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EVALUATION OF SUITABILITY OF COARSE AGGREGATES FOR CONCRETE IN MEKELLE AREA, ETHIOPIA

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DECLARATION

I declare this is my original work and this thesis do not incorporate without acknowledgment any material previously submitted for a Degree in any other university or institute of higher learning.

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ABSTRACT

Aggregates constitute the bulk of the total volume of concrete and hence influence the strength of concrete to great extent. It is essential that aggregates used in construction purposes are strong and durable. Construction aggregate is crushed rock material used in concrete which make up most of engineering works. The main objective of this research was to assess the quality of coarse aggregates and evaluate their suitability for concrete of the limestone rock material sources in Mekelle area, northern Ethiopia. As there was no previous studies on the quality of aggregates in Mekelle this research was designed to better understand the properties and qualities of aggregates used in the project area. The study involved assessment of the different sources of rocks for concrete aggregates, collecting representative samples and laboratory analysis. The study mainly focused on 20-30km radius from Mekelle city and 10 representative quarry sites were analyzed. The properties used to assess the suitability of rocks as aggregate materials include tests like: Los Angeles Abrasion (LAA), Aggregate crushed value (ACV), sieve analysis, flakiness index, moisture content, unit weight, specific gravity and water absorption. Results of the analysis show that the ACV of aggregate varies between 5.9% and 19.7%, the LAA value ranges from 24.94% to 33.62%, the water absorption ranges from 0.34% to 0.76%, and the moisture content falls below one percent. All the test result shows that the aggregate fulfill the ASTM standard requirement except moisture content is below the minimum ASTM requirement. This research has given a better understanding of the quality and suitability of rock material used for concrete in Mekelle area, Ethiopia.

Key words: coarse aggregate, concrete

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ACRONYOMS

ACV	Aggregate Crushing Value
a.s.l	above sea level
ASTM	American Society for Testing and Materials
BGS	British Geological Survey
BS	British Standards
C	Coarse Side
DM	Design Memorandum
ERA	Ethiopia Road Authority
F	Fine Side
GIS	Geographic Information System
GPS	Global Positioning System
LAA	Los Angeles Abrasion
MTM	Michigan Test Method
NMA	National Meteorological Agency
PED	Pre construction Engineering and Design
TRL	Transport Research Laboratory
UEPG	European Aggregates Association
WAV	Water Absorption Values

1. Introduction

1.1 Background of the study

Natural sand, gravel and various sizes of crushed stones produced by a crushing process are called aggregates. Aggregates are used in many areas as construction materials. Aggregates are used in the construction sector in buildings and infrastructures for concrete, light weight concrete and plaster material (Karakas, 2013).

Aggregates are granular materials used in construction for their granularity. The most common natural aggregates of mineral origin are sand, gravel and crushed rock. They are produced from natural sources, quarries and gravel pits and in some countries from sea-dredged materials (Miliutenko, 2009).

Aggregate is a mixture of materials in the concrete mix. It is a mixture of basic material in which the content consists of three fourths of the concrete mix. In addition to the concrete mix materials are composed of water, cement and additives, if necessary. Because the total quantity of aggregate in a concrete mixture is large, the strength and durability of a concrete depends on the characteristics of aggregate itself (Jeffery, 2010).

Concrete is a versatile and most popular construction material in the world. Aggregates are known to be particles of rock or equivalent which, when brought together in a bound or unbound condition, form part or whole of an engineering or building structure. Aggregates, both fine and coarse, take about 65-75% by volume of concrete and are important ingredients in concrete production. The quality of concrete produced is much influenced by the properties of aggregate. The dominant rock for coarse aggregate production in Ethiopia is generally basalt while ignimbrite is most commonly used for masonry stone. On the other hand the majority of sand is collected from river beds (Abebe, 2005).

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. Normal unit weight aggregate is generally produced in Ethiopia by crushing parent rocks using mechanical crushers or traditional methods (Abebe, 2005).

In Mekelle area there are four lithologic rock units, dolerite, sandstone, limestone-marl-shale intercalation and bedded limestone. Each rock units are subdivided further based on engineering geological characteristics, a parameter that dominantly controls the engineering geological properties (Tenalem, 1998). The main focus of this research is, therefore, to review sources and production of aggregates, assess the suitability of available rocks for concrete production, and suggest better ways of aggregate production and usage for optimum concrete production in the study area.

1.2 Statement of the Problem

Aggregates are the backbone of a concrete because the largest parts of the concrete are the aggregate material. In Mekelle area there are many quarry sites used for the production of aggregates for concrete. Most of these quarry sites have been under operation for many years and are used traditionally. The qualities of these aggregates were not properly evaluated for their suitability for concrete though used traditionally. Aggregates constitute the bulk of the total volume of concrete and hence they influence the strength of concrete. Aggregate expansion can occur also from freezing of the aggregates in saturated conditions, concrete can produce cracking and loss of strength (woods, 1988). Aggregates are commonly contaminated by silt, clay, mica, coal, humus, wood fragments, other organic matter, chemical salts, and surface coating and encrustations (Woods, 1988).

Such contaminating substances in concrete act in a variety of ways to cause unsoundness, decreased strength and durability, their presence complicates processing and mixing operations. They may increase the water requirement, may cause the concrete to be physically weak or susceptible to breakdown by weathering (Woods, 1988). The shape and surface texture of the aggregate particles and their grading are important factors influencing the workability and strength of concrete (BGS, 2013).

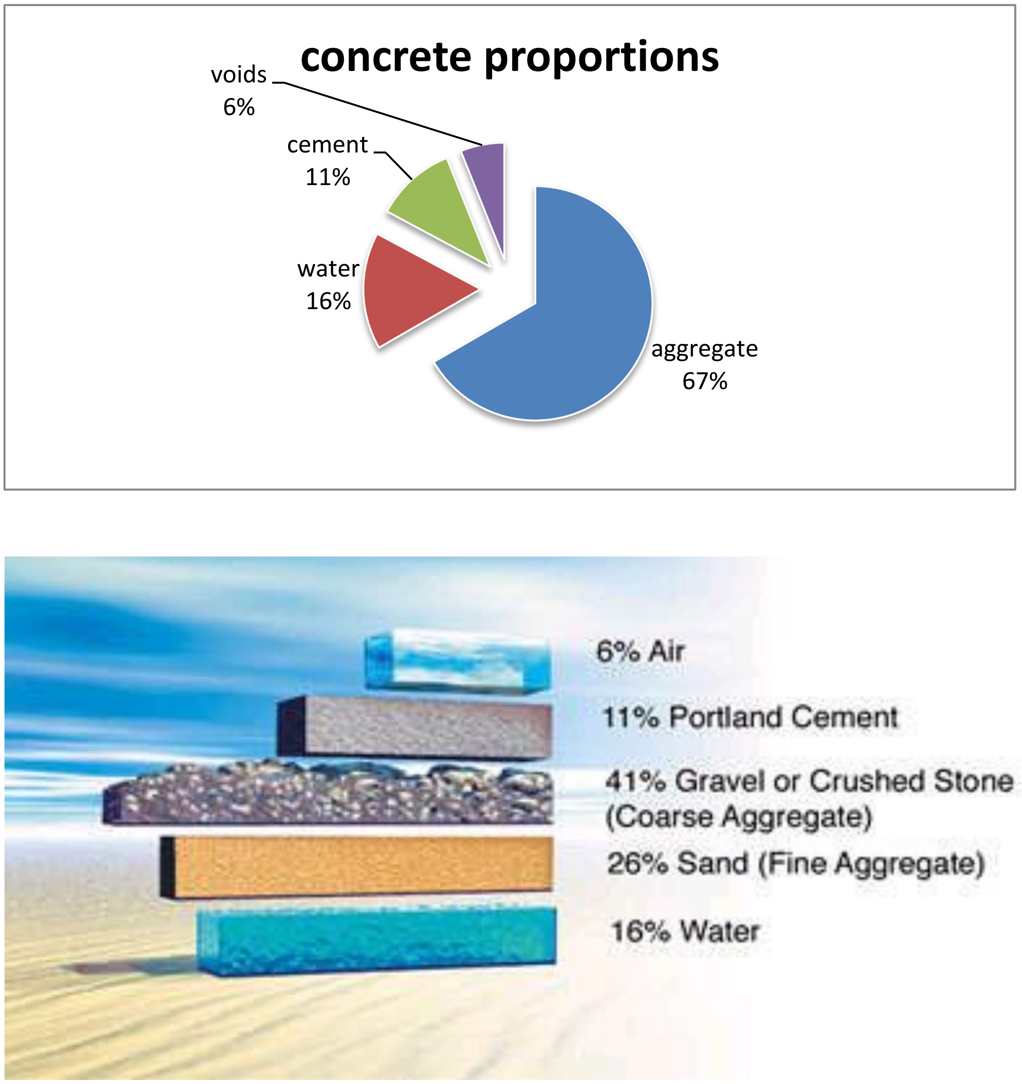

Figure 1-1: Proportion of materials in concrete **(Awe, 2007)**

Proper evaluation of the quality of aggregates is therefore highly important and this research focuses on evaluating quality of aggregates of limestone origin commonly and traditionally used for concrete production in Mekelle area, Ethiopia.

1.3 Research Question

1. What is the major types of rock sources used for concrete aggregates in Mekelle area?
2. What is the suitability and quality of the aggregate for concrete comparing with ASTM standards?
3. What are the best recommended aggregate sources for use in concrete in Mekelle area?

1.4 Objective

1.4.1 General objective

The main objective of this research is to evaluate the properties of coarse aggregates used for concrete in Mekelle area, Ethiopia.

1.4.2 Specific objective

1. To determine the physical and mechanical properties of coarse aggregate sources commonly used in Mekelle area, Ethiopia.
2. To evaluate the quality and suitability of the coarse aggregates by comparing with ASTM standard requirement of aggregates for concrete.
3. To recommend the best quality aggregate sources used for concrete in Mekelle area.

1.5 Significance of study

This study is significant for the following reasons

- ✓ It is the first research work to evaluate the quality of aggregates around Mekelle and this will help for better understanding of the quality of the materials.
- ✓ The study will have paramount importance to the government, community and to the contractors who are involved in construction using concrete.
- ✓ It can be used as one source of information for further research.

1.6 Scope of the study

This research focuses on evaluating major rock sources for aggregate in Mekelle area in terms of their suitability and quality for concrete use. For this purpose representative samples were collected from the different quarry sites around Mekelle area and different tests were carried out. Results of the analysis were compared with the ASTM standard requirements of aggregates for concrete use.

