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The Importance of Standardization of Aggregate in Ethiopian Construction Industry

By

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Abstract

Concrete is one of the versatile and widely used building materials in the world Construction industry. Fine and coarse aggregates make about 70% by volume of concrete production. It goes without saying that the quality of concrete is thus strongly influenced by aggregate's physical and mechanical properties as well as chemical composition of the parent aggregate making material. Since most of these materials are from natural sources in Ethiopian case like from rivers and from natural quarry site, their quality and composition vary from time to time. Each truck of sand from the same place at different time may not be the same and it is difficult to design mix proportion for each truck of sand and this call for a standardization of materials in Ethiopia.

In my research I made concrete C-25, C-30 and C-40 as control mix by standardizing the aggregate to the Ethiopian standard and other recommendation. By using the property of this standardized aggregate mix design was made for control mixes, keeping the mix proportion constant, aggregates from different sources were used to make concrete of the same classes as control mix.

Compressive strength test were made at 3rd, 7th and 28th days for control mixes and for mixes with nonstandard aggregates. Target mean strengths were achieved for control mix by using Derba Cement 260kg/m^3, 280kg/m^3 and 380kg/m^3 for C-25, C-30 and C-40 respectively. On the other hand concrete with non standard aggregate didn't achieve target mean strength rather up to 48% reduction in strength was observed.

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Declaration

I, the undersigned, declare that the thesis is my original work, has not been presented for a degree in any other universities and that all sources of materials used for the thesis have been duly acknowledged.

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CHAPTER ONE

1.0 Introduction

The word concrete comes from the Latin verb”concretus” which means to grow together. Concrete is basically a mixture of two components: aggregates and paste. The paste, comprised of Portland cement and water, binds the aggregates (usually sand and gravel or crushed stone) into a rocklike mass as the paste hardens because of the chemical reaction of the cement and water [1].The ability of concrete to be cast to any desired shape and configuration is an important characteristic that can offset other shortcomings. Concrete can be cast into soaring arches and columns, complex hyperbolic shells, or into massive, monolithic sections used in dams, piers, and abutments. On-site construction means that local materials can be used to a large extent, thereby keeping costs down. Good-quality concrete is a very durable material and should remain maintenance free for many years when it has been properly designed for the service conditions and properly placed. Through choice of aggregates, or control of paste chemistry and microstructure, concrete can be made inherently resistant to physical attack, such as from cycles of freezing and thawing or from abrasion, and from chemical attack, such as from dissolved sulfates or acids attacking the paste matrix or from highly alkaline pore solutions attacking certain aggregates [1].

1.1 Advantages of Concrete

Because of the high impact of energy costs on material costs and the (usually) accompanying production of carbon dioxide (which contributes to global warming),significant attention is given to the energy requirements of construction materials. In this regard, concrete comes out ahead of most other construction materials. In the first place, concrete requires less energy to produce than does steel.

This is because steel is made by high-temperature process (300GJ/M^3), where as only a small component of the concrete, the cement, requires pyro-processing (22GJ/M^3) [1].

The major energy costs of concrete are in cement and reinforcing steel, but the energy consumption of an equivalent steel structural element can be considerably greater. Second energy requirements can be decreased for concrete by incorporating supplementary cementing materials, such as fly ash, silica fume, and blast furnace slag. These byproducts of other industrial processes not only reduce the quantity of cement required to achieve a given strength, but can be used to attain strengths greater than can be achieved using Portland cement alone [1]. Higher strengths translate into smaller cross-sections, and, thus, lower quantities of concrete. On the other hand cement content of high strength concrete is higher than low strength concrete. Third, concrete buildings can be more energy efficient to operate because of the thermal properties of concrete. Concrete conducts heat slowly and is able to store considerable quantities of heat from the environment that can be released during cool periods. It is possible to design buildings to take advantage of this thermal inertia. Last but not least, concrete has considerable aesthetic possibility that can be expressed through the use of color, texture, shape, and so on. All of these advantages combine to make concrete very versatile and adaptable [1].

It is an established fact that the compressive strength of concrete is influenced by, among other things, the quality and proportion of fine and coarse aggregate, the cement paste and the paste-aggregate bond characteristics. These, in turn, depend on the macro- and microscopic structural features including total porosity, pore size and shape, pore size distribution and morphology of the hydration products, and the bond between individual solid components. Other qualities of concrete such as durability and abrasion resistance are also highly dependent on the aggregate, which in turn depends on strength of parent rock, purity, surface texture, gradation and so on [3].

1.2 Objective of the research

The objective of the research is to investigate the effect of using standardized aggregates (aggregates that fulfill Ethiopian standards ES C. D3. 201 requirements) compared with the use of non standardized aggregates (aggregates that do not fulfill Ethiopian standards ES C. D3. 201 requirements) on concrete properties.

Finally; after making the above comparison, conclusions and recommendations are drawn out.

CHAPTER TWO

Literature Review

2.1 Introduction

Concrete is basically a mixture of two components: aggregates and paste. The paste, comprised of Portland cement and water, binds the aggregates (usually sand and gravel or crushed stone) into a rocklike mass as the paste hardens because of the chemical reaction of the cement and water. Supplementary cementitious materials and chemical admixtures may also be included in the paste [2].

2.2 Cement

Portland cements are hydraulic cements composed primarily of hydraulic calcium silicates. The most common hydraulic cement used in construction today is Portland cement. Hydraulic cements set and harden by reacting chemically with water. During this reaction, called hydration, cement combines with water to form a stone like mass, called paste. When the paste (cement and water) is added to aggregates (sand and gravel, crushed stone, or other granular material) it acts as an adhesive and binds the aggregates together to form concrete, the world's most versatile and most widely used construction material [2].

2.2.1 Composition of Portland cement

Portland cement is made by grinding together its principal raw materials, which are [6]:

1. Argillaceous, for example silicates of alumina in the form of clays and shale's ,and
2. Calcareous, for example calcium carbonate in the form of limestone, chalk, and marl which is a mixture of clay and calcium carbonate.

The mixture is then burned in a rotary kiln at a temperature between 1300 and 1500^0c.

The material partially fuses in to a clinker which is taken from the kilns, cooled and then passed on to ball mills where gypsum is added and it is ground to the required fineness. The resulting cement is allowed to contain small strictly limited percentages of materials not required, some disadvantageous for some uses, such as iron oxide and sulpher trioxide. Table 2.1 shows oxide composition ranges for Portland cements indicate a general idea of the composition of cement [6].

Table 2.1 Oxide content of Portland cement row materials

Oxides	Ranges
Lime (CaO)	60-70%
Silica (SiO_2)	17-25%
Alumina(Al_2O_3)	3-8%
Iron Oxide(Fe_2O_3)	0.5-6%
Sulphur trioxide(SO_3)	1.0-3%
Magnesia (MgO)	0.1-4%
Soda (Na_2O) and /or potash(K_2O)	0.5-1.3%

The above constituents forming the raw materials used in the manufacturer of Portland cement combine to form compounds in the finished product. The following four compounds are regarded as the major constituents of cement: tricalcium silicate ($3CaO.SiO_2$ or C_3S), dicalcium silicate ($2CaO.SiO_2$ or C_2S), tricalcium aluminate ($3CaO.Al_2O_3$ or C3A), and tricalcium aluminoferrite ($4CaO.Al_2O_3.Fe_2O_3$ or C_4AF).These compounds are different in rate of reaction, heat liberation and cementing value [6].

2.2.2 Types of Cement

Types of Portland cement can be varied by changing the relative proportions of its prominent chemical compounds, by the degree of fineness of the clinker grinding and/or by adding some pozzolanic materials. As a result, there are several types of cements for different purposes.

Some of them are: - Ordinary Portland Cement (OPC), Rapid Hardening Portland cement, Sulphate Resisting Portland Cement, Low heat Portland Cement, Portland Pozzolana Cement (PPC). But, only Ordinary Portland cement and Portland Pozzolana Cements are produced in Ethiopia. A pozzolan is defined in ASTM C 618 as “a siliceous or siliceous and aluminous material, which in itself possesses little or no cementations value but which will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementations properties.” They are composed of similar materials and react with the products of hydrating cement to create additional cementitious binder. Glassy non-crystalline forms of silica, alumina, and iron are principally responsible for the pozzolanic reaction with calcium hydroxide (lime). In concrete, lime results from the hydration of Portland cement. Pozzolanic material can be used to modify and improve plastic and hardened properties of concrete. There are calcite types and volcanic soil pozzolanic materials found in Ethiopia near Zeway and between Wolenchite and Metehara and their analyses and chemical compositions was done by researchers in laboratory [5].

AASHTO M 85, Specification for Portland cement, uses type designations I through V for Portland cement .Type I portland cement is a general-purpose cement suitable for all uses where the special properties of other types are not required. Its uses in concrete include pavements, floors, reinforced concrete buildings, bridges, tanks, reservoirs, pipe, masonry units, and precast concrete products [2].

Type II Portland cement is used where precaution against moderate sulfate attack is important. It is used in normal structures or elements exposed to soil or ground waters where sulfate concentrations are higher than normal but not unusually severe. Type II cement has moderate sulfate resistant properties because it contains no more than 8% tricalcium aluminates (C3A) [2].

Sulfates in moist soil or water may enter the concrete and react with the hydrated C3A, resulting in expansion, scaling, and cracking of concrete. Some sulfate compounds, such as magnesium sulfate, directly attack calcium silicate hydrate.
Use of Type II cement in concrete must be accompanied by the use of a low water to cementitious materials ratio and low permeability to control sulfate attack.
Concrete exposed to seawater is often made with Type II cement [2].

Type III Portland cement provides strength at an early period, usually a week or less. It is chemically and physically similar to Type I cement, except that its particles have been ground finer. It is used when forms need to be removed as soon as possible or when the structure must be put into service quickly. In cold weather its use permits a reduction in the length of the curing period [2].

Type IV Portland cement is used where the rate and amount of heat generated from hydration must be minimized. It develops strength at a slower rate than other cement types. Type IV cements is intended for use in massive concrete structures, such as large gravity dams, where the temperature rise resulting from heat generated during hardening must be minimized [2].

Type V Portland cement is used in concrete exposed to severe sulfate action principally where soils or ground waters have high sulfate content.
It gains strength more slowly than Type I cement. The high sulfate resistance of Type V cement is attributed to low tricalcium aluminate content, not more than 5% [2].

2.3 Aggregate

Aggregate is granular material such as sand, gravel, crushed stone, blast-furnace slag, and lightweight aggregates that usually occupies approximately 60 to 75% of the volume of concrete. Aggregate properties significantly affect the workability of plastic concrete and also the durability, strength, thermal properties, and density of hardened concrete[4].The quality of aggregate is considerably important because at least three-quarters of the volume of concrete is occupied by it [6].

This indicates that it is impossible to get good quality concrete without good quality aggregates. Aggregate has both economical and technical advantages in making concrete.

There are two main reasons for increasing the amount of aggregates in concrete. The first is that cement is more expensive than aggregate, so using more aggregate reduces the cost of producing concrete. The second is that most of the durability problems, e.g. shrinkage and freezing and thawing, of hardened concrete are caused by cement. Generally, concrete shrinkage increases with increase in cement content; aggregates, on the other hand, reduce shrinkage and provide more volume stability. Furthermore, cement production is a key source of carbon dioxide (CO_2) emissions, and reducing its usage should be a goal for concrete production Various projects have explored methods of minimizing cement in concrete; amongst the most common of those is replacing cement with cementitious and pozzolanic materials such as fly ash [7].

In choosing aggregate for use in a particular concrete, attention should be given among other things to three important requirements [8].

1) Workability, when fresh for which the size and gradation of the aggregate should be such that undue labor in mixing and placing will not be required.
2) Strength and durability when hardened for which the aggregate should be:
    a) Be stronger than the required concrete strength
    b) Contain no impurities which adversely affect strength and durability
    c) Not go in to undesirable reaction with the cement
    d) Be resistant to weathering action
3) Economy of the mixture –meaning to say that the aggregate should be :
    a) Available from local and easily accessible deposit or quarry
    b) Well graded in order to minimize paste hence cement requirement

2.3.1 Aggregate Properties

The shape of three-dimensional bodies is rather difficult to describe, and it is therefore convenient to define certain geometrical characteristics of such bodies [6].

The shape of the aggregate particles influences paste demand, placement characteristics such as workability and pump ability, strength and cost. Shape is related to sphericity, form, angularity, and roundness [7].

- The sphericity measures how nearly equal are the three principal axis of the aggregate (length *L*, width *W*, and height *H*).
  The sphericity increases as the three dimensions approach equal values.
- The form or the shape factor, describes the relative proportions of the three axes of a particle. It helps distinguish between particles that have the same sphericity
- The angularity describes the proportions of the average radius of curvature of corners and edges to the radius of maximum inscribed circle
- The roundness describes the sharpness of the edges and corners

Particle shape can be classified by the following descriptions:

Sphericity & form: cubical, spherical, flat or elongated.

Angularity & roundness: Angular, sub angular, sub rounded, rounded, and well rounded

A classification sometimes used in the United States is as follows [6]:

Well-rounded –no original faces left

Rounded – faces almost gone

Sub rounded- considerable wear faces reduced in area

Sub angular-some wear but faces untouched

‘*Angular*- little evidence of wear

The descriptions of angularity and roundness are illustrated in Figure 2.1: [7]

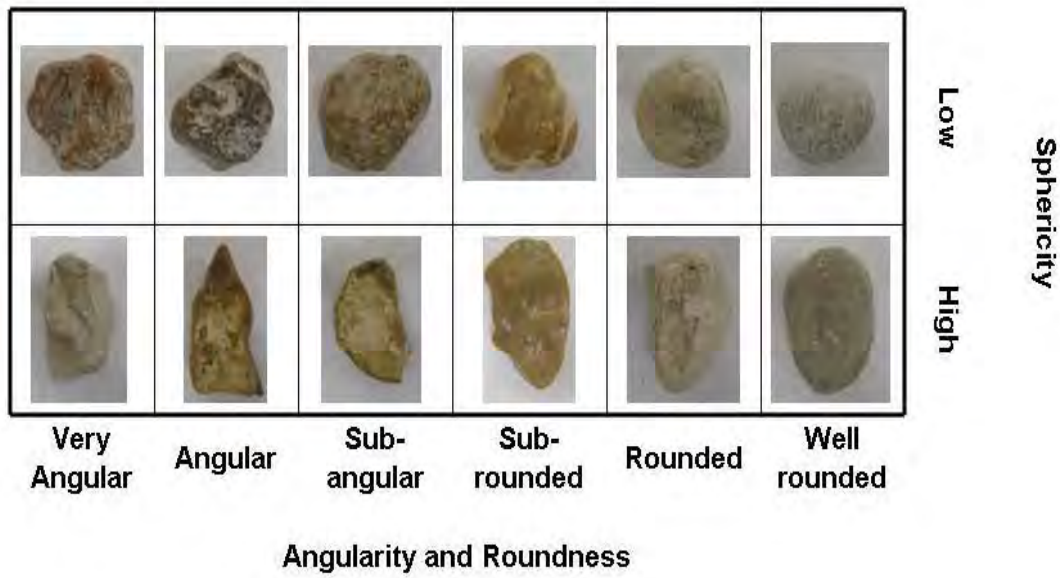

Figure 2.1: Particle Shape [7]

Round or nearly cubical shaped aggregates are desirable due to the ease in which they move in the mixing and handling process. However, aggregate can also contain flat or elongated shapes.

