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The Effect of Egg and Lime on the Compressive Strength of Mortar

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ABSTRACT

The Effect of Egg and Lime on the Compressive strength of Mortar

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In Ethiopia there is a saying that tells buildings like Fasiledes castle of Gondar were built from materials that did not include cement. This saying describes the buildings as made from stones using lime mortar, consisting of sand, lime and egg parts, as a binder. This saying gave a motivation for this research to investigate the effect of egg parts on the compressive strength of mortar.

This research concentrates on the effect of egg albumin and egg shell on the compressive strength of mortar since there is already good known material on lime and the effect of the egg albumin and egg shell with regards to cement can be studied on mortar without the addition of aggregates.

In this research a method of comparison is applied, in which a control mix that is mixture of only sand, cement and water with a 1:2.75 cement to sand ratio and a 0.5 water cement ratio mixtures having different proportions of egg albumin which is the part of the egg that contains protein and egg shell which is the waste part of the egg as a partial replacement of sand in addition to sand, cement and water keeping the cement to sand and water cement ratio consistent with that of the control mix.

During this research a total of 108 mortar cubes were utilized and as a result it is found that the compressive strength of mortar can be increased by more than 10% with the addition of 1% egg albumin of the total volume of mortar without increasing the amount of cement, keeping the water cement ratio consistent. But the compressive strength of the mortar decreases with the addition of egg albumin more than 1%. And by the addition of eggshell with the volume of 5% of the fine aggregate, the compressive strength of the

mortar has increased by more than 13% compared to the mortar made with only cement, sand and water keeping the same water cement and sand to cement ratio.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

In the past, in Ethiopia, legends tell that buildings like Fasiledes castle at Gondar were built by using materials that didn't include cement at all. They used other materials like eggs and lime stone instead of concrete. And somehow it was strong enough to stay for a long time without collapse. Although this was the fact known at the beginning of the study, Interview conducted to the supervisor of the renovation of the castle showed that the binding material used to bind the stone aggregates together was only lime mortar and the part about the egg was just a rumor created by the Italians to make peace with the people of Gondar as the Italians needed too much egg for food and didn't want the villagers to think that the Italians didn't like the traditional food of the people of Gondar, according to interview conducted on the site.

Even though the initial assumption that the binding element used in the construction of Fasiledes Castle was made up of lime mortar mixed with egg was not real and there is already good material (study) conducted on lime mortar, this study is dedicated on the study of the effect of egg on the compressive strength of concrete based on the fact that the different parts of the egg like the egg albumin and the egg shell have their own distinctive properties that makes them very interesting to study the effect that they may have on the compressive strength of a cement mortar if they were added in different proportions in to the cement mortar mix.

1.2 SCOPE OF THE STUDY

Since the purpose of the study mainly depends on studying the effect of the added material in accordance with cement and since the binding property of the cement with the added material and the corresponding compressive strength can be studied using mortar without having to use aggregates, this study is conducted using mortars having the same water cement ratio and the same sand to cement ratio but having different proportions of the added materials, which in this case are egg albumin and egg shell.

1.3 STATEMENT OF THE PROBLEM

In Ethiopia, there are buildings that have a great historical significance and that have managed to stay strong for a very long time. And there is a saying that tells these buildings, for example Fasiledes castle of Gondar, were made from stones using lime mortar consisting of lime sand and egg parts as a binding material. Thus an attempt should be done to see the effect of egg parts on the compressive strength of mortar.

Egg parts consist of different components in which one of them is egg shell. Egg shell is a waste material that may be recycled into construction materials. In this research, it is intended to examine the effect of egg shell on the compressive strength of cement mortar.

1.4 OBJECTIVE OF THE STUDY

1.4.1 General objective

- To examine the effect that egg albumin and egg shell may have on the compressive strength of a cement mortar.

1.4.2 Specific objective

- To find out the materials used at the construction of Fasiledes castle of Gondar and to test the compressive strength of the mortar used.
- To investigate the effect of egg albumin on the compressive strength of a cement mortar if it is added in different percentages of the total volume of mortar.
- To investigate the effect of egg shell on compressive strength if it is added as a partial replacement for sand in the production of mortar.

CHAPTER TWO

LITERATURE REVIEW

2.1 MATERIALS

In this section the materials that are intended to be used in this research such as, mortar, lime, cement , egg albumin, egg shell and water are discussed in detail.

2.1.1 Mortar

Mortar is a composite material made up of inert materials of varying sizes, which are bound together by a binding medium. Mortar contains fine aggregate in addition to cement, water and air. The cement, water, and air combine to form a paste that binds the aggregates together. Thus, the strength of mortar is dependent on the strength of the aggregate matrix bond.[1]

Mortar	Portland cement	Paste
	Water	
	Air (entrapped or entrained)	
	Fine aggregate (sand)	Aggregate
	Admixture (if required)	

The entire mass of the mortar is deposited or placed in a plastic state and almost immediately begins to develop strength (harden), a process which, under proper curing conditions, may continue for years.

2.1.1.1 Water Cement Ratio

The water–cement ratio is the ratio of the weight of water to the weight of cement used in a concrete or mortar mix and has an important influence on the quality of concrete produced. A lower water-cement ratio leads to higher strength and durability, but may make the mix more difficult to place. Placement difficulties can be resolved by using plasticizers or super-plasticizers.[2]

Too much water will result in segregation of the sand and aggregate components from the cement paste. Also, water that is not consumed by the hydration reaction may leave the concrete as it hardens, resulting in microscopic pores (bleeding) that will reduce the final strength of the concrete. A mix with too much water will experience more shrinkage as the excess water leaves, resulting in internal cracks and visible fractures (particularly around inside corners) which again will reduce the final strength.

2.1.2 Lime

Lime is one of the oldest known cementing materials, which is readily available and inexpensive: Lime is found in many parts of the world in its natural form as a rock of varying degree of hardness. It is mainly composed of calcium oxide (CaO), which in its pure form associates with CO_2 to give white $CaCo_3$. However, lime deposits are generally found mixed with impurities such as Co_2, $Fe_2\ 0_3$, and $MgCo_3$. Depending on the impurities, lime deposits acquire different colors.[8]

2.1.2.1 Classification of Lime

1. **Quick lime**

The manufacture of non-hydraulic lime consists in heating or burning the lime stone in some form of vertical kilns to a temperature of 1000 ^{0}C calcium carbonate is decomposed into calcium oxide and carbon dioxide according to the following reaction.

$$CaCO_3 \sim CaO+CO_2 \uparrow$$

The CO_2 is driven off, leaving the CaO (calcium oxide), which is known as quick lime or caustic lime, white in color and having a specific gravity of about 3.4 in its pure form.[9]

This quick lime is highly caustic and possesses a great affinity for water, readily combining with about 30% of its own weight. It is slow in sculling & takes much time in hardening. It is Used for plastering and white washing but not suitable for being used as mortar because of its poor strength & slow hardening.

Fresh burned lime has so much affinity for water that it will quickly absorb moisture and carbon dioxide from the atmosphere and becomes air-slaked, and loses its cementing qualities. It must therefore be kept in dry storage and carefully protected from dampness until used.

2. Hydrated Lime (Slaked Lime)

Quick Lime can never be used as such for construction purposes but must be mixed with water. The quick lime in the presence of water reacts to form calcium hydroxide together with a great evolution of heat. [7]

$CaO+H_2O \Rightarrow Ca(OH)_2 + heat$

This process is called slaking & the product (calcium hydroxide) is called slaked lime or hydrated lime. The rate of reaction depends mainly on the purity of the lime. In slaking process, the following phenomena are observed:

- considerable heat is energetically evolved
- excess water in the form of vapor is driven off
- considerable & sudden expansion that makes the lime burst into pieces & finally become powder or pasty
- an increase in absolute volume in forming calcium hydroxide $Ca(OH)_2$

There are two types of slaking: Wet-Slaking and Dry-Slaking, Depending on the amount of water added.

A. Wet-Slaking

Lime is slaked or hydrated at the building site by mixing quicklime, which is delivered in lump form, with an excess of water and the resulting slaked lime (milk of lime) should be passed through a fine sieve to remove slow slaking particles (lime putty) and then left to mature for several days. If the mixing is made directly in a watertight box or a hole dug in the ground the lime must be continually stirred by a shovel or a stick during the slaking process to reduce all un-hydrated particles which might hydrate later in the building and cause popping, pitting, and disintegration, especially objectionable in wall plaster or expansion of brickwork.

B. Dry-Slaking

If the operation is carefully controlled, as it can be in a factory so that just sufficient water is added to hydrate the quick lime, the lumps break down in to a dry powder known as Dry hydrate or hydrated lime. It is obtained by adding almost exactly the theoretical quantity of water required to change the burnt lime into hydrate of lime. The proportion of lime and water and stirring are scientifically carried out by mechanical means, and the product is very dependable (trustworthy). It is reduced to a fine powder and shipped in paper bags ready for use. Lime has a certain advantage over quicklime. It is a better product and is of uniform quality because it is manufactured under controlled conditions.

3. Hydraulic lime

This lime, which hardens to some extent by an internal reaction, is prepared by burning impure limestone that contains clay producing compounds similar to those present in Portland cement. It is strong but less fat or plastic than non-hydraulic lime.

Hydraulic lime is manufactured in the same way as quick lime, although a somewhat higher temperature is required in burning. Hydraulic lime presents some difficulty in slacking. While it must be thoroughly slacked, like non-hydraulic lime; considerable care is required to provide just sufficient water and no excess, since excess water would lead to premature hardening. The exact amount of water required can only be determined by experience with the particular lime concerned. Clearly, hydraulic lime cannot be soaked overnight to improve its workability.[10]

2.1.2.2 Setting and hardening of lime

Slaked lime hardens or sets by gradually losing the water through evaporation and absorbing carbon dioxide from the air thus changing back from calcium hydroxide, Ca $(OH)_2$ to calcium carbonate, $CaCO_3$ or limestone.

The cycle is completed in the chemical changes from the original limestone, through burning, slaking, and setting.