1.7 Limitation

The major limitations of this research were shortage of time and financial resources. As a result, the research has focused on ten representative quarry sites around Mekelle area. Despite these limitations maximum effort was made to produce quality data through proper field and laboratory analysis.

2 Literature Review

2.1 Introduction

The properties of concrete are directly related to those of its constituents and as such aggregate used in a concrete mix. The following chapters describe the definition of aggregates and identify the aggregate flow, what is important to understand when comparing the current systems of aggregate provision. A short overview about the modern situation of aggregate provision in the world and in the studied regions is also provided.

2.2 Definition and types of aggregate

Aggregate is one of the main ingredients producing concrete. It covers 75% of the total for any one concrete mix. The strength of the concrete produced is dependent on the properties of aggregates used (Jeffery, 2010). Aggregate is the most fundamental component of construction (Williamson, 2005). According to the Department of Transportation Michigan (2009) the material may be from natural sand and/or gravel deposits, quarried bedrock, slag from steel mills or copper refineries, debris from mining operations, or crushed Portland cement concrete.

- ***Natural Gravel Aggregates*** – These aggregates occur in natural, unconsolidated deposits of granular material which are derived from rock fragments such as boulders, cobbles, pebbles and granules and may be rounded, crushed or a combination of both. These deposits may be found either above or below the water table. Natural gravel aggregates consist predominantly of particles larger than the No. 4 sieve (4.75 mm).
- ***Crushed Stone Aggregates*** – These aggregates are derived from the crushing of quarried bedrock.

It should be noted that Natural Gravel Aggregates and Crushed Stone Aggregates are both included in the Standard Specifications for Construction under the definition of Natural Aggregates.

Crushed stone

The product resulting from the artificial crushing of rock, boulders, or large cobblestones, substantially all faces of which have resulted from the crushing operation (Langer, 1988).

- Sand:-Granular material passing the 3/8-inch (9.5-mm) sieve, almost entirely passing the No. 4 (4.75-mm) sieve, and predominantly retained on the No. 200 (75-µm) sieve that results from natural disintegration and abrasion of rock or processing of completely friable sandstone.
- Coarse aggregate:-Aggregate predominantly retained on the No. 4 (4.75-mm) sieve (composed mainly of gravel-size particles) (Langer, 1988).
- Fine aggregate:-Aggregate passing the 3/8-inch (9.5-mm) sieve, almost entirely passing the No. 4 (4.75-mm) sieve, and predominantly of sand-size particles) (Langer, 1988).

2.2.1 Rocks

The rock outcrops in Mekelle area are systematically characterized. There are four lithologic rock units: dolerite, sandstone, limestone-marl-shale intercalation, and bedded limestone. Each rock units are subdivided further based on engineering geological characteristics, a parameter that dominantly controls the engineering geological properties (Tenalem, 1998).

2.2.1.1 Dolerite

This rock unit shows variations in degree of jointing and weathering. Hence based on these parameters this lithologic rock unit is divided into engineering subgroups, closely spaced jointed dolerite and widely spaced jointed dolerite (Tenalem, 1998).

A. Closely Spaced Jointed Dolerite:

It is greenish gray and dark in color, medium to coarse grained and the grains are irregular in form, angular edges and rough to smooth surface. With minor vesicles (voids) and moderately to highly weathered, spheroidal weathering is typical even though directional weathering along joints and faults are present. The strength is moderately weak to moderately strong.

B. Widely Spaced Jointed Dolerite:

It is dark in colour, medium to coarse grained, irregular in grain form and sub angular edges and rough to smooth surface, with no vesicles and fresh to slightly weathered, and rarely spheroidal weathering. The material strength is strong to extremely strong. The joints are vertical to sub vertical, planar and relatively smooth, have strong to very strong wall strength.

- ✓ **Sandstone:**

It is reddish and light yellowish in colour, medium to coarse grained, and grains show irregular form, angular edges and rough to smooth surface. Degree of weathering is slight to moderate and slightly laterized. The intact rock strength ranges from 13.5 to 58 Mpa. Joint surface is planar and rough and its wall strength is weak to strong. Joint aperture is variable, narrow to moderately wide (Tenalem, 1998).

2.2.1.2 Limestone-Marl-Shale Intercalation

From engineering geological point of view these layers have different properties.

A. Limestone:

This intercalation layer is black and in places yellowish in colour, crystalline, bedded and slightly weathered. Intact strength ranges from 17 to 125 Mpa. Joint spacing ranges from 0.5 to 1 m. Joint surfaces are planar and smooth and its wall strength is moderately strong to strong. Joint opening varies from less than 0.2 to 4 cm. Some joints are filled with calcite, dry and slight weathering features are common along joint walls.

B. Shale:

This intercalation layer is light yellowish in colour, bedded, fine to very fine grained and moderately weathered, fissile, but in places it is massive. Its strength is generally weak to moderately strong (8.8 to 55 Mpa). It is affected by vertical and horizontal joints. The spacing of the vertical and sub-vertical joints ranges from 10 to 100cm. Joint surfaces are planar and smooth; its wall strength is weak and tight. The joints are dry and moderately to highly weathered.

C. Marl:

It is bedded yellowish to grayish in colour, fine grained, and moderately weathered. Its intact strength ranges from weak to strong; a value up to 26 MPa is measured. Two sets of joints are common in this layer, which are vertical to sub vertical, with a spacing of 0.10 to 1.50 m, separation of 0.2 to 1.50cm. Other third set is a horizontal joint parallel to bedding plane, narrow and closely spaced (Tenalem, 1998).

2.2.1.3 Bedded Limestone

This rock unit shows slight variation due to intensity of fracturing in limited areas (south of Mekele and Messobo area). Yellow and black colors are typical, crystalline, well bedded and fresh to slightly weathered. Its material strength ranges from 17 to 225 Mpa. It forms steep cliffs and water falls. Joint spacing and separation ranges from 0.4 to 2 m and 0.1 to 3 cm respectively (Tenalem, 1998).

2.2.2 Strength of aggregate

The strength of coarse aggregates could have a measurable effect on concrete strength and the properties of a coarse aggregate depend on the properties of the basic rock, the crushing process and the subsequent treatment of the aggregate in terms of separation into fractions, segregation and contamination (Day, 2009).

Most rocks have adequate basic strength for use in most grades of concrete. Even manufactured and naturally occurring lightweight aggregates, which can be readily crushed under a shoe heel, are used to make concrete with an average strength up to 40 MPa (although they do require a higher cement content than dense aggregates). Exceptions to this are some sandstones, shales and limestones (although other limestones are very strong and amongst the best aggregates for many purposes). A different type of exception is that use involving wear and impact resistance can require a more stringent selection of rock type (Day, 2009).

Generally however the stability of a coarse aggregate is more important than its strength. Rock which exhibits moisture movement (swelling and shrinking) will add to concrete shrinkage. Again sandstone tends to be amongst the offenders, but some basalts will also display moisture movement and some conglomerates may be quite strong mechanically and yet literally fall part under a few cycles of wetting and drying (Day, 2009).

2.2.3 Sampling

According to the Department of Transportation Michigan(2009) the basic procedure has been summarized in the following paragraphs. To obtain a sample increment of an aggregate product using a scoop or square point shovel: (1) remove the surface area of the material to be sampled; (2) dig down into the material approximately one foot or the thickness of the material has been placed on the grade.

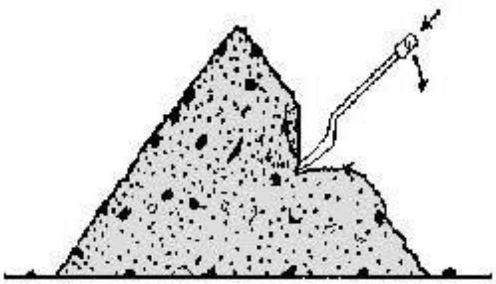

Figure 2-1: Shovel Taking Sample

As illustrated in Figure 2.1, insert the shovel or scoop at the base of the hole. Push the shovel into the material and pull it upward to fill the shovel or scoop. Empty it into the sample container. The three areas back-bladed are arranged from the fine to coarse sides of the stockpile.

2.2.4 Aggregates

2.2.4.1 General

One of the most important factors in establishing the quality and economy of concrete is determination of the quality and quantity of aggregates available to the project. Preliminary investigation to determine potential aggregate sources should be performed during the feasibility phase, and detailed investigations should be performed during the Pre-construction engineering design (PED). The aggregate qualities and their respective limits must be documented in a DM (design memorandum) and will be used in preparation of specifications for the project (Brown, 1994).

(1) Sources of aggregate (Government or commercial). The decision to investigate a government source or only commercial sources is based on appraisal of the economic feasibility of an onsite source when compared to commercial sources that contain aggregate of adequate quality and that are within economic hauling distance of the project. If a government source is investigated, it will be owned or controlled by the government and will be made available to the contractor for the production of aggregate.

(2) Minor structures. For minor structural projects, the source of aggregate need not be listed since a quality requirement is specified by reference to ASTM C 33 (Brown, 1994).

2.2.4.2 Site investigation for aggregate sources

(1) According to Brown, the general objectives of the site investigation are to determine the required aggregate quality, quantity and proximity of aggregate available to the project. The required aggregate quality is stated in the appropriate Design memorandum as a list of aggregate properties and their respective acceptance test limits. Preliminary investigations to determine the potential sources and the required aggregate quality shall be performed during the feasibility phase and the results documented in the engineering appendix to the feasibility report. (Brown, 1994).

(2) Service records. Service records can be of great value in establishing the quality of aggregate where reliable information on the materials used to produce the in situ concrete, construction procedures, and job control are available.

(3) Field exploration and sampling of undeveloped sources. In undeveloped potential quarries, field explorations should consist of a general pattern of core borings arranged to reveal the characteristic variations and quality of material within the deposit. Representative portions of the cores should be logged in detail and should be selected for laboratory testing. Additional information on the exploration of undeveloped quarry sources is available. In the case of undeveloped alluvial deposits, explorations should consist of a sufficient number of test pits, trenches, and holes to indicate characteristic variations in quality and quantity of material in the deposit.

(4) Field exploration and sampling of developed sources. In commercial sources, a thorough geologic evaluation should be made of the deposit from which the raw materials

are being obtained to determine the extent of the deposit and whether or not material remaining in the deposit may be expected to be essentially the same as that recovered from the source at the time of the examinations. In quarries and mines, working faces should be examined, logged, sampled, photographed, and when considered necessary, mapped (Brown, 1994).

