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# Experimental study on the impact of clay particles in coarse aggregate on concrete compressive strength

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**ABSTRACT**

Coarse aggregates often contain a layer of small particles bounded strongly or weakly to the aggregate surface (a surface coating). This experimental study evaluates the impact of clay particles in the coarse aggregates on compressive strength of concrete. The tests were conducted on the most used concrete constituents in Addis Ababa city in Mafcon Engineering and construction (PLC) laboratory. Tests for compressive strength of concretes are carried out by six cubes of size 15cm*15cm*15cm. All test specimens are prepared in accordance to the ACI mix-design. The concrete is poured in the mould and tempered properly so as not to have any voids. After 24-hours these moulds are removed and test specimens are put in potable water for curing. For all concrete strengths studied in this research the specimens are tested by compression testing machine after 7 days curing and 28 days curing. The clay quantity in the coarse aggregates used for this study are 0%,2.5%,5%,7.5% ,10%and 15% by weight. For all those percentage of clay quantities, the type of water, quantity of sand and quantity cement have not been changed and the all results were compared to the properties of concrete which does not contain clay particles in coarse aggregates. Also additional two tests were performed having a more contaminate or high clay particles (dust particles) in the coarse aggregates and high crushed values of coarse aggregate on production from different locations of supplied aggregates. From this study it was found that the concrete compressive strength is inversely proportional to the quantity of clay particles contained in coarse aggregates.

**Key words**: clay particles; Dust; coarse aggregates; compressive strength; concrete; tests; mixes; deleterious

# 1. INTRODUCTION

Concrete is a mixture of cement, fine aggregate, coarse aggregate and water. Concrete is a variable material having broad strength range. It is well recognized that coarse aggregate plays an important role in concrete, and concrete failure is usually connected to the use of different coarse aggregates. Previous research associates the presence of some type of micro-fines on the surface of these aggregates with deleterious properties of concrete. A large fraction of micro-fine gravel coatings consist of clay minerals. Due to their small size and large surface areas as well as differing chemistries, these minerals likely can be expected to be major components of reactivity in concrete systems. It has been widely reported that presence of clays in cement reduces the compressive strength and increases shrinkage in the resulting concrete [19]. However, the exact mechanism by which these clays in coarse aggregate affect the properties of concrete has not been established. Therefore, the effect of clay particles in coarse aggregates on concrete compressive strength is central to this experimental study.

It is necessary that aggregates for making concrete should be free from impurities, Micro-fines and clay particles. Micro-fines could be classified into three major types: stone dust, clay minerals, or calcium carbonate [19]. The characteristics of the clay fraction vary depending on the type of clay mineral. For example, some types of clay are held so tightly to the aggregate surface that they may not be displaced during washing, while other types of clay may be released into the water and are removed during aggregate washing or concrete mixing [17]. The term "clay" refers to a naturally occurring material composed primarily of fine-grained minerals, which is generally plastic at appropriate water contents and will harden with dried or fired. Clay coatings consist of clay particles that are held tightly to aggregate surface. Because the material usually adheres to the aggregate even after the concrete is mixed, it is believed to interfere with the aggregate-cement paste bond [10]. The relationship between concrete mix proportions and compressive strength has been a matter of interest for several researchers [2]. For normal strength concrete, the water cement ratio (w/c) is the major factor controlling most of the physical properties of concrete, and fine and coarse aggregates is considered as the strongest phase. Therefore, it is not only sufficient to relate compressive strength to the water-cement ratio of concrete, but also to other parameters that have a considerable influence on the development of concrete properties. In such a case, fine and coarse aggregates must be properly selected depending on their physical and mechanical properties [7, 9, and 33].

Several studies were carried out to investigate the effect of types, proportions, physical and mechanical properties of dusts and clay particles on concrete mechanical strength. However, researches focusing on the effect of dusts and clay particles in coarse aggregate are still limited and its effect is not yet well established.

The present paper investigates the influence or impact of the proportion of clay particles on the compressive strength of concrete using different types and rates of dusts and clay particles. The main objective of this study was to clarify the influences of type and proportion of clay particles in coarse aggregates on the compressive strength of concrete and to suggest a rational use of coarse aggregate materials. The study also describes work that is aimed at improving the understanding of the effect of clay particles in coarse aggregates on concrete compressive strength.

# 2. MATERIAL AND METHODS

A series of eight batches were made to cast a concrete for this experimental study. A series of six batches with clay contents of 0%, 2.5%, 5%, 7.5%, 10% and 15% with in percentage of coarse aggregates and mix with the other concrete making materials and the quantities of sand and cement have not been changed to determine the impact of clay contaminants on the physical properties of concrete. A series of two concrete batches are to be mix with high content of clay particles in the coarse aggregates that obtain from the selected construction sites (different locations) to compare the results on the properties of concrete.

## 2.1 Materials

Materials which are used in this research are:

### 2.1.1. Cement

Ordinary Portland cement is the one, which is commonly used in Ethiopia for concrete production. Therefore, **Dangote type I ordinary Portland cement** were used for this experiment. The manufacture of cement requires stringent control, and a number of tests are performed in the cement works laboratory to ensure that the cement is of the desired quality and that it conforms to the requirements of the relevant national codes and standards. These tests are; consistency test, fineness test, setting time test, soundness test, strength test, etc.

### 2.1.2. Sieve analysis and grading

This is the process of screening a sample of aggregate into size fractions each consisting of particles of the same range size i.e. particle size distribution. Sieve analysis is done by passing the dried aggregate through a series of standard test sieves beginning with the one sufficiently coarse to pass all the material. The diameters of test sieves and mesh apertures are given in AASHTO M 6-93 and ASTM C -136 standards. Having completed the sieving, the weights of aggregate retained in each sieve in turn are recorded. The weights and percentages of aggregate passing each test sieve are then computed. The results of sieve analysis are represented graphically in charts known as grading curves/charts. By using these charts, it is possible to see at a glance if the grading of a given sample conforms to that specified or it is too fine or coarse or deficient on a particular size. In the curves, the ordinates represent cumulative percentages passing. Grading is of importance as it affects the workability of concrete. The development of strength corresponding to a given water/cement ratio requires full compaction and this can only be achieved with a sufficiently workable mix. It is necessary to produce a mix that can be compacted to a maximum density with a reasonable amount of work. The main factors governing the desired aggregate grading are;

1. Surface area of aggregate. This determines the amount of water necessary to wet all the solids/particles.
2. The relative volume occupied by the aggregate.
3. The workability of the mix. The aggregate must contain a sufficient amount of material passing 300mm sieve to improve workability.
4. The tendency to segregation. It is essential for the voids in the combined aggregate to be sufficiently small to prevent the cement paste from passing through and separating out.

In the construction industry of Ethiopia the manuals used for the sieve analysis and other laboratory tests are AASHTO and ASTM and therefore I used these manuals for particle size distribution of aggregates.

**Sand**

River sand is used and sieve analysis was carried out to whether it meets the AASHTO or BS standards and the result is given in table1 below.

