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**Resistance to Chloride Penetration of Mortar Using Eggshell as a Partial
Replacement of Sand**

A Thesis in Structural Engineering

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A Thesis Submitted in Partial Fulfillment of The Requirements for The Degree of Master of
Science in Structural Engineering.

The undersigned have examined the thesis entitled “**Resistance to Chloride Penetration of Mortar Using Eggshell as a Partial Replacement of Sand**” presented by **Betelhem Aziz**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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UNDERTAKING

I declare that the Study presented in this thesis by the title “**Resistance to Chloride Penetration of Mortar Using Eggshell as a Partial Replacement of Sand**” is my own original work, except where explicitly stated otherwise by reference or acknowledgment.

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ABSTRACT

Concrete became more in demand as the building sector grew. Which leads to ongoing quarrying and causes the depletion of natural resources due to excessive mining of natural sand. Also the increase in demand and consumption of egg leads to waste production which will impact the environment. Utilizing of waste materials will reduce the need for natural aggregate, energy, and environmental damage. This study explores the possibility of substituting sand partially with eggshell in mortar production, with a focus on its effects on compressive strength, flexural strength, and chloride penetration resistance. Eggshells, a readily available waste material, offer a sustainable alternative to traditional sand, addressing both environmental and resource depletion concerns. Mortar samples with varying percentages of eggshell powder replacing sand (0%, 10%, 20%, 25%, and 30%) were prepared and subjected to standard testing procedures. The experimental results indicate a decrease in both compressive and flexural strengths with the inclusion of eggshell, compared to control samples. Specifically, the compressive strength decreased by up to 16%, 38%, 44% and 49% with 10%, 20%, 25%, and 30% replacement respectively the flexural strength saw a reduction of up to 7.8%, 22%, 31% and 43% with 10%, 20%, 25%, and 30% replacement respectively. Despite these reductions in mechanical properties, a replacement up to 5% is acceptable. For flexural strength 25% is acceptable. The resistance to chloride penetration increases as the percentage of eggshell increases with 0% and 10% replacement showing similar results and 30% showed the highest increase in chloride penetration. And also, there is a decrease in the density of mortar samples with eggshell than the controlled samples because of the light weight of eggshell which can be used for reduction of the overall weight of the structure.

Key words :- eggshell, fine aggregate, compressive strength, flexural strength, chloride penetration resistance, mortar.

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1. INTRODUCTION

1.1 Background

Sand is a basic component of concrete, which is made by combining it with aggregates, water, and cement. Sand serves as filler, giving the concrete mixture volume and stability and boosting its strength and durability [1]. For every tonne of cement used to make concrete, the construction sector needs six to seven times as much sand and gravel [2]. According to the United Nations Environment Programme (UNEP), the demand for sand mining has tripled over the last 20 years, with a projected 50 billion tons produced year in 2019 and its extraction from rivers and marine ecosystems can lead to erosion, salination of aquifers, loss of protection against storm surges and impacts on biodiversity, which pose a threat to livelihoods through, among other things, water supply, food production, fisheries, or to the tourism industry [3]. In addition to negatively affecting economic and social development, the massive amount of sand being extracted at the moment is seriously harming rivers, deltas, and coastal and marine ecosystems. Examples of these effects include land loss due to coastal or river erosion, lowering of water levels, and reductions in the amount of available sediment [4]. The excessive extraction and environmental concerns has prompted the exploration of alternative materials to mitigate the impact on the environment. Researchers have been looking on substitute materials in recent years that can be utilized in place of some of the natural sand in concrete manufacturing. Eggshell waste is one such resource that the food industries produce in significant amounts. Eggshells have been found to possess pozzolanic properties, making them a potential sustainable alternative to sand and cement in concrete mixes. This creative solution not only solves environmental issues but also shows how waste materials can be used in construction projects. The industry can promote environmentally friendly practices and lessen their need on traditional resources by using eggshells in mortar mixes as a partial replacement for sand.

1.2 Statement of the problem

The rapid growth of the construction industry has led to an increased demand for natural resources, particularly sand, which is a critical component in concrete production. This has resulted in the over-extraction of sand, leading to severe environmental degradation, depletion of natural resources, and negative impacts on ecosystems. Concurrently, the

disposal of eggshell waste from the poultry industry also in Ethiopia poses a significant environmental challenge, as eggshells are often discarded in landfills, contributing to pollution and waste management issues.

The concept of sustainable construction practices necessitates exploring alternative materials that can mitigate environmental impacts while maintaining or enhancing the properties of construction materials. This thesis investigates the potential use of eggshells as a partial replacement for sand in mortar production. The primary focus is to determine the feasibility, performance, and environmental benefits of incorporating eggshell powder into mortar mixtures on the compressive strength, flexural strength and resistance to chloride penetration.

1.3 Objective

1.3.1 General objective

The general objective of this thesis is to investigate the feasibility and effectiveness of incorporating eggshells as a partial substitute for sand in mortar production, with the aim of enhancing sustainability in the construction industry and addressing environmental issues related to sand mining and eggshell waste disposal.

1.3.2 Specific objectives

- To assess the impact of eggshell on the mechanical properties of mortar, including compressive strength and flexural strength.
- To evaluate the durability performance of mortar with eggshell, by focusing on resistance to chloride penetration.
- To determine the optimal replacement level of eggshell by considering the effect on mortar's strength and waste utilization.

1.4 Scope of the study

In this study, the impact of eggshell on mortar's mechanical and durability performance is investigated in a lab setting. The mechanical characteristics of mortar are evaluated using the compressive and flexural strength tests by replacing eggshell as sand in 10%, 20%, 25% and

30% by weight. Moreover, it makes an effort to assess the resistance to chloride penetration using colorimetric method.

Micro-structural and chemical analysis should be done in order to provided a more comprehensive understanding of the interaction between eggshell and cement hydration products but in this thesis due to limitation of resources and laboratory facilities it was not done.

1.5 Significance of the Study

This thesis investigating the use of eggshell as a partial replacement for sand in mortar holds significant promise for promoting sustainable and cost-effective construction practices. By exploring the potential of eggshells, a readily available waste product, the research contributes to waste reduction and resource conservation. Eggshell incorporation could lessen the reliance on natural sand resources and the environmental impact associated with sand extraction. Furthermore, utilizing eggshells as a partial replacement material has the potential to reduce the overall cost of mortar and concrete production. The study's findings can be valuable for construction professionals seeking environmentally friendly and potentially cost-effective alternatives for mortar production. Ultimately, this research can contribute to the development of sustainable construction materials.

1.6 Organization of the Thesis

The thesis is divided into five main chapters. A general summary of the thesis is provided in the first chapter, which also includes some background information on mortar, sand extraction, and eggshell as well as the goal, scope, and significance of the research. The second chapter provides a detailed and properly cited literature of prior research that is relevant and associated with the study. The third chapter describes the materials and their properties, the techniques used, and the testing methods used to ensure the research's completion. The experimental test results are presented in tables and graphs in Chapter four, along with a thorough discussion of the outcomes and also the economic and environmental consideration of using eggshell as a partial substitute for sand. The study's conclusions are finally presented in Chapter five, along with suggestions for additional research.

2. LITERATURE REVIEW

The worldwide building material concrete which consists of a blend of cement, fine aggregates (such as sand), and coarse aggregates combined with water that solidifies over time has transformed the world by making it possible to build strong, long-lasting structures [5]. Global demand for construction materials is rising as a result of the substantial increase in urbanization and a large-scale infrastructure project and also the rise in construction projects and reliance on traditional concrete materials are causing a shortage of construction materials and driving up construction costs [6, 7].

