cost-effective solution with enhanced workability, strength, reduced water absorption, and improved resistance to sulfate attack in comparison to traditional concrete. It also promotes safety and streamlines construction processes, bringing about a revolution in the industry. However, it is important to note that there are challenges, such as the rising cost of PEG-400. The scope of the current study focused on evaluating workability, compressive strength, flexural strength, water absorption, sulfate attack resistance, SEM analysis, XRD analysis, and economic considerations.

Future investigations will encompass further assessments of various concrete properties such as

- Tensile strength, and modulus of elasticity.
- Chloride attack and sulphuric acid tests will be conducted to assess the long-term durability of concrete.
- Study the properties of self-curing concrete with different types of materials, by partial replacement of cement.
- Study on the effects of weather condition on the properties of self-curing concrete.

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APPENDIX

Appendix A: Tables for ACI concrete mix design

Appendix A1: Factor based on the grade of concrete

Specified characteristic compressive strength (fck,Mpa)	Required average compressive strength (f'ck,Mpa)
<21	fck + 7
21-35	fck + 8.5
>35	1.1 * fck + 5

Appendix A2: Recommended slumps for various types of constructions

Types of constructions	Slump (cm)	
	Minimum	Maximum
Reinforced foundations, walls, and footings	2	8
Plain footings, cassoins ,and substructure walls	2	8
Beams and reinforced walls	2	10
Building columns	2	10
Pavements and slabs	2	8
Heavy mass concrete	2	8

Appendix A3: Approximate mixing water requirements for different slumps and maximum sizes of aggregates.

Slump (cm)	Water kg/m3 of concrete for indicated max. sizes of aggregate (mm)							
	10	12.5	20	25	40	50	70	150
Non-air entrained concrete								
2 – 10	205	200	185	180	160	155	145	125
8 – 10	225	215	200	195	175	170	160	140
15 - 18	240	230	210	205	185	180	70	0
Approx. amount of entrapped air in nonentrained concrete (%)	3	2.5	2	1.5	1	0.5	0.3	0.2
Air entrained concrete								
3 – 5	180	175	165	160	145	140	135	120
8 - 10	215	206	190	185	170	165	160	0
Recommended average total air content (%)	8	7	6	5	4.5	4	3.5	3

Appendix A4: Estimated water cement ration for average compressive strength concrete.

Compressive strength at 28 days (MPa)	Water cement ratio by mass	
	Non-air entrained	Air entrained
45	0.38	0
40	0.42	0
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.6
15	0.79	0.71

Appendix A5: Volume of coarse Aggregate per unit Volume of concrete.

Maximum size of aggregate	Volume of dry rodded coarse aggregate per unit volume of concrete for different fineness modulus		
	2.6	2.8	3
10	0.50	0.46	0.44
12.5	0.59	0.55	0.53
20	0.66	0.62	0.60
25	0.71	0.67	0.65
40	0.76	0.72	0.70
50	0.78	0.74	0.72
70	0.81	0.77	0.75

Appendix B: Different Test Results

Appendix B1: Detail slump value for fresh concrete that blended with OPC for each mix code three trail was tested.

No	Mix Code	Percent Added (%)	Trail	Slump result(mm)	Average(mm)
			1	29	
			2	30	
1	PEG0	0	3	31	30
			1	39	
			2	41	
2	PEG1	1	3	40	40
			1	44	
			2	46	
3	PEG1.5	1.5	3	45	45
			1	51	
			2	50	
4	PEG2	2	3	49	50
			1	54	
			2	53	
5	PEG 2.5	2.5	3	58	55
			1	59	
			2	61	
6	PEG3	3	3	60	60

Appendix B2: Detail result of compressive strength for different mix code at different curing Periods.