Table 2.1. Particle size distribution of natural sand AASHTO M 6-93 Or ASTM C 136

| **Weight Before washing** | **Sample 1 1500** | | | | | | |
|---|---|---|---|---|---|---|---|
| AASHTO Sieve Size mm | Weight Retained | %. Retained | % pass | AASHTO M-6 | | BS 882 | |
| | | | | Lower | Upper | Lower | Upper |
| 9.5 | 0 | 0 | **100** | 100 | 100.0 | 100 | 100.0 |
| 4.75 | 60 | 4.00 | **96.00** | 95 | 100.0 | 89.0 | 100.0 |
| 2.36 | 200 | 13.33 | **82.67** | 80 | 100.0 | 60.0 | 100.0 |
| 1.18 | 250 | 16.67 | **66.00** | 50 | 85.0 | 30.0 | 100.0 |
| 0.600 | 455 | 30.33 | **35.67** | 25 | 60.0 | 15.0 | 100.0 |
| 0.300 | 227 | 15.13 | **20.53** | 10 | 30.0 | 5.0 | 70.0 |
| 0.150 | 201 | 13.40 | **7.13** | 2 | 10.0 | 0.0 | 15.0 |
| 0.075 | 107 | 7.13 | **0.00** | | | | |
| pan | 0.00 | 0.00 | **0.00** | | | | |
| Total Sum | 1500g | | **FM** | **2.92** | | | |

From the above table 2.1 the gradation of sample of sand used is within the upper and lower limit of the standards. It is therefore satisfactory to be used for the concrete preparation

**Coarse Aggregates**

A crushed aggregate of maximum size 25 mm is used. Sieve analysis was carried out and proportioned to meet the Ethiopian standards and the result is given in table 2.2 below.

Table 2.2. Grading requirements for coarse aggregates (ESC.D3.201)

| weight before washing | sample-1 6015g | | | | | |
|---|---|---|---|---|---|---|
| Sieve size(mm) | Weight Retained(gm) | % Retained | Cumulative coarser (%) | Cumulative passing (%) | ES C.D3.201 | |
| | | | | | lower | upper |
| 37.5 | - | - | - | - | 95 | 100 |
| 25 | 2390 | 39.73 | 39.73 | **60.27** | - | - |
| 19 | 1018 | 16.92 | 56.66 | **43.34** | 30 | 70 |
| 12.5 | 950 | 15.79 | 72.45 | **27.55** | - | - |
| 9.5 | 1002.1 | 16.66 | 89.11 | **10.89** | 10 | 35 |
| 4.75 | 407 | 6.77 | 95.88 | **4.12** | 0 | 5 |
| 2.36 | 227 | 3.77 | 99.65 | **0.35** | - | - |
| passing 1.18(pan) | 20.9 | 0.35 | 100.00 | **0** | | |
| Total sum | 6015 | | | | | |

From the above Table 2.2 the gradation of sample of crushed aggregate used is within the upper and lower limit of the standards. It is therefore satisfactory to be used for the concrete preparation.

### 2.1.3 Specific gravity and Absorption capacity

The specific gravity of a substance is the ratio between the weight of the substance and that of the same volume of water. This definition assumes that the substance is solid throughout. Aggregates, however, have pores that are both permeable and impermeable; whose structure (Size, number, and continuity pattern) affects water absorption, permeability, and specific gravity of the aggregates [1].

**Fine aggregates**

Natural river sand is used for this experiment with a recommended oven dry specific gravity and absorption capacity. The specific gravity Absorption capacity of the fine aggregate was determined using 3 different pycnometers so that the average can be taken. For each test, 500gm of dry fine aggregate was used. The result is presented in Table 2.3.

Table 2.3. Specific gravity and Absorption capacity of fine aggregates (sand)

| Trial No. | 1 | 2 | 3 |
|---|---|---|---|
| Mass of dry sand sample in gm | 500 | 500 | 500 |
| Mass of oven-dry sand sample in air(gm)=A | 484.5 | 483.6 | 484.03 |
| Mass of pycnometer+Water in gm=B | 1240 | 1246 | 1242 |
| Mass of pycnometer + Water+Sand in gm=C | 155.4 | 1552.6 | 1553.7 |
| Water Absorption(%)=((500-A)/A)*100 | 3.2 | 3.4 | 3.33 |
| Average water absorption (%) | **3.31** | | |
| Bulk specific gravity =A/(B+500-C) | 2.61 | 2.5 | 2.57 |
| Average bulk specific gravity | **2.56** | | |

**Coarse Aggregates**

The specific gravity and absorption capacity of the coarse aggregates was determined by using approximately 2kg of coarse aggregate sample was taken and submerged in water for 24 hours. The aggregates were then taken out and their surface was dried using a towel to remove the excess moisture. After determining their masses, the aggregates were carefully immersed into a beaker filled with water, after which volume of the displaced water was measured. The results obtained for specific gravity and absorption capacity of coarse aggregates are shown in Table 2.4 and Table 2.5.

Table 2.4 Specific gravity and absorption capacity of normal coarse aggregates

| Trial No | 1 | 2 | 3 |
|---|---|---|---|
| Weght of oven dry sample in air=A | 2540.35 | 2512 | 2530.6 |
| Weght of saturated-surface-dry (SSD) sample in air(g)=B | 2581 | 2549.7 | 2575.9 |
| Weight of saturated sample in water (g)=C | 1643.6 | 1652.56 | 1652.3 |
| Absorption capacity (%)=((B-A)/A)*100 | **1.6** | **1.5** | **1.79** |
| Average absorption capacity (%) | **1.63** | | |
| Bulk specific gravity= A/(B-C) | **2.8** | **2.8** | **2.74** |
| Average specific gravity | **2.75** | | |

Table 2.5. Specific gravity and absorption capacity of clay coarse aggregates

| Trial No | 1 | 2 | 3 |
|---|---|---|---|
| Weght of oven dry sample in air=A | 2526 | 2512.4 | 2500 |
| Weght of saturated-surface-dry (SSD) sample in air(g)=B | 2595.5 | 2584 | 2570 |
| Weight of saturated sample in water (g)=C | 1392.6 | 1491.6 | 1458.9 |
| Absorption capacity (%)=((B-A)/A)*100 | 2.75 | 2.85 | 2.8 |
| Average absorption capacity (%) | **2.8** | | |
| Bulk specific gravity= A/(B-C) | **2.1** | **2.3** | **2.25** |
| Average specific gravity | **2.22** | | |

### 2.1.4 Silt content of sand

Sand is a product of natural or artificial disintegration of rocks and minerals. Sand is obtained from glacial, river, lake marine, residual and wind –blown (very fine sand) deposits. These deposits, however, do not provide pure sand. They often contain other materials such as dust, loam and clay that are finer than sand. The presence of such materials in sand used to make concrete or mortar decreases the bond between the materials to be bound together and hence the strength of the mixture. The finer particles do not only decrease the strength but also the quality of the mixture produced resulting in fast deterioration. Therefore it is necessary that one make a test on the silt content and checks against permissible limits. According to the Ethiopian Standard it is recommended to wash the sand or reject if the silt content exceeds a value of 6% [1]. Natural sand is used for this experimental study and the result is given below.

Silt content (%) =(amount of silt deposited above the sand/amount of clean sand)*100

=(height of silt/height of sand )*100

=(0.5cm/9cm)*100=5.6% .

Therefore, according to the experiment it satisfies the criteria as specified.

### 2.1.5 Loose and compacted Unit Weight (kg/m3)

Unit weight can be defined as the weight of a given volume of graded aggregates. It is thus a density measurement and is also known as bulk density. But this alternative term is similar to bulk specific gravity, which is quite a different quantity, and perhaps is not a good choice. The unit weight effectively measures the volume that the graded aggregate will occupy in concrete and includes both the solid aggregate particles and the voids between them. The unit weight is simply measured by filling a container of known volume and weighing it. Clearly, however, the degree of compaction will change the amount of void space, and hence the value of the unit weight. Since the weight of the aggregate is dependent on the moisture content of the aggregate, constant moisture content is required. Oven –dry aggregate is used in this test laboratory.