Sand is a major component of concrete, and its extraction and processing have caused significant ecological problems because natural alluvial sand is fundamentally a non-renewable resource, the degradation of ecosystems for both flora, animals and human groups is made worse by sand mining [8]. Sand and gravel mining from river systems can have direct or indirect effects on rivers. Direct effects are those when the loss of material immediately causes an ecosystem's impact, as in the case of loss of habitat (removal of floodplains or removal of gravel beds). The physical changes in the river system, which in turn cause ecosystem changes that spread throughout the system is an indirect impact like removing material from a river can change the sediment budget, river hydraulics, or channel, all of which can affect how ecosystems function and where their habitats are distributed [6]. Instream sand-and-gravel mining results in the deterioration of rivers by reducing the depth of the streambed, potentially causing bank erosion. Rivers and estuaries get deeper together with the enlargement of coastal inlets and river mouths as a result of the sand being removed from riverbeds and coastal regions [9].

The World Wildlife Fund (WWF) issued a warning in 2018 regarding the dangers of sand mining in river deltas, including the Yangtze and Mekong, as there is insufficient sediment to prevent flooding and thereby increases the likelihood of climate-related disasters [10]. Due to this the industry is looking for alternatives that work better in building as a result of the growing demand for natural sand [11]. Nowadays, there is a lot of research being done on sustainable concrete usually, industrial and municipal wastes are used as substitute materials [5].

Sludge from water treatment facilities, waste products produced during agricultural activities, and any type of rubbish produced by agricultural establishments are all considered solid

waste [12]. Eggshells are agricultural waste products generated by fast-food restaurants, bakeries, and hatcheries for chicks, to name a few. They are generally regarded as useless and are discarded which contribute to pollution, they can also contaminate the environment and cause ecological issues [13, 14]. Researchers are currently exploring the potential of utilizing chicken eggshells, an agricultural waste, in medical and dental treatments. Eggshells contain a significant amount of pure CaCO_3 and have low porosity, making them a valuable resource for such applications [15].

In the last ten years, there has been a notable surge in egg production worldwide. The FAO reports that the total amount of eggs produced increased by 24% in a decade, from 61.7 million tonnes in 2008 to 76.7 million tonnes in 2018 [16].

In Ethiopia, the consumption of eggs is increasing. It is anticipated to increase 0.9% from 45,000 metric tons in 2021 to an estimated 47,000 metric tons by 2026. Demand has increased annually on average by 1.5% since 2017. Ethiopia ranked 82nd globally in terms of consumption in 2021. It was surpassed by Croatia with 45,000 metric tons. The next three greatest consumers were the United States, India, and Japan, in that order [17]. The average annual consumption per person is 161 eggs, calculated by dividing the world's total egg production in 2018 by the world's population of 7.6 billion. About 8.3 million metric tons (MT) of egg shells were produced by the global egg industry in 2019, the majority of which were disposed of in landfills. In contrast, the processing industry produced an estimated 2.4 million MT of egg shells, which were recovered after breaking [18]. Due to the enormous population growth in this emerging world, many countries will confront serious environmental concerns. When waste concentrations in the environment are excessive, it can pose a serious threat to plants, animals, and people [13].

2.1 Eggshell chemical composition and physical characteristics

2.1.1. Chemical composition of eggshell

Eggshells are mostly made of calcium carbonate, although they can also include a variety of other organic and inorganic substances [19]. It is a semipermeable membrane having pores that allow moisture and air to pass through [20].

✓ Major Components:

Calcium Carbonate (CaCO₃): This mineral compound constitutes the primary bulk of eggshells, typically encompassing around 94% and weighing 5.5 grams of the eggshell's weight [19, 21].

✓ Organic Compounds:

Eggshells contain glycoproteins that are helpful for making cosmetics. It also contains glycosaminoglycans, keratin, and dermatan sulfate, which are helpful for making collagen and synthesizing other goods including chitin. It includes sialic acid, a sial-oligosaccharide with anti-influenza and other medicinal activities [22].

✓ Minor Components:

In addition to calcium carbonate, eggshells contain small quantities of 1% magnesium carbonate and 1% calcium phosphate [12].

Table 2.1 composition of eggshell [12].

Components	Percentage
Calcium carbonate	94-97%
Phosphorus	0.3%
magnesium	0.2%
Sodium, Potassium, Manganese, Iron, copper - traces	traces
Organic Matter	<2%

2.1.2 Physical characteristics

✓ Particle Size and Shape:

- ◆ Shape: Crushed eggshells can feature a combination of irregular shapes, including fragments with sharp edges and various angles. The size of these irregular pieces typically depends on the crushing or grinding method used [23].
- ◆ Size: The size of crushed eggshells varies depending on the intended application. When ground into a fine powder, the resulting particles can have a size distribution ranging from a few millimeters to the micrometer scale [24].

✓ Density and Strength:

- ◆ Density: The average density of the shell, which includes all mineral matter and the areas between the mineral shell's outer surface and the surface through the points of the mammillae, was calculated by regressing the shell weight on the shell volume. The result was $2.241 \pm 0.004 \text{ g/cm}^3$ [25].
- ◆ Strength: eggshell is surprisingly high for its thinness and weight. It can withstand a tremendous amount of force before breaking. In fact, a properly formed eggshell can support up to 130 pounds of weight without breaking [26].

✓ Porosity:

- ◆ Porosity: The large end of the egg has more pores than the little end due to the porous nature of the shell. (The eggshell of a chicken has roughly seven thousand pores.) This makes it possible for gasses to pass through the shell. Through the pores, moisture and carbon dioxide are released, while oxygen and other atmospheric gases take their place [27].

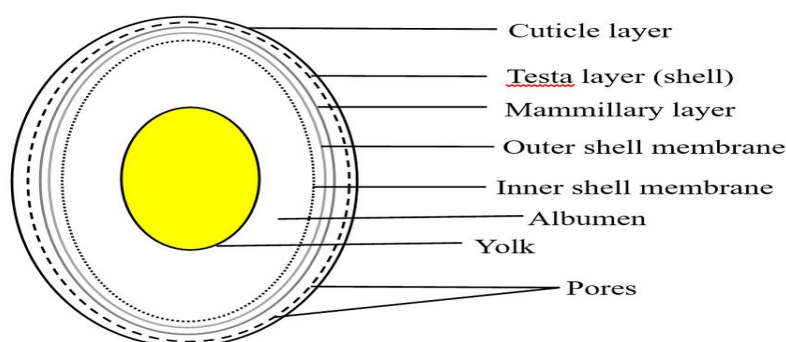


Figure 2.1 Structure of an eggshell [28]

2.2 Sand chemical composition and physical characteristics

2.2.1 Chemical composition of sand

Sand is a granular material composed of finely divided rock and mineral particles. Sand's composition varies, depending on where it comes from but its grain size is what distinguishes it. Grain sizes in sand are coarser than in silt and smaller than in gravel and the most frequent minerals found in sand are quartz, feldspar, mica, and a variety of other minerals [29, 30].

✓ Silica (SiO_2):

The mineral that occurs most frequently in sand is quartz, which is made up of silicon dioxide (SiO₂) molecules organized in a crystalline pattern. Due to its hardness, durability, and chemical stability, silica makes up a significant portion of most sands [30].