Methods used to measure the shape of aggregates are the elongation factor and flatness factor (ASTM C 125). A flat particle has a width/thickness ratio greater than or equal to 3, while an elongated particle has a length/width ratio greater or equal to 3 [7].

The shape of an aggregate influences the workability of the mixture as well as the void content and packing density. For the same amount of paste, a mixture with round or cubical shaped aggregate will have better workability than a mixture with flaky and elongated aggregates. Moreover, for the same mass of aggregates, round and cubical aggregates produce mixtures with higher packing, which results in a lower void content. The decreased percentage of voids lowers the amount of cement paste required for that particular mixture.

The higher particle's compactness (the closer it is to a sphere or cube), the lower its surface area per unit weight and therefore the lower its demand for mixing water in concrete and the lower the amount of sand needed in the mixture to provide workability. More angular and less spherical coarse aggregates require higher mixing water and fine aggregate content to provide a given workability [4].

As mixing water is increased water cement ratio is also increased and hence the strength of concrete is decreased.

Surface texture is the degree to which the surface may be defined as either:
1) being rough or smooth or 2) coarse grained or fine grained
The surface texture influences the workability, quantity of cement and bond between particles and the cement paste. Rough-textured angular grains bond better with the cement paste to generate higher tensile strengths. Although rougher textures lead to better bond between paste and aggregate, they also lead to harsher mixtures, as texture roughness increases, the internal friction increases between the aggregates, and therefore more paste is needed to achieve a given workability [7].
Failure of a concrete strength specimen most often starts as micro cracks between the paste or mortar and the surfaces of the largest coarse aggregate particles. This is a bond failure mode. Angular, rough-textured aggregates, for example, have an increased surface area for bond to the cement paste when compared with rounded, smooth particles of similar size [4].

2.3.2 Grading

Grading refers to the distribution of particle sizes present in an aggregate. The grading is determined in accordance with ASTM C 136, "Sieve or Screen Analysis of Fine and Coarse Aggregates." A sample of the aggregate is shaken through a series of wire-cloth sieves with square openings, nested one above the other in order of size, with the sieve having the largest openings on top, the one having the smallest openings at the bottom, and a pan underneath to catch material passing the finest sieve [4].That portion of an aggregate passing the 4.75 mm (No. 4) sieve and predominantly retained on the 75 μm (No. 200) sieve is called "fine aggregate" or "sand," and larger aggregate is called "coarse aggregate" [4].

Gradation plays an important role in the workability, segregation, and pumpability of the concrete. Grading changes are more prevalent than shape and surface texture in the case of coarse aggregates. For example, uniformly distributed aggregates require less paste which will also decrease bleeding, creep and shrinkage while producing better workability, more durable concrete and higher packing. A graded aggregate, as opposed to a single-size aggregate, will have a greater packing density [7]. The volume of the voids between roughly spherical aggregate particles is greatest, when the particles are of uniform size. When a range of sizes is used, the smaller particles can pack between the larger there by decreasing the void space and lowering paste requirement. Using a larger maximum aggregate size can also reduce the void space [1].

There are several reasons for specifying grading limits and nominal maximum aggregate size, they affect relative aggregate proportions as well as cement and water requirements, workability, pumpability, economy, porosity, shrinkage, and durability of concrete. Variations in grading can seriously affect the uniformity of concrete from batch to batch. Very fine sands are often uneconomical; very coarse sands and coarse aggregate can produce harsh, unworkable mixtures. In general, aggregates that do not have a large deficiency or excess of any size and give a smooth grading curve will produce the most satisfactory results [2].

2.3.2.1 Maximum Aggregate Size

The maximum size of the coarse aggregate influences the paste requirements of the concrete, and the optimum grading of the coarse aggregate depends on the maximum aggregate size. As defined by ASTM C 125, the maximum size of coarse aggregate is the smallest sieve opening through which the entire sample passes.

In practice, it is considered that if only a small amount of aggregate is retained on a sieve, it will not significantly affect the properties of the concrete. Thus, it is usual to use a nominal maximum size, which is the smallest sieve opening through which the entire sample is permitted to pass, but need not do so. A percentage (usually 5-10%) of the sample weight may be retained on this sieve.

ASTM grading requirements are based on nominal maximum size [1].The largest maximum size of aggregate practicable to handle under a given set of conditions should be used. Using the largest possible maximum size will result in:

a) Reduction of cement content

b) Reduction in water requirement

c) Reduction of drying shrinkage [11].

The maximum size of aggregate that can be used generally depends on the size and shape of the concrete member and the amount and distribution of reinforcing steel. The maximum size of aggregate particles generally should not exceed:

1. One-fifth the narrowest dimension of a concrete member
2. Three-quarters the clear spacing between reinforcing bars and between the reinforcing bars and forms
3. One-third the depth of slabs

These requirements may be waived if, in the judgment of the engineer, the mixture possesses sufficient workability that the concrete can be properly placed without honeycomb or voids [2].

2.3.2.2 Effect of Aggregate Optimization on Concrete Properties

Concrete mixtures with well-graded or optimized gradations have a less likely chance to segregate and will minimize finishing labor. The wear resistance of concretes with optimized gradations is greater than concretes with gap graded aggregate. In addition, by optimizing gradation, the water to cementitious (*w/c*) ratio of a concrete mixture can be lowered, thus producing a stronger, less permeable, and more durable concrete.

Variations in grading can seriously affect the uniformity of concrete from batch to batch. Very fine sands are often uneconomical; very coarse sands and coarse aggregate can produce harsh, unworkable mixtures [2].

2.3.3 Fine-Aggregate Grading

The most desirable fine-aggregate grading depends on the type of work, the richness of the mixture, and the maximum size of coarse aggregate. In leaner mixtures, or when small-size coarse aggregates are used, a grading that approaches the maximum recommended percentage passing each sieve is desirable for workability. In general, if the water-cement ratio is kept constant and the ratio of fine-to-coarse aggregate is chosen correctly, a wide range in grading can be used without measurable effect on strength. However, the best economy will sometimes be achieved by adjusting the concrete mixture to suit the gradation of the local aggregates [2].

Fine aggregate grading has a greater effect on workability of concrete than coarse aggregates. Manufactured sands require more fines than natural sands to achieve the same level of workability, probably due to the angularity of the manufactured sands particles [11].

Formerly two classes of fine aggregate were recognized but it has been shown that by adjusting the ratio of the fine to coarse aggregate a good concrete could be obtained with either classes of aggregate. In 1954 the revision to BS 882 considers four grading zones. In BS 882:1973 the division into zones is based primarily on the percentage passing the 600µm sieve .The main reason for this is that a large number of sands divide themselves naturally at just that size, grading above and below being approximately uniform. Furthermore, the content of particles finer than the 600µm sieve has considerable influence on the workability of the mix and provides a fairly reliable index of the overall specific surface of the sand [6]. Table 2.2 shows the grading requirement of British standard and ASTM for fine aggregate. BS 882 divides the grading in to four zones, zone 1 is coarser and zone 4 is finer. Grading zone 2 and 3 is optimum grading zones and approach to ASTM standard.

Since the British standard is wider than ASTM standard, the local fine aggregate may fit to one of the zones and it is better to adapt to Ethiopian standards.

Table 2.2 BS and ASTM grading requirement for fine aggregate [6].

Sieve size		Percentage by weight passing sieves				
		BS 882:1973				ASTM standard C33-78
BS	ASTM No.	Grading Zone 1	Grading Zone 2	Grading Zone 3	Grading Zone 4	
9.5mm	3/4in	100	100	100	100	100
4.75mm	3/16in	90-100	90-100	90-100	95-100	95-100
2.36mm	8	60-95	75-100	85-100	95-100	80-100
1.18mm	16	30-70	55-90	75-100	90-100	50-85
600µm	30	15-34	35-59	60-79	80-100	25-60
300 µm	50	5-20	8-30	12-40	15-50	10-30
150 µm	100	0-10	0-10	0-10	0-15	2-10

Sand falling in to any of the above zone can generally be used in concrete althogh under some circumstances the suitability of a given sand my depend on the grading and shape of coarse aggregate.Sudjsted value of coarse to fine aggregate ratio is given in table 2.3 as follows [6].

Table 2.3 Suggested proportion by weight of coarse to fine aggregate for sand of different zones

Maximum size of coarse aggregate		Coarse /fine aggregate ratio for sand of different zones			
mm	in	Zone 1	Zone 2	Zone 3	Zone 4
9.52	3/8	1	1.5	2	3
19.05	3/4	1.5	2	3	3.5
38.10	$1^1/_2$	2	3	3.5	-

2.3.3.1 Fineness Modulus

Using the sieve analysis results, a numerical index called the fineness modulus (FM) is often computed. The FM is the sum of the total percentages coarser than each of a specified series of sieves, divided by 100.

The specified sieves are 75.0, 37.5, 19.0, and 9.5 mm (3,1.5, 3/4, and 3/8 in.) and 4.75 mm, 2.36 mm, 1.18 mm, 600µm, 300 µm, and 150 µm (No. 4, 8, 16, 30, 50, and 100). Note that the lower limit of the specified series of sieves is the 150 µm (No. 100) sieve and that the actual size of the openings in each larger sieve is twice that of the sieve below. The coarser the aggregate size, the higher the FM. For fine aggregate used in concrete, the FM generally ranges from 2.3 to 3.1 as called for in ASTM C 33[4].

It is used as an index to the fineness or coarseness and uniformity of aggregate supplied, but it is not an indication of grading since there could be an infinite number of grading which will produce a given fineness modulus. The following limits may be taken as guidance [9]:

Fine sand:	F.M. 2.2 - 2.6
Medium Sand:	F.M. 2.6 - 2.9
Coarse Sand:	F.M. 2.9 - 3.2

Sand having a fineness modulus more than 3.2 will be unsuitable for making satisfactory concrete [9]. However, it is clear that one parameter, the average, cannot be representative of a distribution: thus the same fineness modulus can represent an infinite number of totally different size distributions or grading curves. The fineness modulus cannot, therefore, be used as a description of a grading of an aggregate but it is valuable for measuring slight variations in the aggregate from the same source .that is as a day to day check [6].

2.3.4 Coarse-Aggregate Grading

The grading for a given maximum-size coarse aggregate can be varied over a moderate range without appreciable effect on cement and water requirement of a mixture if the proportion of fine aggregate to total aggregate produces concrete of good workability. Mixture proportions should be changed to produce workable concrete if wide variations occur in the coarse-aggregate grading.

Since variations are difficult to anticipate, it is often more economical to maintain uniformity in manufacturing and handling coarse aggregate than to reduce variations in gradation. The maximum size of coarse aggregate used in concrete has a bearing on the economy of concrete. Usually more water and cement is required for small-size aggregates than for large sizes, due to an increase in total aggregate surface area [2].

The actual grading requirements for coarse aggregate depend to some extent on the shape and surface characteristics of the particles. For instance, sharp, angular particles with rough surfaces should have a slightly finer grading in order to reduce the possibility of interlocking and to compensate for the high friction between the particles [6].

2.3.5 Bulk Density

The bulk density or unit weight of an aggregate is the mass or weight of the aggregate required to fill a container of a specified unit volume. The volume referred to here is that occupied by both aggregates and the voids between aggregate particles [2]. The bulk density is used to convert quantities by weight to quantities by volume for batching concrete. Bulk specific gravity determined on the saturated surface-dry basis is used if the aggregate is wet, that is, if its absorption has been satisfied. Conversely, the bulk specific gravity determined on the oven-dry basis is used for computations when the aggregate is dry or assumed to be dry [ASTMC128].

2.3.5 .1 Factors Affecting Bulk Density

Bulk density depends on the moisture content of the aggregate. For coarse aggregate, increasing moisture content increases the bulk density; for fine aggregate, however, increasing moisture content beyond the saturated surface-dry condition can decrease the bulk density. This is because thin films of water on the sand particles cause them to stick together so that they are not as easily compacted. The resulting increase in volume decreases the bulk density.

Other properties that affect the bulk density of an aggregate include grading, specific gravity, surface texture, shape, and angularity of particles. Angularity increases void content while larger sizes of well-graded aggregate and improved grading decreases void content. The rodded bulk density of aggregates used for normal weight concrete generally ranges from 1200 to 1760 kg/m3 [4].

2.3.6 Specific Gravity

The density of the aggregate is required in mix proportioning to establish weight-volume relationships. The density is expressed as the specific gravity, which is a dimensionless ratio relating the density of the aggregate to that of water [1].

$$SG=\frac{\text{density of solid}}{\text{density of water}} \qquad \text{------------------ [Eq.2.1]}$$

Because the aggregate mass varies with its moisture content, specific gravity is determined at fixed moisture content. Four moisture conditions are defined for aggregates depending on the amount of water held in the pores or on the surface of the particles [4].

1. Damp or wet—Aggregate in which the pores connected to the surface are filled with water and with free water also on the surface.
2. Saturated surface-dry—Aggregate in which the pores connected to the surface are filled with water but with no free water on the surface.
3. Air-dry—Aggregate that has a dry surface but contains some water in the pores.
4. Oven-dry—Aggregate that contains no water in the pores or on the surface.

The bulk specific gravity is defined as the ratio of the weight in air of a given volume of a material at the standard temperature to the weight in air of equal volume of distilled water at the standard temperature.

For use in the computation of concrete mixes the bulk specific gravity is always determined for saturated surface dry aggregates [9].

Most natural aggregates have relative densities between 2.4 and 2.9 with corresponding particle (mass) densities of 2400 and 2900 kg/m3 [2].

2.3.7 Absorption and Surface Moisture

2.3.7.1Mixing Water and Water-Cementitious Material Ratio

The various moisture states in which an aggregate may exist have been described previously. Two of these—oven-dry and saturated surface-dry—are used as the basis for calculations of specific gravity. Aggregates stockpiled on the job are seldom in either of these states. They usually carry some free or surface moisture that becomes part of the mixing water. Freshly washed coarse aggregates contain free water, but because they dry quickly, they are sometimes in an air-dry state when used, and they absorb some of the mixing water [4]. The mixing water in a batch of concrete is all the water present in the concrete, with the exception of absorbed water within aggregate particles. Mixing water is the sum of the masses of free or surface moisture on the fine and coarse aggregate and the mass of water added separately, such as through a water meter or weigh batcher at the plant or through a truck mixer water system or added to the mixer in some other way. Mixing water is the water in freshly mixed sand-cement grout, mortar, or concrete exclusive of any previously absorbed by the aggregate [4].

The w/cm is the mass ratio of mixing water to cementitious material.

2.3.7.2 Absorption and Total Moisture Content

To calculate the mixing water content of concrete, the absorption of the aggregates and their total moisture contents must be known.

Absorption represents the total water contained in the aggregate in the saturated surface-dry condition and the surface moisture (or free moisture) is the water in excess at the saturated surface-dry state.