**Sand**

Table 2.6. Loose and compacted unit weight of sand

| Trial No. | 1 | 2 | 3 |
|---|---|---|---|
| loose Mass of sand (gm) | 2567.4 | 2559.2 | 2545.6 |
| Average (Kg) | 2.5574 | | |
| Volume of cylinder (m3) | 0.0019 | | |
| Loose Unit Weight of sand (KG/M$^3$) | Mass/volume of cylinder=1346.0 | | |
| compacted Mass of sand (gm) | 2768.8 | 2793.4 | 2771.2 |
| Average (Kg) | 2.7778 | | |
| Volume of cylinder (m3) | 0.0019 | | |
| Compacted Unit Weight of sand (KG/M$^3$) | Mass/volume of cylinder=**1462.0** | | |

**Coarse aggregates**

Table 2.7. Loose and compacted unit weight of coarse aggregates

| Trial No. | 1 | 2 | 3 |
|---|---|---|---|
| loose Mass of coarse aggregates (gm) | 3075.6 | 3095.8 | 3062.6 |
| Average (Kg) | 3.078 | | |
| Volume of cylinder (m3) | 0.0019 | | |
| Loose Unit Weight of coarse aggregates (KG/M$^3$) | Mass/volume of cylinder=1620.0 | | |
| compacted Mass of sand (gm) | 3357.5 | 3347.7 | 3315.4 |
| Average (Kg) | 3.3402 | | |
| Volume of cylinder (m3) | 0.0019 | | |
| Compacted Unit Weight of coarse aggregates (KG/M$^3$) | Mass/volume of cylinder=**1758** | | |



**2.1.6 Moisture content**

Water-cement ratio affects the workability and strength of concrete specimens. A design Water-cement ratio is usually specified based on the assumption that aggregates are inert (neither absorb nor give water to the mixture). But in most cases aggregates from different sources do not comply with this i.e. wet aggregates give water to the mix and driver aggregates (those with below saturation level moisture content) take water from the mix affecting, in both cases, the design water-cement ratio and therefore workability and strength of the mix. In order to correct for these discrepancies, the moisture content of aggregates has to be determined.

**Sand**

$$\text{Moisture content of sand (\%)} = \frac{(\text{Weight of original sample (g) - Weight of oven dry sample (g)}) * 100}{\text{weight of oven dry sample (g)}}$$

$$= \frac{(442.15-435.1) * 100}{435.1} = 1.62\%$$

**Coarse aggregates**

$$\text{Moisture content of coarse aggregates (\%)} = \frac{(\text{Weight of original sample (g) - Weight of oven dry sample (g)}) * 100}{\text{weight of oven dry sample (g)}}$$

$$= \frac{(769.47-764.5) * 100}{764.5} = 0.65\%$$

**2.1.7 Clay particles**

For this experimental study screening of large size clay particles from the three locations of different types was performed for the percentage of clay contents in coarse aggregates. Three types of clay particles are collected and both mix to gather in a mould in order to give reasonable changes in the behaviour of the concrete compressive strength. The mixed clay particles used for this experimental study was in the figure below.

Figure 2.1. Sample of Clay particles

**3.5.8 Water**

The water used for mixing and curing of concrete is free of materials that significantly affect concrete quality like rate of hardening, strength and durability of concrete, or which promote efflorescence or the rusting of steel reinforcement. For this experiment potable water is generally considered satisfactory for mixing concrete.

**3.5.9 Flakiness index (FI)**

Flakiness index is one of the tests used to classify aggregates and stones. Aggregates are classified as flaky when they have a thickness of less than 60% of their mean sieve size. This test is used to determine the quantity of aggregate particles that are elongated, instead of cubicle, in shape. It is important in certain applications, such as concrete, where an elongated shape has a larger surface area and therefore will require greater quantities of cement in order to produce concrete of the required strength. According to BS-812 the maximum value for flakiness index of coarse aggregates is 35%. Through visual inspection, tests are conducted with high flakiness and clay aggregates to analyse the result with normal aggregates and the result is given in table 2.8 and table 2.9.

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Table 2.8. Flakiness Index for the normal aggregate ASTM D422

| Flakiness Index Test | | | | |
|---|---|---|---|---|
| Fraction Prepared for the test | | Weight of fraction consisting of at least 200pieces W1(g) | Thickness gauge (mm) | Weight of aggregates passing thickness gauge. W2(g) |
| Passing through BS sieve | Retained on BS sieve | | | |
| 60 | 50 | 1410 | 33.9 | 230 |
| 50 | 37.5 | 1050 | 26.3 | 180 |
| 37.5 | 28 | 810 | 19.7 | 160 |
| 28 | 20 | 680 | 14 | 132 |
| 20 | 14 | 520 | 10 | 92 |
| 14 | 10 | 400 | 7.2 | 74 |
| 10 | 6.3 | 230 | 4.9 | 59 |
| Total | | 5100 | 927 | |
| Flakiness Index (%)=(w2/w1)*100 | | | 18.18 | |

Table 2.9. Flakiness Index for the clay aggregate ASTM D422

| Flakiness Index Test | | | | |
|---|---|---|---|---|
| Fraction Prepared for the test | | Weight of fraction consisting of at least 200pieces W1(g) | Thickness gauge (mm) | Weight of aggregates passing thickness gauge. W2(g) |
| Passing through BS sieve | Retained on BS sieve | | | |
| 60 | 50 | 1460 | 33.9 | 385 |
| 50 | 37.5 | 1150 | 26.3 | 315 |
| 37.5 | 28 | 760 | 19.7 | 320 |
| 28 | 20 | 745 | 14 | 280 |
| 20 | 14 | 462 | 10 | 240 |
| 14 | 10 | 350 | 7.2 | 160 |
| 10 | 6.3 | 260 | 4.9 | 120 |
| Total | | 5187 | 1820 | |
| Flakiness Index (%)=(w2/w1)*100 | | | 35.09 | |

### 2.1.10 Aggregate Crushing Value Test

The objective is to evaluate the resistance of aggregates against a gradually applied load. According to BS812 the maximum value for aggregate crushed value of coarse aggregates for concretes subjected two wearing surfaces is 30%.

Table 2.10. Result of Aggregate crushed Value test for normal aggregates BS-812

| Aggregate Crushing value Test | | |
|---|---|---|
| **Test No.** | **1** | **2** |
| Mass of Aggregate before test,passing 14.0mm and retain 10.0mm sieves =M1 (g) | 1240 | 1320 |
| Mass of Aggregate before test,passing 2.36mm sieves =M2 (g) | 236 | 240 |
| ACV(%)=(M2/M1)*100 | 19.03 | 18.182 |
| **Average ACV(%)** | **18.61** | |



Table 2.11. Result of Aggregate crushed Value test for clay coarse aggregates BS.

| Aggregate Crushing value Test | | |
|---|---|---|
| **Test No.** | **1** | **2** |
| Mass of Aggregate before test,passing 14.0mm and retain 10.0mm sieves =M1 (g) | 1150 | 1200 |
| Mass of Aggregate before test,passing 2.36mm sieves =M2 (g) | 368 | 420 |
| ACV(%)=(M2/M1)*100 | 32.00 | 35 |
| **Average ACV(%)** | **33.50** | |

### 2.2 Concrete Mix –Design

This section describes the method of determining the compressive strength of concrete cubes including the different quantity of clay particles in the coarse aggregates. This is the process of selecting the correct proportions of cement, fine and coarse aggregate and water to produce concrete having the properties specified and desired in accordance to the ACI design procedures. The entire work carried out for design mix proportions of concrete is for C-25 grade concrete with 0% clay and using different quantities of clay particles in proportion to the coarse aggregates for which effect of these clays on workability and compressive strength are determined. The approach to be adopted for specifying mix parameters will be with reference to the weights of materials in a unit volume of fully compacted concrete. This method will result in the mix being specified in terms of the weights in kilograms of different materials required to produce 1m$^3$ of finished concrete. All the proportions of the concrete making materials are mixing with the different quantity of clay particles in percentage of coarse aggregates to determine the effects on concrete compressive strength.