✓ Feldspar:

It contains feldspar minerals such as microcline, orthoclase, and plagioclase. They can differ in color and hardness and contribute diversity to the mineral makeup [30].

✓ Mica:

Some sands contain mica minerals, such as biotite and muscovite. These are tiny, platy minerals that can give the sand a shimmering or reflecting appearance [30].

✓ Rock Fragments:

The sand may contain tiny rock pieces or mineral grains from the nearby geological formations, depending on where it came from. Pieces of different rocks and minerals may be among these bits [30].

✓ Heavy Minerals:

Heavy minerals like magnetite, ilmenite, garnet, and zircon can be found in some sands. Because these minerals are denser than quartz, they can collect in specific places to produce colorful or black sands [30].

2.2.2 Physical characteristics

✓ Particle Size and Shape:

◆ Shape: The shape of sand is composed of two components: sphericity, which refers to how closely the grain resembles a sphere, and roundness, which indicates whether the grain has sharp or smooth edges [31].

◆ Size: Sand grains typically range in size from 0.05 to 2 millimeters in diameter [32]. Sands used in construction are classified based on their grains size; fine sands have the smallest grains (Particle sizes vary from 0.075 mm to 0.425 mm), followed by medium sands (The range of particle sizes is 0.425 mm to 2 mm.) making it coarser than fine sand but more finely grained, and coarse sands (Particle sizes vary from 2mm up to 4.75mm) [33].

✓ Density and Strength:

- ◆ Density: The density of dry sand is 1602 kg/m³. It remains undisturbed and in its original state, having been compressed and dried out by rain and gravity over ages [34].
- ◆ Strength: The silty sand's maximum tensile strength is 1,448 Pa, fine sand's is 1,416 Pa, and medium sand's is 890 Pa [35].

✓ Porosity:

- ◆ Porosity: Under a variety of sorting coefficients and particle sizes, the average porosity of sand was found to be 37.7%, 42.3%, and 46.3% under packed, natural (in situ), and loose packing conditions, respectively [36].

2.3 problem of chlorine in RC structures and effect of eggshell incorporation on concrete

The surface of the concrete acts as a barrier to keep out water and other harmful substances. These harmful substances, which shorten the concrete structure's life cycle and start damaging processes, include sulfates, carbon gas, and chloride ions [37]. Certain chemicals, like calcium, potassium, or sodium chloride, may be safe in other contexts, but not when it comes to concrete, particularly fresh concrete [38]. The penetration of chloride ions into concrete happens by capillary suction, diffusion (ion transport due to variations in ion concentration), and occasionally ionic migration [37]. When a compound like hydrogen chloride dissolves in water or the element chlorine gains an electron chloride ion (Cl⁻) is formed if these chloride ions come into contact with the steel bar, their surface absorbs them, encouraging the hydration of the metallic ions and the formation of a soluble FeCl₂ complex [39,41]. The process of corrosion occurs when hydrochloric acid is created chemically by the interaction of chloride ions with passive materials in the surrounding steel. Concrete will eventually fracture, spall, and fail as a result of the hydrochloric acid eating away at the steel reinforcing [39]. The primary factor causing reinforced steel corrosion in concrete is chloride ions; Chlorides that enter the concrete through areas exposed to sea water or sea spray after construction are typically the cause of chloride-induced corrosion they can also be found as impurities in the initial concrete mixture if moisture and oxygen are also present to support the reaction [40, 41,42]. Four conditions need to be met for corrosion to happen: An electrolyte, a metallic link, and a minimum of two metals at distinct energy

levels—or two places on a single metal—are required [42]. Chloride-induced corrosion starts when the concentration of chloride at the steel bars reaches a point where it eliminates the thin passive layer of corrosion products that shields the steel bars from corrosion at the end of construction (because of the high alkalinity of the concrete) with the primary issue of the steel corrosion is the concrete cover's spalling [43,39]. There are two different kinds of visible cracks in concrete, with the production of oxide causes horizontal fissures in the materials' interface, which cause the concrete cover to peel off when a steel's tensile strength is exceeded, vertical fissures develop [39].

2.3.1 Chloride penetration resistance of concrete

The term "chloride penetration" describes the extent to which environmental chloride ions seep into the concrete. Chloride permeability study is a crucial factor that influences how long concrete lasts [48]. Chloride intrusion is one of the main ways that the environment can attack a structure. It causes the reinforcing steel to corrode, which lowers the structure's strength, serviceability, and looks. This could result in the building being repaired or replaced too soon. Generally, to stop this kind of deterioration, very impermeable concrete is used to keep chlorides from entering the structure all the way down to the reinforcing steel bar [49]. Although present, these chloride ions are not likely to cause problems unless they exist in unusually high concentrations. Since corrosion of steel reinforcing is generally considered to begin at a chloride ion content of between 0.025 percent and 0.033 percent by weight of concrete, knowledge of chloride content can aid in determining the likelihood of the onset or presence of corrosion [40]. There are different methods to determine the chloride penetration depth of concrete some are listed below;

2.3.1.1 AASHTO T259: Standard Method of Test for Resistance of Concrete to Chloride Ion Penetration (Salt Ponding Test)

The AASHTO T259 test, often known as the salt ponding test, is a long-term test. The resistance of concrete specimens to chloride ion penetration is determined using this method. Its purpose is to ascertain how differences in the characteristics of concrete affect the material's ability to withstand the penetration of chloride ions [50].

Three slabs with a surface area of 300 mm square and a minimum thickness of 75 mm are needed for the test. After being moist cured for 14 days, the slabs are kept for 28 days at 50%

relative humidity in a drying room. The slabs' top and bottom faces are not sealed, but their sides are. Following the conditioning phase, the top surface is ponded with a 3 percent NaCl solution for 90 days, while the bottom face is left in contact with the drying environment. After this period of time, the slabs are taken out of the drying environment, and the concentration of chloride in slices that are 0.5 inches thick is measured [49].

2.3.1.2 Bulk Diffusion Test (NT BUILD 443)

On one plane surface, a concrete specimen saturated with water is exposed to sodium chloride-containing water. Thin layers are ground off parallel to the specimen's exposed face after a predetermined amount of exposure time, and the layers' chloride content is measured [51].

By putting the sample in a mill or lathe with a diamond-tipped bit, the chloride profile of the concrete may be evaluated. Because the sample is level, the bit's axis of advancement is perpendicular to the sample's surface. The concrete sample is ground into dust at each depth using a pass, and the dust is gathered afterwards. This process is iterated down to ever deeper levels, with depth increments of approximately 0.5 mm. Next, the powder's chloride content is ascertained using AASHTO T260 [49].

2.3.1.3 AASHTO T277: Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration (Rapid Chloride Permeability Test)

A 100 mm (4 in.) diameter core or cylinder sample must be taken from the concrete being evaluated as part of the test procedure. From the material, a 50 mm (2 in.) specimen is cut. The cylindrical specimen is coated on one side with epoxy, which is dried and then placed in a vacuum chamber for three hours. The sample is let to soak for eighteen hours after being vacuum-saturated for one hour. After that, it is put into the test apparatus (the device schematic is shown in the test technique). A 3% NaCl solution is placed into the test cell's left-hand side (-). 0.3N NaOH solution is poured into the test cell's right-hand side (+). After connecting the system, a 60-volt potential is applied for six hours. Every half an hour, readings are collected. The sample is taken out of the cell after six hours, and the number of coulombs that flowed through the specimen is computed [52].

2.3.1.4 Electrical Migration Techniques

Material is transported through electromigration, which is the result of ions gradually moving through a conductor as a result of momentum transfer between diffusing metal atoms and conducting electrons [53].