1. When burnt, the limestone loses its carbon dioxide and becomes oxide of lime or quicklime.

$$CaCO_3 + Heat \Rightarrow CaO + CO_2$$

2. When slacked, the oxide of lime combine with water and becomes hydroxide, slacked, or hydrated lime.

$$CaO + H_2O \Rightarrow Ca(OH)_2 + Heat$$

3. When setting, the calcium hydroxide loses its water through evaporation and absorbs carbon dioxide from the air, becoming Ca C03 or limestone once more.

$$Ca(OH)_2 + CO_2 \Rightarrow CaCO_3 + H_2O$$

2.1.2.3 Lime as a material of construction

Lime was used as main binding material in all types of construction till 19th century when Portland cement was manufactured. Even now, lime can compete with Portland cement quite satisfactorily in many types of construction. It is used: -

- As mortar (lime mortar) mixed with sand. The usual mixtures for mortar are 1 part of lime to 3-6 parts of sand by volume. Lime mortar will not harden under water, and in all cases exposure to air is necessary for prompt (timely) setting. Lime mortar without addition of cement should never be used in foundations or where exposed to moisture.
- Lime is used in cement mortars and plasters to make it more workable. The resulting mortar is called compo-mortar
- As plaster (lime plaster)
- As a whitewash, it gives a sparkling white finished at a very low cost.
- As lime concrete, which is similar to cement concrete and is made by mixing lime, sand and coarse aggregate in proper proportions.
- As an important constituent of sand -lime bricks, which are quite popular in advanced countries

2.1.3 Lime mortar used at Fasiledes castle of Gondar

The initial assumption at the start of this research was that the mortar used for the construction of Fasiledes castle located in Gondar, Ethiopia was a mixture of Egg, slaked lime, sand and water. But information gathered by visiting Fasiledes castle and by interviewing authorities and the general manager in charge of rehabilitation of Fasiledes are listed as follows:

Fig.2.1 Fasiledes castle of Gondar

- The assumption that egg was added to the lime mortar was a rumor created by the Italians to get peace with the people of Gondar because they were consuming a lot of eggs for food and they didn't need the people of Gondar thinking that they don't want to eat their cultural food. Thus the mortar used to build Fasiledes castle of Gondar was a mixture of lime, sand and water.
- The lime used for the lime mortar was a slaked lime stored in a hole dug in the ground and was constantly stirred. By the time that the sample was taken for this research, the stored slaked lime was taken for this research; the stored slaked lime was two years old. And by the time the tests were done to examine the compressive strength of the lime mortar, the slaked lime was three years old. It was stored in a container for 1 year. The slaked lime gains more strength the longer period of time it is stored, according to the general manager.

- The mix proportion that they were using for the rehabilitation and what is thought was used at the construction of Fasiledes castle of Gondar was 3:1 lime to cement ratio by volume and as much water as needed to make the mortar workable. The lime is constantly stirred until it becomes smooth before it is used in the mortar mix.
- The curing of the lime mortar after it is casted and hardened needs the water's intensity to be so low cause too much water could flood the lime. Thus it needs low amount of water over a long period of time to gain its strength.

Oral tradition tells that egg whites were used as ingredients of mortars, which are used to bind building materials together for the construction of churches, and other architectural structures, during the Spanish colonial period in the Philippines. To examine if this oral tradition is true or not, mortar samples were collected and organized from 2003 to 2008, to examine the presence of protein in the mortars since egg albumin is mostly composed of proteins. To see if egg whites were used as mortar colonial period churches were qualitatively tested for proteins using biuret test, which is a general test for proteins. It is positive for all compounds containing two or more peptide bonds. The nitrogen of the two peptide bonds formed a violet coordination complex with cupric ions. The violet color is an indication of positive reaction for egg white/ovalbumin. The test resulted are negative for all mortar samples. It could be that there were really no whites or the qualitative analysis is infeasible due to the fact that proteins were already modified and degraded.[11]

The research[11], showed that the oral tradition telling that egg whites were used as ingredients of mortars have a very good chance of being false. These proves that the information gathered by interview at the site of Fasiledes castile of Gondar has a very good chance of being true.

2.1.4 Structure of Egg

An average sized egg weighs approximately 57 grams. Of this weight, the shell constitutes 11 percent, the white, 58 percent, and the yolk, 31 percent. Normally these proportions do not vary appreciably for small or large eggs, Eggs are specially valuable grams of protein. One egg contains about 6 to 7 grams of protein. Eggs also contain an abundant supply of minerals, such as iron and phosphorous.[17]

Egg whites are generally used as adhesive which, is a compound that adheres or bonds two items. Historically they were used to produce proteinacous paint binder, which is a substance used to attach a pigment to a substrate . Together with egg yolks, they are also used as ingredients for tempera, which is a paint that uses an oil water emulsion as binder, where the two substances being miscible by an emulsifying agent such as egg yolk. Egg whites are also used as varnish and also oral tradition tells that egg whites were used as ingredients of mortar.[11]

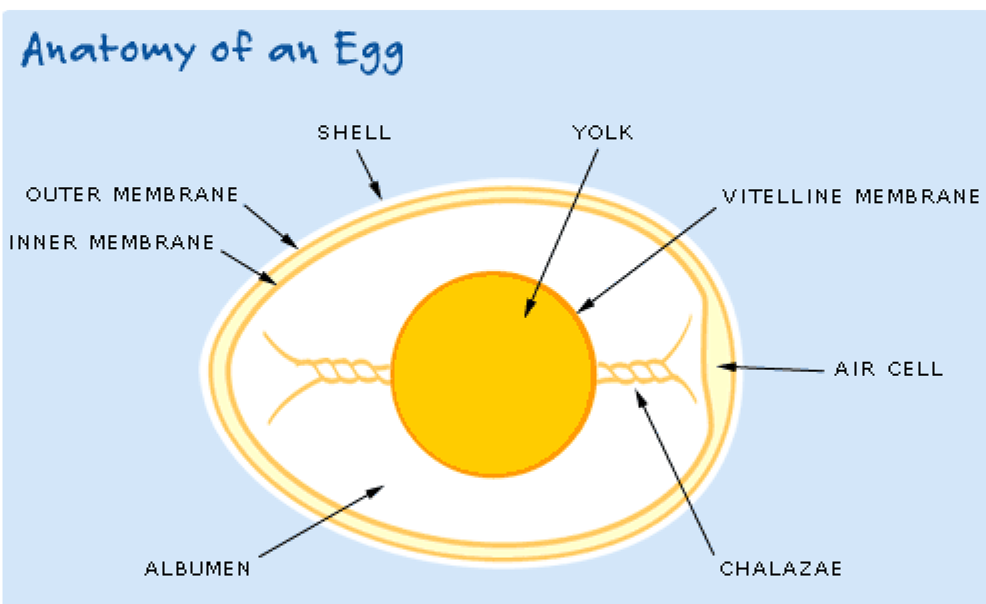

Fig. 2.2 Anatomy of an egg

2.1.4.1 Egg Albumin

The albumin in an egg is the clear or misty substance that surrounds the yellow yolk, and helps to provide nutrition for the growing embryo in the egg. Whole eggs have been a valuable protein source for generations but in present times with improved knowledge of the values of the different parts of the egg, it is known that the yolk is mostly fat and the albumin is protein and water.

The egg white is about two thirds of the total egg's weight out of its shell, with nearly 92% of that weight coming from water. The remaining weight of egg comes from protein. Egg white is an alkaline solution and contains approximately 40 different proteins. Below is a list of the proteins found in egg white by percentage.[13]

-54% Ovalbumin	-12% Ovotransferrin	-11% Ovomucoid
-4% Ovoglobulin G2	-4% Ovoglobulin G3	-3.5% Ovomucin
-3.4% Lysozyme	-1.5% Ovolinbitor	-1% Ovoglycoprotien
-0.8% Flavoprotien	-0.5% Ovomacroglobulin	-0.05% Avidin
-0.05% Crystatin		

Egg albumin, because of its protein concentration, is a powerful 'binding agent' in food. Proteins are slightly elastic in nature, as well as tending to bind together.

Egg contains high percentage of protein composition which are mostly composed of amino acids, which may influence cement properties

A number of experimental studies showed that the higher the alkali content in the cement, the lower the ultimate strength of the corresponding test specimens. From the study with 199 commercial portland cement, it was concluded that a higher cement alkali content statistically resulted in a higher dynamic modulus of elasticity measured on corresponding concrete specimens after 14 days. And it was concluded that a higher alkali content in cement accelerates the strength development in the short term but decreases the ultimate strength. [12]

2.1.4.2 Egg Shell

The outer cover of the egg, the egg shell comprises 10-11% of total egg weight. On the average the eggshell weighs 5-6g, with remarkable mechanical properties of breaking strength (>30N) and is 300 – 350 micrometer thick. This structure plays a crucial role in protecting the contents of the egg from the microbial and physical environment and in controlling the exchange of water and gases. The calcium content of the egg shell is approximately 1.7 – 2.5g. [13]

An average egg shell contains

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

Specific Gravity of Egg Parts

Egg part	Specific Gravity
Shell	2.325
Yolk	1.032
Albumin	1.038
Shell membranes	1.075

2.2 EXPERIMENTS

In this section the procedures of the experiments that need to be done for this research are explained.

2.2.1 Method of total solid

To obtain the amount of total solids in a fluid, the method of total solids is performed as explained below

Apparatus required

1. Crucible
2. Oven
3. Desiccators
4. Analytical Balance
5. Dish Tongs

Procedure

1. Switch on the balance
2. Note down the initial dry weight of the crucible (A)
3. Take the sample fluid in the crucible
4. Weigh the crucible with the sample fluid (B)
5. Place the crucible inside the oven
6. After drying in the oven cool to room temperature in desiccators
7. Note down the final dry weight of the crucible (C)

Analysis

Total Solid in the fluid (%) =(C-A)/ (B-A)*100

CHAPTER THREE

EXPERIMENTAL STRATEGY AND PROGRAM

3.1 EXPERIMENTAL STRATEGY

In this research, there are three materials that need to be studied separately. To start with lime mortar with proportions as were used in the construction of Fasiledes castle of Gondar will be examined for its compressive strength. Next the effect of egg albumin on the compressive strength of a cement mortar, by substituting different percentages of the total volume of mortar with egg albumin is studied. At last, the effect of egg shell on the compressive strength of a cement mortar as a partial substitution of fine aggregate is examined. The egg shell used is the percentage by volume of the fine aggregate keeping the cement to sand ratio constant with that of the control mix.