### 2.2.1 Summary of Quality tests

Quality tests for mix design of concrete is very helpful to achieve better strength, durability, homogenous and impervious structures by deciding the relative proportions of ingredients of concrete having in mind that the fresh concrete is workable. The quality tests used for the input parameters of the ACI Mix Design process are listed in table 2.12.

Table 2.12. Quality Test result

| Nº | Test type | Test result | |
|---|---|---|---|
| | | Sand | C-Aggregate |
| 1 | Organic impurity | - | - |
| 2 | Silt and clay content (%) | 5.60 | - |
| 3 | Fineness Modulus | 2.92 | 2.58 |
| 4 | Loose Unit Weight (kg/m3) | 1346 | 1620 |
| 5 | Compacted Unit Weight (kg/m3) | 1462 | 1760 |
| 6 | Water Absorpition(%) | 3.31 | 1.63 |
| 7 | Moistur Content (%) | 1.62 | 0.65 |
| 8 | Bulk Spesific Gravity | 2.56 | 2.75 |

### 2.2.2 Stages in Mix –Design

From the ACI concrete mix design the following procedures are used for this experimental study. These are:

- Required material information
- Choice of slump
- Maximum aggregate size
- Estimation of mixing water and air content
- Water/cement ratio
- Calculation of cement content
- Estimation of coarse and fine aggregates content
- Mix proportions/Trial batch

### 2.2.3 Batching of concrete materials

Following the mix design process, concrete materials (Cement, Fine and Coarse Aggregates) should be prepared early enough before the concrete works begins. This allows the smooth running of the experimental study. Batching of materials was done by weight basis. The advantage of weight method is that bulking of aggregates (especially fine aggregates) does not affect the proportioning of materials by weight unlike batching by volume method [19]. Batching of concrete materials by weight may be expressed as follows;

Wt (C) + Wt (CA) + Wt (FA) + Wt (Air) = Wt (CC)

Where;

Wt (C) = Weight of cement

Wt (CA) = Weight of coarse aggregate

Wt (FA) = Weight of fine aggregate

Wt (Air) = Weight of entrained air

Wt (CC) = Weight of compacted concrete

### 2.2.4 Productions of Trial mix

The main objective to make trial mixes is to check whether or not the particular aggregates or cement selected for use will behave as anticipated. Adjustments may be made to the original mix proportions, if necessary, will differ according to how much the results of the trial mixes differ from the design values. Based on these, the courses of actions which may be contemplated are;

- To use trial mix proportions in the production of mixes
- To modify the trial mix proportions slightly in the production of mixes
- To prepare further trial mixes incorporating major changes to the mix proportions

The mix design adopted gave the weights in kilograms of the different materials required to produce one cubic metre of compacted concrete. The batch weights for the trial mix were obtained directly by multiplying each of the constituents contents by the volume of the mix required. For instance, in the production of the normal mix;

- Six cubes of 150mm each were required which is 3-cubes for 7-days and 3-cubes for 28 days.
- Volume of one cube; 0.15m x 0.15m x 0.15m = 0.003375m3
- Considering Wastage eight cubes volume of concrete to be caste for the experiment. Therefore, total volume = 8x 0.003375 = 0.027m3
- Volume of mix required; 0.027m3 ≅ 0.03m3

**Normal Mixing trial and Special Mix trials**



Table 2.13. Adjusted mass of materials per 1m$^3$ of concrete with 0% of clay particles

| Material | Mass per 1m$^3$ | mass for 0.03 m$^3$ |
|---|---|---|
| coarse aggregates | 1160k.g/m3 | 34.8 |
| Natural Sand | 686k.g/m3 | 20.58 |
| Cement | 315k.g/m3 | 9.45 |
| Water | 195k.g/m3 | 5.85 |
| Clay (%) | 0 | |
| Air | 1.5 | |
| Estimated Concrete Density | 2417.503 | |

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Table 2.14. Adjusted mass of materials per 1m3 of concrete with different percentage of clay particles with the same quantity of sand and cement

| Sepecial Mixing trial | % of clay | Mass of coarse aggregates (k.g/m3) | Mass of clay (k.g/m3) | Mass of Water (K.g/m3) |
|---|---|---|---|---|
| 2 | 2.5 | 1131 | 29 | 201.6 |
| 3 | 5 | 1102 | 58 | 206.325 |
| 4 | 7.5 | 1073 | 87 | 207.9 |
| 5 | 10 | 1044 | 116 | 211.05 |
| 6 | 15 | 986 | 174 | 217.35 |

## 2.3 Methods

### 2.3.1 Testing the properties of fresh concrete
**Slump test**

**Introduction**

Slump test has been used extensively in site work to detect variations in the uniformity of mix of given proportions. It is useful on the site as a check on the variations of materials being fed to the mixer. An increase in slump may mean that the moisture content of aggregate has increased or a change in grading of the aggregate, such as the deficiency of fine aggregate. Too much or too low slump gives an immediate warning and enables the mixer operator to remedy the situation.

The test was done according to BS 1881 – 102:1983 which describes the determination of slump of cohesive concrete of medium to high workability. The slump test is sensitive to the consistency of fresh concrete. There are three kinds of slumps to be required in the test. The test is valid if it yields a true slump, this being a slump in which the concrete remains substantially intact and symmetrical.

1. True slump- where the concrete just subsides, keeping its shape approximately
2. Shear slump – where the top half of the cone shears off and slips sideways down an inclined plane
3. Collapse slump – where the concrete collapses completely

The first one is associated with workable mix while the other two are usually associated with harsh mixes that lack cohesion [20].

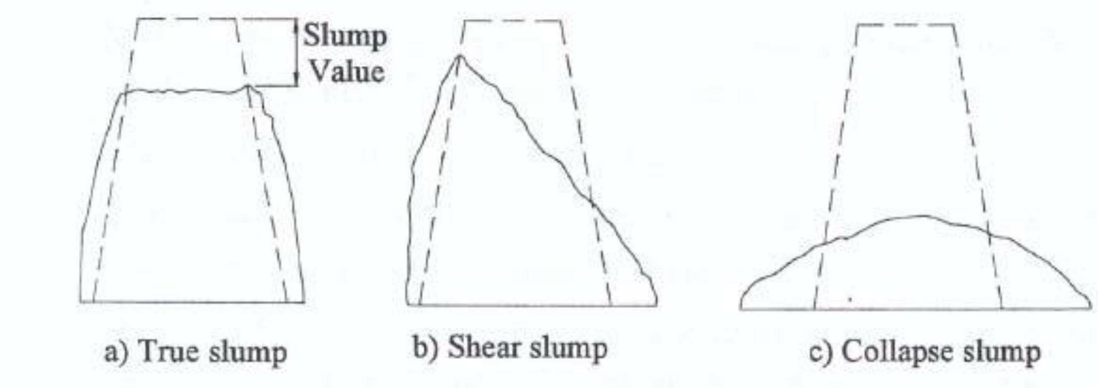


Figure 2.2. Kinds of slumps

**Objective**

- To determine the slump of fresh concrete mix

**Apparatus**

- Standard mould which is a frustum of a cone complying with BS 1881 – 102: 1983.
- Slump cone with bottom diameter 20cm,top diameter 300cm and height 30cm
- A standard flat base plate preferably steel.
- A standard tamping rod.
- Standard graduated steel rule from 0 to 300mm at 5mm intervals.
- A scoop approximately 100mm wide.
- Tamping road of 16mm diameter and 60mm long

**Procedure**

The inside surfaces of the mould were cleaned and oiled to prevent adherence of fresh concrete on the surfaces. The mould was placed on the base plate and firmly held. The cone was then filled with fresh concrete in three layer with each layer compacted with 25 strokes of the tamping rod. After filling the mould, the top surface was struck off by means of rolling action of the tamping rod. Immediately after filling, the cone was slowly and carefully lifted and after removal of the mold the slump of the unsupported concrete was measured and recorded.