A two-chamber cell is used for electrical migration testing, and the concrete sample serves as the partition between the two chambers. Though it can be any size, the concrete sample is typically a disk with a diameter of 100 mm and a length of between 15 and 50 mm. The test's time will depend on the disk's thickness, but a large enough disk is needed to prevent aggregate interface effects. There might be a weak transition zone surrounding the aggregate that runs the majority of the length of the sample if the size of the aggregate and the thickness of the specimen are similar. Then, while the chloride concentration of the downstream (anode chamber) solution is being monitored—typically by periodically removing small aliquots and determining the chloride concentration of these samples—a voltage is given to push the chloride ions through the concrete. Calculating diffusion coefficients is made possible by the variation in chloride concentration over time [49].

2.3.1.5 The colorimetric method

The colorimetric technique for spraying silver nitrate is commonly employed in experimental projects where the concrete under test is determined to be saturated and carbonation-free [54]. Spraying silver nitrate has been utilized in conjunction with ASTM C 1202/05's accelerated test chlorides migration protocol. Following the migration test, it entails sprinkling slices of broken concrete with aqueous solutions of AgNO_3 0.1 M. This process results in the production of two distinct zones one is brown and represents a region free from chlorides, and the other is whitish and has AgCl precipitate, indicating the presence of chlorides [55]. Carbonation can cause interference with the colorimetric method of spraying silver nitrate solution on cementitious materials, potentially leading to a false positive result. Therefore, there is a signal for the presence of chloride ions in areas that do not necessarily have chlorides but rather have carbonates with a pH of less than 10 [54]. Since the penetration of chloride is not consistent taking seven measurements at regular intervals, and their mean is found With the exception of the 10 mm at each end of the specimen. Because the ends may become contaminated by the solution that seeps through throughout the experiment, they are not included in the measurement [55, 56]. The average of all of them yields the outcome. If

the other five measurements are valid and there is a reading failure due to aggregation, the measurement should be disregarded or moved to the next step [55].

2.4 Previous studies related to this study

Several studies have explored the potential of using waste including eggshell as a partial replacement for various constituents in concrete. Here's a summary of some relevant findings:

Ibrahim et al. [11], Uses eggshells in place of 5%, 10%, and 15% in place of sand. microstructure, slump, water absorption, unit weight, splitting strength, flexural strength, modulus of elasticity, and strength at 28 days of age were tested. The results showed a decreased water absorption, decrease in slump value dropped as the eggshell sand increases and an increment in compressive strength. The unit weight of ESS concrete was 4.31% lower than that of concrete made with natural sand. With replacement ratios of eggshell sand, fly ash and silica fume improved the mechanical component of the bond.

Abdussabur Raji and Samuel Tomi Aina [44], The traditional fine aggregate was completely substituted. came to the conclusion that it is not practical to use eggshells fully as fine aggregate.

M.Bhuvaneshwari [45], Workability, compressive strength, split tensile strength, and flexural strength of the concrete were tested by replacing sand with 0%, 5%, 10%, 15%, 20%, and 25% of eggshell. Compared to other percentages, 20% of eggshell aggregate in concrete yields better outcomes.

V.Gunasekaran's research, [7] replacing 10–30% of the eggshell the results showed that the compressive strength increased, with the highest improvement observed in the concrete mix with 20% egg shell replacement.

O. F. Rajab et al. [46], replaces sand by 0%, 5%, and 10% with eggshell. The results showed an improvement in mortar's flowability, but resulted in compressive and flexural strength reduction.

According to Nadia Razali et al.'s study, [47] replacing eggshell powder in mortar at a rate of 20% can improve early compressive strength, decrease sorptivity, and slows down the carbonation rate of concrete.

Yeong Yu Tan et al. [56], As an alternative to regular Portland cement, eggshell powder was used in volumes of 5%, 10%, 15%, and 20%. The findings demonstrated that the compressive and flexural strengths of concrete were significantly increased by water-cured eggshell concrete, reaching up to 51.1% and 57.8%, respectively. Eggshell powder filled in the existing spaces in the concrete, making it more impermeable, reducing the rate of water absorption by around 50%. However, because eggshell includes a significant quantity of calcium, which interacts rapidly with acid and alkali solutions, the compressive strength of eggshell concrete steadily diminishes as the amount of eggshell powder increased during immersion in these solutions.

Sagar Paruthi and et al.[57], After replacing cement with ESP, concrete's tensile, flexural, and compressive strengths all rise by roughly 10% to 30%. But when we use ESP to replace up to 20% of the cement, the mechanical qualities are at their highest. However, the tensile and compressive strengths decrease by 10% following a 20% or more replacement. And also When the percentage of cement replacement with ESP is increased, mortar workability diminishes, the slump cone value increases, and the compaction factor decreases with increasing ESP addition. The addition of ESP lowers the amount of water that clay bricks absorb. The temperature at which clay brick burns determines its final strength, which is reached after five hours of burning.

Mohd Yunus Ishak Muhammad and Nazrif [58], Investigated the workability and mechanical properties of eggshell blended batches via slump test and three destructive tests, respectively, in order to determine the suitability of eggshell powder as the partial replacement. This was done by substituting 10–30% of eggshell powder with Portland cement. Thus, as the amount of eggshell powder increases, the workability decreases in the range of 30–70% while the results of all three destructive tests drop in the range of 13–48%.

Nisar Ahmed Gabol and et al. [59], The study's primary goal was to ascertain the workability and reinforcing qualities of concrete, such as its tensile, flexural, and compressive strength, by substituting 0%, 2.5%, 5%, 7.5%, and 10% of ESP by weight for cement. The test findings demonstrated that ESP 7.5% enhanced tensile strength by 9.6% and that, after a 28-day cure, ESP 7.5% could achieve a maximum strength of 8%. Fresh concrete becomes less workable as the percentage of ESP rises.

Eggshell powder was used to replace 5%, 10%, 15%, and 20% of the cement by weight. The flow table test was used to evaluate the fresh property, and the cement mortar's compressive

strength at 7, 14, and 28 days was used to evaluate the hardened property. According to test results, mortar with 10% ground eggshell powder delivers the best compressive strength. The results of the microstructural analyses showed that adding 10% more powdered eggshell produced good strength.

2.5 Gap analysis

All previous studies point to the potential use of eggshells in concrete as a partially substitute material, but a crucial aspect of durability assessment is limited mainly chloride penetration resistance, has not been comprehensively addressed. Existing research primarily focuses on compressive strength, flexural strength, and workability some also tried to investigate the effect on carbonation and sorptivity. Understanding chloride penetration resistance is essential for evaluating the long-term performance of concrete in environments exposed to chlorides, such as marine structures, deicing salts, or waste water treatment facilities. This highlights the significance of your research, which addresses the gap by conducting chloride penetration tests on concrete specimens incorporating eggshell at varying replacement percentages. In this research carbonation test was not conducted due to financial and time limitation. Micro-structural and chemical analysis should be done in order to provided a more comprehensive understanding of the interaction between eggshell and cement hydration products but in this thesis due to limitation of resources and laboratory facilities it was not done.

3. MATERIALS AND METHODOLOGY

3.1 Introduction

This chapter describes the materials and methodology used in the investigation of the impact of using eggshell as a partial replacement of sand in mortar on its flexural strength, compressive strength, and resistance to chloride penetration. In order to properly address the research objectives, the methodology will outline the methods required in creating mortar samples with different percentages of eggshell replacement, conducting relevant tests, and analyzing the results to address the research objectives effectively.