2.3 Properties of Aggregate

According to Abebe (2005), the physical properties like specific gravity, porosity, thermal behavior, and the chemical properties of an aggregate are attributed to the parent material. The shape, size and surface texture which are essential for concrete workability and bond characteristics between the aggregate and cement paste are, however, attributes of the mode of production. It is, therefore, essential to understand the mechanical, physical and chemical properties of aggregate and its modes of production in an effort to produce the required quality of concrete at a minimum price.

The effect of these properties on concrete strength is investigated through the use of different combinations of fine and coarse aggregates from sand, gravel, quarry crushed rock (Awe, 2007)

2.3.1 Aggregate Size, Shape and Surface Texture

According to the literature the use of larger maximum size of aggregate affects the strength in several ways. First, since larger aggregates have less specific surface area and the aggregate–paste bond strength is less; aggregate fails along surfaces of aggregates resulting in reduced compressive strength of concrete. Therefore, it is the general consensus that smaller size aggregates should be used to produce higher strength concrete. Particle shape and surface texture influence the properties of freshly mixed concrete more than the properties of hardened concrete. Rough-textured, angular, and elongated particles require more water to produce workable concrete than smooth, rounded and compact aggregate. Consequently, the cement content must also be increased to maintain the water-cement ratio. Generally, flat and elongated particles are avoided or are limited to about 15 percent by weight of the total aggregate (Abebe, 2005).

Properties of aggregate in bulk that are influenced by their shape and surface texture (Stroeven, 2006).

2.3.2 Mechanical Properties

(Awe, 2007) According to Awe the properties of aggregates that affect concrete strength are size, surface texture, types etc. The effect of these properties on concrete strength is investigated through the use of different combinations of fine and coarse aggregates from sand, gravel, quarry dust and granite.

Both the shape and surface texture of aggregates influence the strength of concrete, especially so for high strength concrete. Generally, flexural strength is more affected than compressive strength. It is generally understand that the compressive strength of concrete cannot significantly exceed that of the major part of the aggregate contained therein, although it is not easy to determine the crushing strength of the aggregate itself. The aggregate crushing value (ACV) test is prescribed by different standards, and is a useful guide when dealing with aggregates of unknown performance Toughness can be defined as the resistance of aggregate to fai1ure by impact, and it is usual to determine the aggregate impact value of bu1k aggregate based on ASTM standard (Abebe, 2005).

The Los Angeles Abrasion test combines the processes of attrition and abrasion, and gives results which show a good correlation not only with the actual wear of the aggregate in concrete but also with the compressive and flexural strength of concrete when made with the same aggregate.

2.3.3 Physical Properties

According to Abebe the physical properties of aggregates include specific gravity, porosity, absorption capacity, moisture content, unsoundness due to volume changes and thermal properties and need a close scrutiny.

2.4 Concreting aggregate

For concrete some of the most important parameters are particle-size distribution, resistance to impact, volume stability/frost susceptibility, relative density and water absorption, as well as the absence of deleterious constituents, such as mudstone or chalk. The properties of the aggregate affect concrete characteristics such as density, strength, durability, thermal conductivity and shrinkage. The shape and surface texture of the aggregate particles and their grading are important factors influencing the workability and strength of concrete. The aggregates must be strong enough not to reduce the bulk shear strength of the concrete, and they should have a low porosity. Concrete aggregate should also be clean (with limits on clay, silt and dust content) and not contain impurities (e.g. mudstone, pyrite, coal, mica) that would affect the strength or durability of the concrete (BGS, 2013).

2.4.1 Effects of Aggregates on Concrete

The aggregate (both fine and coarse) makes up about 80% of the volume of the concrete.

Grading and size of aggregate both affect the amount of water needed to obtain workability. There should be a continuum in the size of grains from small to large:- smaller grains fill the interstices between the larger grains, keeping the amount of cement paste to a minimum. The improved workability means that less water is required and a stronger concrete is produced. This in turn limits the amount of shrinkage and deformation (Peter, 2008).

Aggregate characteristics that can be controlled include grading, moisture content, removal of abnormally light particles, and to some degree, particle shape. Economic factors usually determine the degree to which processing can be directed to produce the best compromise between desirable aggregate properties and economy (Adams, 2001).

2.4.2 Basic processing of Aggregates

According to Adams (2001), processes typically employed to provide aggregate of satisfactory grading begin at the face of the quarry or pit. In the case of quarried ledge rock, finished product grading and cleanliness may be influenced by the effectiveness of the operations of stripping overburden, drilling, and blasting. In addition, the moisture content of the “shot rock” in the muck pile can have an effect on the balance of the processing operations. It is necessary to have a well-designed plant for efficient production of consistently graded concrete aggregates.

2.4.2.1 *Crushing*

In this phase of the processing of quarried ledge rock, the first operation is primary crushing. Primary crushers may be of the compression type (jaw or gyratory) or the impact type (single or double impeller). Feed size to primary crushers may be controlled to maximize output through the use of grizzly feeders, sloping heavy bars, or rails variably spaced such that quarry fines can be separated out and pieces too large for the crusher "scalped off." Further reduction is generally required to produce concrete aggregate. At some plants the largest particles may be separated for sale as rip rap, and in many plants the finer sizes from about 11/2 in. (38 mm) down are separated and stocked as a "crusher run" product for construction work. These later stage crushers are most often of the compression type (cone crushers) or, where the rock is not too abrasive, the impact type (single or double impeller, hammer mill, or cage mill). Where the deposits contain sound boulders or cobbles, the necessary operations are similar to those described above for ledge rock. Where the top size in the deposit is about 3 in. (75 mm) or less, the primary crushing stage is unnecessary. Some aggregate plants may regularly run two coarse aggregate production circuits—one for crushed and the other for uncrushed gravel. Production of aggregate generally requires crushing and screening of a nature similar to that required for quarried rock (Adams, 2001).

2.4.2.2 Screening

Once the raw materials, stone, gravel, or slag have been reduced to the desired overall size range, usually below 3 in. (75 mm), it is then necessary to separate them further into fine aggregate and coarse aggregate, usually two or more size ranges as described in ASTM C 33. This is most often accomplished by means of vibrating screens or perforated plates with appropriate square, round, or rectangular openings and in some cases by means of cylindrical revolving screens. The screening equipment operates best, producing the most consistently graded products, when fed at a uniform rate. Plant screens are never 100 percent efficient (they never accomplish completely clean separation of all particles small enough to pass the screen openings), but their efficiency is optimized by insuring uniformity of feed so that all particles have the opportunity to pass through the openings. The uniformity of the concrete depends on the uniformity of the constituent materials, the bulk of which are aggregates (Adams, 2001).

2.4.2.3 Washing

Processing of many aggregates requires washing to remove salt, clay, or other tenacious coatings that may adhere to the particles and interfere with the cement paste to aggregate bond. Washing is more often necessary for gravel aggregates from deposits that contain clays than for ledge rock or slag aggregates produced as described above. However, some sedimentary ledges are inter-bedded with clay or shale and do require vigorous washing to remove these materials. Some specifications may require a more restrictive limit on minus 75 μm (No. 200) material in coarse aggregate than permitted by ASTM C 33. Handling of a coarse aggregate will generally cause a slight increase in the fines content, making the extremely restrictive limits difficult to meet without rewashing (Adams, 2001).

2.4.3 Control of particle shape

According to literature the particle shape of crushed aggregates is largely dependent on the crushing equipment used. Experience has shown that equipment that produces acceptable particle shape with one type of rock will not necessarily produce acceptable shape with another type. Particle shape can often be improved by the insertion of an additional crusher in the line between the primary crusher and the final crusher. Crushers generally produce favorable particle shape when used in processing a wider variety of rock types than can be accommodated by impact crushers. Particle shape is a difficult property to define and specify. Coarse aggregate shape is sometimes specified in terms of allowable percentages by weight of flat or elongated particles, defined in terms of length, width, and thickness of a circumscribing rectangular prism. ASTM D 3398 established an index of particle shape and texture (Adams, 2001).

2.4.4 Handling of aggregates

The most careful control of the manufacture of aggregates at the plant can be negated quickly through abuse in handling, storage, loading out, transporting to the job site, and batching. Even with effective quality control at the processing plant there will always be a degree of variability between units of volume and within lots as well. To define and correct any excessive variability in the material as shipped, a statistically sound sampling program should be followed. Randomly selected batches or sub lots should be sampled according to ASTM D 75. Faulty or excessive handling of processed aggregate may result in one or all three principal problems that may affect the properties of concrete mixtures (Adams, 2001).

- The first is segregation, which destroys the grading uniformity.
- The second is contamination, or inadvertent inclusion of deleterious material.
- A third problem, lack of successful maintenance of uniform and stable moisture content in the aggregates as batched, further complicates the production of uniform concrete.

2.4.4.1 Environmental concerns

According to Admas (2001), some jurisdictions have strict environmental regulations for dust control. Care must be taken to satisfy these regulations; however, quality aggregates still must be produced. The dust collection equipment, designed to reduce pollution, removes some of the fine materials that are sometimes produced while processing aggregates. Some of this equipment will also reintroduce the collected dust back onto the material belt at the final drop location at a controlled rate. When this type of equipment is used, quality assurance testing must be performed after this point to maintain proper grading and cleanliness for the intended specifications.

3 Methodology and Materials

3.1 Description of Study Area

Mekelle is a city found in the Northern part of Ethiopia and is serving as the capital of Tigray national Regional State. Mekelle city is one of the seven zones of Tigray Region. It is located some 783 kilometers north of the capital Addis Ababa, at $13^{0}26'$ to $13^{0}36'$ North latitudes and $39^{0}25'$ to $39^{0}33'$ East longitudes with an average elevation of 2084 meters above mean sea level. The total area of the city by the year 2011 was about 135.21 km^2. Its municipality is believed to have been established in the early 1940s. The town is bounded by mountain ranges in the east and north (MAO, 2010).