The research strategy is schematically presented in fig.3.1, where the E.Al and E.Sh stand for egg albumin and egg shell respectively. The percentages for the Egg albumin indicate the percentage by volume of the total volume of mortar that is replaced with egg albumin and the percentage of the egg shell indicate the percentage by volume of the fine aggregate that is replaced by egg shell. The control mix is the mix that is produced by mixing cement, sand and water without the addition of egg albumin and egg shell.

In the case of studying the effect of egg albumin on the compressive strength of a cement mortar, the percentage of the egg albumin added starts at 0% of the total volume of the cement mortar then the percentage is increased in 4% intervals until a maximum o 7% of egg albumin is reached. After studying the results obtained from these specimens, the maximum percentage and the intermediate percentages may be increased.

In the case of studying the effect of egg shell on the compressive strength of a cement mortar, the percentage of the egg albumin added starts at 0% partial substitution of fine aggregate then the percentage is increased in 2.5% intervals until a maximum of 20% of fine aggregate is replaced by egg shell. After studying the results obtained from these specimens, the maximum percentage and the intermediate percentages may be increased.

To study the compressive strength o a lime mortar a total of three specimens for the 7th day and a total of three specimens for the 28th day were used. Accordingly for studying the effect of egg albumin and egg shell on the compressive strength o a cement mortar, a total of six specimens were used for each percentage of egg albumin or egg shell where three of the specimens are broken at the age of 7 days and the other three of the specimen are broken at the age of 28 days.

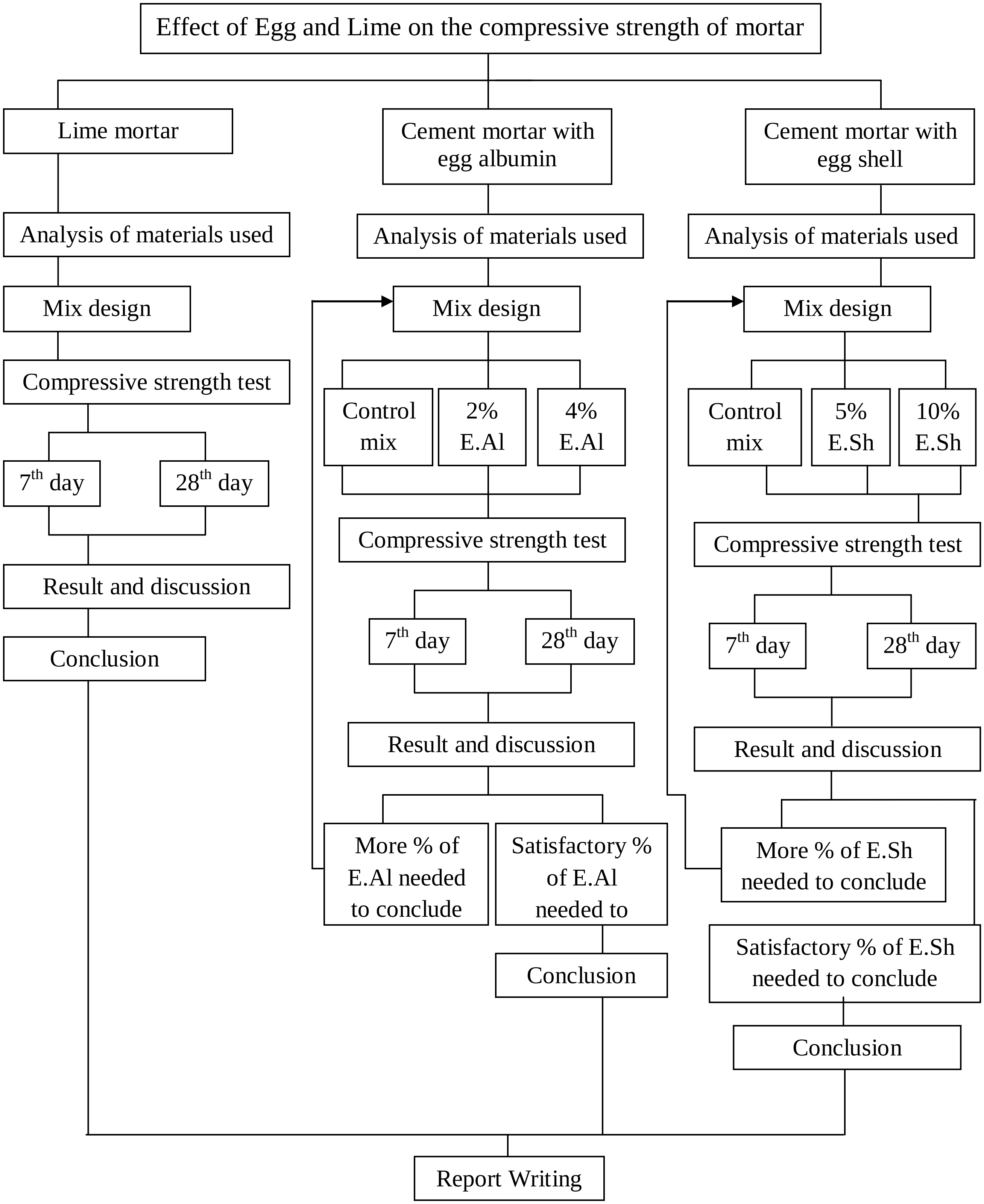

Fig. 3.1 Schematic presentation of the research strategy

3.2 MATERIALS

The different properties of the materials that are used in this research are explained in the next subsections by putting the materials through the required experiments to investigate their properties that are required for the research.

3.2.1 Water

Water shall be free from objectionable quantities of oil, acid, alkali, salt, organic matter, or other deleterious materials and shall not be used until the source of supply has been approved. In this research potable water supplied by Hawassa municipality was used for all concrete mixes.

3.2.2 Cement

Cement is a mixture of various chemical compounds which are lime(CaO), Silica(SiO_2), Alumina (Al_2o_3), Iron Oxide(Fe_2O_3), Magnesium Oxide(MgO), Na_2O, and Sulphur Trioxide. All ingredients have their own specific roles and variation in the proportion of these elements affects the properties of cement. Ordinary Portland cement is the most commonly used cement in the world today. In this research an ordinary Portland cement known as Derba cement of 42.5 grade and a density of 3.15 g/cm^3 is used.

3.2.3 Egg Albumin

Only the egg albumin which is the clear or misty substance that surrounds the yellow yolk is used, since it is the part of the egg that contains different kinds of protein, which are mostly composed of amino acid.

The egg is beaten until it is foamy to increase its ability to mix with the mortar mix.

Fig. 3.2 Egg albumin foam

To obtain the amount of total solids in a fluid, the method of total solids is performed as explained in section 2.2.1. In this research the amount of total solids present in egg albumin, i.e., the amount of water present in egg albumin must be known so that when mixing mortar containing egg albumin, the amount of water in the egg albumin will be decreased from the amount of water needed for the mortar mix so that the water cement ratio remains constant.

The water content in the egg albumin was tested by using three samples and the results are as follows:-

Table 3.1 Measurements for water content of egg albumin

Sample	Wt of Dish(g)	Total Weight before oven	Total weight after oven
1	256.0	281.5	257.5
2	243.5	267.5	244.5
3	244.5	266.5	246.0

Egg albumin before oven drying

Egg albumin after oven drying

Fig.3.3 egg albumin before and after oven drying

Table 3.2 Calculation of water content of egg albumin

Sample	Net weight before oven drying(g)	Net weight after oven drying(g)	Wt of water(g)	Percentage of water
1	25.5	1.5	24	$\frac{24}{25.5} \times 100 = 94.1\%$
2	24	1	23	$\frac{23}{24} \times 100 = 95.8\%$
3	22	1.5	20.5	$\frac{20.5}{22} \times 100 = 93.2\%$

The water content in the egg albumin can be calculated by taking the average of the three samples.

Water content in egg albumin= $\frac{94.1 + 95.8 + 93.2}{3} = 94.37$

Thus, Egg albumin contains 5.63 % total solids and the rest of the egg albumin which is 94.37% is liquid.

3.2.4 Egg Shell

In this research, Egg shell is included in the mortar mix as a partial replacement of fine aggregate which is assumed to increase the compressive strength of the cement mortar.

Since it is substituted in place of fine aggregate, it has to fulfill the required properties of fine aggregate.

Before the egg shell is used in the mortar mix, it has to be washed, sun dried and grinded in a certain way to make it obtain the properties of fine aggregate, which is that aggregates must pass through a no.4 (4.74mm) sieve and predominantly retained on a No. 200(75µm) sieve. In this research a food processor is used to reduce the egg shell into the required size.

3.2.4.1 Silt Content

Since the egg shell is washed before it is grinded, the presence of silt is not a concern.

3.2.4.2 Sieve analysis and Fineness Modulus

The particle size distribution of the egg shell is within the range of requirements for fine aggregate according to ES C.D3. 201. The grading requirement for fine aggregate according to ES C.D3. 201 is as follows.

Table.3.3 Sieve analysis results and standard for egg shell

Sieve Size	Percentage Passing ESC D3.201	Cumulative % retained	% passing of the egg shell used
9.5mm	100-100	0	100
4.75mm	100-95	0	100
2.36mm	100-80	1.69	98.31
1.18mm	85-50	23.69	76.31
600µm	60-25	55.61	44.39
300µm	3010	74.94	25.06
150µm	10-2	93.6	6.4