The total water content of a damp or moist aggregate is equal to the sum of absorption and surface moisture content. It should be noted that if the aggregates are dry they absorb water from the mixing water and there by affect the workability and, on the other hand, if the aggregates contain surface moisture they contribute extra water to the mix and thereby increase the water/cement ratio. Both these conditions are harmful for the quality of concrete. In making quality concrete, it is very essential that corrective measures should be taken both for absorption and free moisture so that the water/cement ratio is kept as exactly as per the mix design [9].

Absorption is computed as a percentage by subtracting the oven-dry mass from the saturated surface-dry mass, dividing by the oven-dry mass, and multiplying by 100. In concrete technology, aggregate moisture is expressed as a percent of the dry weight of the aggregate [4].

$$\text{Absorption, \%, } = \frac{WSSD - WOD}{WOD} \times 100 \text{ --------------- [Eq.2.2]}$$

2.3.8 Classification of Aggregate

Depending on their weight aggregate can be classified as a) Normal weight aggregates b) Light weight aggregate c) Heavy weight aggregates

Normal weight aggregates can be further classified as natural aggregates and artificial aggregates [11]

Natural	**Artificial**
Sand, gravel, crushed rock	Broken brick,
Such as Granite, Quartzite, Basalt,	air-cooled slag
Sandstone	sintered fly ash bloated clay

Aggregates can also be classified on the basis of the size of the aggregates as *coarse aggregate* and *fine aggregate*.

2.3.8.1 Source

Almost all natural aggregate materials originate from bed rocks. There are three kinds of rocks, namely, igneous, sedimentary and metamorphic. These classifications are based on the mode of formation of rocks. It may be recalled that igneous rocks are formed by the cooling of molten magma or lava at the surface of the crest (trap and basalt) or deep beneath the crest (granite) [11].

The sedimentary rocks are formed originally below the sea bed and subsequently up. Metamorphic rocks are originally either igneous or sedimentary rocks which are subsequently metamorphosed due to extreme heat and pressure [11].

The concrete making properties of aggregate are influenced to some extent on the basis of geological formation of the parent rocks together with the subsequent processes of weathering and alteration. Within the main rock group, Say granite group, the quality of aggregate may vary to a very extent owing to changes in the structure and texture of the main parent rock from place to place [11].

2.3.8.2 Aggregates from Igneous Rocks

Most igneous rocks make highly satisfactory concrete aggregate because they are normally hard, tough and dense. The most widespread of all the igneous rocks are basalts. Basalts are dark colored, fine grained extrusive rocks. The mineral grains are so fine that they are impossible to distinguish with the naked eye or even a magnifying glass. Most basalt is volcanic in origin and was formed by the rapid cooling and hardening of the lava flows. Some basalt is intrusive having cooled inside the Earth's interior [9].

2.3.8.3 Aggregates from Sedimentary Rocks

The quality of aggregates derived from sedimentary rocks will vary in quality depending upon the cementing material and the pressure under which these are originally compressed. Some siliceous sand stones have proved to be good concrete aggregate. Similarly, the limestone also can yield good concrete aggregate.

The thickness of the stratification of sedimentary rock may vary from a fraction of a centimeter to many centimeters. If the stratification thickness of the parent rock is less it is likely to show up even in an individual aggregate and thereby it may impair the strength of the aggregate. Such rocks may also yield flaky aggregates. The degree of consolidation, the type of cementation, the thickness of layers and contamination, are all important factors in determining the suitability of sedimentary rock for concrete aggregates [9].

2.3.8.4 Aggregates from Metamorphic Rocks

Many metamorphic rocks particularly quartzite and gneiss have been used for production of good concrete aggregates [9].

2.3.9 Aggregate Production Methods in the Ethiopian Construction Industry

2.3.9.1 Fine Aggregate

Natural fine aggregate or sand is dredged from river beds in most parts of Ethiopia. Finely crushed aggregate is also used in some parts of the country where natural sand is not available.

In most parts of the country, though the quality varies significantly one from the other, fine aggregate is available abundantly at least for the present [9].

2.3.9.1.1 Sources of Fine Aggregates

As most of the aggregate used in Ethiopia is from river beds mostly fine aggregate is not produced in wet seasons. One reason for this is that since the river over flows in that period it would not be possible for sand producers to get into the river bed and collect the sand. The other reason is that most sand production sites are not accessible by vehicles in this period [9].

For the purpose of this research I visited different quarry sites to collect sand samples. From these sites Alemtena is most probably the largest one; according to the information from local people about 300 trucks are loaded with sand per day during winter season. The site off set distance from Alemtena town is around 20km and it is difficult to transport sands from the site during rainy season because of the access road. During my journey to the site because of small rain I observe the problem of the road and struggling of the trucks with sand. This is contributing factor for increasing price of sand from time to time. As known the major source of sand in Ethiopia is river bed and all have the same problem during rainy season.

2.3.9.1.2 Production Methods

Sand production sites are not mechanized. The production is done by local people of the area using traditional method of collecting the sand from the river bed by donkey (carrying capacity of not greater than 70 kg or 0.05 m3 per trip), depositing it to a place where vehicles can get in. Fig. 2.2 and Fig 2.3 show the primitive but the usual way of producing sand in Koka 90 kms south east of Addis Ababa. Fine aggregate demand of Addis Ababa is met by sand produced in this same manner.

Finally, the collected sand is loaded manually on dump trucks and is then transported to the actual site or concrete production plants and is directly used for actual concrete production or related works. Some part of it might be sent to construction material suppliers and is sold out for users who need the sand in varying amount.

The production method of sand in Ethiopia is so primitive that the sand produced in this manner is exposed to the following situations [9].

1. Since it is collected in a primitive manner by human labour using small hand tools, it is susceptible to a greater degree of non-uniformity; this non uniformity can be expressed by its gradation.
2. Since it is transported by donkey and collected somewhere in an unprepared ground, it is susceptible to contamination by deleterious substances.
3. There is no room for quality check up.
4. There is no room for modern production of standardized product.
5. Most sand producers are local farmers who have no detail technical knowledge about the material they produce. The only knowledge they have doesn't go far from what they are informally heard from their product customers.
6. The local producers are quite numerous in a single local area that it is difficult to get consistent supply from a specific area.
7. Since the sand itself is naturally available material it is quite difficult to get a consistent supply from same location even in hour's interval.
8. There is wastage of material in the process.

The following figures shows how modern sand processing is taking place and how Ethiopian trend is buck ward. In Modern Sand Processing operations like screening, washing, separation and fractional classification is done in a plant.

In Ethiopia illiterate people without knowing anything about recommendations and standards, produce the sand and load to truck without any processing. Mix designers are proportioning the mix by using a sample from a truck and apply to the whole project. It is, therefore, practically impossible to get similar quality of sand in one day from those purchased in the Addis Ababa distribution centers.

Even in large construction sites, it is practically impossible to guarantee similar quality of fine aggregate materials for all concreting work adding to the difficulty of producing the same quality of concrete using the same prescribed mix proportion [3].

Fig: 2.2 Modern way of sand processing [9]

Fig: 2.3 Traditional way of sand production in Ethiopia [3]

Fig: 2.4 Traditional way of sand production in Ethiopia [3]

Fig 2.5 A Truck with sand in deteriorated access road around Alemtena.

Fig 2.6 Deteriorated access road around Alemtena to sand source.

Fig **2.7** While taking sample of coarse aggregate around Akaki.

2.3.9.2 Coarse Aggregates

Coarse aggregate is produced in Ethiopia using aggregate crushers and by crushing manually using human labor and small hand tools. Especially, in rural areas and in construction sites where the coarse aggregate demand is low manual crushing is normally experienced. In addition, the crusher plants vary in size and production quality [9].

The normal weight coarse aggregates for the Ethiopian construction sector are produced by both, traditional and modern means.

Traditionally coarse aggregate is produced by heating a boulder at a higher temperature and crushing it by a hammer using a manual labor to the required approximate sizes. Aggregates produced using such method are usually flaky and do not satisfy the grading requirements set by standard recommendations.

Nevertheless, such aggregates are used for construction in areas where aggregates crushing machine(s) is not available and quality control is not a criteria in the execution of the work [3].

2.3.10 Deleterious Substances in Aggregates

Materials in aggregates, which may affect adversely the strength or durability of concrete, or reinforcement in concrete are termed deleterious materials. There are three broad categories of deleterious substances, these are: -

i. Impurities interfering with the process of hydration of cement.
ii. Coatings preventing the development of good bond between aggregate and the cement paste, and
iii. Unsound particles which are weak or bring about chemical reaction

The impurities in the form of organic matter interfere with the chemical reactions of hydration. These impurities are generally consisting of decayed vegetable matter (mainly tannic acid and its derivatives) and appearing in the form of humus or organic loam are more likely to be present in fine aggregate than coarse aggregate, which is easily washed [10].

Clay and other fine materials in aggregate may affect the quality of concrete if present in excess amount. Clay may be present in the form of surface coatings which interfere with the bond between aggregate and the cement paste. Since good bond is essential to ensure a satisfactory strength and durability of concrete, the problem of clay coating is an important one. The other two fine materials which can be present in aggregate are silt and crusher dust. Silt is a material between 2Sm and 60 Sm reduced to this size by natural process of weathering; silt may thus be found in aggregate obtained from natural deposits.

On the other hand, crusher dust is a fine material formed during the process of crushing rock into crushed coarse and fine aggregate.

The soft or loosely adherent coatings can be removed by washing. The well-bonded chemically stable coatings have no harmful effect except that the shrinkage may be increased. However, aggregates with chemically reactive coatings, even if physically stable, can lead to serious trouble.

Silt and fine dust, if present in excessive amount, increases the surface area of the aggregate and hence the amount of water required to wet all particles in the mix, thereby reducing the strength and durability of concrete [10].

In our case Ethiopian standard limits silt content to 6%. But as most of our sand source is natural deposit or river bed, silt content is much higher than the standard. Researches show that silt content of sand is up to 33%.In my research I investigated that silt content of Alemtena sand is 18% and that of Koka sand is 17%.In most cases this sand is directly used for making concrete and even if washed it is for formality and not to the standard. That is why most of our Engineers sticking to specify C-25 and C-30. Some contractors fail to make C-25 because of lack of knowledge how to handle aggregate, how to mix, and how to cure concrete. On the other hand researches indicate that high strength concrete like C-80, C-90 etc was produced in the laboratory by properly grading, washing, proportioning, mixing and curing of concrete. On the other hand enforcing regulation and timely supervision is weak in our construction industry.

During taking concrete construction course my group and I made C-40 and C-70 easily by following standards and recommendations in preparing our aggregate and proportioning the mix without using admixtures.

2.3.11 Benefits of Standardization

The important general benefits are as follows:

1. Standardization helps reduce inventory items on site.
2. It helps in evolving better means of communication about the material being considered.
3. It forms a base for further inventory analysis.
4. The specification of items can be more clearly spelled out, making quality control firm. By using national standards, it is easier to locate sources of supplies.

The importance of standardization in the construction industry especially for construction materials cannot be overemphasized. Industry has become increasingly interested in assessing its economic efficiency, and thus is more interested in the role of standardization. Systematic and reliable results can be attained on a common basis [9].

CHAPTER THREE

3.1 Methodology

The difference between standard and non standard aggregate in making concrete was investigated by making different classes of concrete. Fine aggregate from Alemtena and Dire Dawa was washed, screened and blended to satisfy Ethiopian standard (aggregate AD).Coarse aggregate from Dukem the so called 03 and 02 were blended and washed to satisfy Ethiopian standard (aggregate D). Derba cement and tap water from Addis Ababa Institute of Technology (AAiT) laboratory was used throughout the mix. By using this standardized aggregate the control mix proportion for C-25 and C-30 was made because these classes of concrete are mostly used in Ethiopian construction Industry. Another control mix is C-40, is made by coarse aggregate from Akaki and its maximum size was limited to 20mm and fine aggregate from Meki and Koka was washed and blended to the requirement of Ethiopian standard.

To compare with the above standardize mixes aggregates from different sources, like fine aggregate from Langano,Meki,Alemtena,Koka and Mojo were collected and put in the laboratory. Coarse aggregate from Akaki,Dukem and Sululta were used without any treatment. By keeping the mix proportion constant the slump and compressive strength for C-25, C-30 and C-40 were investigated and the result was compared with the control mix. Compressive strength test was made at 3, 7 and 28 days. The ratio of 3^{rd} and 7^{th} day strength to the 28^{th} day strength was investigated to determine how much percentage of strength can be gained at 3^{rd} and 7^{th} days when compared with 28 days strength, both for control mix and other mixes with non standard aggregate. Strength development at different ages was illustrated graphically for control mixes (mix with standard aggregate) and mixes with non standard aggregate. Based on the test results analysis and discussion were made.

The difference between concrete made by standard aggregate and nonstandard aggregate, by considering their compressive strength, was investigated.

Cost of washing and standardizing sand was analyzed by considering current labor cost in Ethiopia.

Finally conclusions and recommendations are given.

CHAPTER FOUR

Mix Design and Physical Properties of Aggregate

4.1 Aggregate for control mix of C-25 and C-30

To make control mix for C-25 and C-30, fine aggregate from Alemtena and Dire Dawa was washed and blended to the requirement of Ethiopian standards. Coarse aggregate from Dukem was blended and a maximum size of 38mm was used. The properties of these aggregates will be discussed in the following sections.

4.1.1Silt Content

Impurities can be classified as solid materials or soluble substances. Solid materials are generally present in a very finely divided state, passing the 75-µm sieve. Such material will appreciably increase the water requirements for workable concrete and reduce the abrasion resistance of hardened concrete if present in large amounts. The fine fraction is also likely to adhere to the surfaces of the large aggregate particles, isolating those particles from the surrounding concrete and causing a reduction in strength. Materials in this class are commonly silt, rock dust, and organic matter [1].

Ethiopian standard limits silt content to 6%. Fine aggregate with silt content more than this limit has to be washed or rejected. In Ethiopian case the main source of fine aggregate is river bed and most of the time silt content is more than 10%. For the purpose of this research I collected fine aggregate from different sources and their silt content is by far more than the limits set by Ethiopian standard. Silt content of Alemtena sand before washed was17% and that of Dire Dawa sand was 8%, which both of them are unacceptable to the Ethiopian standard. I washed and reduced the silt content for Alemtena sand to 2.6% and that of Dire Dawa to 3.7% and acceptable to the requirement of Ethiopian standard. Absorption capacity of the standardized sand was 2.3.

4.1.2 Gradation of fine aggregate

Sieve analysis was done for Dire dawa sand and Alemtena sand to compare with gradation requirement of Ethiopian standard. Since both fine aggregate did not satisfy Ethiopian standard, I blend the aggregate as 53% Dire Dawa sand and 47% Alemtena sand as shown in table 4.1.