Figure 2.3. Fresh concrete filled in the mould and after removal of mould

**Workability**

Workability may be described as the consistence of a mix such that the concrete can be transported, placed and finished sufficiently easily and without segregation. Workability may also be specifically defined as the amount of useful work necessary to obtain full compaction i.e. the work done to overcome the internal friction and the surface friction between the individual particles in concrete and also between the concrete and the surface of the mould or of the reinforcement. The concrete should have sufficient cohesiveness in order to resist segregation and bleeding.

The main factor affecting workability is the water content of the mix expressed in Kilograms per cubic metre of concrete. If the water content and other mix proportions are fixed, workability is governed by the maximum size of aggregate, shape and texture. The free – water required to produce concrete of a specified slump depends upon the characteristics of the aggregate. The grading of coarse aggregates, provided it complies with the requirements of BS 882, has little effect on water requirement of a concrete mix. The grading of fine aggregate has a considerable effect on the water requirement of the concrete.

### 2.3.2 Determination of Compressive strength

**Introduction**

The major goal of concrete structure is carrying loads coming to them. These loads may be dead, live, earthquake, wind or snow types or their combination. The concrete produced, therefore, must not fail under the action of any of such loads.

The most common test for hardened concrete involves taking a sample of fresh concrete and putting it into a special cube moulds so that, when hard, the cubes can be tested to failure in a special machine in order to measure the strength of concrete.

The results obtained from compression tests on hardened concrete cubes are used to check that its strength is above the minimum specified and to assess the control exercised over the production of concrete. The strength of concrete specimen is affected by factors water-cement ratio, degree of compaction and curing temperature. Care should be taken, therefore, in preparing samples for testing. As water-cement ratio goes up above a certain level the strength will decrease accordingly. Compaction reduces the amount of entrapped air and therefore increases the strength of concrete (for each 1% air entrapped there will be a 5 to 6% loss of strength). Curing temperature affects the hydration of cement and hence the duration of the strength gain (cubes kept at about $10^{o}$c will have their 7-day strength reduced by 30% and their 28-day strength reduced by 15%). These calls for proper cure of test cubes at a recommended temperature 20 $^{o}$c [23].

**Casting Cubes**

The specimens were cast in iron moulds generally 150mm cubes. This conforms to the specifications of BS 1881 – 3:1970. The moulds surfaces were first cleaned and oiled on their inside surfaces in order to prevent development of bond between the mould and the concrete. The moulds were then assembled and bolts and nuts tightened to prevent leakage of cement paste.

After preparing trial mixes, the moulds were filled with concrete in three layers, each layer being compacted using a poker vibrator to remove as much entrapped air as possible and to produce full compaction of concrete without segregation. The moulds were filled to overflowing and excess concrete removed by sawing action of steel rule. Surface finishing was then done by means of a trowel. The test specimens were then left in the moulds undisturbed for 24 hours and protected against shock, vibration and dehydration.

**Curing cubes**

Curing may be defined as the procedures used for promoting the hydration of cement, and consists of a control of temperature and of the moisture movement from and into the concrete. The objective of curing was to keep concrete as nearly saturated as possible, until the originally water – filled space in the fresh cement paste was filled to the desired extent by the products of hydration of cement. The temperature during curing also controls the rate of progress of the reactions of hydration and consequently affects the development of strength of concrete. The cubes were placed in a curing pond/tank at a temperature of 20 ± 2◦C for the specified period of time.

Figure 2.4. Cubes in a curing tank

## Compressive Test

After curing the cubes for the specified period, they were removed and wiped to remove surface moisture in readiness for compression test. The cubes were then placed with the cast faces in contact with the platens of the testing machine that is the position of the cube when tested should be at right angles to that as cast. The load was applied at a constant rate of stress of approximately equal to 15N/mm2 to failure. The readings on the dial gauge were then recorded for each cube.

Figure 2.5. Compressive Test machine

The crushing strength is influenced by a number of factors in addition to the water/cement ratio and degree of compaction [19]. These are;

- **The type of cement and its quality** – both the rate of strength gain and the ultimate strength may be affected.
- **Type and surface of the aggregate** – affects the bond strength.
- **Efficiency of curing** – loss in strength of up to 40% may result from premature drying out.
- **Temperature** – in general, the initial rate of hardening of concrete is increased by an increase in temperature but may lead to lower ultimate strength. At lower temperatures, the crushing strength may remain low for some time, particularly when cements of slow rate of strength gain are employed, but may lead to higher ultimate strength, provided frost damage does not occur.
- **Age** – when moisture is available, concrete will increase in strength with age, the rate being greatest initially and progressively decreasing over time. The rate will be influenced by the cement type, cement content and internal concrete temperature.

## Apparatus and Specimens for compressive testing

All the apparatus used for this experiment is from the construction materials laboratory manual. For all concrete strengths studies in this research the specimens will test at the age of 7 days and 28 days. All test specimens are prepared in accordance with the ACI mix design. The tests adopted during the mixing of concrete are taking the workability test (slump test) for afresh concrete and compression test for a hardening concrete. The following apparatus are required for each test:

- **Compression test Apparatus**
- ✓ Standard mould of size 15cm*15cm*15cm
- ✓ Tamping road 16mm diameter and 60mm long
- ✓ Vibrating machine to vibrate the above moulds
- ✓ Weighing equipment of 20 kg capacity

- ✓ Trowel
- ✓ Compression testing machine 100 tones
- **Compressive test general Procedures**

The following steps are the procedures for the experimental study:

1. Prepare all concrete making materials and the quantities of clay particles with a percentage of 0%, 2.5%, 5%, 7.5, 10% and 15% of the coarse aggregate proportions. In addition to this coarse aggregate with high flakiness index and high dust content, small clay particles are conducted two mixes for the determination of the quality of coarse aggregates.
2. Prepare a concrete sample the adjustment of mix proportion with the allowable water cement ratio to fill eight cubes of one trial mix prepare all materials of cement, sand, dry coarse aggregates, clay particles and water by weights in kilograms.
3. First mix cement, sand, coarse aggregates and clay particles in dry thoroughly. Then by adding water and mix thoroughly for a period of not less than 3min to have concrete of uniform colour.
4. Check the workability of the concrete by slump test in accordance to ACI mix design.
5. Fill minimum of six cubes mould, three for 7 day testing and three for 28 day testing. Taker to oil the inner surface of the mould before placing concrete. Fill the concrete in the moulds in layers approximately 5cm thick.
6. Vibrate the cubes in the standard vibrating machine for 2 minutes. Compact each layer with not less than 35 strokes per layer using a tamping road. Level the top surface and smoothen it with a trowel.
7. The test specimens (cubes) area stored in moist air for 24 hours and after this period the specimens are marked and removed from the moulds and kept submerged in clear fresh water until taken out prior to test.
8. Test the cubes for crushing in a compression testing machines immediately after age of 7 days curing and 28 days curing.
9. Take the dimension of the specimen to the nearest 0.2m.clean the bearing surface of the testing machine. Place the specimen in the machine in such a manner that the load shall be applied to the opposite sides of the cube cast. Align the specimen centrally on the base plate of the machine.
10. Rotate the movable portion gently by hand so that it touches the top surface of the specimen. Apply the load gradually without shock and continuously at the rate of 140kg/cm2/minute till the specimen fails. Recorded the maximum load and note any unusual features in the type of failure.