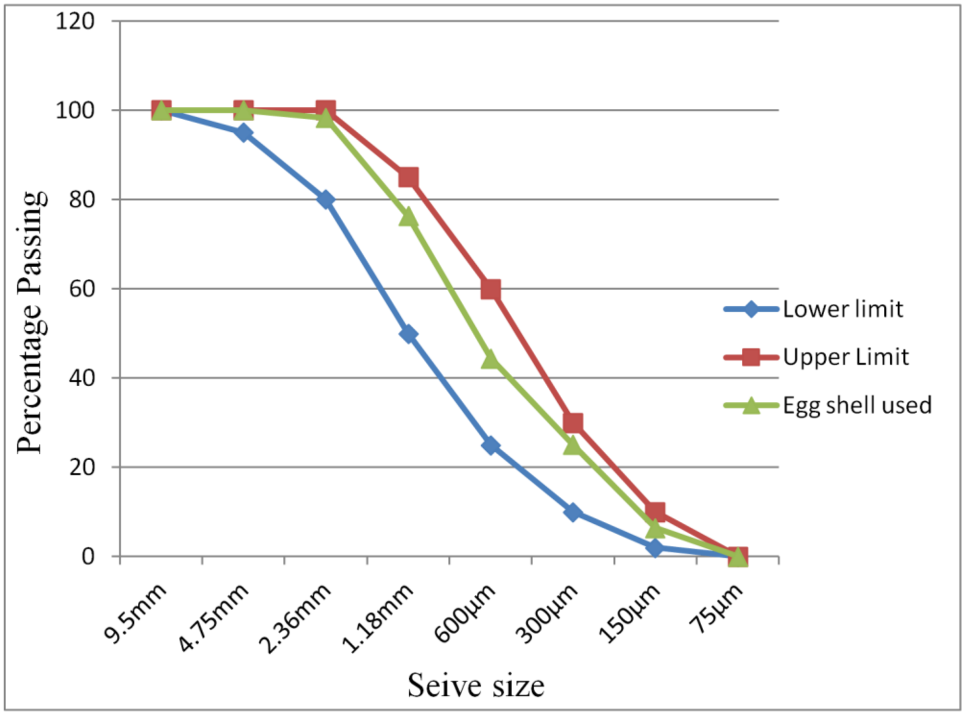

Fig.3.4 Gradation test for egg shell used

$$\text{Fineness modulus} = \frac{\text{cummulativ e coarser(\%)}}{100} = \frac{249.53}{100} = 2.5$$

Table.3.4 Specification for fineness modulus

Type of Sand	FM
Fine	2.0 to 2.8
Medium	2.8 to 3.2
Coarse	3.2

The egg shell used in this research is fine egg shell.[5]

3.2.4.3 Specific gravity and absorption capacity of egg shell

According to AASHTO 18, Bulk specific gravity (Bulk dry specific gravity) is the ratio of the weight in air of a unit volume of aggregate at a stated temperature to the eight in air of an equal volume of gas free distilled water at the stated temperature. Bulk SSD Specific gravity is the ratio of the weight in air of a unit of aggregate, including the weight of water with in the voids filled to the extent achieved by submerging in water for approximately 15 hours, to the weight in air of an equal volume of gas free distilled water at the stated temperature. Apparent specific gravity is the ratio of the weight in air of a unit volume of the impermeable portion of aggregate (does not include the permeable pores in aggregate) to the weight in air of an equal volume of gas free distilled water at the stated temperature. Absorption is the increase in weight of aggregate due to water in the pores of the material, but not including water adhering to the outside surface of the particles.

The specific gravity and absorption tests of the egg shell are performed according to ASTM C127 and C128 and the results are shown as follows:

- Bulk specific gravity = 2.02
- Bulk specific gravity(SSD basis) = 2.15
- Apparent specific gravity = 2.33
- Absorption capacity = 6.61

The absorption capacity of the egg shell is high compared to the sand used and thus the egg shell has more voids than the sand. The absorption of the egg shell needs to be taken into account if a mix with an egg shell in a dry condition is used

Table 3.5 Summary of test results for eggshell used

No	Test Description		Test Result
1	Fineness modulus		2.5
2	Specific Gravity	Bulk	2.02
		Bulk(SSD)	2.15
		Apparent	2.33
3	Absorption		6.61%

3.2.5 Sand

Aggregates passing through a No 4(4.75mm) sieve and predominantly retained on a No. 200(75µm) sieve are classified as fine aggregate. In this research, sand that has been washed to remove the dust and fines that it may contain is used.

3.2.5.1 Silt Content

Since the sand used in this research was washed before the tests was done, the silt content present was not major. Silt content test was done on the sample of sand and it was 3.8% which meets the restriction stated in the Ethiopian standard, which states that the silt content should not be more than 6%.

3.2.5.2 Sieve analysis and Fineness Modulus

The particle size distribution of the fine aggregate is within the range of the grading requirement for fine aggregate according to ES C.D3. 201. The grading requirement for fine aggregate according to ES C.D3. 201 is as follows.

Table.3.6 Sieve analysis results and standard for the sand used

Sieve Size	Percentage Passing ESC D3.201	Cumulative % retained	% passing of the egg shell used
9.5mm	100-100	0	100
4.75mm	100-95	0	100
2.36mm	100-80	5	95
1.18mm	85-50	21.36	78.64
600µm	60-25	51.29	48.71
300µm	30-10	81.97	18.03
150µm	10-2	96.9	3.1

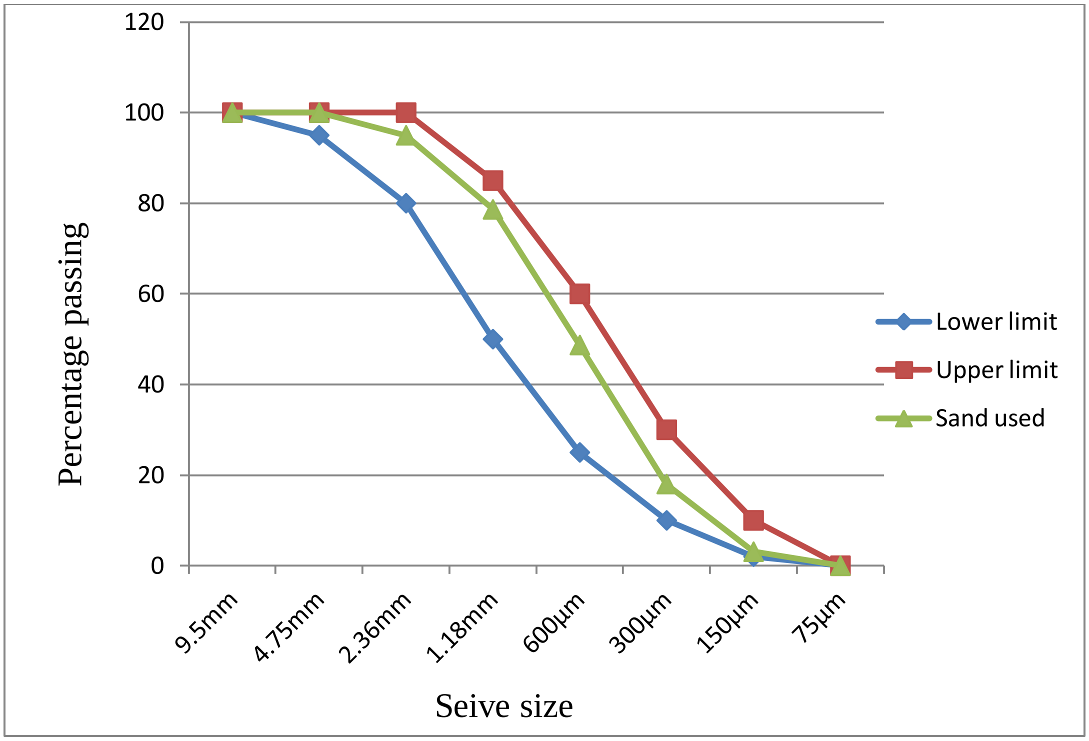

Fig.3.5 Gradation for sand used

$$\text{Fineness modulus} = \frac{\text{Cummulativ e coarser(\%)}}{100} = \frac{256.52}{100} = 2.56$$

The sand used in this research is fine sand.[5]

3.2.5.3 Specific gravity and absorption

The specific gravity and absorption tests of the sand are performed according to ASTM C127 and C128 and the results are shown as follows:

- Bulk specific gravity = 2.47
- Bulk specific gravity(SSD basis) = 2.56
- Apparent specific gravity = 2.72
- Absorption capacity = 3.63%

Table.3.7 Summary of test results for sand used

No	Test Description		Test Result
1	Silt Content		3.8%
2	Fineness modulus		2.56
3	Specific Gravity	Bulk	2.47
		Bulk(SSD)	2.56
		Apparent	2.72
4	Absorption		3.63%

3.3 METHODOLOGY

3.3.1 Lime mortar

The lime mortar is prepared at the proportion shown in section 3.4.1 and its compressive strength will be determined.

3.3.2 Mortar mix containing egg albumin

Control Mix

The Effect of the added egg albumin on the compressive strength of mortar is studied by comparison. The mortar cubes that contain egg albumin in different proportions will be compared to the mortar cube that does not contain any egg particles which is referred to as the control cube from here on.

Mortar mix containing egg albumin

Since the compressive strength of mortar is inversely proportional to the water cement ratio, the amount of water in the egg albumin needs to be decreased from the amount of water added in the control mix when calculating the amount of water added to the trial mixes that contain egg albumin to make the water cement ratio consistent.

The percentages of the egg albumin added are percentages of the total volume of cement mortar.

3.3.3 Mortar mix containing Egg shell

In this part of the research it is intended to investigate the effect that egg shell may have on the compressive strength of a cement mortar without changing the water cement ratio and the cement to sand ratio of the control mix, by using egg shell as a partial substitution of fine aggregate. Thus the percentages of egg shell added shows the percentage by volume of fine aggregates and this percentage is added to the mortar mix keeping the cement to fine aggregate ratio constant with that of the control mix.

3.4 MIX DESIGN OF MORTAR

The mix proportions that are needed to investigate the compressive strength of a lime mortar, the effect of egg albumin on the compressive strength of a cement mortar and the effect of egg shell on the compressive strength of a cement mortar are explained in the subsections that follow.

3.4.1 Mix proportion for lime mortar

- The mix proportion used for the mix of lime mortar was taken from an interview conducted with the supervisor that was in charge of the rehabilitation of the Fasiledes castle of Gondar at the site. And the proportion was 1:3 lime to sand ratio by volume.

- To measure the sand, which has a specific gravity of 2.56, a specified volume was used and the weight of the sand that corresponds to three times that volume was used.

- Since the lime has water in it is difficult to measure the lime in weight, thus the lime is measured by volume.

- By the time that the slaked lime is taken from the container, where it was stored, it looks like it is thick and that it doesn't contain much water. But after it is beaten well with a hand shovel it can be seen that it has a significant amount of water in it, that it becomes more fluid than it was. Thus the water that is added to the mix is added until the lime becomes workable, since finding out the amount of water in the slaked lime is difficult.