3.2 Materials

The materials used in this study include cement, fine aggregate, crushed eggshell and water.

3.2.1 Cement

Ordinary Portland cement acts as the glue in mortar, holding all the ingredients together. This directly impacts the mortar's final strength and durability or how well it resists wear and tear. In this research an ordinary Portland cement with a density of 3.15 g/cm³ and a grade of 42.5 is used.

3.2.2 Fine Aggregate

Aggregate that almost completely passes the 4.75-millimeter (No. 4) sieve, passes the 9.5-millimeter (3/8-inch) sieve, and is primarily retained on the 75-micrometer (No. 200) sieve is referred to as fine aggregate ASTM C-125 [62]. Natural river sand was used in this study for all test specimens. The fine aggregate was thoroughly cleaned and dried before used.

3.2.2.1 Sieve Analysis

The gradation or particle size distribution of fine aggregate can be determined with the aid of sieve analysis. By giving information on the percentage of material that passes through each sieve size, it is possible to classify sand into several grading categories, such as well-graded and poorly-graded.

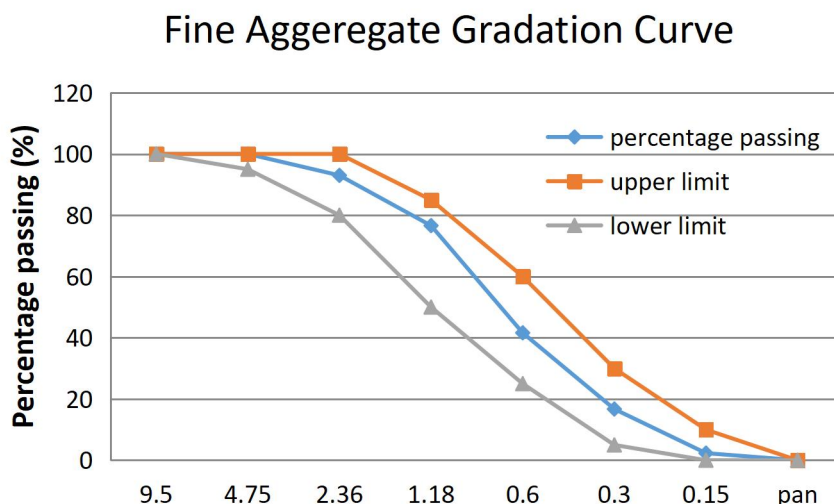


Figure 3.1 Grain size distribution of sand

According to ASTM C-33 [63] the fineness modulus of fine aggregate should normally be between 2.3 and 3.1. the fineness modulus of the sand used were 2.7 so the sand used in this study is fine sand. Additional data are attached to ANNEX A-1.

3.2.2.2 Silt Content

A silt content test should be carried out to evaluate the quality of the sand. A fine particle with a size smaller than 150 microns is referred to as silt content. If there is any water present, it becomes unstable [64]. The sand used for this research were washed using tap water in order to minimize the silt content, then the silt content presented was examined and found to be 3.33%.

3.2.2.3 Specific gravity and absorption capacity

Specific gravity or relative density is the ratio of aggregate's mass to the mass of a volume of water equal to the volume of the aggregate particles. This quantity is also known as the aggregate's absolute volume ASTM C128-22 [65].

According to ASTM C128

- ✓ **Bulk Specific Gravity (G_{sb}):** is the weight in air of a unit volume of aggregate at a certain temperature divided by the weight in air of an equivalent volume of gas-free

distilled water at the same temperature. This does not contain spaces between particles; rather, it only covers permeable and impermeable voids inside the aggregate particles.

- ✓ **Bulk Specific Gravity (SSD Basis):** is the weight in air of a unit volume of aggregate, including the weight of water inside the permeable voids, divided by the weight in air of an equivalent volume of gas-free distilled water at a certain temperature.
- ✓ **Apparent Specific Gravity (Gsa):** is the weight of a volume of aggregate, including the water inside the permeable spaces, divided by the weight of an equal volume of gas-free distilled water at a given temperature.
- ✓ **Absorption Capacity:** is the percentage of the dry mass that the aggregate particle mass increases as a result of water absorbed into the pores.

Table 3.1 Test result summary for sand

No	Test description	Test result	
1	Fineness modulus	2.7	
2	Specific gravity	Bulk	2.43
		Bulk (SSD)	2.5
		Apparent	2.62
5	Absorption	3.09	

3.2.3 Eggshell

The outer layer of a hard-shelled egg and some egg types with a soft outer coat is called an eggshell [66] .

3.2.3.1 Sieve Analysis

Eggshell has been washed, sun dried and grinded using a food processor to maintain the properties of sand.

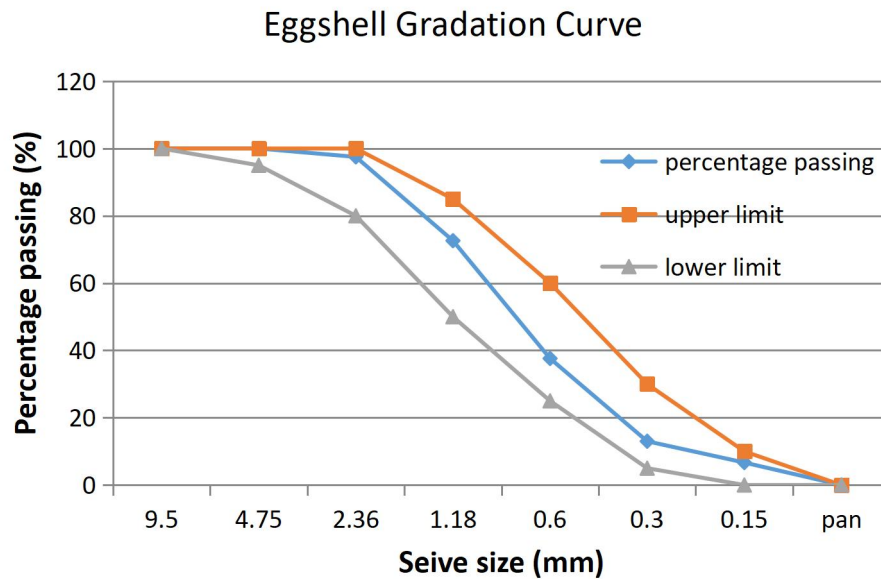


Figure 3.2 Grain size distribution of eggshell

$$Fineness\ modulus = \sum \frac{\text{cumulative coarser}(\%)}{100} = \frac{272.62}{100} = 2.73$$

3.2.3.2 Silt Content

The eggshell used was washed using tap water manually after collecting so the silt content test was not carried out hence it is not significant.

3.2.3.3 Specific gravity and absorption capacity

Table 3.2 Test result summary for eggshell

No	Test description	Test result	
1	Fineness modulus	2.73	
2	Specific gravity	Bulk	2.06
		Bulk (SSD)	2.17
		Apparent	2.29
5	Absorption	4.78	

3.2.4 Water

The water used must be clean, fresh and free from chemicals, silt, oil, clay, and suspended solids to prevent contaminants from affecting the mortar's strength and durability. For this research tap water supplied by AAWSA was used.

3.3 Methods and Procedures

The main goal of this study is to determine the effect of incorporating eggshell as a partially substitute of sand on the compressive strength, flexural strength and chloride penetration resistance of mortar samples. The methods used to attain this goal will be discussed in detail.