Note: load at failure of the three cubes average strength of 3 cubes is to be taken for considering compressive strength

## 3. RESULTS AND DISCUSSION

### 3.1 RESULTS

#### 3.1.1 Slump Test and water-cement ratio

The concrete mixture is prepared with a different percentage of clay particles in coarse aggregate without changing the quantity of sand and cement for each mixes. The test result for the normal control mix and five special mixes varies the slump test and water cement ratio for every mixes is given in table below.

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Table 3.1. Slump and water used for each percentage of clay

| Slump test and W/C ratio result | | | |
|---|---|---|---|
| **Type of mix** | **Slump(mm)** | **Amount of Water used in litre for 1m3** | **Water-Cement Ratio** |
| Normal mix (0% clay) | 60 | 195.3 | 0.62 |
| Special mix-1(2.5% clay) | 58 | 201.16 | 0.64 |
| Special mix-2(5.0% clay) | 54 | 206.3 | 0.655 |
| Special mix-3(7.5% clay) | 50 | 207.9 | 0.66 |
| Special mix-4(10.0% clay) | 44 | 211.05 | 0.67 |
| Special mix-5(15.0%) | 38 | 217.35 | 0.69 |

### 3.1.2 Compressive Strength Test result

The concrete samples were subjected to compressive strength tests. Concrete compressive strength was determined at 7 and 28 days. Six concrete mixes were prepared with different rates (0%, 2.5%, 5%, 7.5%, 10%, and 15%) of each type of clay particles in the coarse aggregates. Also an additional two tests were performed for Coarse Aggregate with dust and clay particles and Coarse Aggregate with high Flakiness index, high aggregate crushed value, and clay particles. The summary of the average compressive strength of concrete test results for 7 and 28 days with the different percentage of clay particles in coarse aggregates are listed in table below.

Table 3.2. Summary of average Compressive strength of concrete with percentage change of clay particles in coarse aggregates

| Percentage of clay | 7 days Average compressive strength | 28 days Average compressive strength |
|---|---|---|
| 0.0% | 19.37 | 23.4 |
| 2.5% | 18.36 | 21.77 |
| 5.0% | 17.49 | 20.26 |
| 7.5% | 16.93 | 18.97 |
| 10.0% | 16.04 | 17.41 |
| 15.0% | 11.92 | 14.62 |

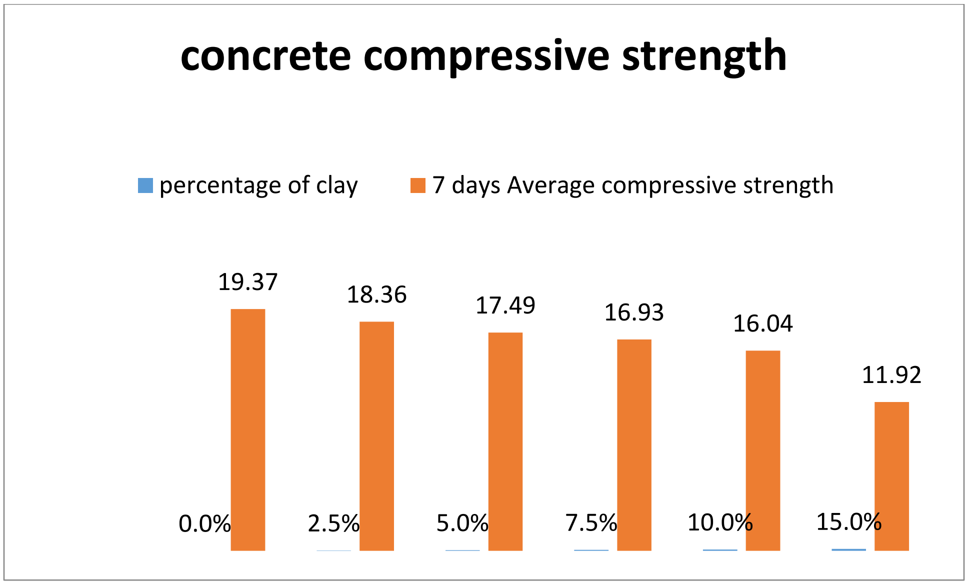


Figure 3.1. Compressive strength after 7-days

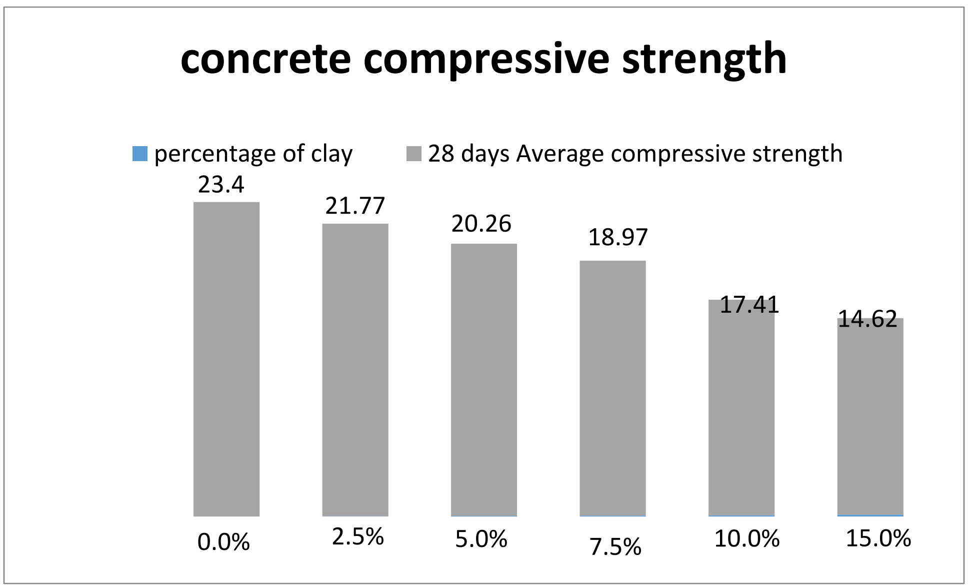


Figure 3.2. compressive strength after 28-days

Table 3.3. Summary of average Compressive strength of concrete with different type of coarse aggregates

| Coarse Aggregate Type | 7 days Average compressive strength | 28 days Average compressive strength |
|---|---|---|
| Coarse Aggregate with dust and clay particles | 17.27 | 19.88 |
| Coarse Aggregate with high Flakiness, high aggregate crushed value ,and clay particles | 16.36 | 17.55 |

Figure 3.3. Coarse Aggregate with dust and clay particles

Figure 3.4. Coarse Aggregate with high Flakiness, high aggregate crushed value, and clay particles

## 3.2 DISCUSSION

### 3.2.1: Effect of clay particles in coarse aggregates on concrete compressive strength

The concrete compressive strength decrease at the age of 7 days (Figure 4.3) and the seven-day compressive strength losses 5.21% for 2.5% clay content, 9.71% for 5% clay content, 12.6% for 7.5% clay content, 17.19% for 10% clay content, and 38.46% for 15% clay content.