Fig.3.6 a) lime mortar by the time that it was taken from container b) lime mortar after it is beaten with a a hand shovel

3.4.2 Mix design for cement mortar containing Egg albumin

Egg albumin consists of 94.37% water and the other 5.63% is protein. Thus in 1% volume of egg albumin there are

$$0.01m^3 \text{ egg albumin} = 0.01 * \frac{94.37}{100} \text{Water} + 0.01 * \frac{5.63}{100} \text{Egg protein}$$

$$= 0009437 \text{ water} + 0.000563 \text{ Egg protein} \ldots\ldots\ldots\ldots \ldots\ldots\ldots\ldots (1)$$

This volume of water needs to be accounted in the total volume of water to keep the water cement ratio constant with the water cement ratio of the control mix. Thus the volume of egg that needs to be considered in the mix design is the volume of the egg protein which is 5.63% of the egg albumin. Although when the actual water for the mix design is measured, the amount of water in the egg albumin needs to be decreased and the volume of egg albumin needs to be measured as equal to $0.01m^3$.

Trial 1 – Control Mix(0% egg albumin)

- Sp. gr $(SSD)_{sand}$ = 2.56 - (As explained under section 3.2.5.3)
- Sp. gr cement=3.15
- Water cement ratio w/c by mass = $\frac{Mw}{Mc}$ = 0.5

- According to AASHTO design manual recommends Ms/Mc to be 2.75 and this value is used throughout this research for mortar mix.

$$Mw/Mc = 0.5$$

$$Mc = 0.5Mc$$

$$\delta wVw = 0.5(\delta cVc)$$

Where:- $\delta w = 1\, g/cm^3 \quad and \delta c = 3.15\, g/cm^3$

$$Vw = 0.5 * 3.15 * Vc$$

$$Vw = 1.575Vc \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$Ms/Mc = 2.75$$

$$Ms = 2.75Mc$$

$$\delta sVs = 2.75(\delta cVc)$$

$$2.56Vs = 2.75 * 3.15 * Vc$$

$$Vs = \frac{2.75 * 3.15}{2.56} Vc = 3.384Vc \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$Vtotal = Vw + Vc + Vsand + Vair \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Substituting (2) and (3) in to (4)

$$1m^3 = 1.575Vc + Vc + 3.38Vc + 0.03m^3$$

$$1m^3 - 0.03m^3 = 1.575Vc + Vc + 3.38Vc$$

$$0.97m^3 = 5.955Vc$$

$$0.97/5.955 = Vc$$

$$Vc = 0.1629m^3$$

$$Mc = 3.15 * Vc = 3.15 * 0.1629 * 10^3 = 513.14Kg$$

$$Vw = 1.575Vc$$

$$= 1.575 * 0.1629m^3 = 0.2566m^3$$

$$Mw = 10^3\, L/m^3 * 0.2566m^3 = 256.57L$$

$$Vs = 3.384 * 0.1629m^3 = 0.5512m^3$$

$$Ms = 2.56 * 103 \, Kg/m^3 * 0.5512m^3 = 1411.07Kg$$

$$Vtotal = 0.1629 + 0.2566 + 0.5512 + 0.03 = 1$$

Trial 2- 1% egg albumin

Substituting eq. (1) (2) (3) in to eq. (4), gives

Vtotal = Vactual water + Vc + Vsand + Vwater in egg albumin + Vprotien in egg albumin + Vair

=Vw + Vc + Vsand + Vprotien in egg albumin + Vair

Where Vw= Vactual water + Vwater in egg albumin

Note: The volume of water and solid in egg albumin are explained under section 3.2.3

$$Vtotal = 1m3 = 1.575Vc + Vc + 3.38Vc + 0.000563 + 0.03$$

$$1 - 0.000563 - 0.03 = 5,955Vc$$

$$0.9699437 = 5.955Vc$$

- $Vc = \frac{0.969437}{5.955} = 0.1628m^3$

  $$Wc \;\; 3.15 * 103 * 0.1628 = 512.82Kg$$

- $Vw = 1.575Vc = 1.575 * 0.1628 = 0.2564m^3$

  $$Mw = 10^3 * 0.2564 = 256.4L$$

- $Vs \;\; 3.38 * 0.1628 = 0.5503m^3$

  $$Ms = 2.56 * 10^3 * 0.5503 = 1408.8Kg$$

- $Wegg\ albumin = 10^3 * 0.01 = 10L$

Vw in egg albumin = $\frac{94.37}{100}$ * 10L = 9.437L

Vw = V actual water + V waer in egg albumin

V actual water = Vw – Vwater in egg albumin

- V actual water = 256.4L – 9.437L = 247L

NOTE: The mix design for trial 3 and 4 which are mixes containing 2% egg albumin and 3% egg albumin are done in the same manner as trial 2

Table.3.8 Summary of mix design of cement mortar containing egg albumin

% Egg albumin		Cement	Sand	Egg Albumin	Water
0	Volume(m^3)	0.1629	0.5512	0	0.2566
	Mass(Kg)	513.14	1411.1	0	256.57
1	Volume(m^3)	0.1628	0.5503	0.01	0.2564
	Mass(Kg)	512.8	1408.8	10	247
2	Volume(m^3)	0.1627	0.5499	0.02	0.2562
	Mass(Kg)	512.5	1407.7	20	237.33
3	Volume(m^3)	0.1626	0.5496	0.03	0.2561
	Mass(Kg)	512.19	1407	30	227.79

3.4.3 Mix Design for cement mortar containing Egg Shell

-sp. gr (SSD) = 2.56 - (as explained under section 3.2.5.3)

-sp. gr (GSb)Egg = 2.02 - (as explained under section 3.2.4.3)

-sp. gr cement = 3.15

-absorption of egg shell = 6.61% - (as explained under section 3.2.4.3)

- Water cement ratio w/c by mass = 0.5

$Mw\ \ 0.5Mc$

$0.97m^3 = 5.955Vc$

$\delta wVw = 0.5(\delta cVc)$

Where $\delta wVw = 1\,{}^{g}\!/\!{}_{cm^3}$ and $\delta c = 3.15\,{}^{g}\!/\!{}_{cm^3}$

$Vw = 0.5 * 3.15 * Vc$

$Vw = 1.575Vc$..(1)

- According to AASHTO design manual recommends Ms/Mc to be 2.75 and this value is used throughout this research for mix design of mortar.

${}^{Ms}\!/\!{}_{Mc} = 2.75$

But Ms = Megg shell + Msand

$$= \delta_{ES} V_{ES} + \delta s Vs$$

$$= 2.02 V_{ES} + 2.56 Vs$$

- $Ms = 2.75 Mc$

$$= 2.75 * \delta c Vc = 2.75 * 3.15 Vc = 8.6625 Vc \ldots\ldots\ldots (2)$$

- $2.02 V_{ES} + 2.56 Vs = 8.6625 Vc$

Trial 1 - control mix (0% egg shell)

NOTE – the percentage is percentage of fine aggregate that is substituted by egg shell

- Substituting VES = 0*Vs =0, in to equation (2), it becomes;

$$2.02 V_{ES} + 2.56 Vs = 8.6625\ Vc$$

$$0\ + 2.56 Vs = 8.6625 Vc$$

$$Vs = \frac{8.6625}{2.56} Vc = 3.384 Vc \ldots\ldots\ldots (3)$$

$$Vtotal = Vw + Vc + Vsand + Vair \ldots\ldots\ldots (4)$$

Substituting (1) and (3) in to (4)

$$1m^3 = 1.575Vc + Vc + 3.38Vc + 0.03m^3$$

$$1m^3 - 0.03m^3 = 1.575Vc + Vc + 3.38Vc$$

$$0.97m3 = 5.955Vc$$

$$0.97 / 5.955 = Vc$$

- $Vc = 0.1629 m^3$

$$Mc = 3.15 * Vc = 3.15 * 0.1629 * 10^3 = 513.14 Kg$$

- $Vw = 1.575 Vc$

$$= 1.575 * 0.1629 m^3 = 0.2566 m^3$$

$$Mw = 10^3 \, L/m^3 * 0.2566 m^3 = 256.57 L$$

- $Vs = 3.384 * 0.1629 m^3 = 0.5512 m^3$

  $Ms = 2.56 * 10^3 \, Kg/m^3 * 0.5512 m^3 = 1411.07 Kg$

Trial 2- 1% of fine aggregate is substituted with egg shell

Vw = 1.575Vc - (From trial 1, equation (1))

V_{ES} = 0.01Vs

Absorption of egg shell = 6.61%

Substituting V_{ES} = 0.01Vs into equation 2 gives

$2.02VES + 2.56Vs = 8.6625Vc$

$2.02 * 0.01Vs + 2.56Vs = 8.6625Vc$

$0.0202Vs + 2.56Vs = 8.6625Vc$

$2.5802Vs = 8.6625Vc$

$Vs = \frac{8.6625}{2.5802} Vc = 3.357 Vc$..(5)

$VES = 0.01Vs = 0.01 * 3.357Vc = 0.03357Vc$...(6)

Substituting equation (1) (5) and (6) in to equation (4) gives,

$V_{total} = V_w + V_c + V_{sand} + V_{Egg\ Shell} + V_{air}$

$1m3 = 1.575Vc + Vc + 3.357Vc + 0.03357Vc + 0.03$

$0.97m^3 = 5.9655 Vc$

- $Vc = \frac{0.97}{5.96557} = 0.1626 m^3$

  $Mc = 3.15 * 0.1626 * 10^3 = 512.19 Kg$

- $Vw = 1.575Vc = 1.575 * 0.1626 = 0.2561 m^3$

  $Mw = 10^3 * 0.2561 = 256.1 L$

  Added Water (to account for the absorption of egg shell)

  $= \frac{6.61 * 11.11}{100}$ = 0.55ml

  Total Water = 256.1 + 0.73 = 256.83ml

- $Vs = 3.357Vc$
  $0.97m^3 = 5.955Vc$
  $0.97m^3 = 5.955Vc$
  $0.97m^3 = 5.955Vc$

- $Vs = 3.357Vc = 3.357 * 0.1626 = 0.5458m^3$
  $Ms = 2.56*0.5458*10^3 = 1397.25Kg$
- $V_{ES} = 0.03357Vc = 0.03357 * 0.1626 = 0.0055m^3$
  $M_{ES} = 2.02*0.0055*10^3 = 11.11Kg$

NOTE: The mix design for trials 3 to trial 10 is performed in the same manner as trial 2