3.3.1 Mix Design

In this experiment different mortar mixes were prepared by replacing sand with eggshell using different level of replacement. Table 3.5 displays the mix proportion that was used to prepare the mortar.

Table 3.3 Detail description of the concrete mix notations

No	Mix notation	Detailed description
1	ES 0	Mortar mix with 0% eggshell sand
2	ES 10	Mortar mix in which 10% sand was replaced with eggshell sand
3	ES 20	Mortar mix in which 20% sand was replaced with eggshell sand
4	ES 25	Mortar mix in which 25% sand was replaced with eggshell sand
5	ES 30	Mortar mix in which 30% sand was replaced with eggshell sand

Where; ES stands for eggshell.

3.3.2 Mix proportion for lime mortar

The mixture was made by combining water to cement at a mass ratio of 0.5 and cement to sand at a 1:2.75 ratio. After adding cement, eggshell, and sand to the mixer, it was dry mixed for roughly five minutes. After adding the water to the mixture, the mixer was run for 150 seconds at various speeds. Following mixing, the freshly combined mortar was placed into cube molds measuring 70 mm by 70 mm by 70 mm and prism molds measuring 160 mm by 40 mm by 40 mm. A vibrating table was then used to compact the material.

When the vibration is done the excess mortar was skimmed off and the top surface was leveled. After 24 hours the mold was removed and the specimens were placed in a curing pond till the testing day.

Table 3.4 Quantity of ingredients for cubic meter of mortar

No	% of eggshell (kg)	Sand (kg)	Eggshell (kg)	Cement (kg)	Total water (kg)
1	0	1391.25	0	505.89	252.9
2	10	1271.18	110.34	502.36	256.45
3	20	1169.68	203.06	499.7	259.51
4	25	1125.28	244.2	498.02	260.66
5	30	1083.42	282.33	496.9	261.97

3.3.2.1 Flexural and Compressive Strength Determination

Flexural and compressive strength test at specific curing ages (7,14 and 28 days) were conducted to determine the optimum level replacement, to see if adding eggshell will fastens the hydration process of mortar and gives early strength. A total of 18 samples were casted for flexural and destructive compressive strength test. BS EN 1015-11 [67] was used to determine the compressive and flexural strengths.

- Flexural Strength Test: The standard describes the three-point bending test method for measuring the flexural strength of the mortar specimens. A load is applied at the midpoint of a horizontally supported beam until failure. The flexural strength is calculated based on the maximum load, specimen dimensions, and support span.
- Compressive Strength Test: The standard specifies the procedure for measuring the compressive strength of the mortar specimens. The halves resulting from the flexural strength test can be used for this purpose, or separate specimens can be prepared. The mortar cubes are placed between compression platens and loaded until failure. The compressive strength is calculated based on the maximum load and the cross-sectional area of the specimen.

3.3.2.2 Chloride Penetration Resistance

The resistance to chloride penetration of the mortar samples was evaluated by the chlorimetric method using silver nitrate. The depth of chloride penetration will be measured, by fill the spray bottle with the 0.1N silver nitrate solution. Gently spray the solution onto the sample surface, ensuring even coverage. In areas with no chlorides, the silver nitrate will react with the mortar and form a brownish precipitate (silver oxide). In areas with chloride penetration, a white precipitate of silver chloride (AgCl) will appear. Then measure the depth using a ruler at an interval of 10mm and takes the average. For this test a total of 10 samples were prepared.

4. RESULTS AND DISCUSSION

4.1 Introduction

This section of the thesis presents the findings from the investigation into the use of eggshell as a partial replacement for sand in mortar production. It aims to provide a comprehensive analysis of the experimental data collected, highlighting the effects of incorporating eggshell on the mechanical properties, durability, and overall performance of mortar mixtures. The results of the research were presented in a table and graphically, then analyzed in detail by comparing them to existing research and relevant standards.

4.1.1 Compressive strength of mortar

Compressive strength tests were conducted on normal mortar and mortars with eggshell as a partial replacement of sand at 7, 14, and 28 days of age. The compressive strength variation as measured by the compressive strength test is shown in Figure 4.1.

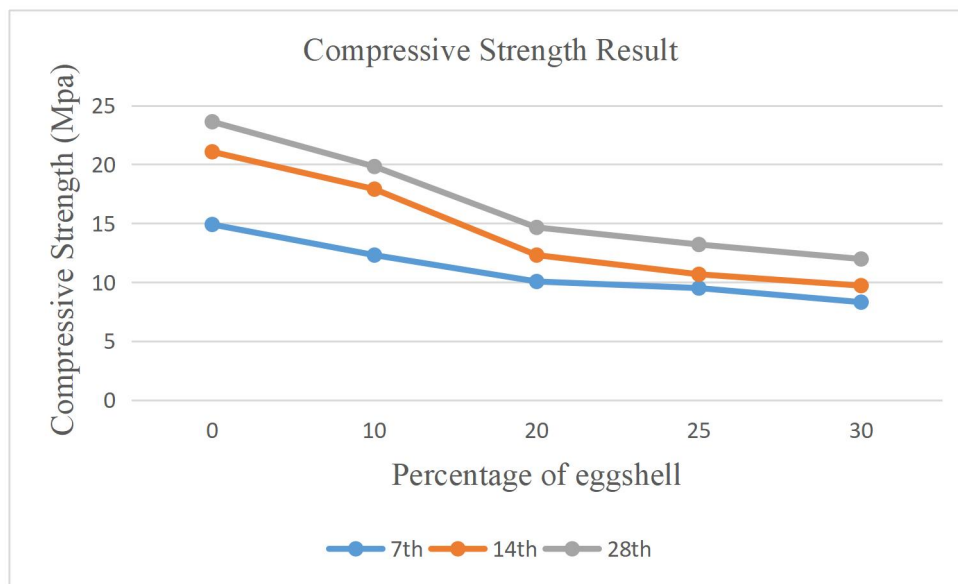


Figure 4.1 Average compressive strength result of the mortar mix

The mortar's compressive strength result for the 7th, 14th, and 28th days was plotted graphically, as seen in the Figure. The result shows that as the quantity of eggshell sand increases the compressive strength of the mortar decreases for all testing ages. This can be the result of the difference in strength between the natural sand and the eggshell (eggshell is

weaker than sand). similar findings were found by O F Rajab and et.al and Sebastin S.and et.al [46,13].

Analysis of variance (ANOVA) is done to compare an appropriate replacement of eggshell as the result shown in Figure 4.1 is declining. Thus, using a 95% confidence interval the lower limit corresponding to the compressive strength of 23.45MPa (at 0% replacement level) was determined and the value was found to be 22.2MPa. This result is corresponding to a replacement level of 5%. Hence, it is an optimal percentage of replacement of an eggshell and it can be used to replace sand.

4.1.2 Flexural strength of mortar

Flexural strength tests were also conducted on normal mortar and mortars with eggshell as a partial replacement of sand were tested at 7, 14, and 28 days of age. Figure 4.2 displays the variation in Flexural strength as determined by the Flexural Strength test.