Figure 3-1: Map of the of study area **(MAO, 2010)**

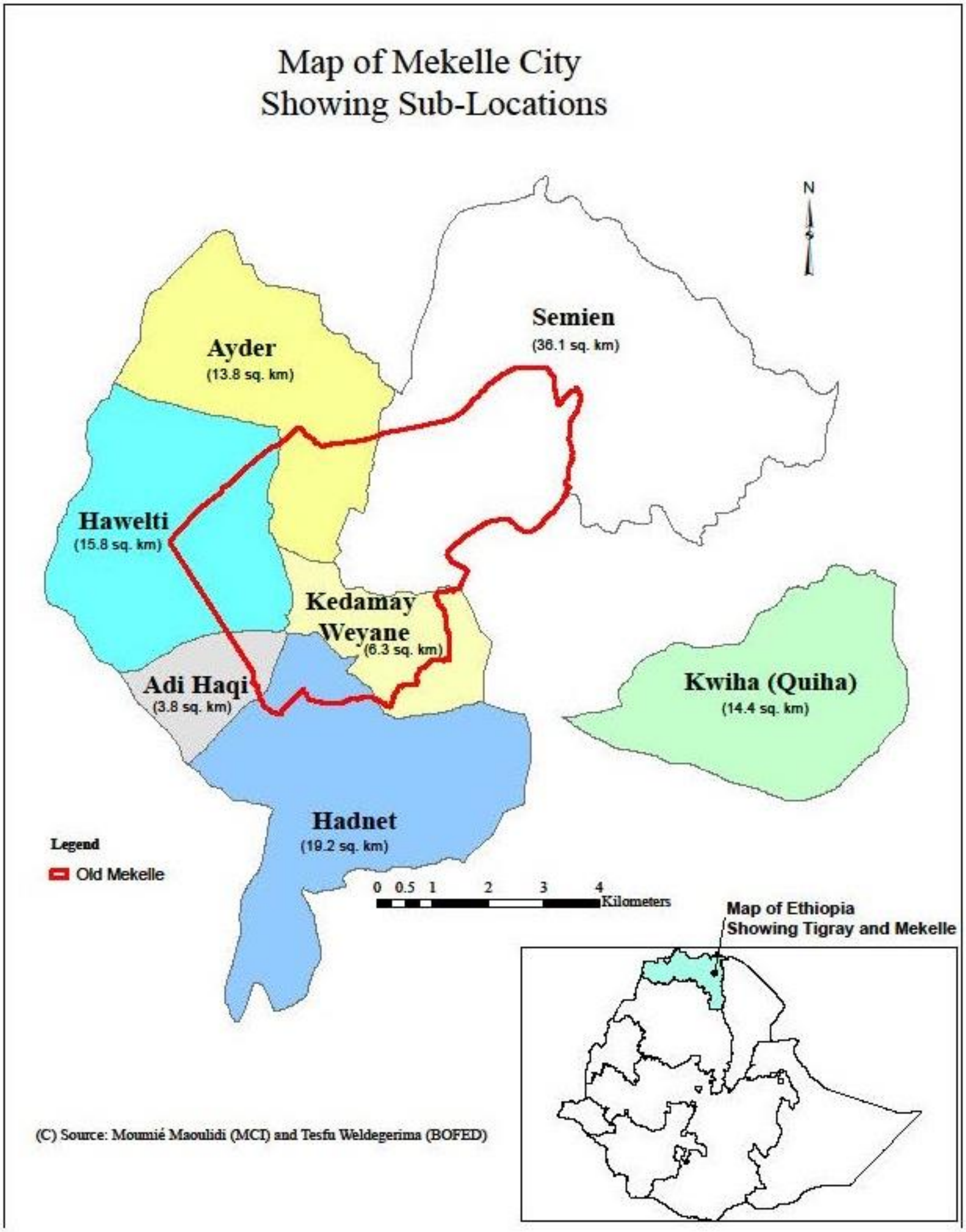

Figure 3-2: The specific sites (MAO, 2010)

3.1.1 Climate

3.1.1.1 Precipitation

Mekelle City exhibits distinct rainy and dry seasons. The average annual rainfall of the city reaches 663 mm. The City gets its maximum amount of rainfall during the summer season (June, July and August). Moreover, Mekelle City gets 74.69% of its total annual rainfall during the summer season. Likewise, August is the wettest while December is the driest months of Mekelle City (NMA, 2009)y.

3.1.1.2 Temperature

The overall average monthly minimum and average monthly maximum temperature of Mekelle City reaches 11.33 ^{0}C and 24.16 ^{0}C respectively. Therefore, the average annual temperature of the city is 17.75 ^{0}C and its annual range of temperature is 4.5^{0}C. Besides, winter season (December to February) is the coldest while spring season (March to May) is the warmest (NMA, 2009).

3.1.2 Description of the Study Area

The major quarries of aggregates for concrete in Mekelle area are summarized in Table 3.1, with a summary of the locations, the type of the rock material and their color (in fresh and weathered states).

Table 3-1: Location, rock type and color of the material sources for aggregates around Mekelle area, Ethiopia

Location				Description			
Site Name	**East**	**North**	**Elevation**	**Fresh color**	**weathered color**	**Rock type**	**Origin of rock**
Shugal Sordo	568115	1492045	2345	Grey to black	Yellowish	limestone	Sedimentary
Melate	563192	1491372	2263	black	black to whitish	limestone	Sedimentary
Kuean	566003	1492837	2357	black	grey to yellowish	limestone	Sedimentary
Dalule	560780	1493696	2222	black	grey	limestone	Sedimentary
May Keyeh	557020	1474272	2314	black	yellowish	limestone	Sedimentary
Emba Awuer	550784	1482276	2231	grey to black	whitish to yellowish	limestone	Sedimentary
Adi Kelkel	551178	1480605	2205	black	yellowish to gray	limestone	Sedimentary
Shegul Adi Hagera	548398	1481381	2042	grey to black	yellowish	limestone	Sedimentary
May Hebei	547774	1481201	2018	black	yellowish	limestone	Sedimentary
May Anbesa	541723	1496105	1989	black	yellowish	limestone	Sedimentary

3.2 Methodology

The methods used in this research include review of literatures on previous study and on basic principles or theories related to the research topic. Field assessment of main quarry sites used as sources of coarse aggregates around Mekelle were carried out. Samples were collected from representative sites and laboratory tests were carried out. Based on the theories and laboratory tests performed, the results obtained have been analyzed and discussed thoroughly. Finally the results of the research have been reported and compared with the standard requirements of ASTM using different aggregate qualities. This study was designed in such a way that important and reliable data on the quality of the aggregates for concrete in Mekelle be properly evaluated.

3.2.1 Field identification

Simple visual observations were done by carefully assessing the aggregate, in the study area mainly in the quarry sites. Ten quarry sites were identified for the study and 10 samples were collected from the crushers. The names of quarry sites include; Shugal, Melate, Kuean, Dalul, May-Keyeh, Emba-Awer, Adi Kelkel, Adi Hagera, May Hebei and May-Anbesa quarry sites. The rock for aggregate in the field were broken by using sledge hammer and rock breaker in to smaller size specimens.

3.2.2 Sample collection

The major rocks used as source of aggregates around Mekelle city were assessed. In order to get the desired physical and mechanical test results representative samples were collected from the different quarry sites. Representative sampling method was used to obtain these samples. Depending on the test to be carried out, different sample sizes were collected (Table 3.2).

Table 3-2: Size of samples collected for the different type of laboratory tests from each site.

No	**Type of test**	**weight of sample (kg)**
1	Aggregate Crushed Value	55
2	Gradation (sieve analysis)	45
3	Specific gravity and Water absorption	50
4	Unit weight	50
5	Moisture content	50
6	Los Angeles Abrasion	50
7	Flakiness index	45

3.2.3 Laboratory tests

All the physical and mechanical property tests: - were carried out at civil engineering department, Mekelle Institute of Technology, Mekelle University. For each site, seven different tests were carried out and two samples for each, average values were taken. The following laboratory tests were carried out (Table 3.3).

Table 3-3: Name of tests carried out and their uses

Tests carried out	Standard Specifications	Purpose
Aggregate Crushing Value (ACV) Test	ASTM C 503	Used to evaluate the resistance of aggregates against to gradually applied load.
Los Angeles Abrasion (LAA) Test	ASTM C 131	Used to evaluate how the aggregate is sufficiently hard to resist the abrasion effect.
Specific Gravity and Water Absorption	ASTM C 127-01	Used to determine the bulk and apparent specific gravity and absorption
Flakiness index test	IS part-I Standard	Used to classify aggregates and used to determine the flaky part of coarse aggregates
Sieve Analysis	ASTM C 136	Used to determine the particle size distribution of coarse aggregates
Moisture content of aggregates	ASTM C 566-84	Used to determine the moisture content of coarse aggregate
Unit weight of aggregates	ASTM C29/ C29M-97	Used to determine the unit weight of coarse aggregates

3.3 Materials used for the research

In all types of aggregate varieties, GPS has been used to delineate the deposit boundary readings north, east and the elevation was saved in the GPS and finally imported to Arc view GIS an Arc view GIS package has also been used to produce geological map for field sample collection, canvas bags and shovel were used. The equipment's used for laboratory test are compression machine, Los Angeles machine, sieves, steel tamping rod, a steel cylinder, balance, oven, container, and gauges for flakiness index. Lastly the data would be analyzed using Excel spreadsheets, charts and tables that was of great help in making tables, computations etc.

4. Results and Discussions

4.1 The major rock sources used for concrete aggregates in Mekelle area

The major rocks in Mekelle area are sedimentary rocks, which include limestone, sandstone and shale, as well as intrusive igneous rocks like dolerites. The limestones are the most dominant sources of coarse aggregates in Mekelle area, and the fresh color varies from black and grey to black. The weathered limestone has variable color: yellowish, grey, black to whitish and grey to yellowish. ASTM defines limestone as a sedimentary rock composed primarily of calcite (calcium carbonate) or dolomite (calcium magnesium carbonate). Samples were collected from the different limestone sources with different colors.

As observed in the field, the limestones in Mekelle areas include fresh as well as weathered ones. The dominant color of the site is fresh color (70%) whereas the rest observed color is weathered.

4.2 Laboratory test results

This section discusses on the laboratory tests conducted to determine the physical and mechanical properties of the aggregates. A total of 119 tests were carried out for the samples collected from the ten quarry sites.

The prime objective of the different tests was to evaluate and classify the aggregate materials based on their quality. For the coarse aggregate materials tests were performed according to ASTM specification and the following tests were performed.

- Aggregate Crushed Value test
- Los Angeles Abrasion test
- Specific gravity and absorption test
- Moisture content test
- Unit weight test
- Gradation tests (sieve analysis) and flakiness index

Characterization of the physical and mechanical properties of the aggregate considered in this research involved the comparison of the average values of the test results to the respective ASTM standard for each type of test. Based on this comparison the suitability and quality of aggregates for concrete use is evaluated.

4.2.1 Aggregate crushing value

The aggregate crushed value result is summarized in Table 4.1. As can be noted from this Table, some variation in the average aggregate crushed values was found for the samples from ten sites 10 samples. Each aggregate type in this group has ACV not out of the standard specification of ASTM C 503 requirement which is 30%. From the ten sites, a sample from Kuean has minimum ACV of 5.9% while samples from Adi Kelkel showed high ACV of 19.1% though within the ASTM C 503 requirements.