Table.3.9 Summary of mix design of cement mortar containing egg albumin

Trial no	% of Egg Shell		Cement	sand	Egg Shell	water	Added Water	Total water
1	0	Volume(m^3)	0.1629	0.5512	0	0.2566		
		Mass(Kg)	513.14	1411.07	0	256.57	0	256.57
2	1	Volume(m^3)	0.1626	0.5458	0.03357	0.2561		
		Mass(Kg)	512.19	1397.25	11.11	256.1	0.73	256.83
3	2.5	Volume(m^3)	0.1623	0.5448	0.0135	0.2556		
		Mass(Kg)	511.24	1394.69	27.27	255.6	1.8	257.4
4	5	Volume(m^3)	0.1619	0.527	0.0264	0.255		
		Mass(Kg)	509.99	1349.12	53.33	255	3.53	258.53
5	7.5	Volume(m^3)	0.1614	0.5157	0.0387	0.254		
		Mass(Kg)	508.41	1320.19	78.174	254.2	5.17	259.37
6	10	Volume(m^3)	0.161	0.504	0.0505	0.254		
		Mass(Kg)	507.15	1292.3	101.97	253.6	6.74	260.34
7	12.5	Volume(m^3)	0.1606	0.4946	0.0618	0.253		
		Mass(Kg)	505.89	1266.18	124.84	252.9	8.25	261.15

8	15	Volume(m^3)	0.1602	0.4849	0.0727	0.252		
		Mass(Kg)	504.63	1241.34	146.85	252.3	9.71	262.01
9	17.5	Volume(m^3)	0.1598	0.475	0.083	0.252		
		Mass(Kg)	503.37	1216	167.66	251.7	11.08	262.78
10	20	Volume(m^3)	0.1595	0.466	0.093	0.251		
		Mass(Kg)	502.42	1192. 96	187.86	251.2	12.42	263.62

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 INTRODUCTION

In this chapter the results obtained from the experimental programs of testing the compressive strength of lime mortar mixed in laboratory in a mix proportion used in the rehabilitation of Fasiledes Gondar, the compressive strength of cement mortar containing egg albumin in different percentages and the compressive strength of cement mortar containing egg shell in different proportions are discussed in detail.

4.2. COMPRESSIVE STRENGTH OF LIME MORTAR

In this research, the lime mortar was mixed in a proportion of 1:3 lime to sand ratio in volume and as a result the specimen failed at an average compressive strength of 200kPa at the age of 7 days and at an average compressive strength of 440kPa at the age of 28 days.

The compressive strength of a lime mortar is very small as compared to that of a cement mortar and in my opinion, the strength of the historical Fasiledes castle of Gondar came from the stones used to build it together and the lime mortar was used to bind the stones together.

4.3. COMPRESSIVE STRENGTH OF MORTAR CONTAING EGG ALBUMIN

The compressive strength of cement mortar that contained egg albumin in different percentages were tested and analyzed. The detailed results of the laboratory tests are shown in the appendix. The average 7^{th} day and 28^{th} day compressive strength test results are shown as follows.

Table.4.1 7th day Compressive strength of cement mortar containing egg albumin

Sample No	% Egg albumin	7^{th} day Compressive Strength of mortar	
		Load(kN)	Strength(MPa)
1	0	36.25	14.49
2	1	38.93	15.56
3	2	31.92	12.76
4	3	27.39	10.95

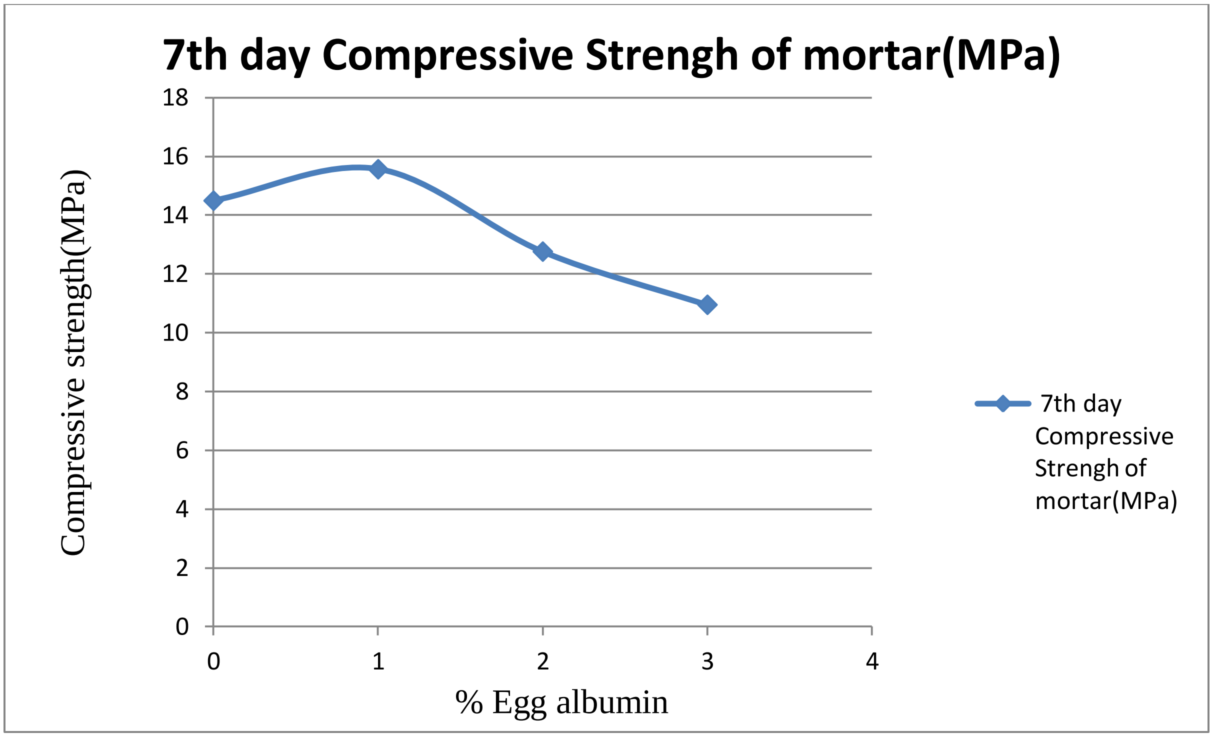

Fig.4.1 7th day Compressive strength of cement mortar containing egg albumin

Table.4.2 28th day Compressive strength of cement mortar containing egg albumin

Sample No	% of Egg albumin	28th day Compressive Strength of mortar	
		Load(kN)	Strength(MPa)
1	0	55.37	22.11
2	1	61.24	24.47
3	2	50.83	20.29
4	3	44.79	17.89

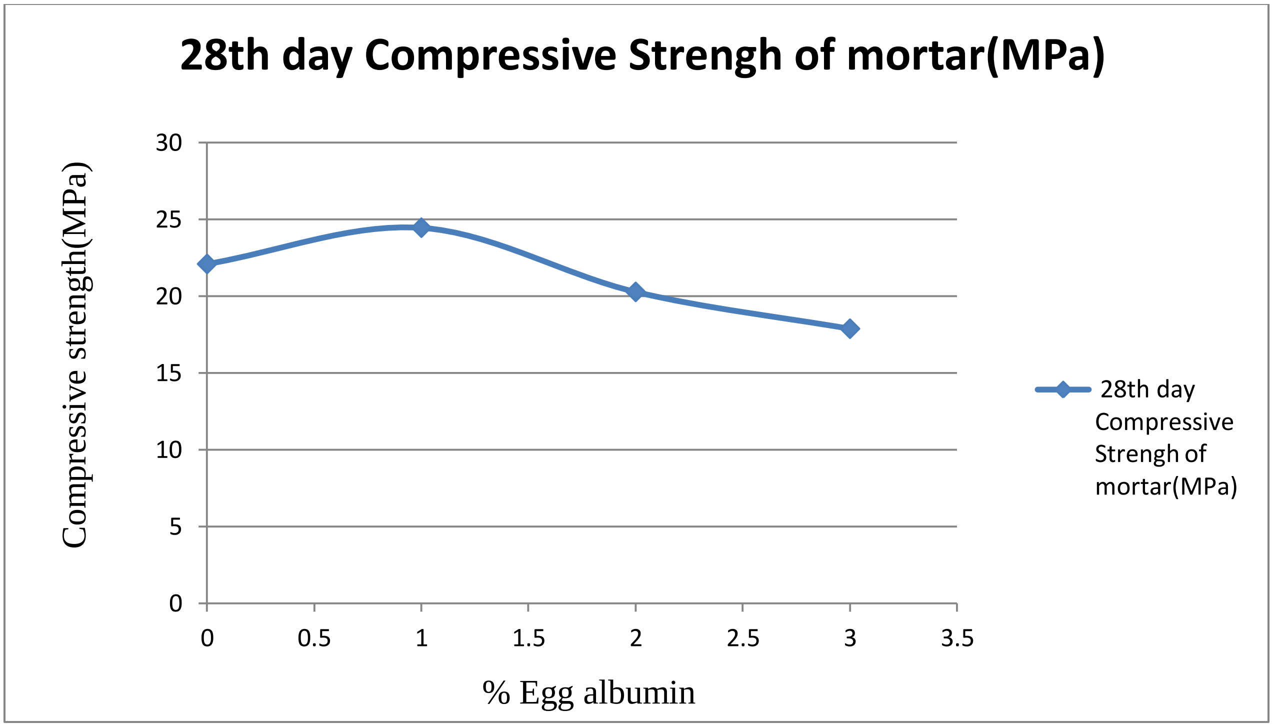

Fig.4.2 28th day Compressive strength of cement mortar containing egg albumin

As shown in the above tables, the cement mortar at the addition of 1% of egg albumin shows an increase in the compressive strength as compared to the control cement mortar which does not contain any amount of egg albumin. In my opinion, this is probably the effect of the proteins in the egg albumin on the mortar, because of the property of proteins that have the potential for bonding interactions with other proteins and surfaces. This can easily be seen if the egg white was spilled on two eggs and it is dried, it is impossible to pull the two eggs apart without breaking at least one of them. But by the addition of more amount of egg albumin, the mortar alkali content will increase since the egg albumin is an alkaline solution which may have harmful effect on the mechanical properties of aggregates which are not susceptible to alkali - silica reaction.

4.4. COMPRESSIVE STRENGTH OF CEMENT MOTAR CONTAING EGG SHELL

The compressive strength of cement mortar that contained different percentages of Egg Shell was tested and analyzed. The detailed results of the laboratory tests are shown in the appendix. The average 7th day and 28th day compressive strength test results are shown as follows.