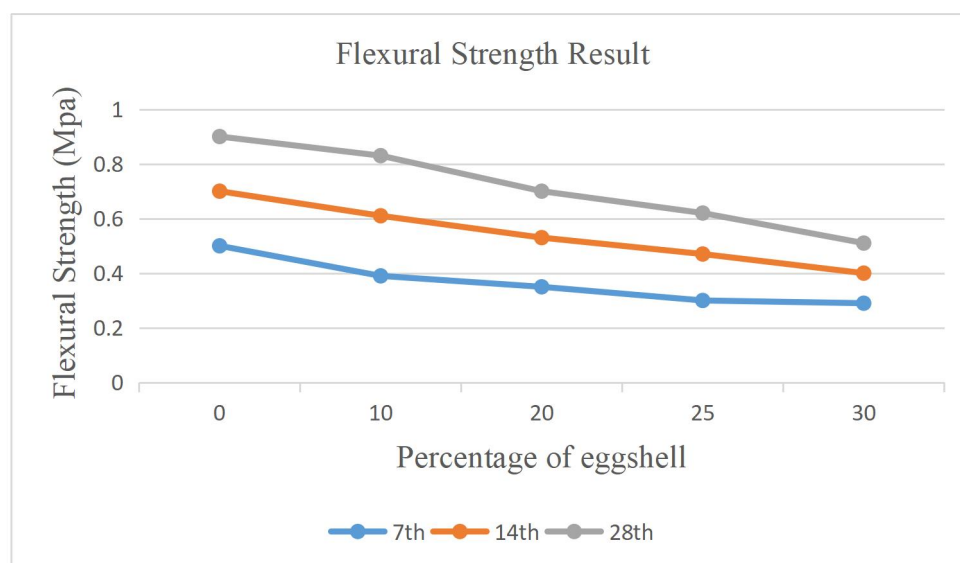


Figure 4.2 Flexural strength result of the mortar mix

The mortar's flexural strength result for the 7th, 14th, and 28th days was plotted graphically, as seen in Figure 4.2. Additionally, the outcome demonstrates that, throughout all testing ages, the flexural strength of the mortar decreases with an increase in eggshell sand quantity. similar findings were found by O F Rajab and et.al [46].

Analysis of variance (ANOVA) is done to compare an appropriate replacement of eggshell as the result shown in Figure 4.2 is declining. Thus, using a 95% confidence interval the lower

limit corresponding to a flexural strength of 0.9MPa (at 0% replacement level) was determined and the value was found to be 0.62MPa. This result is corresponding to a replacement level of 25%. Hence, it is an optimal percentage of replacement of an eggshell and it can be used to replace sand.

The decrease in flexural and strength could be due to several factors

- ✓ Eggshell composition: The mineral composition of eggshells, primarily consisting of calcium carbonate, influences their strength and structural integrity. The purity and crystalline structure of calcium carbonate in eggshells can affect their mechanical properties.
- ✓ Eggshell processing: The method used to process and prepare eggshells, such as cleaning, drying, and grinding, can impact their strength.
- ✓ Chemical interactions: Chemical interactions between eggshells and other components in the mortar mix can impact the strength properties.
- ✓ The difference in strength between sand and eggshell in this study the sand used was strong.

All the above factors could be the cause for the reduction in both flexural strength and compressive strength of mortar.

4.1.3 Chloride penetration resistance test

The chloride penetration test was conducted first by exposing the mortar to chloride by immersing the 70mm × 70mm × 70mm samples to a solution of salt and water for 24 hrs. the colorimetric test was conducted and the result showed that the resistance to chloride penetration decreases as the percentage replacement increases. In the test, change in color after applying 0.1N silver nitrate solution for the determination of chloride penetration depth was observed. Up to 20% replacement level there were no significant penetration of chloride penetration even 0% and 10% replacement showed similar results but for 25% and 30% replacement the depth of penetration increases. The results were measured in the interval of 10mm and the average of them were taken after discarding the 2 corner 10mm results. Similar findings were found by Nadia Razali [47] but the research was done on sorptivity of mortar samples. Fig 4.3 shows the variation of chloride penetration depth for different

replacement level. Figure 4.4 below shows the change in colour of mortar specimen due to chloride attach.

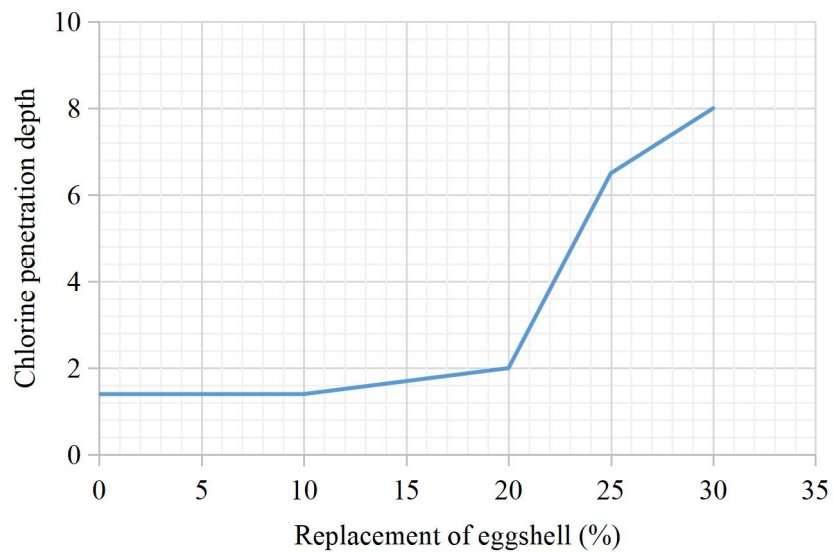


Figure 4.3 Chloride penetration resistance result of the mortar mix



Figure 4.4 Change in colour of mortar specimen due to chloride attach

4.2 Environmental and economic consideration

4.2.1 Environmental consideration

Using eggshells as a partial replacement for sand in mortar can help reduce the amount of waste generated from egg consumption. Eggshells are a common household waste product that can be re-purposed in construction applications, promoting a more sustainable waste

management practice. As mentioned previously In Ethiopia, the consumption of eggs is increasing. It is anticipated to increase 0.9% from 45,000 metric tons in 2021 to an estimated 47,000 metric tons by 2026. which intern increases the west generated and the need for additional landfills for the disposal which will affect the environment. By utilizing eggshells in construction materials, there is a potential to reduce the carbon footprint associated with traditional sand extraction and processing. This can contribute to lower greenhouse gas emissions and overall environmental impact. Also using eggshells as a substitute for sand can help conserve natural resources by reducing the demand for sand extraction, which is a finite resource that is often extracted unsustainably.

4.2.2 Economic consideration

There may be potential cost savings associated with using eggshells as a partial replacement for sand. Eggshells are typically a west which are free material, that could lead to reduced material costs in construction projects. And also, the increment in resistance to chloride penetration with eggshell mortar compared to the controlled mix can result in improved durability and longevity of the structure. This can lead to long-term cost savings by reducing maintenance and repair costs over the lifespan of the building or infrastructure.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study aimed to evaluate the feasibility of using eggshell as a partial replacement for sand in mortar, focusing on its effects on compressive strength, flexural strength, and chloride penetration resistance. The following conclusions can be drawn from the experimental results:

1. The mortar samples' compressive strength with eggshell a decrease in compressive strength as compared to the controlled mortars or mortars without eggshell.
2. The flexural strength of mortar samples with eggshell a decrease in compressive strength as compared to the controlled mortars or mortars without eggshell.
3. The chloride penetration resistance decreases as the eggshell content increases.
4. The weight of mortar samples with eggshell decreases which can reduce the overall structural weight.
5. Eggshells are waste materials which have no cost compared to sand which can decrease the cost of the construction.