Table 4-1: Aggregate Crushing Value test result

Site name	Aggregate Crushed Value (%)	ASTM requirement (max)
1.Shugal Sordo	12	30
2.Melate	13.2	30
3.Kuean	5.9	30
4.Dalule	15.1	30
5.May Keyeh	19.61	30
6.Emba Awuer	14.0	30
7.Adi Kelkel	19.7	30
8.Shegul Adihagera	8.6	30
9.May Hebei	15.7	30
10.May Anbesa	16.3	30

4.2.2 Los Angeles abrasion test

The samples from all the quarry sites were tested for LAA and results of the test are summarized in Table 4.2. Results of the test show that for all the samples the LAA value is within the allowable ASTM requirement (maximum value of 50%) Though, there is some variation in the composition and the texture of the samples tested from the different sites. As can be noted from Table 4.2, the maximum LAA was 33.62 for samples from Adi Kelkel quarry site while the lowest LAA value was 24.94% for samples from Kuean. According to these results of the tests, these aggregates can be used for concrete. All the tests results are within ASTM C131standards.

Table 4-2: Los Angeles Abrasion test result

Site name	Average value of Los Angeles Abrasion (%)	ASTM requirement (max)
Shugal Sordo	25.94	50
Melate	27.87	50
Kuean	24.94	50
Dalule	29.29	50
May Keyeh	30.77	50
Emba Awuer	28.66	50
Adi Kelkel	33.62	50
Shegul Adihagera	25.23	50
May Hebei	29.43	50
May Anbesa	29.36	50

4.2.3 Specific Gravity and Water Absorption

Results of the analysis shown in (Table 4.3) are the aggregates fulfill the ASTM C 127 requirements for specific gravity as the values range between 2.62 and 2.706. Water absorption ranges from 0.34% to 0.76.0%, and indicates very low effective porosity. It lies within the specification (<2%) of ASTM C 128 requirements. Low WAV prevents access of reactants to aggregate to attack and therefore aggregates should be strong enough. The least water absorption value was observed for samples from Shugal Sordo and Shegul Adihagera sites with water absorption value of 0.34%.The higher water absorption value was obtained for samples from May Keyeh with water absorption value of 0.76%.

Table 4-3: Specific Gravity and water absorption test results

Site name	Specific Gravity			Water absorption (%)
	Apparent	Bulk (Dry)	Bulk (S.S.D)	
Shugal Sordo	2.693	2.668	2.677	0.34
Melate	2.694	2.658	2.671	0.51
Kuean	2.688	2.663	2.672	0.35
Dalule	2.646	2.62	2.630	0.38
May Keyeh	2.70	2.646	2.666	0.76
Emba Awuer	2.706	2.671	2.684	0.49
Adi Kelkel	2.702	2.658	2.674	0.62
Shegul Adihagera	2.674	2.65	2.659	0.34
May Hebei	2.694	2.659	2.672	0.49
May Anbesa	2.686	2.655	2.667	0.43

4.2.4 Moisture content

As shown below (Table 4.4) the results of laboratory test show that the moisture content of the samples varied from 0.21 to 0.37 The average value of the moisture content of each aggregate is less than the minimum ASTM C 566 standard requirement, which is 0.4%. The moisture content of the aggregate has not fulfilled the standard specification of ASTM.

Table 4-4: moisture content of coarse aggregate test results

Site name	Moisture content (%)	Minimum moisture content
Shugal Sordo	0.22	0.4
Melate	0.24	0.4
Kuean	0.21	0.4
Dalule	0.29	0.4
May Keyeh	0.33	0.4
Emba Awuer	0.26	0.4
Adi Kelkel	0.37	0.4
Shegul Adihagera	0.24	0.4
May Hebei	0.27	0.4
May Anbesa	0.31	0.4

4.2.5 Unit weight of coarse aggregate

Results of the laboratory tests (Table 4.5) show that the smallest unit weight of the coarse aggregate is 1.52 while the highest is 1.63. The approximate bulk unit weight of aggregate commonly used in normal weight aggregate has unit weight of 1520-1680 kg/m^3. This shows that the aggregates from the different sites are with the ASTM standard requirements for normal weight aggregates.

Table 4-5: unit weight of coarse aggregate test results

Site name	Unit weight g/cc
Shugal Sordo	1.52
Melate	1.52
Kuean	1.53
Dalule	1.63
May Keyeh	1.55
Emba Awuer	1.61
Adi Kelkel	1.52
Shegul Adi Hagera	1.53
May Hebei	1.54
May Anbesa	1.57

4.2.6 Gradation

The gradation of an aggregate is normally expressed as total percent passing various sieve sizes and results of the analysis is given in Table 4.6. The graph shows below similar values of percentage drawn in one graph to explain clearly with their upper and lower limit (Figure 4.1-4.2). As shown below in the graph site-3, site 5 and site 10 are out of the upper and lower limits of the standard specifications.

Table 4-6: grain size results of percentage passing

Sieve size (mm)	% passing									
	1	2	3	4	5	6	7	8	9	10
37.5	100	100	100	100	100	98.3	100	100	100	100
28.0	97.2	97.7	88.7	97.4	98.3	96.4	100	93.9	95.3	100
20	59.8	68.4	26.8	61.4	77.1	70.9	70.5	46	60.5	79.6
14	9.8	29.5	1.3	9.3	21.4	30.5	15.6	8.3	19.2	17.1
10	0.3	4	0.1	0.2	3	12.4	1.3	0.7	5.2	1.1
6.3	0.17	2.02	0.06	0.13	1.53	6.52	0.65	0.39	2.67	0.55
5.0	0.1	0.1	0.1	0	0.1	0.4	0.1	0.1	0.1	0

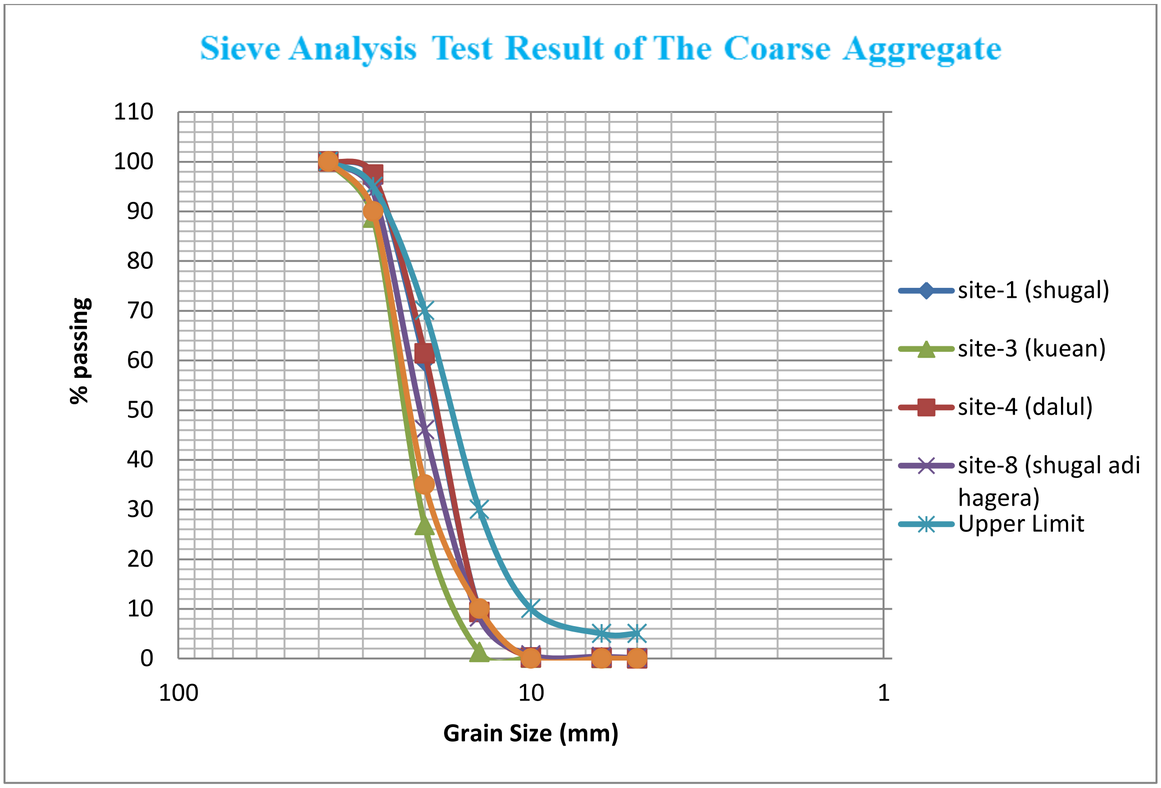

Figure 4-1: Particle size distribution curve for the different quarry sites

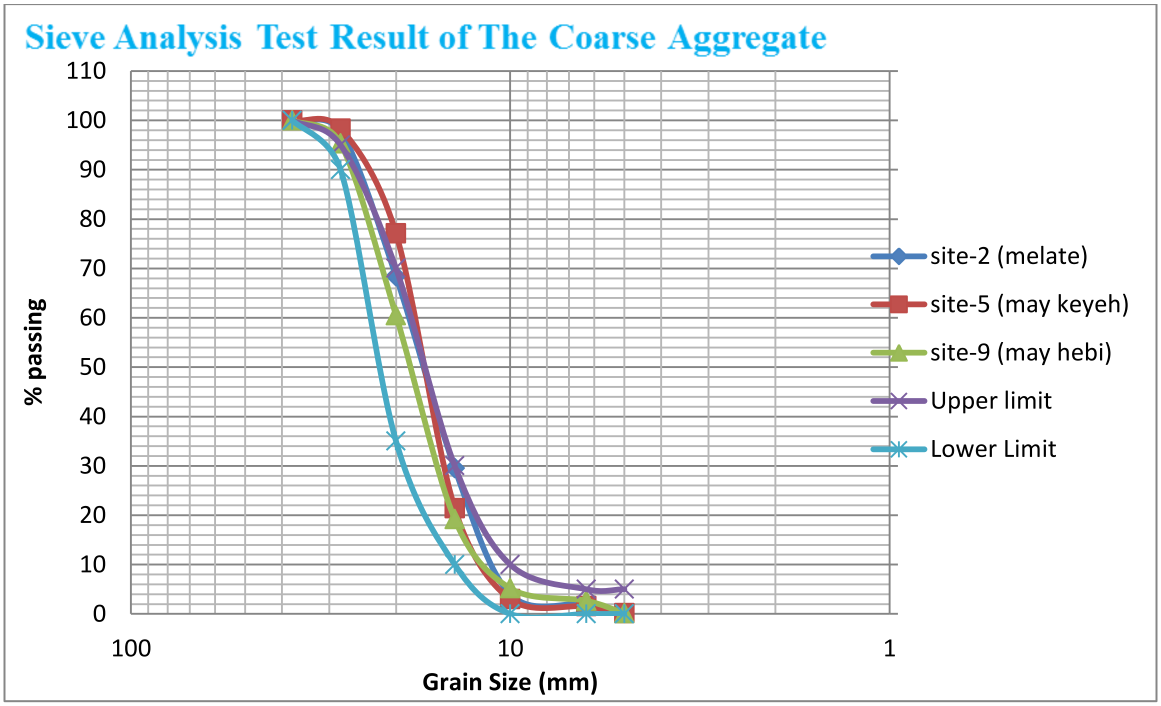

Figure 4-2: Particle size distribution curve for the different sample

4.2.7 Flakiness index

Flakiness index test was carried out for the samples collected from the different quarry sites and results are indicated in Table 4.7. From the test result Adi Kelkel (site-7) was flakier than the other site.