Table.4.3 7th day Compressive strength of cement mortar containing egg shell

Sample No	% Egg shell	7th day Compressive Strength of mortar	
		Load(kN)	Strength(MPa)
1	0	36.74	14.69
2	1	40.82	16.32
3	2.5	42.81	17.1
4	5	45.01	17.98
5	7.5	41.47	16.58
6	10	37.96	15.17
7	12.5	35.53	14.2
8	15	31.87	12.72
9	17.5	28.06	11.21
10	20	24.92	9.95

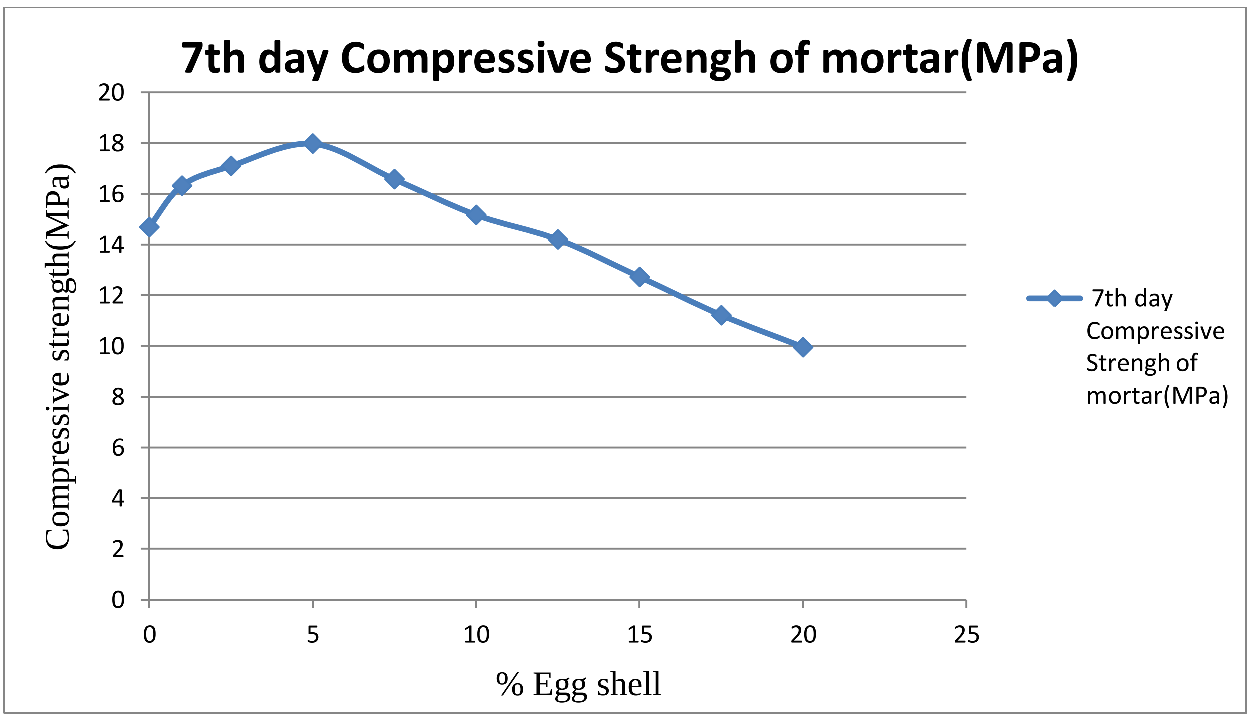

Fig.4.3 7th day Compressive strength of cement mortar containing egg shell

Table.4.4 28th day Compressive strength of cement mortar containing egg shell

Sample No	% of Egg shell	28th day Compressive Strength of mortar	
		Load(KN)	Strength(MPa)
1	0	56.28	22.5
2	1	59.16	23.64
3	2.5	61.65	24.62
4	5	64.48	25.76
5	7.5	60.96	24.36
6	10	57.99	23.18
7	12.5	54.24	21.66
8	15	49.9	19.94
9	17.5	44.06	17.6
10	20	40.62	16.23

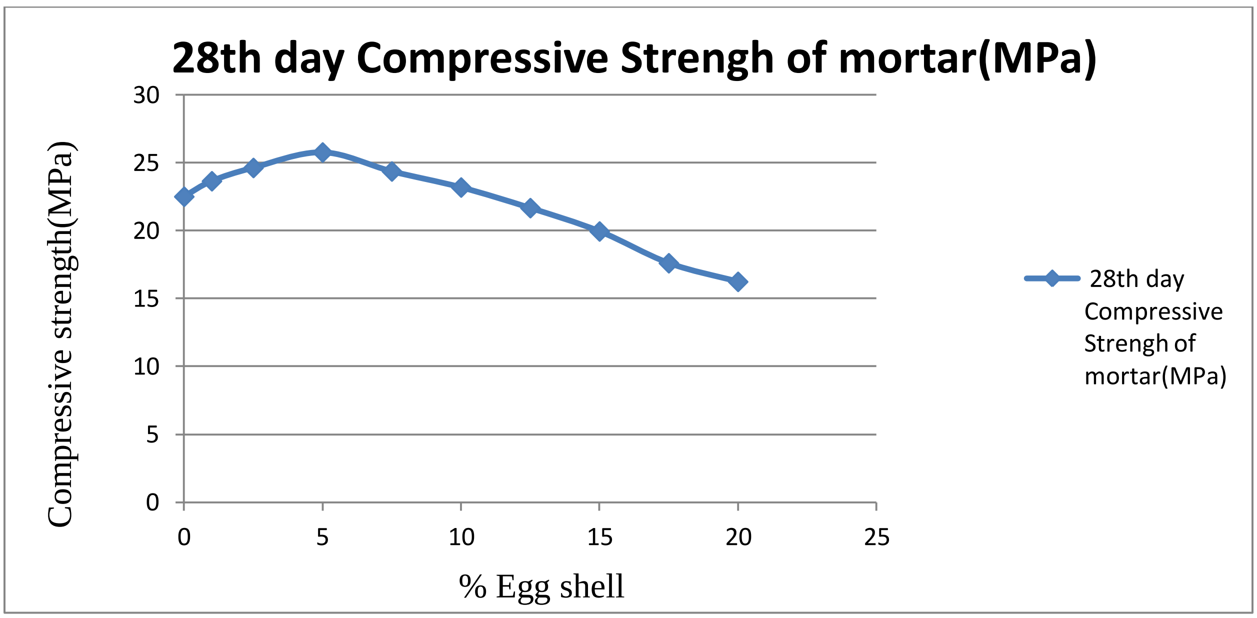

Fig.4.4 28th day Compressive strength of cement mortar containing egg shell

As shown in the above tables, it can be seen that the cement mortar that has an Egg Shell of 1%, 2.5%, 5%, 7.5%, and 10% have a higher compressive strength than the control mix which has 0%percentage of egg shell. In my opinion the increase is due to a natural cementary property in the eggshell which is mostly limestone. After being wet, the egg shell packed into a smaller space than they occupied when dry and were much harder to handle. Water picks the particles more closely together with cement and sand. Such a matrix probably fills the voids of the aggregate and makes a more uniform mortar and increases the compressive strength.

Fig. 4.5 Egg shell after being wet

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CHAPTER FIVE

ENVIRONMENTAL AND ECONOMIC ANALYSIS

5.1 INTRODUCTION

End products are materials that are not prime products for which an initial user has no further use in terms of his/her own purposes of production, transformation or consumption, and of which is needed to be disposed. Wastes may be generated during the extraction of raw materials, the processing of raw materials and other human activities. Residuals recycled or reused at the place of generation are excluded.[14]

5.2 ENVIRONMENTAL ASPECT

Each year, close to 30% of the eggs we consume are broken and processed or powdered in to foods such as cake mixes, mayonnaise, noodles, and fast foods. That translates in to over 50 million cases of eggs (at 30 dozen eggs to the case) used annually by the food industry, which creates a big problem.

Egg shell waste is a serious matter in the “egg breaking” industry. Companies are paying a great amount of money each year to dispose of egg shells in landfills and the fills are reaching capacity. On top of that, many landfill owners do not want eggshells because the protein rich membrane which adheres to the shell attracts rats and other vermin.[15]

In 2006 E.C, The total egg production in Ethiopia was estimated at 36,624 tones,[3]. On average an egg weighs 55 go 60g,[13]. This makes the annual production estimation of eggs to be 636,939,130 eggs in 2006. An egg shell weighs 10-11% of the total weight of an egg which is 5-6g,[13]. Thus the average annual egg shell waste in Ethiopia is estimated at 3,503 tones. The egg albumin is about two thirds of the total weight of the egg out of its shell,[13]. This makes the average annual egg albumin estimation at 22,080 tones.

By using egg shell as a part of a mortar and again as a part of concrete would have a great solution for decreasing the serious matter of egg shell wastes.

5.3 ECONOMICAL ASPECT

Successful reuse of Egg shell would have a great impact on the food industry, not only by disposing off the waste eggshell but also by eliminating the expenses for its disposal.

Using egg shell as part of the mortar decreases both the volume of both cement and fine aggregate in the mix design of the mortar. Thus, since the egg shell is a waste material collected from various food industries it will not be costly, thus using it in a mortar or concrete mix will decrease the price needed to make the same mortar or concrete without the egg shell.

Table.5.1 Cost analysis of cement mortar with egg shell

Material	Market cost	Amount in 1m^3 mortar		Cost for 1m^3 of mortar (birr)		Cost reduction in 1m3 mortar (%)
		0% egg shell	10% egg shell	0% egg shell	10% egg shell	
Cement (birr/Kg)	4.8	513.14	507.15	2463.072	2434.32	
Sand (birr/m^3)	437.5	0.5512	0.504	241.15	220.5	
Egg shell (birr/Kg)	.25	0	101.97	0	25.49	
Total Cost				2704.222	2680.3	1

Average cost of 50kg cement is 240 birr

Average cost of 16m3 sand is 7000 birr

Average cost for transportation of 1kg Egg shell is taken as 25cents

The cost analysis shows a 1% decrease in the cost of mortar when using 10% of egg shell as a partial substitution of fine aggregates. Economically the cost decreased was very small, but using egg shell as a partial replacement of fine aggregates will decrease the amount of sand used, thus decreasing the alteration of landfills and river sides to extract sand. Besides the use of egg shells in mortar or concrete decreases the amount of waste eggshells that will be dumped on landfills, leaving the environment more clean.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSION

This research was conducted to examine the compressive strength of lime mortar used for the rehabilitation of Fasiledes castle of Gondar and to examine the effect that egg albumin and egg shell could have on the compressive strength of a cement mortar. And from the testes performed and the results obtained the following conclusions may be concluded.