5.2 Recommendations

1. Further research should be conducted to determine the optimal percentage of eggshell powder replacement that balances mechanical strength (compressive and flexural strengths) and durability (resistance to chloride penetration).
2. Investigate the long-term effects of eggshell powder on concrete properties, including durability under various environmental conditions.
3. The eggshell must be boiled before crashed to be used as sand in order to remove the eggshell membrane (the white thin layer inside the eggshell) in order to reduce the water absorption of the eggshell.

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APPENDIX

Annex A - Results of aggregate physical property

A-1 Fine aggregate tests

➤ Silt content

A=Amount of silt deposited= 10ml

B=Amount of clean Sand = 300ml

Silt Content (%) = (A/B) *100 = (10/300) *100 = 3.33 %

➤ Sieve analysis

Sieve size (mm)	percentage passing ASTM C33	Weight retained (g)	Percent retained	Cumulative Percent retained	Percent passing.
9.5	100	0	0	0	100
4.75	95-100	0	0	0	100
2.36	80-100	35	7	7	93
1.18	50-85	82	16.4	23.4	76.6
0.6	25-60	175	35	58.4	41.6
0.3	5-30	124.4	24.88	83.28	16.72
0.15	0-10	72	14.4	97.68	2.32
pan	0	11.6	2.32	100	0

$$\text{Fineness modulus} = \sum \frac{\text{cumulative coarser}(\%)}{100} = \frac{269.76}{100} = 2.7$$

➤ Specific gravity and Absorption of fine Aggregate

$$\text{Bulk Specific Gravity} = \frac{A}{B + S - C} = 2.43$$

$$\text{Bulk Specific Gravity(SSD)} = \frac{S}{B + S - C} = 2.5$$

$$\text{Apparent Specific Gravity} = \frac{A}{B + A - C} = 2.62$$

$$\text{Absorption capacity} = \frac{S-A}{A} * 100 = 3.09\%$$

Where;

A = mass of oven-dry specimen in air, g = 485

B = mass of pycnometer filled with water, g = 705

S = mass of the saturated surface-dry specimen, g = 500

C = mass of pycnometer with specimen and water to the calibration mark, g = 1005

A-2 Eggshell tests

➤ Sieve analysis

Sieve size (mm)	percentage passing ASTM C33	Weight retained (g)	Percent retained	Cumulative Percent retained	Percent passing.
9.5	100	0	0	0	100
4.75	95-100	0	0	0	100
2.36	80-100	12.5	2.5	2.5	97.5
1.18	50-85	124.5	24.9	27.4	72.6
0.6	25-60	175	35	62.4	37.6
0.3	5-30	123	24.6	87	13
0.15	0-10	31.6	6.32	93.32	6.68
pan	0	33.4	6.68	100	0

$$\text{Fineness modulus} = \sum \frac{\text{cumulative coarser}(\%)}{100} = \frac{272.62}{100} = 2.73$$

➤ Specific gravity and Absorption of fine Aggregate

$$\text{Bulk Specific Gravity} = \frac{A}{B + S - C} = 2.06$$

$$\text{Bulk Specific Gravity(SSD)} = \frac{S}{B + S - C} = 2.17$$

$$\text{Apparent Specific Gravity} = \frac{A}{B+A-C} = 2.29$$

$$\text{Bulk Specific Gravity} = \frac{S-A}{A} * 100 = 4.78\%$$

Where;

A = mass of oven-dry specimen in air, g = 485

B = mass of pycnometer filled with water, g = 705

S = mass of the saturated surface-dry specimen, g = 500

C = mass of pycnometer with specimen and water to the calibration mark, g = 1005

Annex B - Results of compressive strength of mortar cubes
B-1 7th day results of compressive strength of mortar cubes

% of eggshell	Compressive strength (Mpa)		Average compressive strength (MPa)
	Left side	Right side	
0	15.3	14.5	14.9
10	12.58	12.2	12.3
20	11.11	9	10.06
25	9.2	9.8	9.5
30	8.9	7.17	8.31

B-2 14th day results of compressive strength of mortar cubes

% of eggshell	Compressive strength (Mpa)		Average compressive strength (MPa)
	Left side	Right side	
0	20.13	22	21.07
10	17	18.8	17.9
20	11.8	13.22	12.3
25	9.79	11.55	10.67
30	9.16	10.25	9.71

B-3 28th day results of compressive strength of mortar cubes

% of eggshell	Compressive strength (Mpa)		Average compressive strength (MPa)
	Left side	Right side	
0	24.13	23.11	23.62
10	20	19.63	19.82
20	15.68	13.81	14.65
25	13.87	12.53	13.2
30	12.17	11.77	11.97

Annex C- Results of Flexural Strength of Mortar Cubes

C-1 7th day results of Flexural Strength of Mortar Cubes

% of eggshell	Flexural (MPa)
0	0.41
10	0.39
20	0.35
25	0.3
30	0.24

C-2 14th day results of Flexural Strength of Mortar Cubes

% of eggshell	Flexural (MPa)
0	0.7
10	0.61
20	0.53
25	0.47
30	0.35

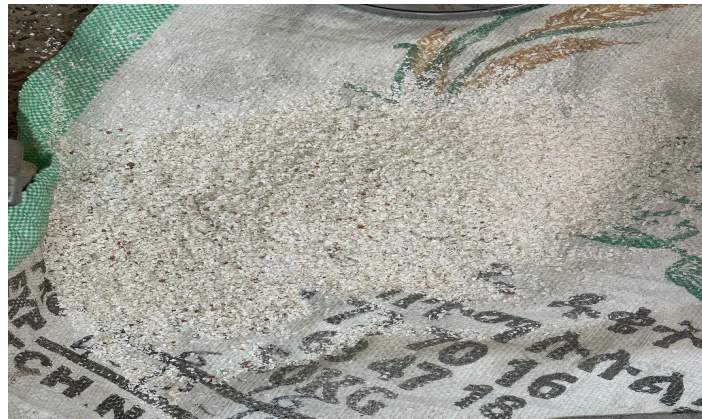
C-3 28th day results of Flexural Strength of Mortar Cubes

% of eggshell	Flexural (Mpa)
0	0.98
10	0.85
20	0.7
25	0.62
30	0.51

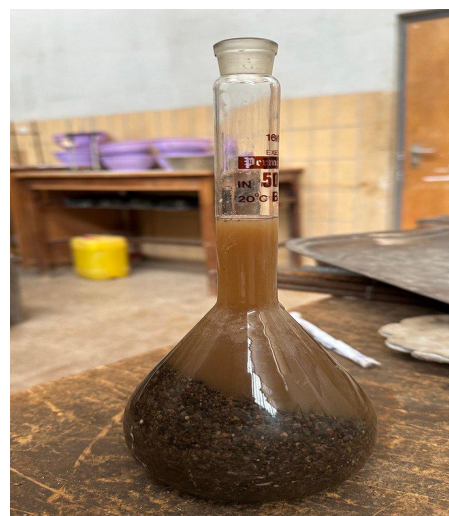
Annex D- Sample photos taken during the research



Pic.1 washed and dried eggshell



Pic 2. Saturated Surface Dry condition test for egg shell



Pic3. photos taken while measuring the Specific Gravity of Egg shell and sand



Pic4. curing of samples



Pic 5. flexural and compressive strength tests



Pic 6. immersion of samples to salt and water solution for chloride penetration test



Pic 7. preparation of 0.1N silver nitrate solution for the determination of chloride penetration depth.



Pic 8. sample photo of change in color after applying 0.1N silver nitrate solution for the determination of chloride penetration depth.