Table 4-7: Flakiness index test results

Site name	Flakiness index	Max ASTM requirement
Shugal Sordo	17%	35%
Melate	21%	35%
Kuean	18%	35%
Dalule	20%	35%
May Keyeh	20%	35%
Emba Awuer	20%	35%
Adi Kelkel	26%	35%
Shegul Adi Hagera	20%	35%
May Hebei	21%	35%
May Anbesa	21%	35%

4.3 Summary of Comparison test results with requirements set in the design specification

Geotechnical analysis provides the physical and mechanical properties of the aggregates, which help to evaluate quality of the aggregates. Most of the laboratory tests were carried out in accordance with the ASTM procedures for coarse aggregate testing. Table 4.8 below shows the standard specifications of ASTM requirement compares with laboratory test results. All tests are fulfilling the ASTM requirement except moisture content.

Table 4-8: physical and mechanical properties of coarse aggregates studied in this research compared to ASTM requirement.

Physical and mechanical property (average)	ACV	Specific Gravity	Unit Weight	Moisture Content	LAA	Flakiness	Absorption
ASTM requirement	<30%	2.4-2.9	1.52-1.68	0.4-4%	<50%	<35%	0.2-2 %
Shugal Sordo	12	2.668	1.522	0.22	25.94	17	0.34
Melate	13.2	2.658	1.519	0.24	27.87	20	0.51
Kuean	5.9	2.663	1.534	0.21	24.94	18	0.35
Dalule	15.1	2.62	1.631	0.29	29.29	21	0.38
May Keyeh	19.61	2.646	1.554	0.33	30.77	20	0.76
Emba Awuer	14.0	2.671	1.608	0.26	28.66	20	0.49
Adi Kelkel	19.7	2.658	1.519	0.37	33.62	26	0.62
Shegul Adihagera	8.6	2.65	1.53	0.24	25.23	20	0.34
May Hebei	15.7	2.66	1.544	0.27	29.43	21	0.49
May Anbesa	16.3	2.655	1.566	0.31	29.36	21	0.43

5 Conclusions and Recommendation

5.1 Conclusions

The major rocks sources in Mekelle area are sedimentary rocks which are limestone, dolerite, sandstone, and shale material types but the rock types of all sites are limestones. There fresh color is black and grey to black when it weathered changes to yellowish, grey, black to whitish, and grey to yellowish. Therefore most rocks composed by chemical composition that is crushed lime stone.

Geotechnical evaluation of aggregates and the aggregate quality were suitable when compared with ASTM standards except the moisture content is below the minimum. The materials have good property according to gradation, aggregate crushed value, Los Angeles Abrasion, and specific gravity for concrete material.

The average values of the sites ACV is between 5.9% and 19.7%, the ASTM standard is not exceed 30% so the result accomplish this requirement, average value of LAA is between 24.94% and 33.2%, the requirement of ASTM is 50% so the result fulfills the requirement. All quarries of the coarse aggregate are best except the moisture content.

5.2 Recommendation

The best quality aggregates used for concrete in Mekelle area are Shugal Adi Hagera, Shugal Sordo, Melate, Emba Awuer, Dalul and May Hebei.

The moisture content of the coarse aggregates are less than the minimum ASTM standard so, it can adds some water in addition to the properly used ratio.

Aggregate are carried out for concrete because it covers highest percent of the concrete laboratory tests do carefully. There is shortage of laboratory tests in Mekelle University so better to add another laboratory test for aggregate.

Also we must give attention for this kind of materials. Because of lack of time the samples material in this study is collected from ten quarry sites only. A better and comprehensive picture would be obtained if more quarries are tested.

These samples cannot represent all quarry sites in Mekelle, the users must have to check the laboratory tests when new materials quarried, checking the rock sources is better before crushed and use it for aggregate.

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Appendix

A. Tables

Laboratory test results

Appendix A-1: aggregate crushed value test result of coarse aggregate

Site-1

Sample No.	1	2	**Remarks**
Size of aggregate, mm.	10 - 14	10 - 14	
Maximum load applied, KN	400	400	
Duration of testing, min.	10	10	
Weight of sample tested, gm.	2716.8	2746.5	
Weight of sample retained on 2.36 mm sieve size, gm.	2387.8	2419.6	
Aggregate Crushing Value, %	12.1	11.9	
AVERAGE AGG. CRUSHING VALUE, %	12.0		

Site name	ACV		
	1	2	Average
Shugal Sordo	12.1	11.7	11.9
Melate	13.1	13.3	13.2
Kuean	6.5	5.4	5.95
Dalule	15.8	14.4	15.1
May Keyeh	20.3	18.9	19.6
Emba Awuer	14.6	13.4	14
Adi Kelkel	19.5	19.8	19.65
Shegul Adi Hagera	9.4	7.9	8.65
May Hebei	15.6	15.8	15.7
May Anbesa	16.3	16.3	16.3

$$\text{ACV} = \frac{\text{Weight of sample tested}}{\text{Weight of sample retained on 2.36 mm sieve size}}$$

Appendix A-2: Los Angeles Abrasion test result of the coarse aggregate

Site-1 (Shugal or Sordo)

Grading selected	Sample 1	Sample 2	Remark
Original wt. Of the sample (W1)	5000	5000	
Weight of aggregate retained on sieve 1.7mm IS sieve (W2)	3719.9	3686.6	
Loss of weight	1280.1	1313.4	
Percentage wear = $\{\frac{W1-W2}{W1}\} *100$	25.602	26.268	
Los Angeles Abrasion value	25.94		

Site name	LAA		
	1	2	Average
Shugal Sordo	25.602	26.268	25.94
Melate	28.23	27.51	27.87
Kuean	24.4	25.49	24.95
Dalule	28.79	29.78	29.29
May Keyeh	31.19	30.35	30.77
Emba Awuer	27.55	29.77	28.66
Adi Kelkel	33.28	33.96	33.62
Shegul Adi Hagera	25.552	24.914	25.23
May Hebei	29.002	29.866	29.43
May Anbesa	29.92	28.79	29.36

Appendix A-3: Specific gravity test result of the coarse aggregate

1. Site -1 (Shugal Serdo)

COARSE AGGREGATE

Description		Test 1	Test 2	Average
A. Mass of Oven Dry Sample	g	3986.3	4113.7	
B. Mass of Dry Sample in Air	g	4000.5	4127	
C. Mass Sample in Water	g	2505.6	2586.1	
Absorption	$\frac{(B-A)*100}{A}$	0.36	0.32	0.34
Test temperature ,^{o}C		23 ± 1.7	23 ± 1.7	23 ± 1.7
Apparent Specific Gravity	$\frac{A}{A-C}$	2.692	2.693	2.693
Bulk Specific Gravity (Dry)	$\frac{A}{B-C}$	2.667	2.670	2.668
Bulk Specific Gravity (S.S.D basis)	$\frac{B}{B-C}$	2.676	2.678	2.677

2. Site 2 (Melate)

Description		Test 1	Test 2	Average
A. Mass of Dry Sample in oven	g	3312.6	3769.3	
B. Mass of Dry Sample in Air	g	3328.8	3789.2	
C. Mass Sample in Water	g	2082.8	2370.6	
Absorption	$\frac{(B - A)*100}{A}$	0.49	0.53	0.51
Test temperature ,°C		23 ± 1.7	23 ± 1.7	23 ± 1.7
Apparent Specific Gravity	$\frac{A}{A - C}$	2.694	2.695	2.694
Bulk Specific Gravity (Dry)	$\frac{A}{B - C}$	2.659	2.657	2.658
Bulk Specific Gravity (S.S.D basis)	$\frac{B}{B - C}$	2.672	2.671	2.671

3. Site 3 (Kuean)

Description		Test 1	Test 2	Average
A. Mass of Dry Sample in oven	g	3425.4	2623.3	
B. Mass of Dry Sample in Air	g	3435.7	2634	
C. Mass of Sample in Water	g	2150.7	1647.6	
Absorption	$\frac{(B - A)*100}{A}$	0.30	0.41	0.35
Test temperature °C		23 ± 1.7	23 ± 1.7	23 ± 1.7
Apparent Specific Gravity	$\frac{A}{A - C}$	2.687	2.689	2.688
Bulk Specific Gravity (Dry)	$\frac{A}{B - C}$	2.666	2.659	2.663
Bulk Specific Gravity (S.S.D basis)	$\frac{B}{B - C}$	2.674	2.670	2.672

4. Site 4 (Dalul)

Description		Test 1	Test 2	Average
A. Mass of Dry Sample in oven	g	3397.4	3824.8	
B. Mass of Dry Sample in Air	g	3410.8	3838.6	
C. Mass of Sample in Water	g	2082.8	2412.7	
Absorption	$\frac{(B - A)*100}{A}$	0.39	0.36	0.38
Test temperature ,^{o}C		23 ± 1.7	23 ± 1.7	23 ± 1.7
Apparent Specific Gravity	$\frac{A}{A - C}$	2.584	2.709	2.646
Bulk Specific Gravity (Dry)	$\frac{A}{B - C}$	2.558	2.682	2.620
Bulk Specific Gravity (S.S.D basis)	$\frac{B}{B - C}$	2.568	2.692	2.630