1. The compressive strength of the cement mortar cubes that contain egg albumin showed an equal and ever slightly higher compressive strength as compared to cement mortar cubes without egg albumin.
2. The compressive strength of cement mortar cubes that used egg shell as a partial substitution of fine aggregates showed an equal and even slightly higher compressive strength as compared to a cement mortar that does not contain egg shell.

6.2. RECOMMENDATION

Depending on the results that are obtained and on the ideas that revealed during this research the following recommendations are stated.

1. In this research, the eggshell used was by considering the eggshell as a fine aggregate and it may give an interesting result if it may be used grinded very fine and as a filler by a partial replacement of cement.
2. From the results obtained in this research, egg shell has a more than 13% increase in compressive strength of mortar, thus the eggshell may have the same effect if it was added in concrete. Thus it will be good if it is tested on concrete and see if it can be applied in current constructions.
3. The egg albumin and egg shell may have an effect in other properties of mortar other than compressive strength and they may have different long term effects, thus these properties may be studied.

6.3 LIMITATIONS

-Chemical analysis works were not conducted due to absence of laboratory equipments and budget

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ANNEX A

A-1 7[th] day compressive strength cement mortar made with addition of egg albumin

% egg albumin	Sample	Weight	L	W	H	Area	Compressive Strength(N)	Compressive Strength(Mpa)
0	1.1.1	288	50.01	50.02	50	2501.5	36471.87	14.58
	1.1.2	288	50.05	50.05	50.02	2505	35195.25	14.05
	1.1.3	289	49.98	50.01	50.01	2499.5	37092.58	14.84
				Average		2502	36253.23	14.49
1	1.2.1	287	50.01	50.02	50	2501.5	39873.91	15.94
	1.2.2	286	50.05	50.01	50.02	2503	38345.96	15.32
	1.2.3	288	50.02	50	50.01	2501	38565.42	15.42
				Average		2501.83	38928.43	15.56
2	1.3.1	288	50.01	50.02	50.05	2501.5	32219.32	12.88
	1.3.2	287	50	50	50.05	2500	31900	12.76
	1.3.3	288	50.02	50.01	50.03	2501.5	31643.98	12.65
				Average		2501	31921.1	12.76
3	1.4.1	288	50.01	50.04	50.01	2502.5	26926.9	10.76
	1.4.2	287	50.05	50.01	50.02	2503	27432.88	10.96
	1.4.3	287	50.02	50.02	50.05	2502	27822.24	11.12
				Average		2502.5	27394.01	10.95

A-2 28th day compressive strength cement mortar made with addition of egg albumin

% egg albumin	Sample	Weight	L	W	H	Area	Compressive Strength(N)	Compressive Strength(Mpa)
0	1.1	287	50.01	50	50.01	2500.5	56211.24	22.48
	1.1	286	50.05	50.1	50.12	2507.51	55215.37	22.02
	1.1	287	50.02	50.05	50.01	2503.5	54676.44	21.84
				Average		2503.84	55367.68	22.11
1	1.2	286	50.02	50.01	50.05	2501.5	61636.96	24.64
	1.2	287	50.01	50.02	50.1	2501.5	60936.54	24.36
	1.2	288	50.03	50.05	50.02	2504	61147.68	24.42
				Average		2502.33	61240.39	24.47
2	1.3	286	50.08	49.98	50.01	2503	50009.94	19.98
	1.3	288	50.1	50.05	50.02	2507.51	51052.9	20.36
	1.3	287	50.12	50.01	50.01	2506.5	51433.38	20.52
				Average		2505.67	50832.07	20.29
3	1.4	287	50.03	50.01	49.98	2502	43935.12	17.56
	1.4	286	50	50.05	50.01	2502.5	44844.8	17.92
	1.4	287	50.1	50.01	50.05	2505.5	45600.1	18.2
				Average		2503.33	44793.34	17.89

ANNEX B

B-1 7th day compressive strength cement mortar made with addition of egg shell

% egg shell	Sample	Weight	L	W	H	Area	Compressive Strength(N)	Compressive Strength(Mpa)
0	5.1	293	50.02	50	50.04	2501	36314.52	14.52
	5.1	291	50	50.02	50.01	2501	36764.7	14.7
	5.1	292	50.01	50.02	50.03	2501.5	37147.28	14.85
				Average		2501.17	36742.17	14.69
1	5.2	291	49.98	50.01	50	2499.5	40241.95	16.1
	5.2	291	50.04	50	50.05	2502	40832.64	16.32
	5.2	292	50	50.02	50.04	2501	41391.55	16.55
				Average		2500.83	40822.05	16.32
2.5	5.3	290	50.05	50.12	50.01	2508.51	43146.37	17.2
	5.3	293	50.01	50	50.03	2500.5	42908.58	17.16
	5.3	291	50	50.02	50.02	2501	42366.94	16.94
				Average		2503.34	42807.3	17.1
5	5.4	290	50.02	50.05	50.04	2503.5	44562.3	17.8
	5.4	290	50.04	50.01	50.02	2502.5	45495.45	18.18
	5.4	290	50.05	50.03	50	2504	44971.84	17.96
				Average		2503.33	45009.86	17.98
	5.5	289	50.01	50	50.02	2500.5	42133.43	16.85
	5.5	290	50	50.02	50.01	2501	41716.68	16.68
7.5	5.5	289	50.02	50.01	50.12	2501.5	40574.33	16.22
				Average		2501	41474.81	16.58
	5.6	288	50	50	50	2500	38400	15.36
	5.6	290	50.01	50.05	50.01	2503	36894.22	14.74
10	5.6	288	50.02	50.03	50.05	2502.5	38588.55	15.42
				Average		2501.83	37960.92	15.17
	5.7	288	50.05	50.01	50.02	2503	36093.26	14.42
	5.7	288	50.04	49.98	50.05	2501	34638.85	13.85
12.5	5.7	287	50.01	50.05	50.03	2503	35867.99	14.33
				Average		2502.33	35533.37	14.2
	5.8	288	50.12	50.04	50.01	2508	32904.96	13.12
	5.8	287	50.02	50.05	50.05	2503.5	30843.12	12.32
15	5.8	287	50.01	50.04	50.04	2502.5	31856.83	12.73
				Average		2504.67	31868.3	12.72
	5.9	286	50.03	50.01	50.02	2502	27822.24	11.12
	5.9	286	49.98	50.04	50.05	2501	28811.52	11.52
17.5	5.9	287	50.04	50.03	50.01	2503.5	27538.5	11
				Average		2502.17	28057.42	11.21
	5.10.	286	50.01	50.05	50.04	2503	25730.84	10.28
	5.10.	285	50.03	50.03	50.01	2503	25405.45	10.15
20	5.10.	286	50.02	50.12	50.01	2507	23615.94	9.42
				Average		2504.33	24917.41	9.95

B-2 28th day compressive strength cement mortar made with addition of egg shell

% egg shell	Sample	Weight	L	W	H	Area	Compressive Strength(N)	Compressive Strength(Mpa)
0	5.1	292	50.03	50.02	50.03	2502.5	56656.6	22.64
	5.1	292	49.98	50.04	50.01	2501	56247.49	22.49
	5.1	291	50.02	50.01	50	2501.5	55933.54	22.36
				Average		2501.67	56279.21	22.5
1	5.2	290	50.05	50.03	50.05	2504	59670.32	23.83
	5.2	291	50	50.01	50.04	2500.5	58686.74	23.47
	5.2	291	50.01	50.03	49.98	2502	59097.24	23.62
				Average		2502.17	59151.43	23.64
2.5	5.3	292	50.12	50.05	50.02	2508.51	61859.86	24.66
	5.3	291	50.01	50.02	50.01	2501.5	61436.84	24.56
	5.3	291	50.02	50.02	50.05	2502	61649.28	24.64
				Average		2504	61648.66	24.62
5	5.4	289	50.05	50.01	50.02	2503	64477.28	25.76
	5.4	290	50.04	50.02	50.04	2503	64927.82	25.94
	5.4	291	50.05	50.01	50.01	2503	64026.74	25.58
				Average		2503	64477.28	25.76
	5.5	287	50.01	50.04	50.02	2502.5	61136.08	24.43
	5.5	288	50.03	50.01	50.03	2502	61048.8	24.4
7.5	5.5	289	50.01	50.03	50.01	2502	60673.5	24.25
				Average		2502.17	60952.79	24.36
	5.6	287	50.02	50.01	50.04	2501.5	58535.1	23.4
	5.6	288	50.04	50.02	50.01	2503	58920.62	23.54
10	5.6	288	50.01	49.98	50.02	2499.5	56513.7	22.61
				Average		2501.33	57989.81	23.18
	5.7	287	50.04	50.12	50.03	2508	54373.44	21.68
	5.7	286	50.01	50.05	50.01	2503	54415.22	21.74
12.5	5.7	287	50	50	50.12	2500	53925	21.57
				Average		2503.67	54237.89	21.66
	5.8	286	50.05	50.01	50.01	2503	50760.84	20.28
	5.8	286	50.01	50.03	50.05	2502	48989.16	19.58
15	5.8	287	50.04	50.01	50.04	2502.5	49924.88	19.95
				Average		2502.5	49891.63	19.94
	5.9	285	50.01	50.04	49.98	2502.5	44744.7	17.88
	5.9	286	50.05	50.01	50.04	2503	43977.71	17.57
17.5	5.9	285	50.03	50.01	50.01	2502	43434.72	17.36
				Average		2502.5	44052.38	17.6
	5.10.	284	50.01	50.04	50.03	2502.5	39839.8	15.92
	5.10.	285	50.02	50.01	50.05	2501.5	41574.93	16.62
20	5.10.	285	50.05	50.03	50.02	2504	40439.6	16.15
				Average		2502.67	40618.11	16.23

ANNEX C

SAMPLE PHOTOS TAKEN DURING THE RESEARCH

Pic. 1 Saturated Surface Dry condition test for egg shell

Pic. 2 Drying of Egg shell after being washed

Pic 3. Measurement for Specific Gravity of Egg shell

Pic 4. Curing of cement mortar cubes

Pic 5. Shape of mortar after compressive strength test