Table 4.1 Sieve Analysis for Alemtena Sand

Size of sieve (mm)	Weight of sieve (gm)	Wt of sieve and retained (gm)	Weight of retained (gm)	Percentage Retained (%)	Cumulative Coarser	Cumulative Passing (%)
9.5	585	585	0	0	0	100
4.75	427	430	3	1	1	99
2.36	383	392	9	2	3	97
1.18	354	391	37	7	10	90
0.6	324	479	155	31	41	59
0.3	302	521	219	44	85	15
0.15	462	526	64	13	98	2
					238	
Fineness Modulus					2.4	

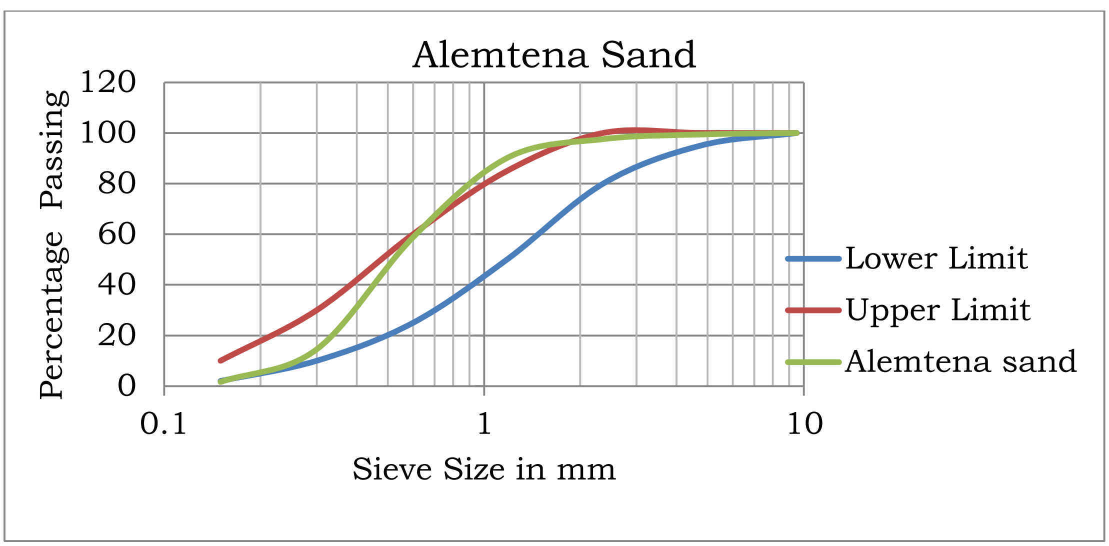

Fig.4.1 Gradation chart for Alemtena Sand

Table 4.2 shows sieve analysis of Dire Dawa sand.

Table 4.2 Sieve Analysis for Dire Dawa Sand

size of sieve(mm)	Weight of sieve(gm)	Wt of sieve and retained (gm)	Weight of retained (gm)	Percentage Retained (%)	Cumulative Coarser	Cumulative Passing (%)
9.5	585	585	0	0	0	100
4.75	427	431	4	1	1	99
2.36	383	421	38	8	9	91
1.18	354	477	123	25	34	66
0.6	324	506	182	37	71	29
0.3	302	425	123	24	95	5
0.15	460	486	26	5	100	0

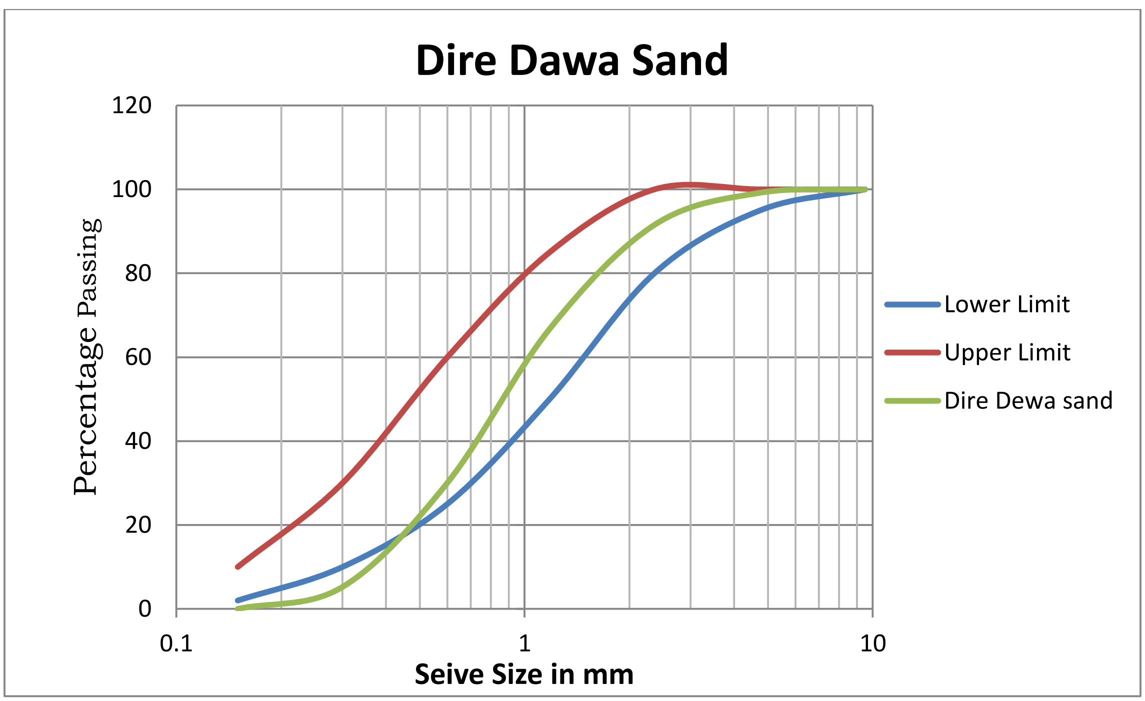

Fig.4.2 Gradation chart for Dire Dawa Sand

The above charts and tables indicate that the gradation of fine aggregate from individual source does not satisfy the Ethiopian standard requirement. The grading of aggregate is very important because it affects the paste requirement of concrete, workability of fresh concrete, packing density and determines the economy of concrete production.

Therefore to produce economical and durable concrete, I blend the two fine aggregate and fulfill the Ethiopian standard for the control mix according to table 4.3.

Table 4.3 Combined Gradation of Dire Dawa and Alem Tena

Size of Sieve(mm)	53% Dire Dawa	47% Alem Tena	Combined Cumulative Passing (%)
9.5	53	47	100
4.75	53	47	99
2.36	49	46	94
1.18	35	42	78
0.6	16	28	44
0.3	3	7	15
0.15	3	1	4

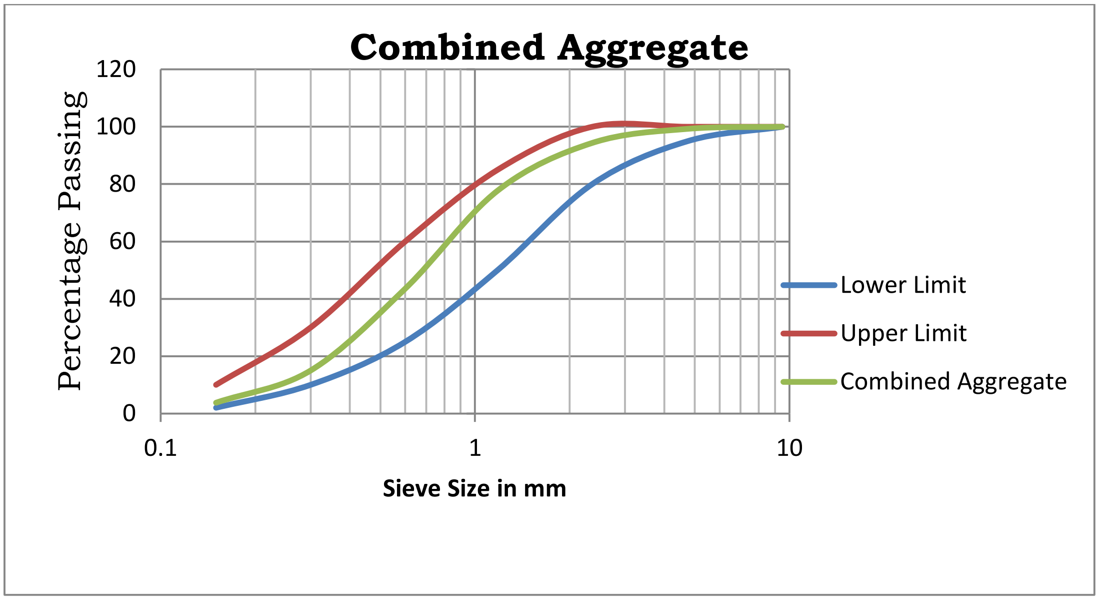

Fig.4.3 Gradation chart for combined aggregate of Dire Dawa and Alemtena

Coarse aggregate from Dukem was used for control mix after washed and blended. Physical properties of coarse aggregate were investigated and described in the table 4.4 as follows.

Table 4.4 Physical property of coarse aggregate from Dukem

Physical property	Dukem Aggregate
Maximum aggregate Size	38mm
Specific Gravity	2.71
Absorption Capacity	2.14
Moisture Content	1.65
Estimated Wet density of concrete	2410Kg/m^3
Actual wet density of concrete	2468Kg/m^3
Shape	Angular
Texture	Rough

From the above table we can observe that specific Gravity and Wet density of concrete are in acceptable range.

4.1.3 Gradation of coarse aggregate

To standardize the aggregate I blend the so called 03, 02 and 01 to improve the packing density, workability, minimize paste requirement then cement content and minimize segregation. Sieve analysis is done and summarizes by table 4.5 and chart.

Table 4.5 Sieve analysis of Dukem Coarse Aggregate

size of sieve (mm)	Weight of sieve (gm)	Wt of sieve and retained (gm)	Weight of retained (gm)	Percentage Retained (%)	Cumulative Coarser	Cumulative Passing (%)
37.5	1083	1083	0	0	0	100
25	1167	2117	950	37	37	63
19	1398	1946	548	21	58	42
12.5	1163	1814	651	25	83	17
9.5	1169	1370	201	8	91	9
4.75	1181	1417	236	9	100	0
sum					367	
Fineness Modulus						3.7

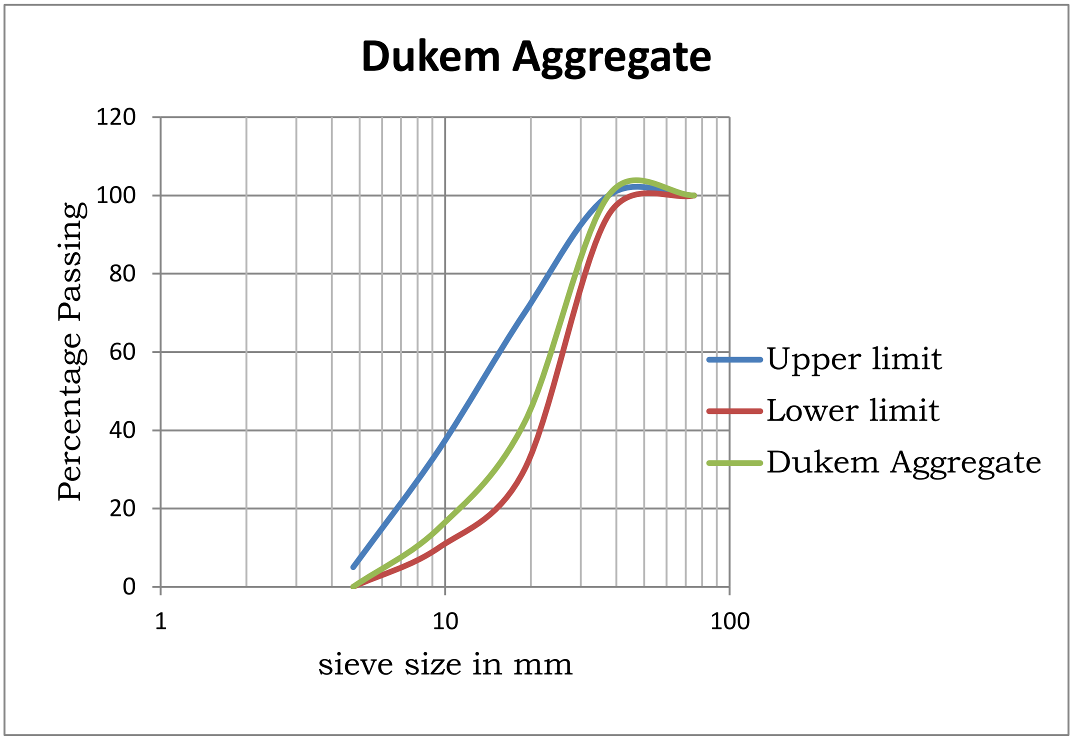

Fig.4.4 Gradation chart for Dukem coarse Aggregate

4.2 Aggregate for control mix of C-40

Fine aggregate from Meki and Koka was blended to standardize the aggregate for control mix of C-40. The silt content of Meki and Koka sand is 16% and 12% respectively before washing. These are unacceptable to Ethiopian standard. After washing the silt content of Meki and Koka sand is 2.53 and 2.13 respectively. Therefore Ethiopian standard is satisfied after washing. Gradation of both sands do not fulfill Ethiopian standards alone, therefore to satisfy the standard I blend the two aggregate by taking 80% from Meki sand and 20% from Koka sand. Therefore the fine aggregate is now standardized with respect to Gradation and silt content. Coarse aggregate from Akaki was used to make C-40. Maximum aggregate size was limited to 20mm and a material passing on sieve size 4.75mm was rejected. Coarse aggregate was also washed to avoid unnecessary deleterious and coating materials which have negative effect on strength of concrete.

4.2.1Gradation

Sieve Analysis is done for individual fine aggregate and blended to satisfy Ethiopian standard. Sieve analysis and gradation charts are detailed in the tables 4.6, 4.7 and 4.8 and figures 4.5, 4.6 and 4.7 respectively.

Table 4.6 Sieve analysis of Meki sand

Size of Sieve(mm)	Weight of sieve (gm)	Wt of sieve and retained (gm)	Weight of retained (gm)	Percentage Retained (%)	Cumulative Coarser	Cumulative Passing (%)
9.5	585	585	0	0	0	100
4.75	429	460	31	6	6	94
2.36	383	435	52	10	16	84
1.18	372	485	113	22	38	62
0.6	324	475	151	30	68	32
0.3	302	423	121	24	92	8
0.15	460	491	31	6	98	2
Sum					318	
Fineness Modulus						3.18

As we can see from the above table percentage passing is below the lower limit of Ethiopian standard on two sieves. The higher fineness modulus also shows that the sand is coarser.