No	Mix Code	Samples	compressive Strength Results (N/mm^2)					
			7th day		14th day		28th day	
			Load (KN)	Strength	Load(KN)	Strength	Load (KN)	Strength
1	PEG0	1	461	22.65	611.35	27.05	723.7	31.68
		2	514	20.78	636.35	29.05	732.7	32.58
		3	497	22.09	649.35	28.09	738.7	33.29
		Average	**491**	**21.84**	**632.35**	**28.06**	**731.7**	**32.52**
2	PEG1	1	564	25.08	701	30.37	836	37.78
		2	586	26.77	705	32.87	831	35.68
		3	578	24.88	734	31.89	839	37.87
		Average	**576**	**25.58**	**713**	**31.71**	**835**	**37.11**
3	PEG1.5	1	530	24.03	690	31.66	793	35.22
		2	506	23.66	709	31.58	788	35.67
		3	548	22.67	712	30.67	796	34.87
		Average	**528**	**23.45**	**704**	**30.31**	**793**	**35.25**
4	PEG2	1	667	28.16	782	40.68	659	41.78
		2	**649**	29.85	814	39.77	668	40.87
		3	632	28.58	844	40.57	640	42.67
		Average	**649**	**28.86**	**813**	**36.14**	**656**	**41.77**
5	PEG2.5	1	543	24.87	683	30.65	804	36.8
		2	538	24.88	698	32.09	813	35.55
		3	557	23.09	709	30.15	820	36.05
		Average	**546**	**24.28**	**697**	**30.96**	**814**	**36.16**
6	PEG3	1	506	22.10	679	30.32	792	35.61
		2	**535**	23.66	686	30.27	789	36.22
		3	526	23.87	691	30.87	819	34.87
		Average	**522**	**23.21**	**686**	**30.49**	**800**	**35.57**

Appendix B3: Water absorption result for each sample at different mix code and curing days.

Mix Code	Samples	Water Absorption (%)					
		7th day			28 th day		
PEG0		O	S	%	O	S	%
	1	690	747	8.26	763	709	7.07
	2	693	745	7.50	764	703	8.68
	3	686	751	9.47	762	712	7.02
	Average	**690**	**748**	**8.4**	**763**	**708**	**7.77**
PEG1	1	685	756	9.39	713	762	6.82
	2	693	753	8.66	717	769	7.25
	3	707	760	6.97	731	778	3.91
	Average	**702**	**756**	**7.7**	**720**	**770**	**6.94**
PEG1.5	1	707	767	7.69	734	784	7.16
	2	699	764	5.12	728	762	5.55
	3	701	760	6.11	729	746	6.82
	Average	**702**	**754**	**7.4**	**715**	**764**	**6.85**
PEG2	1	738	791	7.11	746	791	4.66
	2	726	788	6.13	751	782	5.41
	3	724	784	5.98	748	790	6.19
	Average	**740**	**788**	**6.49**	**748**	**788**	**5.34**
PEG2.5	1	734	773	7.07	701	756	.31
	2	722	785	8.09	709	753	6.45
	3	720	771	8.11	733	760	7.91
	Average	**725**	**776**	**7.03**	**714**	**760**	**6.44**
PEG3	1	702	749	7.49	700	744	6.69
	2	724	767	8.88	702	755	7.12
	3	710	776	6.25	718	762	7.35
	Average	**712**	**764**	**7.3**	**707**	**754**	**6.65**

Appendix B4: Sulphate attack result for each sample at different mix code and 28 curing days

Mix Code	Samples	Sulphate Attack at 28 day			
		W_1 (kg)	W_2(kg)	Weight Loss (kg)	% Loss
PEG0	1	7.673	7.512	0.161	0.02
	2	7.708	7.560	0.148	0.019
	3	7.682	7.473	0.209	0.027
	Average	**7.185**	**7.515**	**0.030**	**0.42**
PEG1	1	7.573	7.315	0.032	0.52
	2	7.562	7.299	0.035	0.46
	3	7.578	7.315	0.036	0.48
	Average	**7.334**	**7.310**	**0.024**	**0.327**
PEG1.5	1	7.527	7.510	0.017	0.19
	2	7.532	7.503	0.035	0.34
	3	7.501	7.484	0.017	0.47
	Average	**7.520**	**7.499**	**0.021**	**0.279**
PEG2	1	7.385	7.373	0.012	0.36
	2	7.329	7.298	0.045	0.47
	3	7.351	7.339	0.026	0.31
	Average	**7.355**	**7.337**	**0.018**	**0.245**
PEG2.5	1	7.227	7.214	0.013	0.16
	2	7.193	7.172	0.021	0.27
	3	7.232	7.213	0.018	0.24
	Average	**7.217**	**7.200**	**0.017**	**0.236**
	1	7.620	7.594	0.028	0.38
	2	7.663	7.654	0.011	0.15
	3	7.531	7.541	0.021	0.29
PEG3	**Average**	**7.612**	**7.596**	**0.016**	**0.21**

Appendix C: Pictures taken during experimental works

Appendix C_1: Pictures captured during conducting unit weight test for fine aggregate and Coarse aggregate

Appendix C_2: Pictures shows casted samples: sized cube for compressive, beam, water absorption test and Sulfate attack test.

Appendix C3: Pictures shows tests for compressive, water absorption test and Sulfate attack.

Appendix C4: Pictures captured during slump test