5. Site 5 (May Keyeh)

Description		Test 1	Test 2	Average
A. Mass of Dry Sample in Oven	g	3887.6	3816.1	
B. Mass of Dry Sample in Air	g	3917.6	3844.5	
C. Mass Sample in Water	g	2447.4	2403.3	
Absorption	(B - A)*100	0.77	0.74	0.76
	A			
Test temperature ,^{o}C		23 ± 1.7	23 ± 1.7	23 ± 1.7
Apparent Specific Gravity	A	2.699	2.701	2.7
	A - C			
Bulk Specific Gravity (Dry)	A	2.644	2.648	2.646
	B - C			
Bulk Specific Gravity (S.S.D basis)	B	2.665	2.668	2.666
	B - C			

6. Site 6 (Emba Awer)

Description		Test 1	Test 2	Average
A. Mass of Dry Sample in oven	g	3249.8	3404.9	
B. Mass of Dry Sample in Air	g	3264.3	3422.8	
C. Mass Sample in Water	g	2047.6	2147.9	
Absorption	$\frac{(B - A)*100}{A}$	0.45	0.53	0.49
Test temperature ,^{o}C		23 ± 1.7	23 ± 1.7	23 ± 1.7
Apparent Specific Gravity	$\frac{A}{A - C}$	2.703	2.709	2.706
Bulk Specific Gravity (Dry)	$\frac{A}{B - C}$	2.671	2.671	2.671
Bulk Specific Gravity (S.S.D basis)	$\frac{B}{B - C}$	2.683	2.685	2.684

7. Site 7(Adikelkel)

Description		Test 1	Test 2	Average
A. Mass of Dry Sample in oven	g	3843.3	3755.5	
B. Mass of Dry Sample in Air	g	3867.4	3778.4	
C. Mass Sample in Water	g	2420.5	2366.2	
Absorption	$\frac{(B - A)*100}{A}$	0.63	0.61	0.62
Test temperature ,^{o}C		23 ± 1.7	23 ± 1.7	23 ± 1.7
Apparent Specific Gravity	$\frac{A}{A - C}$	2.701	2.703	2.702
Bulk Specific Gravity (Dry)	$\frac{A}{B - C}$	2.656	2.659	2.658
Bulk Specific Gravity (S.S.D basis)	$\frac{B}{B - C}$	2.673	2.676	2.674

8. Site 8 (Shugal Adi Hagera)

Description		Test 1	Test 2	Average
A. Mass of Dry Sample in oven	g	3519.2	3367.9	
B. Mass of Dry Sample in Air	g	3531.4	3379	
C. Mass Sample in Water	g	2204.3	2107.5	
Absorption	$\frac{(B - A)*100}{A}$	0.35	0.33	0.34
Test temperature ,^{o}C		23 ± 1.7	23 ± 1.7	23 ± 1.7
Apparent Specific Gravity	$\frac{A}{A - C}$	2.676	2.672	2.674
Bulk Specific Gravity (Dry)	$\frac{A}{B - C}$	2.652	2.649	2.650
Bulk Specific Gravity (S.S.D basis)	$\frac{B}{B - C}$	2.661	2.657	2.659

9. Site 9 (May Hebi)

Description		Test 1	Test 2	Average
A. Mass of Dry Sample in oven	g	3025.9	3185.9	
B. Mass of Dry Sample in Air	g	3039.6	3202.5	
C. Mass Sample in Water	g	1901.4	2004.9	
Absorption	$\frac{(B - A)*100}{A}$	0.45	0.52	0.49
Test temperature ,^{o}C		23 ± 1.7	23 ± 1.7	23 ± 1.7
Apparent Specific Gravity	$\frac{A}{A - C}$	2.691	2.698	2.694
Bulk Specific Gravity (Dry)	$\frac{A}{B - C}$	2.658	2.660	2.659
Bulk Specific Gravity (S.S.D basis)	$\frac{B}{B - C}$	2.671	2.674	2.672

10. Site 10 (May Anbesa)

Description		Test 1	test-2	Average
A. Mass of Dry Sample in oven	g	3375.3	3482.0	
B. Mass of Dry Sample in Air	g	3390.2	3496.3	
C. Mass Sample in Water	g	2119.2	2184.7	
Absorption	$\frac{(B - A)*100}{A}$	0.44	0.41	0.43
Test temperature ,^{o}C		23 ± 1.7	23 ± 1.7	23 ± 1.7
Apparent Specific Gravity	$\frac{A}{A - C}$	2.687	2.684	2.686
Bulk Specific Gravity (Dry)	$\frac{A}{B - C}$	2.656	2.655	2.655
Bulk Specific Gravity (S.S.D basis)	$\frac{B}{B - C}$	2.667	2.666	2.667

Appendix A-4: Moisture content of the coarse aggregate test result

Trial No	1	2
Mass of Wet aggregate, g	2815.30	2718.60
Mass of Dry aggregate, g	2808.90	2713.00
Mass of water, g	6.40	5.60
Mass of dry aggreagate, g	2808.90	2713.00
Water content, %	0.23	0.21
Ave. moisture content,%	0.22	

Moisture content			
Site name	1	2	Average
Shugal Sordo	0.23	0.21	0.22
Melate	0.24	0.24	0.24
Kuean	0.22	0.2	0.21
Dalule	0.29	0.29	0.29
May Keyeh	0.32	0.34	0.33
Emba Awuer	0.3	0.22	0.26
Adi Kelkel	0.41	0.32	0.37
Shegul Adi Hagera	0.29	0.18	0.24
May Hebei	0.26	0.28	0.27
May Anbesa	0.35	0.26	0.31

Appendix A-5: Unit weight of the coarse aggregate test result

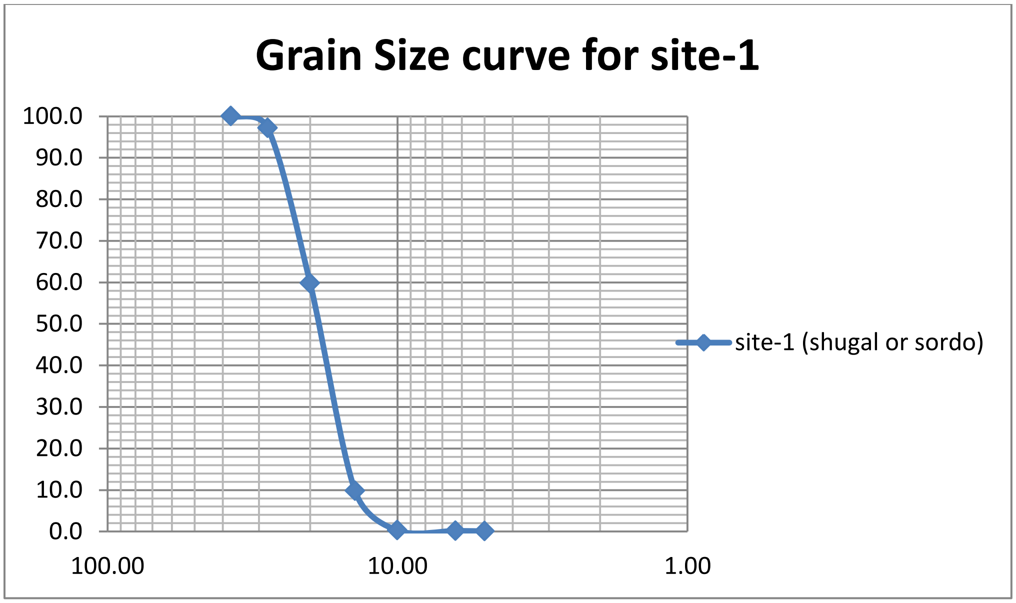
trial number	1	2	remarks
cylinder number	c1	c2	
weight of aggregates, a g	4619.4	4563.8	
volume of cylinder, b cc	3017.54	3017.54	
unit weight of aggregates, (a/b) g/cc	1.531	1.512	
average unit weight of aggregates g/cc	**1.52**		

UNIT WEIGHT			
Site Name	1	2	Average
Shugal Sordo	1.531	1.512	1.52
Melate	1.526	1.513	1.52
Kuean	1.54	1.527	1.53
Dalule	1.633	1.629	1.63
May Keyeh	1.564	1.544	1.55
Emba Awuer	1.609	1.606	1.61
Adi Kelkel	1.526	1.513	1.52
Shegul Adi Hagera	1.526	1.534	1.53
May Hebei	1.545	1.543	1.54
May Anbesa	1.55	1.582	1.57

Appendix A-6: Sieve analysis test result of the coarse aggregate

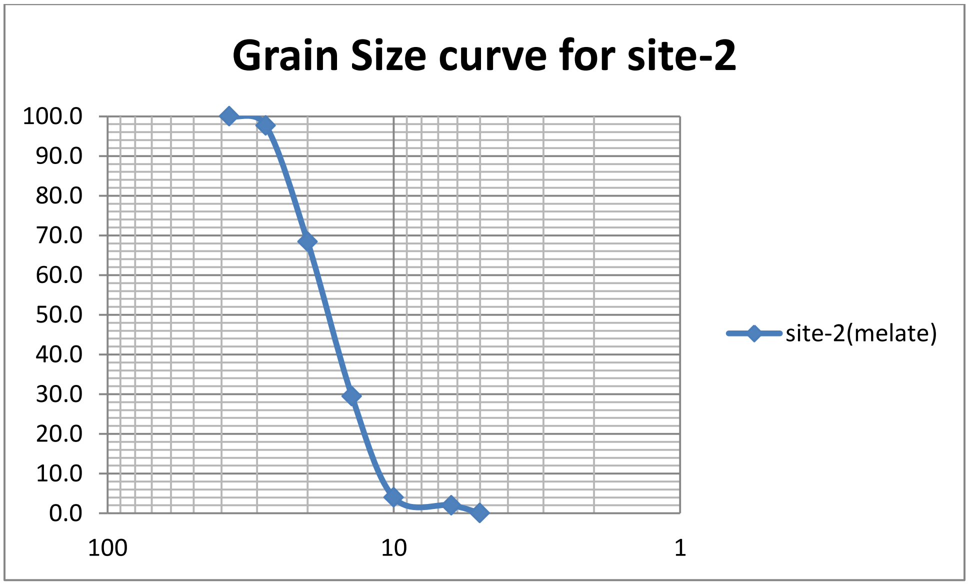
Appendix 2A Site-1 (Shugal or Sordo)

Sieve size (mm)	Weight of sieve	Wt. of sieve+ retained aggregate	Mass Retained (gm)	Percent retained (%)	Com. % retained	Percentage finer (%)
37.50	1707.9	1707.9	0.00	0	0.00	100.0
28.00	1730.2	1828.6	98.40	2.82	2.82	97.2
20.00	1616.8	2920.7	1303.90	37.37	40.19	59.8
14.00	1358.1	3102.6	1744.50	50.00	90.20	9.8
10.00	1326.1	1658.9	332.80	9.54	99.74	0.3
6.3	1360.1	1363.3	3.20	0.09	99.83	0.17
5.00	1372.6	1376.1	3.50	0.10	99.93	0.1
pan	759.1	761.6	2.50	0.07	100.00	0.0
		total	3488.80			