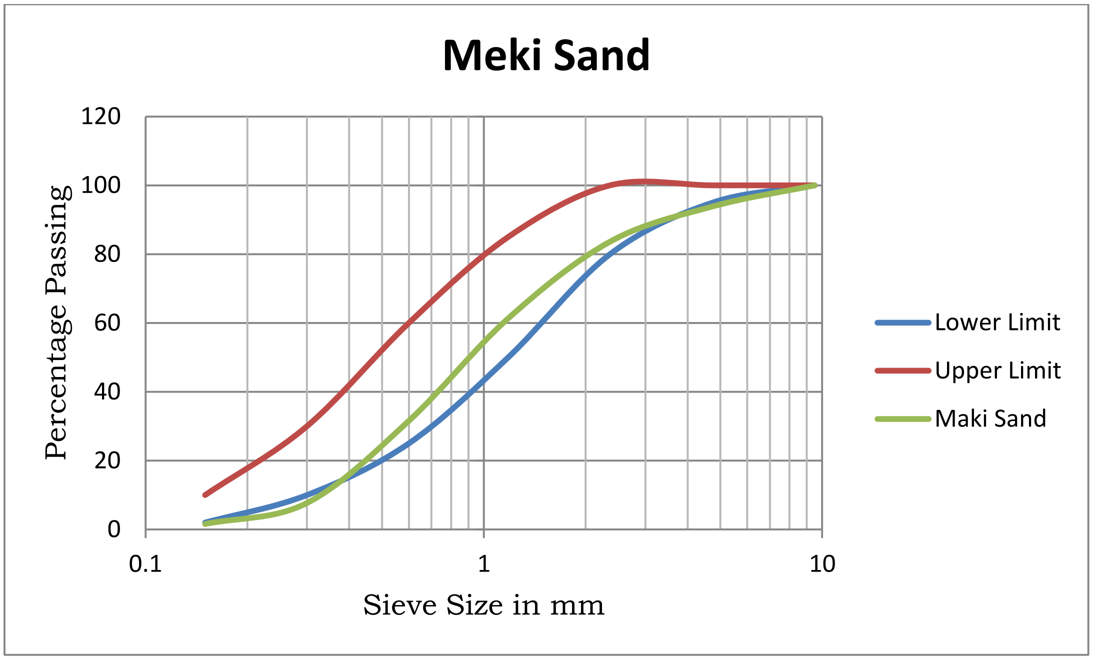

Fig.4.5 Gradation chart for Meki Sand

Table 4.7 shows sieve analysis of koka sand and it is possible to observe that three consecutive sieve is out of recommendation.

Table 4.7 Sieve analysis of Koka sand

Size of Sieve (mm)	Weight of sieve (gm)	Wt of sieve and retained (gm)	Weight of retained (gm)	Percentage Retained (%)	Cumulative Coarser	Cumulative Passing (%)
9.5	585	585	0	0	0	100
4.75	427	428	1	0	0	100
2.36	383	388	5	1	1	99
1.18	354	365	11	2	3	97
0.6	324	364	40	8	11	89
0.3	302	442	140	28	39	61
0.15	462	729	267	53	92	8
Sum					146	
Fineness Modulus						1.5

As we can see from the above table the percentage passing of three consecutive sieves is more than the upper limit of Ethiopian standard and the smaller fineness modulus indicates that the sand is too fine.

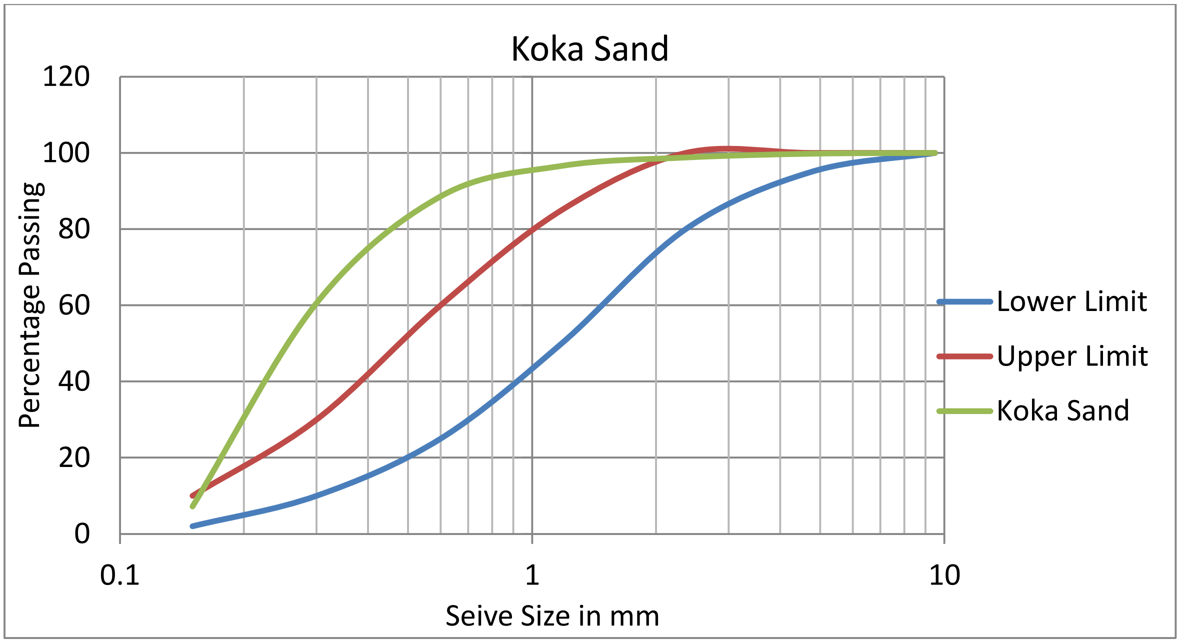

Fig.4.6 Gradation chart for Koka Sand

Table 4.8 Combined Gradation of Meki and Koka sand

Size of Sieve(mm)	80% Meki	20% Koka	Combined Cumulative Passing (%)
9.5	80	20	100
4.75	75	20	95
2.36	67	20	87
1.18	49	19	68
0.6	25	18	43
0.3	6	12	15
0.15	1	1	3

From the above table the combination of Meki sand which is slightly coarser with Koka sand which is very fine satisfies Ethiopian standard. The gradation chart of the combined aggregate is also fit to standard gradation chart.

Different source of coarse aggregate was used for C-40 depending on maximum aggregate size and the source fine aggregate was randomly selected for control mixes.

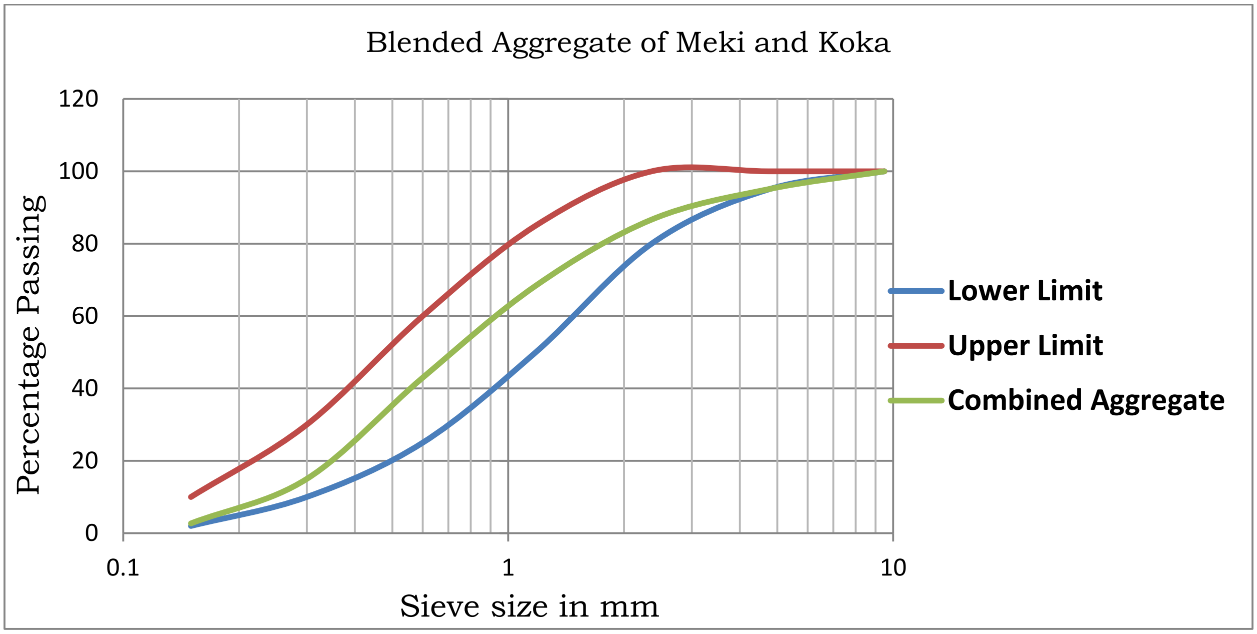

Fig.4.7 Gradation chart for combined sand of Koka and Meki

4.3 Mix Design

The purpose of this research is to find out the difference between standard and nonstandard aggregates in making concrete by keeping the mix proportion constant. The mix proportion for control mixes are done by using the property of standardized aggregate.

DOE mix design method was used to proportion the control mixes. I determined target mean strength by considering 5% defectives for which constant K=1.64 and DOE recommended 8 N/mm^2 standard deviation in the absence of sufficient data; accordingly 8 N/mm^2 was used.

Therefore the margin value of 13 N/mm^2 was added to specified strength.

Derba cement (PPC) was used for all mixes and admixtures were not used. All strength test samples were consolidated by using vibrating table. The mix proportions are given in the table 4.9 as shown blow.

Table 4.9 Mix proportion for control mixes

Concrete class	Cement (Kg/m^3)	Water cement ratio	Free water content (Kg/m^3)	Coarse aggregate (Kg/m^3)	Fine aggregate (Kg/m^3)
C-25	260	0.59	155	1295	700
C-30	280	0.55	155	1420	555
C-40	380	0.45	170	1205	620

By keeping the above proportion constant, twelve mixes were made by using fine aggregate and coarse aggregate from different quarries without washing and blending. I brought fine aggregate from Mojo, Koka, Alemtena, Meki and Langano and Dire Dawa sand from suppliers. Coarse aggregate from Dukem, Akaki and Sululita were used for this research. Physical properties of these aggregates were also investigated and their effect on compressive strength was studied.

4.4 Sample Preparation

Sample for compressive strength test was prepared by only varying the source of aggregate. The detail of sample preparation is illustrated in the table 4.10.

Table 4.10 Sources of samples for control mixes

Mix codes	Source of fine aggregate	Source of coarse aggregate
CC-25	Combined Dire Dawa and Alemtena sand	Dukem
CC-30	Combined Dire Dawa and Alemtena sand	Dukem
CC-40	Combined Meki and Koka sand	Akaki

Table 4.11 Samples for mixes with non standard aggregate

Mix codes	Concrete class	Source of fine aggregate	Source of coarse aggregate
DDC	C-30	Dire Dawa	Dukem
MAC	C-30	Mojo	Akaki
MSC	C-30	Meki	Sululita
MDC	C-25	Mojo	Dukem
MSC	C-25	Meki	Sululita
LAC	C-25	Langano	Akaki
MDC	C-40	Mojo	Dukem
MSC	C-40	Meki	Sululita
LAC	C-40	Langano	Akaki

CHAPTER FIVE

Test Results and Discussion

5.1 Control Mix

The mean compressive strength of control mix tested and cured at the age of 3, 7 and 28 days are shown in table 5.1.

Table 5.1 The mean compressive strength of control mix

	Mean compressive strength (MPa)			Slump (mm)	Target Mean strength (MPa)	Characteristi c strength (MPa)
Test age in days	3	7	28			
CC-25	21.3	28.5	37.8	10	38	25
CC-30	26.0	33.3	42.2	9	43	30
CC-40	34.8	44.9	57.5	0	53	40

As we can see from the above table, with cement content of 260kg/m^3, 280 kg/m^3 and380 kg/m^3 for C-25, C-30 and C-40 respectively the required strengths are achieved. This is achieved by standardizing the aggregate, following the recommendation during proportioning, correct curing and takes care of work man ship in specimens preparation.

5.1.1Rate of Strength Development

Table 5.2 shows the percentage of 28th day attends at 3rd and 7th day.

Table 5.2 The ratio of 3rd and 7th days strength to 28 days strength

Mix	3rd day strength	7th day strength	28th day strength	ratio 3/28 days	ratio 7/28 days
CC-25	21.3	28.5	37.8	56.5	75.5
CC-30	26.0	33.3	42.2	61.7	79.0
CC-40	34.8	44.9	57.5	60.5	78.1
Mean				**59.6**	**77.6**

From the above table we can see that the concrete test specimens gain about 60% of 28th day strength at 3rd day and about 78% of 28th day strength at 7th day.

The following figures show the rate of strength development graphically.