The concrete compressive strength decrease at the age of 28 days (Figure 4.4) and the twenty eight-days compressive strength losses 6.97% for 2.5% clay content,13.42 % for 5% clay content, 18.93% for 7.5% clay content, 31.45% for 10% clay content, and 37.52% for 15% clay content. The loses of concrete compressive strength are summarized in the table 3.4 below.

Table 3.4. Losses of compressive strength in 7days and 28 days

| percentage of clay | 7 days Average compressive strength | Losses 7 days compressive strength in % | 28 days Average compressive strength | Losses 28 days compressive strength in % |
|---|---|---|---|---|
| 0.0% | 19.37 | - | 23.4 | - |
| 2.5% | 18.36 | **5.21** | 21.77 | **6.97** |
| 5.0% | 17.49 | **9.71** | 20.26 | **13.42** |
| 7.5% | 16.93 | **12.60** | 18.97 | **18.93** |
| 10.0% | 16.04 | **17.19** | 17.4 | **25.6** |
| 15.0% | 11.92 | **38.46** | 14.62 | **37.52** |

As can be seen from table 3.4 above the compressive strength of concrete is decreased with the increase of clayey content in coarse aggregates. In the curing times of 7 and 28 days the average percentage reduction of compressive strength of concrete as the clayey content in coarse aggregate increases from 0 % to 15 % is 16.63%, 21.66% respectively. In the 28 days curing time the magnitude of percentage reduction in compressive strength as the clayey content in coarse aggregate increases from 10% to 15% (37.52%) is higher than the magnitude of percentage reduction from 0% to 2.5% (6.97%). Even though there is a reduction of compressive strength with the increase of clayey content in coarse aggregates from 2.5% to 5% and from 5% to 7.5%, it is not as much as the percentage reduction from 7.5% to 10% and from 10% to 15% of clayey content in coarse aggregates. According to the results obtained, the percentage of 15% of clay particles in coarse aggregates reduces the compressive strength by 38.46% and 37.52% for 7days and 28 days respectively compared to concrete control. Hence, the presence of these clay particles in the coarse aggregates is highly affected in the concrete compressive strength. Care must be taken to store the materials in places not exposed to weathered area.

Table 3.5. Result in the percentage of 7 and 28 days concrete compressive strength

| **percentage of clay** | **7 days Average compressive strength** | **Losses 7 days compressive strength in %** | **% of 7 days Average compressive strength** | **28 days Average compressive strength** | **Losses 28 days compressive strength in %** | **% of 28days Average compressive strength** |
|---|---|---|---|---|---|---|
| 0.0% | 19.37 | - | **77.48** | 23.4 | - | **93.6** |
| 2.5% | 18.36 | 5.21 | **73.44** | 21.77 | 6.97 | **87.08** |
| 5.0% | 17.49 | 9.71 | **69.96** | 20.26 | 13.42 | **81.04** |
| 7.5% | 16.93 | 12.60 | **67.72** | 18.97 | 18.93 | **75.88** |
| 10.0% | 16.04 | 17.19 | **64.16** | 17.41 | 31.45 | **69.64** |
| 15.0% | 11.92 | 38.46 | **47.68** | 14.62 | 37.52 | **58.48** |

It is well known that the 7days compressive strength of concrete are expected to achieve a minimum requirement 68.5% of the final designed compressive strength of concrete and the remaining achieves on 28 days designed compressive strength of concrete. As can be observed from table 3.5 the result of the test of compressive strength in 7 days with 2.5% and 5% of clay content in coarse aggregate, the compressive strength of concrete varies gradually and is almost within the range of the maximum allowable recommended by Ethiopian building Code standard (EBCS-2 2013) which is 68.5%. But in 7.5%, 10%and 15% of clay content in aggregate is below the standard of allowable design compressive strength of concrete which is less than 68.5%. Hence, the compressive strength of concrete decreases as the increase the clay content in the coarse aggregate. Also in 28 days completely all percentage of clay content in coarse aggregate are below the recommended designed compressive strength which is less than 99%. This indicates that when increases the age of concrete having high clay content in the aggregate, the concrete compressive strength were decreased and affects the heat of hydration of concrete and it makes the de-bonding effect from the other ingredients. Therefore the presence of clay particles in the coarse aggregates also affects the durability of concrete. This reduction of strength of concrete due to the percentage increment of clayey content in coarse aggregate is due to

a. Particles of clay will be incorporated into the matrix of the cement paste and affect hydration reactions. The other fraction of the coating will remain on the aggregate surface and influence the adhesion of the cement paste to the aggregates.

b. The water absorbed in the clay particles does not contribute for hydration process.

c. As clay content increases, the bond between cement and aggregate particles reduces and the nature of interface between the aggregate and cement reduces, too.

d. At present, the mechanism through which clays influence the physical properties of cement paste has not been conclusively established.

### 3.2.2 Effect of different type of supplied coarse aggregates on the compressive strength

Concrete strength decreased with increase in dust and clay contents in coarse aggregates. This is likely to be due to the increase in the w/c (water-cement) ratio and decrease in density. The incorporation of dusts form a screen on aggregates prevents strong bonding between the aggregates and the binder. As shown in the table 3.6 the results of the compressive strength of the concretes with dusts and clay particles in coarse aggregates at 7days and 28 days are decreased by **10.5%** and **15%** respectively with compare to 0% clay particles in the coarse aggregates without changing the coarse aggregate types. On the other case by changing the coarse aggregate types and by selecting with high flakiness index of 35.09% (from table 2.9 which is above the limit; 35.09%>35%(BS812)), high Aggregate crushed value of 33.5%( from table 2.11 which is above the limit: 33.5%>30%(BS812)) and with high clay particles the results of the compressive strength of the concretes decreases or losses at 7 days and 28 days by **15.5%** and **25%** respectively. The coarse aggregates with high flakiness index and aggregate crushed value with Clay particles was more harmful to the concrete compared to dust and clay particles. The presence of these flaky and high contaminated clay particles caused significant drops in the concrete strength. In general, the strength of concrete is reduced as the quantity of contaminant in the aggregate is increased. Care must be taken to store and supplied the aggregate materials. The very fine particles (dust particles) present in the aggregates must be eliminated either by washing or drying.

Table 3.6. Losses of compressive strength in 7days and 28 days for different types of coarse aggregates

| **Coarse Aggregate Type** | **7 days Average compressive strength** | **Losses 7 days compressive strength in %** | **28 days Average compressive strength** | **Losses 28 days compressive strength in %** |
|---|---|---|---|---|
| **0% clay particles in aggregates** | **19.37** | **-** | **23.4** | **-** |
| Coarse Aggregate with dust and clay particles | 17.27 | 10.8 | 19.88 | 15.0 |
| Coarse Aggregate with high Flakiness, high aggregate crushed value ,and clay particles | 16.36 | 15.5 | 17.55 | 25.0 |

### 4.2.3 Impact of clayey particles in coarse aggregates on water-cement ratio and consistency of fresh concrete

As observed in the figure 4.5 below the slump of the normal aggregate concrete was found to be 60mm and for special mix-five was found to be 38mm. Also from figure 3.6 Slump decreases as the percentage of clay content in coarse aggregates increases. Moreover, from figure 3.7 water-cement ratio increases as the percentage of clay content in coarse aggregates increases. Clayey in nature have the ability to absorb water and in this practical experiments as the clay content in the aggregates increases the water content used for every mix increases. The increase of clay content was followed by an increase in the w/c ratio. This implies an increasing in water-cement ratio will result in decreasing the compressive strength of concrete.