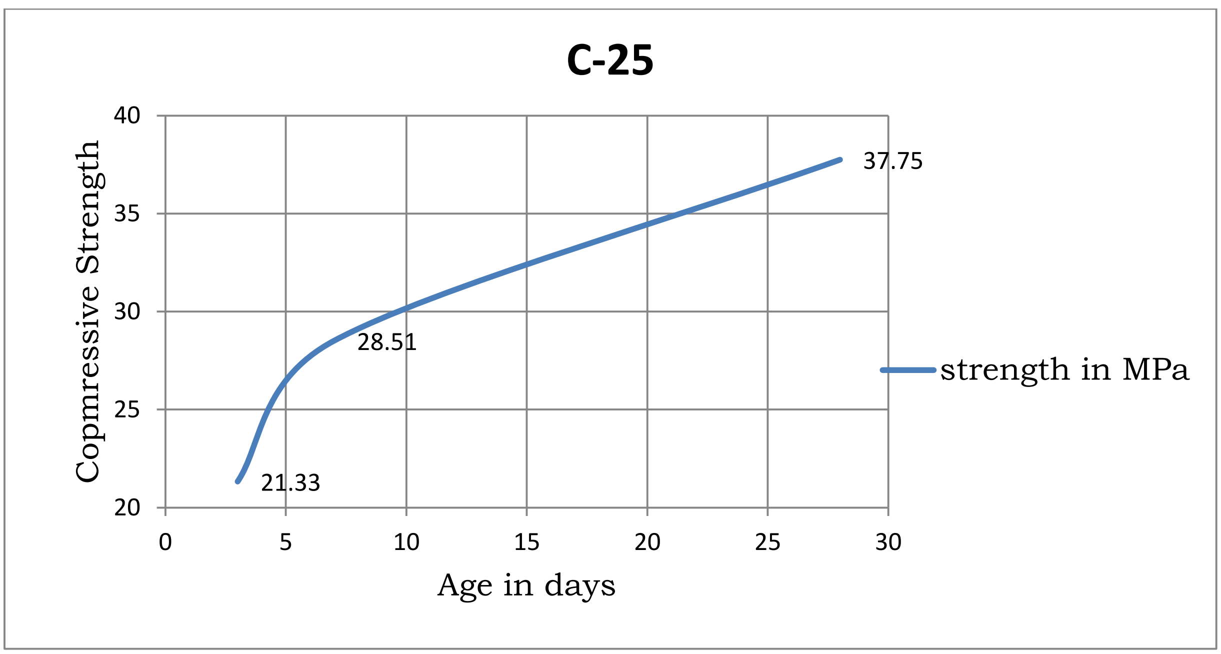

Fig. 5.1 The rate of strength development of C-25

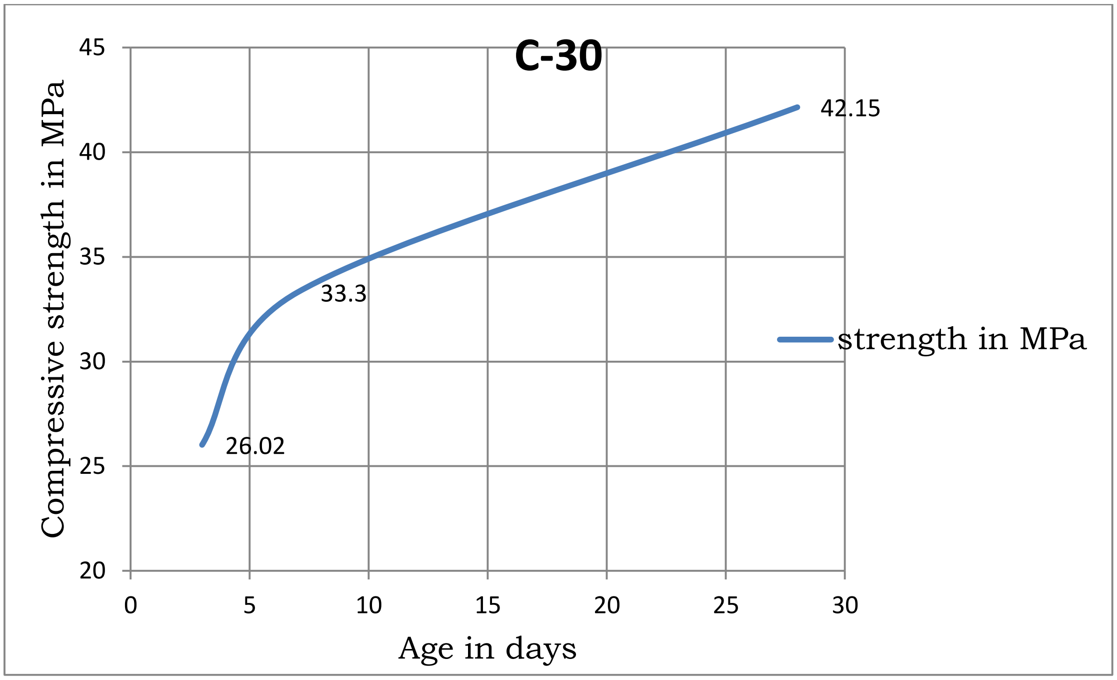

Fig. 5.2 The rate of strength development of C-30

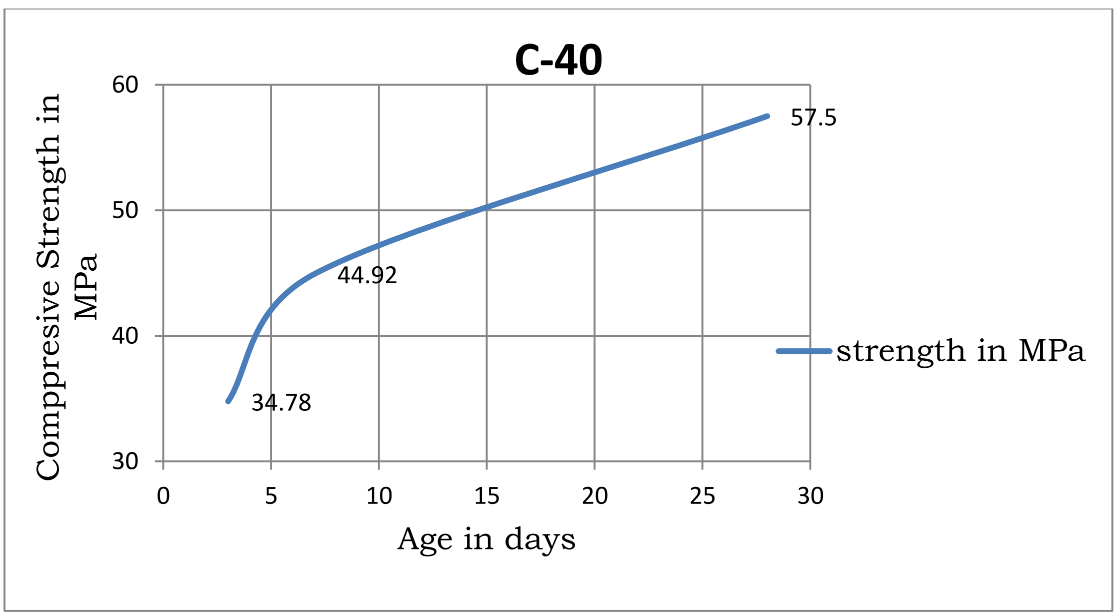

Fig. 5.3 The rate of strength development of C-40

5.2 Mixes with Nonstandard Aggregate

Nine mixes, three for each classes of concrete were made with aggregates brought from quarry directly without washing and blending as control mix but keeping the mix proportion, cement type and water the same as control mix. As these aggregates used directly, detailed investigation like unit weight and water content did not done. The test results of these mixes were compared with that of control mix in the following section.

5.2 .1 Mix MAC and MDC

These mixes were made with sands from Mojo and coarse aggregate from Akaki and Dukem. The mean compressive strength of mixes tested and cured at the age of 3, 7 and 28 days are shown in table 5.3.

Table 5.3 The mean compressive strength of mix MAC and MDC

	Mean Compressive Strength (MPa)			Slump (mm)	Target Mean strength (MPa)	Characteristic strength (MPa)
Test age in days	3	7	28			
MDC-25	13	21.4	29.4	15	38	25
MAC-30	18.3	29.1	35.1	20	43	30
MDC-40	20.2	28.3	37.5	0	53	40

As we can see from the above table, with cement content of 260kg/m^3, 280 kg/m^3 and380 kg/m^3 for C-25, C-30 and C-40 respectively the target mean strengths are not achieved and the 28th day strengths are much below the target mean strengths, even if MDC-25 and MAC-30 achieved characteristic strengths. The lower strengths could be due to the adherence of fine fractions to the surfaces of the large aggregate particles, isolating those particles from the surrounding concrete and causes a reduction in strength. On the other hand water content did not been adjusted, and high water content can reduce strength.

5.2.1.1 Rate of Strength Development

Table 5.4 shows the percentage of 28th days attend at 3rd and 7th day as shown below.

Table 5.4 the ratio of 3 and 7 days with 28 days of mix MAC and MDC

Mix	3 days strength	7 days strength	28 days strength	ratio 3/28 days	ratio 7/28 days
MDC-25	13	21.4	29.4	44.1	72.8
MAC-30	18.3	29.1	35.1	52.2	82.9
MDC-40	20.2	28.3	37.5	53.8	75.4
Mean				**50**	**77.0**

From the above table we can see that the concrete test specimens gain about 50% of 28th day strength at 3rd day and about 77% of 28th day strength at 7th day. Figures 5.4, 5.5 and 5.6 shows the rate of strength development graphically.

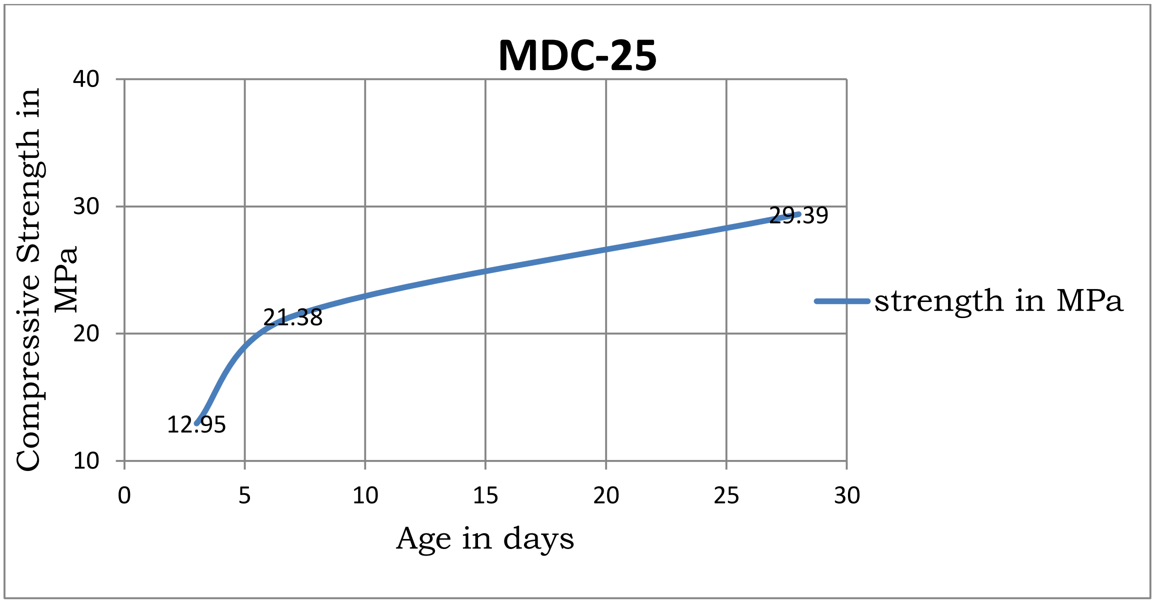

Fig. 5.4 The rate of strength development of MDC-25

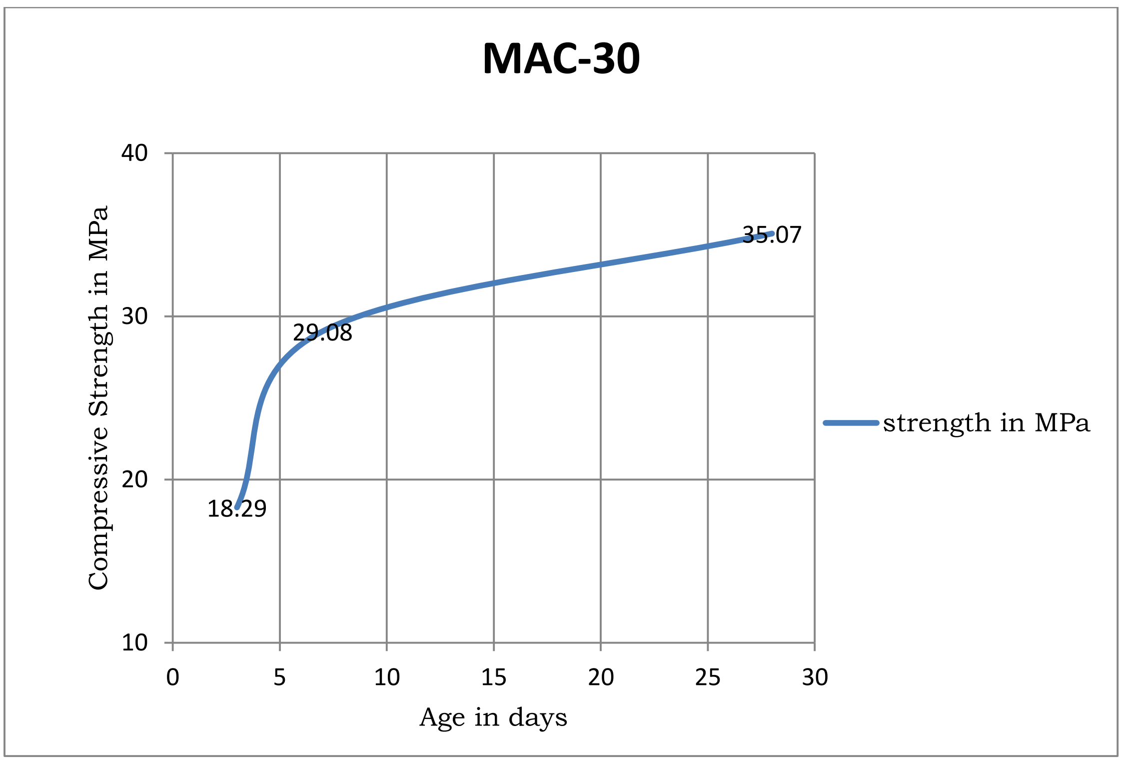

Fig. 5.5 The rate of strength development of MAC-30

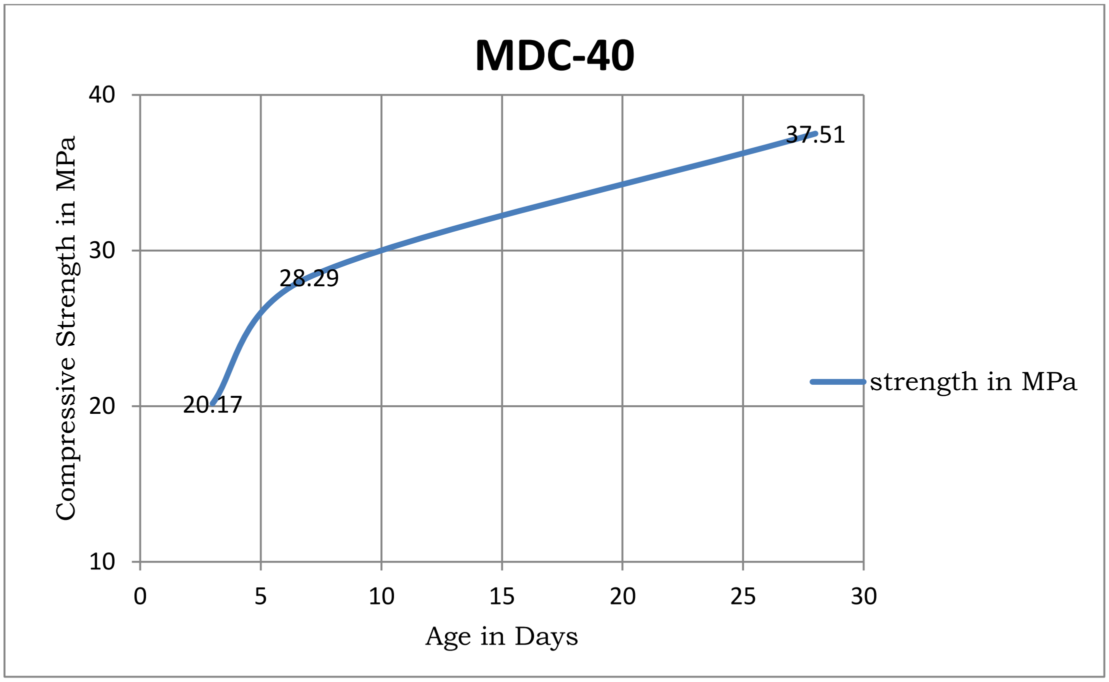

Fig. 5.6 The rate of strength development of MDC-40

5.2.2 Mix LAC

These mixes were made with sands from Langano and coarse aggregate from Akaki. The mean compressive strength of mixes tested and cured at the age of 3, 7 and 28 days are shown in table 5.5.

Table 5.5 The mean compressive strength of LAC mix

	Mean compressive strength (MPa)			Slump (mm)	Target Mean strength (MPa)	Characteristic strength (MPa)
Test age in days	3	7	28			
LAC-25	10.8	16.5	21	60	38	25
LAC-30	11.4	17.1	23.2	65	43	30
LAC-40	17.1	23.3	29.9	80	53	40

As we can see from the above table, even if the cement content remain the same as control mix that is 260kg/m^3, 280 kg/m^3 and380 kg/m^3 for C-25, C-30 and C-40 respectively the result strengths are much less than the target mean strength and the characteristic strength.

5.2.2.1 Rate of Strength Development

Table 5.6 shows the percentage of 28th day strength attends at 3rd and 7th day.

Table 5.6 The ratio of 3 and 7 days to 28 days of mix LAC

Mix	3rd day strength	7th day strength	28th day strength	ratio 3rd/28th day strength	ratio 7rd/28th day strength
LAC-25	10.8	16.5	21	51.2	78.4
LAC-30	11.4	17.1	23.2	49.0	73.5
LAC-40	17.1	23.3	29.9	57.3	77.9
Mean				**52.5**	**76.6**

From the above table we can see that the concrete test specimens gain about 52% of 28th day strength at 3rd day and about 77% of 28th day strength at 7th day.

The following figures show the rate of strength development graphically.

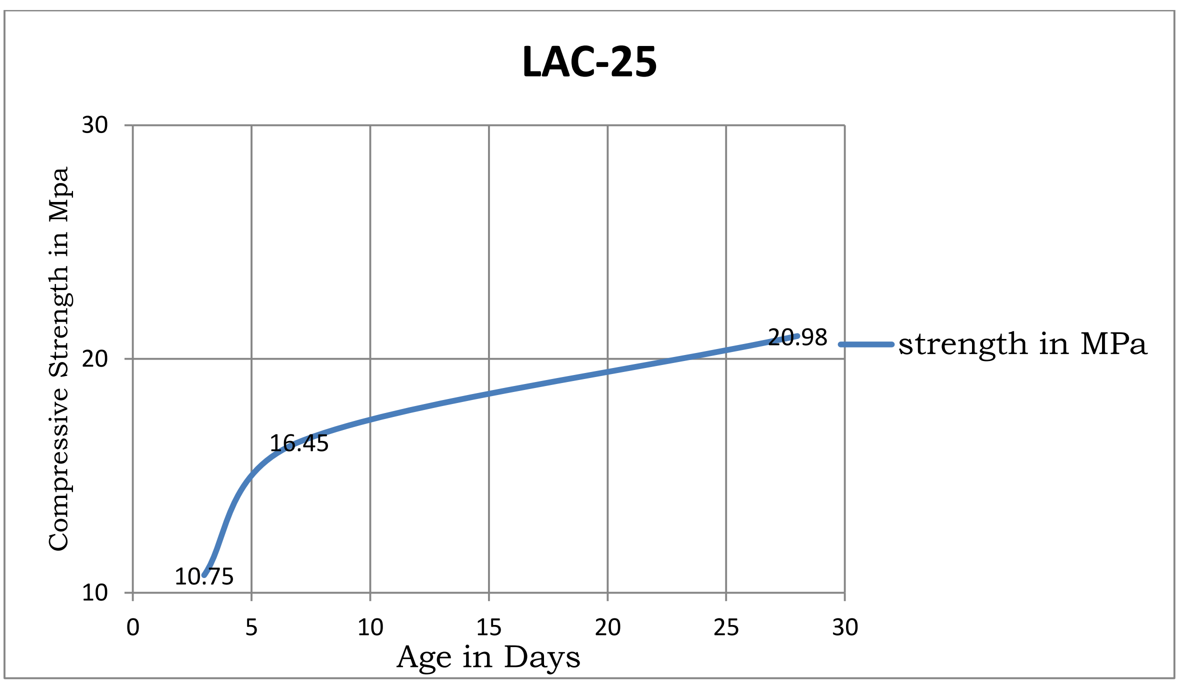

Fig. 5.7 The rate of strength development of LAC-25

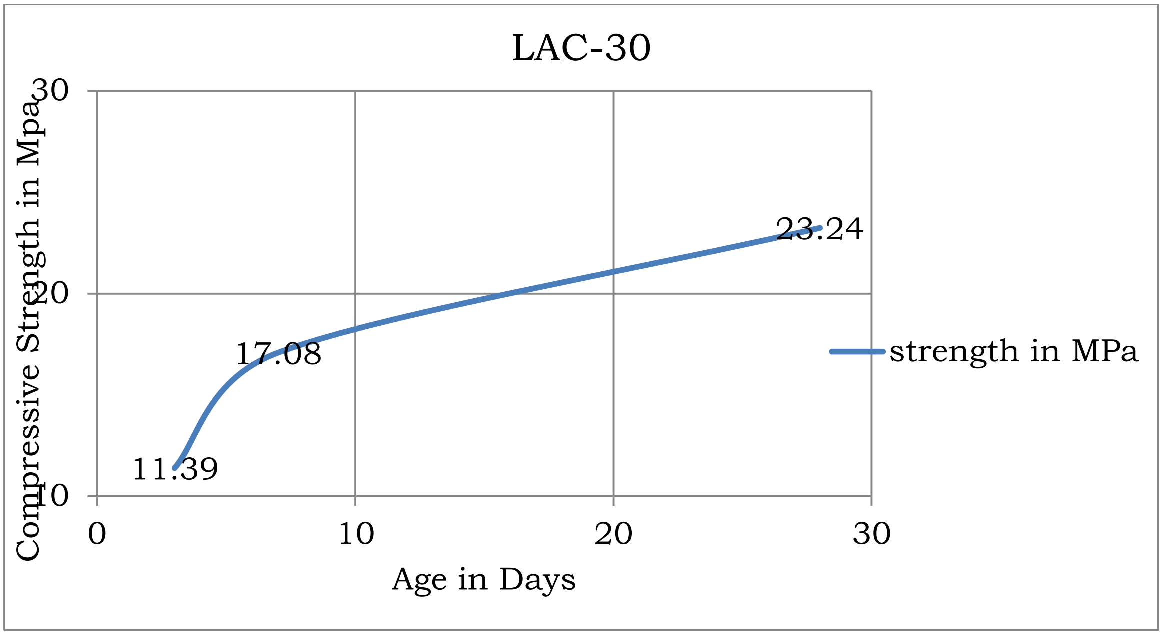

Fig. 5.8 The rate of strength development of LAC-30

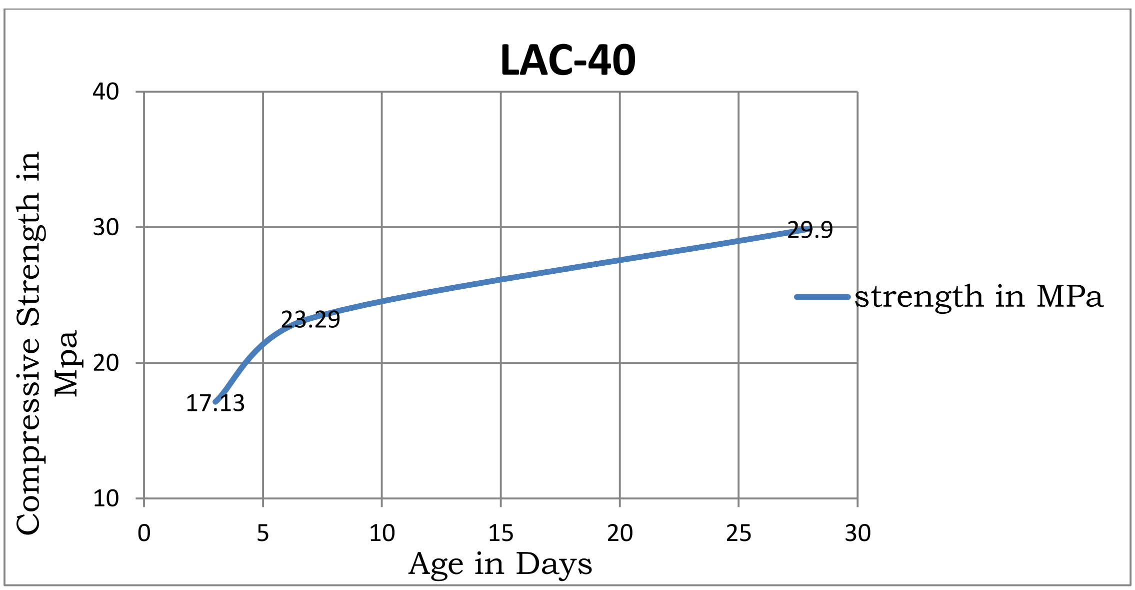

Fig. 5.9 The rate of strength development of LAC-40

5.2.3 Mix MSC

These mixes were made with sands from Meki and coarse aggregate from Sululta. The mean compressive strength of these mixes tested and cured at the age of 3, 7 and 28 days are shown in table 5.7.

Table 5.7 The mean compressive strength of MSC mix

	Mean Compressive Strength (Mpa)			Slump (mm)	Target Mean strength (MPa)	Characteristic strength (MPa)
Test age in days	3	7	28			
MSC-25	14.3	17.9	22.4	12	38	25
MSC-30	19.9	19.6	32	15	43	30
MSC-40	36.7	41.3	52.5	0	53	40

As we can see from the above table, these groups of mixes also fail to achieve target mean strengths except MSC-40 which achieves target mean strength and may need further investigation even if better than other groups.

5.2.3.1 Rate of Strength Development

Table 5.6 shows the percentage of 28th day strength attends at 3rd and 7th day.

Table 5.8 The ratio of 3 and 7 days with 28 days of mix MSC

Mix	3 days strength	7 days strength	28 days strength	ratio 3/28 days	ratio 7/28 days
MSC-25	14.3	17.9	22.4	64.0	80.0
MSC-30	19.9	22.6	32.0	62.3	70.5
MSC-40	36.7	41.3	52.5	69.9	78.8
Mean				**65.4**	**76.4**

From the above table we can see that the concrete test specimens gain about 65% of 28th day strength at 3rd day and about 76% of 28th day strength at 7th day.

The following figures show the rate of strength development graphically for mix MSC.