Figure 3.5. Sample smp test for 15% of clay contents in coarse aggregates

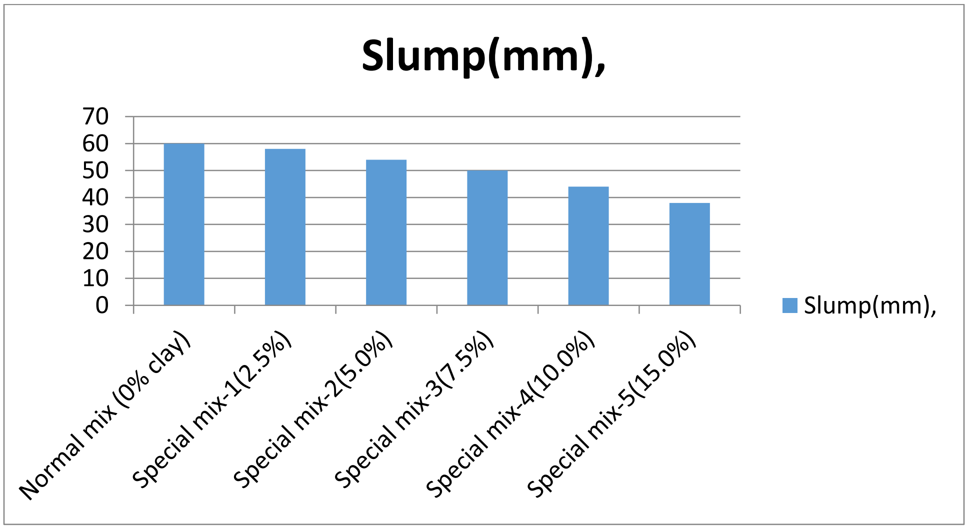


Figure 3.6 Slump test and percentage of clay particles

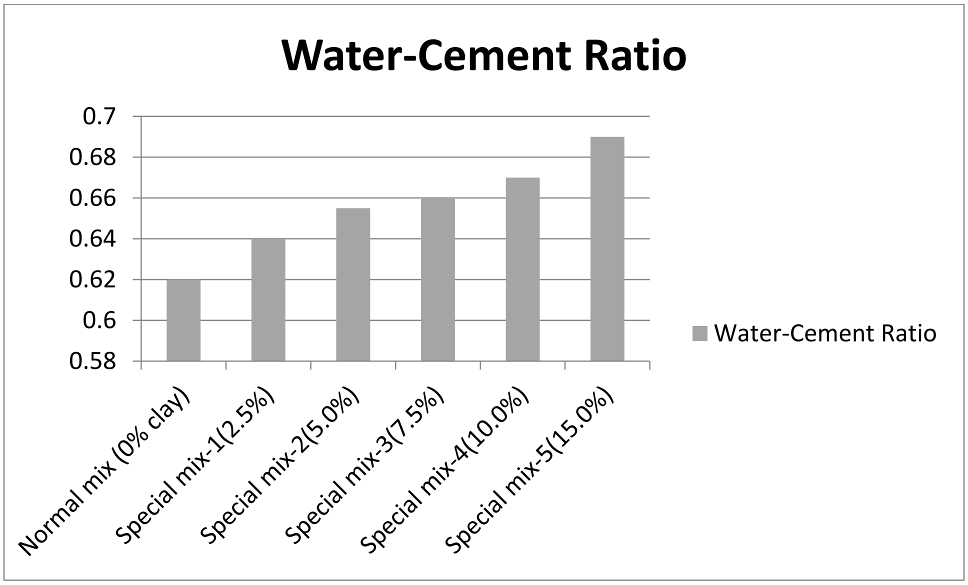


Figure 3.7 Water-cement ratio and percentage of clay particles

Depending on the nature of the swelling in these clays we can envision two different scenarios upon adding the cement powder to the mixture:

1. The dispersed clay has the ability of crystalline swelling. Clayey particles will absorb significant amounts of the mixing water of the mixture leaving a quantity of available water that will yield mixing water smaller than the best possible for hydrating the cement powder. Decreasing in mixing water will reduce the workability of the concrete. This lack of water for hydration is therefore decreases the strength of the concrete.

2. The dispersed clay has the ability for macroscopic swelling. These particular types of clays, when placed in contact with water, experience an-exfoliation of the stacked unit layers. The dispersion of these clays gives way to an aqueous suspension having a large number of very anisotropic Nano-particles. Thus, the viscosity of the water of the mixture in these systems is expected to increase. These thin-layer particles may coat the un hydrated cement compounds added to the concrete mixture and affect the kinetics of hydration. This may have an effect on the physical properties of the resulting concrete ( Isabel Tajedor ea, 2005).

Therefore, it can clearly be seen that a significant amount of clayey content in a cement mixture reduces the amount of water available for the hydration reactions and thereby decreases its workability and alters the course of the pozzolanic reactions. As a result, hardened cement containing clay minerals is expected to have different physical properties from that of cement fabricated without clays. It has been widely reported that presence of clays in cement reduces the compressive strength and increases shrinkage in the resulting concrete.

## 4. CONCLUSIONS AND RECOMMENDATIONS

### 4.1 CONCLUSION

The coarse aggregates used in different construction projects in Ethiopia are not always tested in order to know if the material meets the construction standards. The content of clay particles or impurities in coarse aggregates should always be determined before they are used. When coarse aggregates with 2.5% and 7.5% of clay particles are used, a compressive strength of concrete decreased by 6.97% and 37.52% respectively in respect to 0% of clay content in the coarse aggregates. Hence, from the aforesaid discussion of results above, it can be seen that the higher the clay particles content in coarse aggregates the less compressive strengths and the more reduced workability of the concrete.

The concern having clay particles in coarse aggregates is their water absorption characteristic. This affects the workability of concrete. Another impact on the reduction of concrete compressive strength is the production of too much dust particularly during crushing of coarse aggregates and long-time stokes in the source of production plant. High aggregate crushing value, more flaky aggregates, high dust and clay particles coarse aggregates have a high impact on the compressive strength of concrete.

### 4.2 RECOMMENDATION

- The presence of clay particles and dusts in coarse aggregates caused significant drop in the concrete strength. Care must be taken to store and production the materials in places not exposed to wind and other contaminated areas and debris, especially in arid regions. The clay particles (dust particles) present in the coarse aggregates must be eliminated either by washing or drying.
- Mechanism should be set up, which will make intending contractors to indicate the areas where they intend to source for their coarse aggregates. This will afford the consultant structural engineer to carry out appropriate test on the coarse aggregates from such area and recommend means of mitigating the effect of the clay particles in coarse aggregates if necessary.
- Parties in the construction industry should strive hard and work very intimately so that laboratory tests should be carried out considering the prevailing site conditions and concrete materials handling on site must be done strictly in compliance with laboratory results and specifications so that the desired quality structure can be constructed.

- I would like to recommend further research on the behaviour of clay and dust particles in coarse aggregates in reinforced concrete.
- Further investigation should be done on the long term behaviour of clay aggregate concrete under moderate weather exposure that is external exposure. The content of clay particles in aggregates should never be greater than 2.5%.

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