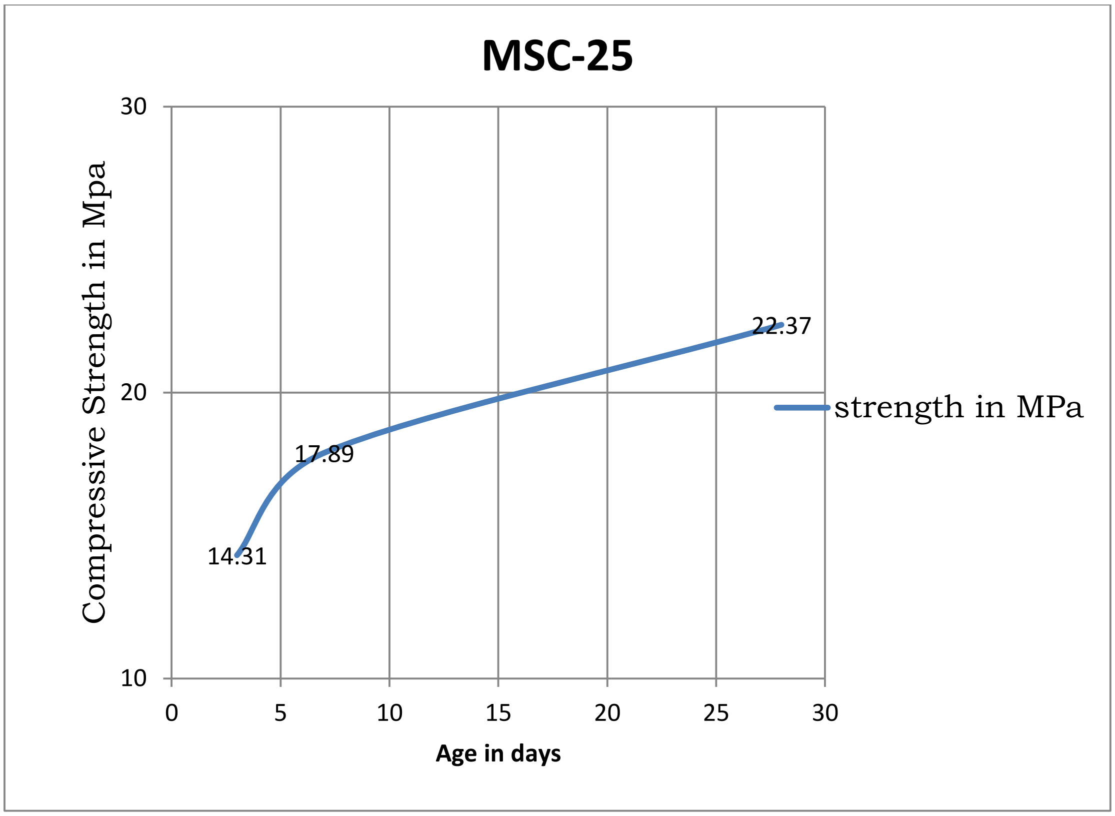

Fig. 5.10 The rate of strength development of MSC-25

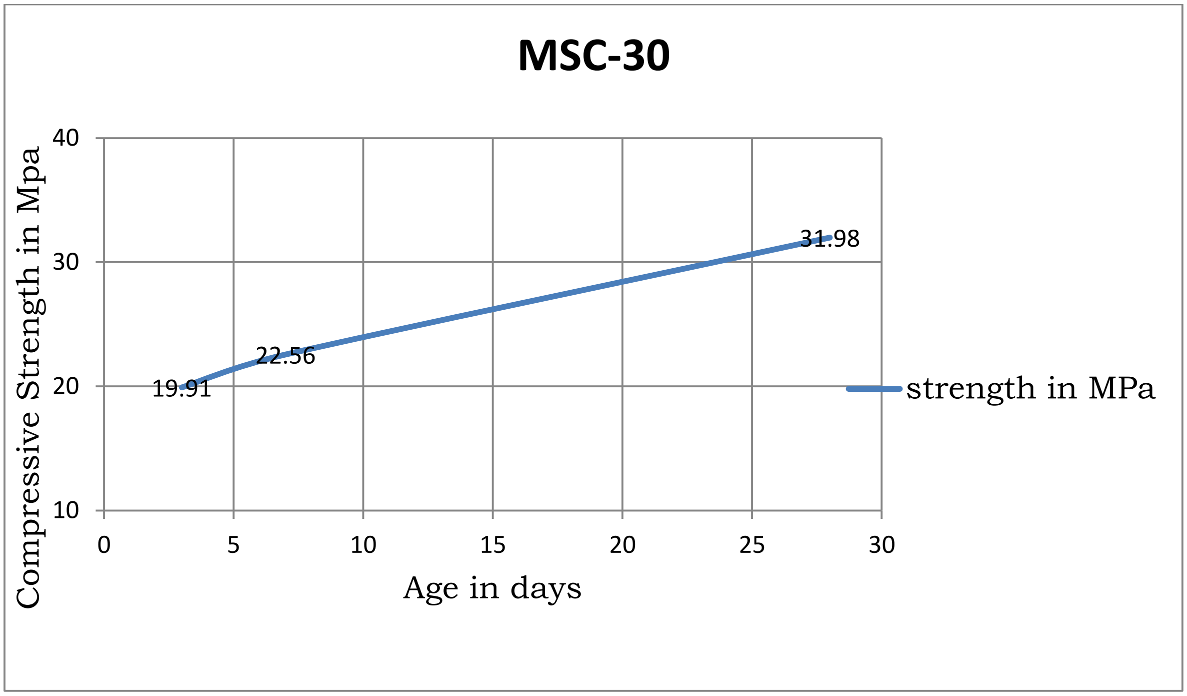

Fig. 5.11 The rate of strength development of MSC-30

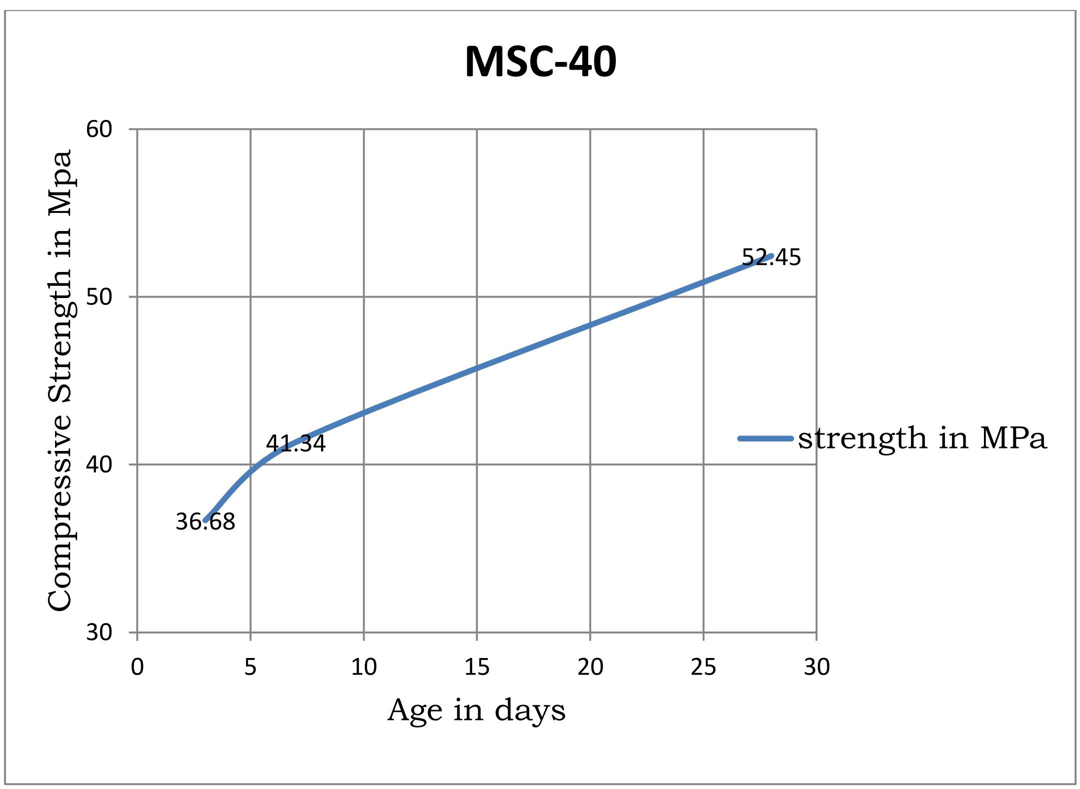

Fig. 5.12 The rate of strength development of MSC-40

CHAPTER SIX

6.1 Comparison of mixes with nonstandard Aggregate against control mix

The comparison of other mixes with control mixes indicate in table 6.1.

Table 6.1 Comparison of other mixes with control mix

Mixes	**control**			**LAC**			**MDC**			**MSC**		
Age of test	3	7	28	3	7	28	3	7	28	3	7	28
C-25	21.3	28.5	37.8	10.8	16.5	21.0	13.0	21.4	29.4	14.3	17.9	22.4
C-30	26.0	33.3	42.2	11.4	17.1	23.2	18.3	29.1	35.1	19.9	19.6	32.0
C-40	34.8	44.9	57.5	17.1	23.3	29.9	20.2	28.3	37.5	36.7	41.3	52.5

The strength difference between control mix and other mixes at 3rd, 7th and 28th days with percentage decrease is presented in tables 6.2, 6.3, and 6.4.

Table 6.2 The comparison 28th day strength between control mix and LAC mix

Concrete class	28th day comp. Strength		Difference (MPa)	% decrease
	Control mix	LAC mix		
C-25	37.8	21.0	16.8	44.4
C-30	42.2	23.2	18.9	44.9
C-40	57.5	29.9	27.6	48.00

Table 6.3 The comparison of 7th day strength between control mix and LAC mix

Concrete class	7th day comp. Strength		Difference (MPa)	% decrease
	Control mix	LAC mix		
C-25	28.5	16.5	12.1	42.3
C-30	33.3	17.1	16.2	48.7
C-40	44.9	23.3	21.6	48.2

Table 6.4 The comparison of 3th day strength between control mix and LAC mix

Concrete class	3th day comp. Strength		Difference (MPa)	% decrease
	Control mix	LAC mix		
C-25	21.3	10.8	10.6	49.6
C-30	26.0	11.4	14.6	56.2
C-40	34.8	17.1	17.7	50.8

As we can see from the above tables mix LAC that is mix made by using fine aggregate from Langano and coarse aggregate from Akaki directly, does not achieve the required strength. All mixes for all concrete class are below the control mix. The percentage decrease in strength at 3rd day is 49.6, 56.23 and 50.75 for C-25, C-30 and C-40 respectively. The percentage decrease in strength at 7th day is 42.3, 48.71 and 48.15 for C-25, C-30 and C-40 respectively. The percentage decrease in strength at 28th day is 44.42, 44.86 and 48.00 for C-25, C-30 and C-40 respectively.

In general we lose from 42.3-56.23% of compressive strength because of nonstandard aggregate irrespective of the same cement type, cement content and water cement ratio. The fine aggregate of these mixes have silt content of 17% and fineness modulus of 1.5.

This indicates that to standardize, the sand have to be washed and have to be blended with coarser sand. The high silt content interferes with bond formation between cement paste and coarse aggregate then reduce strength of concrete. The gradation of coarse aggregate of these mixes does not satisfy Ethiopian standard and this in turns affect the packing density of concrete.

Table 6.5 The comparison of 3rd day strength between control mix and MDC mix

Concrete class	3th day comp. Strength		Difference (MPa)	% decrease
	Control mix	MDC mix		
C-25	21.3	13.0	8.4	39.3
C-30	26.0	18.3	7.7	29.7
C-40	34.8	20.2	14.6	42.0

Table 6.6 The comparison of 7th day strength between control mix and MDC mix

Concrete class	7th day comp. Strength		Difference (MPa)	% decrease
	Control mix	MDC mix		
C-25	28.51	21.38	7.13	25.01
C-30	33.3	29.08	4.22	12.67
C-40	44.92	28.29	16.63	37.02

Table 6.7 The comparison of 28th day strength between control mix and MDC mix

Concrete class	28th day comp. Strength		Difference (MPa)	% decrease
	Control mix	MDC mix		
C-25	37.8	29.4	8.4	22.2
C-30	42.2	35.1	7.1	16.8
C-40	57.5	37.5	20.0	34.8

Again we can see from the above tables mix MDC that is mix made by using fine aggregate from Mojo and coarse aggregate from Dukem directly, does not achieve the required strength. All mixes for all concrete class are below the control mix. The percentage decrease in strength at 3rd day is 39.3, 29.1and 42.00 for C-25, C-30 and C-40 respectively. The percentage decrease in strength at 7th day is 25.00, 12.67 and 37.00 for C-25, C-30 and C-40 respectively. The percentage decrease in strength at 28th day is 22.15, 16.80 and 34.77 for C-25, C-30 and C-40 respectively. From this group also we lose from 12.67-42% of compressive strength because of nonstandard aggregate irrespective of the same cement type, cement content and water cement ratio. The fine aggregate of these mixes have silt content of 20% and fineness modulus of 3.3, which is higher than the recommendation. Therefore this aggregate is coarser with high silt content.

We have to wash and blend with finer sand to standardize the aggregate. The high silt content interferes with bond formation between cement paste and coarse aggregate then reduce strength of concrete. The gradation of coarse aggregate of these mixes does not satisfy Ethiopian standard and this in turns affect the packing density of concrete.

Table 6.8 The comparison of 3rd day strength between control mix and MSC mix

Concrete class	3th day comp. Strength		Difference(MPa)	% decrease
	Control mix	MSC mix		
C-25	21.3	14.3	7.0	32.9
C-30	26.0	19.9	6.1	23.5
C-40	34.8	26.7	8.1	23.3

Table 6.9 The comparison of 7th day strength between control mix and MSC mix

Concrete class	7th day comp. Strength		Difference (MPa)	% decrease
	Control mix	MSC mix		
C-25	28.5	17.9	10.6	37.3
C-30	33.3	19.6	13.7	41.1
C-40	44.9	41.4	3.6	8.0

Table 6.10 The comparison of 28th day strength between control mix and MSC mix

Concrete class	28th day comp. Strength		Difference (MPa)	% decrease
	Control mix	MSC mix		
C-25	37.8	22.4	15.4	40.7
C-30	42.2	32.0	10.2	24.1
C-40	57.5	52.5	5.1	8.8

Again we can see from the above tables mix MSC that is mix made by using fine aggregate from Meki and coarse aggregate from Sululita directly, does not achieve the required strength. All mixes for all concrete class are below the control mix.

The percentage decrease in strength at 3rd day is 32.91, 23.48 and 23.29 for C-25, C-30 and C-40 respectively. The percentage decrease in strength at 7th day is 37.25, 41.14 and 7.97 for C-25, C-30 and C-40 respectively. The percentage decrease in strength at 28th day is 40.74, 24.13 and 8.78 for C-25, C-30 and C-40 respectively. From this group also we lose from 7.97 -40.74% of compressive strength because of nonstandard aggregate irrespective of the same cement type, cement content and water cement ratio. The difference is varied in this group because the strength of C-40 approached the target mean strength. The fine aggregate of these mixes have silt content of 16% and fineness modulus of 3.2, which is somehow coarser. Therefore this aggregate is coarser with high silt content. We have to wash and blend with finer sand to standardize the aggregate. The high silt content interferes with bond formation between cement paste and coarse aggregate then reduce strength of concrete. The gradation of coarse aggregate indicate that some particle sizes are miss and this may resulted in voids in concrete and reduce packing density and then strength and durability of concrete.

CHAPTER SEVEN

Cost Analysis of Aggregate Standardization

7.1 General

To standardize aggregate, we have to wash fine aggregate to reduce silt content, blend to satisfy grading requirement and blend coarse aggregate to satisfy grading requirement. All these activities are labor intensive and it is possible to do in Ethiopia, because we can get daily laborer easily.

Most contractors in Ethiopia tried to achieve the specified compressive strength by using high cement content even for low strength concrete rather than standardizing the aggregate and following the correct concrete mix design procedure. As the same time consultants limit minimum cement content conservatively and this is too much for the required strength. This trend can cause financial and technical problem in our construction industry.

Since cement is the most expensive constituent of concrete, adding too much cement to concrete is increasing project cost and as the same time increase cements demand and cement cost. On the other hand when we increase cement paste to the concrete, it can cause durability problem like drying shrinkage.

7.2 Cost Break Down

The cost of unskilled labor in Ethiopia now is on average 50 birr per day and assuming 8 working hours, it becomes 6.25 birr per hour. By assuming conservatively one laborer can wash up to 1m^3 of sand per hour. To analyze the cost for one meter cube of concrete, by taking C-30 of my control mix ,which I used 555kg/m^3 of sand and 280kg/m^3 of cement and the bulk specific gravity of sand is 2.5.

Then the absolute volume equivalent of 555kg of sand is $\frac{555}{1000\times2.5}$ =0.222m^3.

The labor cost to wash the sand for 1m^3 concrete is 0.2222× 6.25 =1.40 birr. By assuming ½m^3 of water is needed to wash 1m^3 of sand and the cost of water is 5 birr per 1m^3 and we need 0.111m^3 of water to wash 0.222m^3 of sand. Therefore cost of water for 1m^3 concrete is 5× .111=0.56 birr. Therefore it costs about **1.96** birr to wash sand for 1m^3 of concrete. Other cost of standardization like blending is similar with traditional way of concrete production and I didn't consider that. I have not talked with the suppliers considering the cost of production of sand. In most case contractors use 360kg/m^3 up to 400kg/m^3 of cement to produce C-30 concrete. On average I reduced about 100kg of cement per 1m^3 of concrete for C-30.This means I saved about 230 birr per m^3 of concrete in the laboratory.

This indicates that we can reduce the cost of concrete production on site also, even if not like within the laboratory.

CHAPTER EIGHT

Conclusions and Recommendations

8.1 Conclusions

Based on the laboratory test results a single quarry didn't satisfy Ethiopian standard requirement regarding silt content, gradation, fineness modulus etc and the following conclusion can be drawn.

1. Based on my observation to different sites, aggregate production method in Ethiopia is too back ward and does not support with professional personals. The accesses road to major quarry sites is deteriorated and it is difficult to get access by truck especially during rainy season.
2. The silt content of natural sand from river bed is too high to satisfy Ethiopian standard and other literature recommendation. It is possible to satisfy Ethiopian standards and other recommendation by washing the fine aggregate and blending different sands from different sources.
3. It is possible to make concrete on site easily with 280kg/m3, 300kg/m3 and 400kg/m3 for C-25, C-30 and C-40 respectively, if aggregate is standardized and mix design is done correctly.
4. Aggregate quality has great effect on compressive strength of concrete. By keeping constant other things and changing aggregate quality up to 48% of strength reduction was observed during carry out this research work.
5. In Ethiopian construction industry necessary attention has not been given for aggregate quality, handling and standardization. The trend in our construction industry attempts to produce specified concrete by increasing cement content, which is uneconomical. Aggregate is purchased from trucks and nobody worries about standardization.

6. In this research I saved about 230 birr per m^3 of concrete and as the same time produced good quality concrete by standardizing aggregate. In general aggregate standardization in Ethiopian construction industry is important to produce good quality concrete with reasonable price.

8.2 Recommendations

1. Since aggregate is limited resource we have to use it wisely by standardizing and categorizing our aggregate for the specified work. High strength concrete production is possible by using standardized aggregate and following the literature recommendation during proportioning the mix.
2. The number of high rising building is increasing in Addis Ababa and it is difficult to get space to stock concrete making materials on sites. There for it is recommended to focus on ready mix concrete production by standardizing our aggregate. Standardization is important for ready mix plant to produce uniform quality of concrete.
3. Government officials, professional association, practitioners and Universities have to work together to prepare guide line and necessary documents, update standards, enforce regulations, promote ready mix concrete production, improve the way of aggregate production and push to produce high strength concrete in Ethiopian construction industry.

4. In most of developed countries concrete is used for road pavements, in our case asphalt concrete is used for pavements and since asphalt is imported from abroad, its cost is increasing from time to time. Therefore the option of using cement concrete for pavements needs to be followed. Therefore as demand of concrete will increase in our country, necessary attention should be given for aggregate standardization.

5. In this research characteristic strength was attend at 7th day and it is possible to remove formwork after seven days and contractors can save their time and reduce cost of formwork.

6. In this research I did not use additives; since additives increase workability and strength it is recommended.

7. The option for crushed sand in aggregate standardization is recommended

8. The title for future research can be 'The Effect of Aggregate Gradation on Compressive Strength of Concrete'.

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APPENDIX

Cube Compressive Test Results (Raw Data)