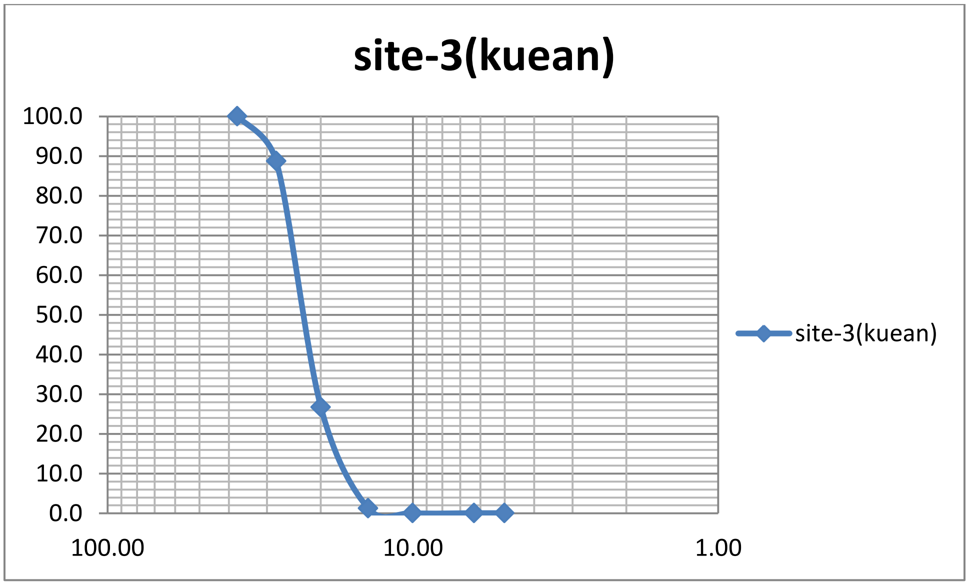
Appendix 2B Site-2 (Melate)

Sieve size (mm)	Weight of sieve	wt of sieve+ retained aggregate	Mass Retained (gm)	Percent retained (%)	Com. % retained	Percentage finer (%)
37.50	1707.9	1707.9	0.00	0	0.00	100.0
28.00	1730.2	1826.4	96.20	2.33	2.33	97.7
20.00	1616.8	2826.5	1209.70	29.25	31.58	68.4
14.00	1358.1	2968.5	1610.40	38.94	70.52	29.5
10.00	1326.1	2381.1	1055.00	25.51	96.02	4.0
6.3	1360.1	1440.8	80.70	1.95	97.98	2.02
5.00	1372.6	1453.6	81.00	1.96	99.93	0.1
pan	759.1	761.8	2.70	0.07	100.00	0.0
		total	4135.70			



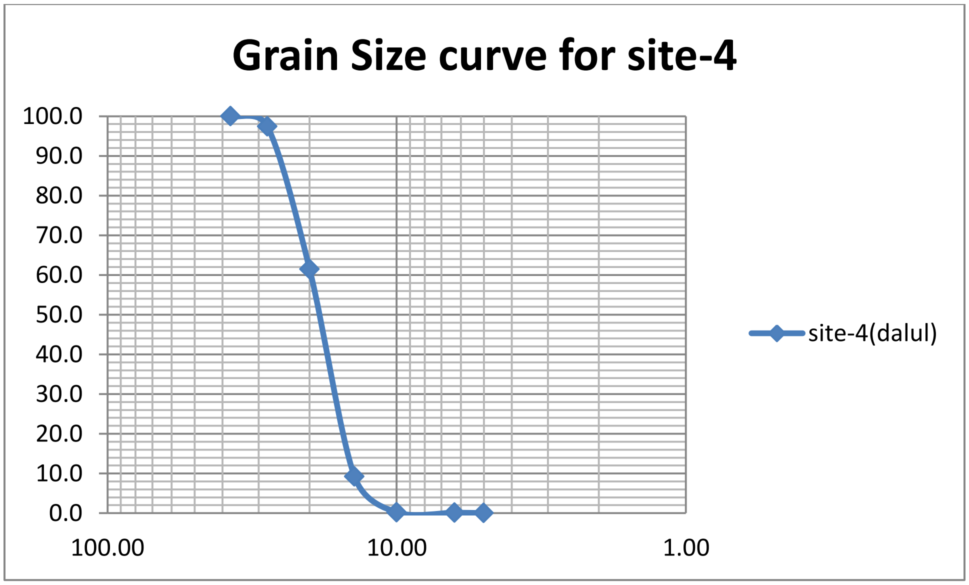
Appendix 2C Site-3 (Kuean)

sieve size (mm)	Weight of sieve	wt of sieve+ retained aggregate	Mass Retained (gm)	Percent retained (%)	Com. % retained	Percentage finer (%)
37.50	1707.9	1707.9	0.00	0	0.00	100.0
28.00	1730.2	2173.2	443.00	11.29	11.29	88.7
20.00	1616.8	4048.3	2431.50	61.95	73.24	26.8
14.00	1358.1	2357.5	999.40	25.46	98.70	1.3
10.00	1326.1	1374.9	48.80	1.24	99.94	0.1
6.3	1360.1	1360.1	0.00	0.00	99.94	0.06
5.00	1372.6	1372.6	0.00	0.00	99.94	0.1
pan	759.1	761.4	2.30	0.06	100.00	0.0
		total	3925.00			



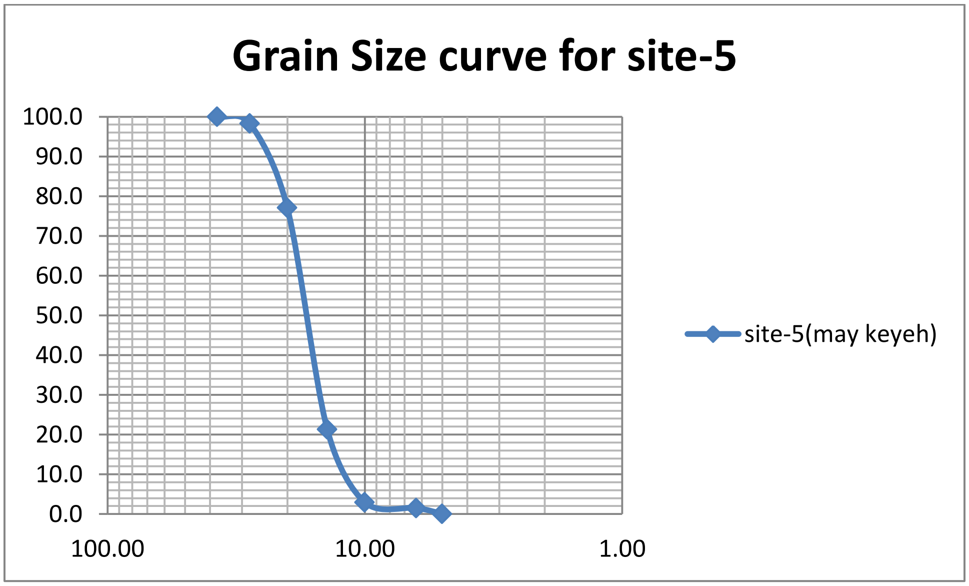
Appendix 2D Site-4 (Dalul)

Sieve size (mm)	Weight of sieve	wt of sieve+ retained aggregate	Mass Retained (gm)	Percent retained (%)	Com. % retained	Percentage finer (%)
37.50	1707.9	1707.9	0.00	0.00	0.00	100.0
28.00	1730.2	1833.6	103.40	2.59	2.59	97.4
20.00	1616.8	3054.9	1438.10	35.97	38.55	61.4
14.00	1358.1	3444.5	2086.40	52.18	90.74	9.3
10.00	1326.1	1687.4	361.30	9.04	99.77	0.2
6.3	1360.1	1364	3.90	0.10	99.87	0.13
5.00	1372.6	1376.4	3.80	0.10	99.96	0.0
pan	759.1	760.5	1.40	0.04	100.00	0.0
		total	3998.30			



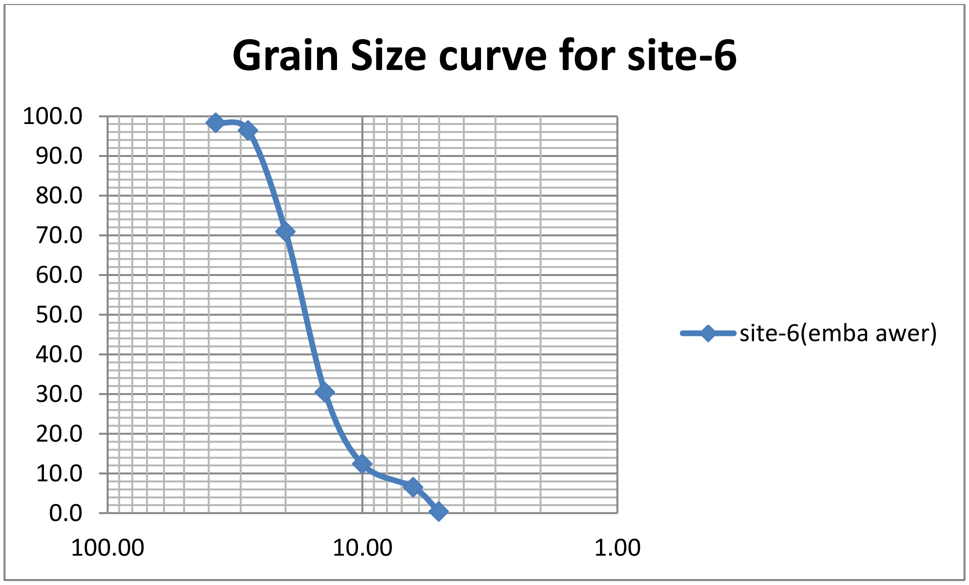
Appendix 2E Site-5 (May-Keyeh)

Sieve size (mm)	Weight of sieve	wt of sieve+ retained aggregate	Mass Retained (gm)	Percent retained (%)	Com. % retained	Percentage finer (%)
37.50	1707.9	1707.9	0.00	0	0.00	100.0
28.00	1730.2	1829.4	99.20	1.71	1.71	98.3
20.00	1616.8	2847.1	1230.30	21.20	22.91	77.1
14.00	1358.1	4590.4	3232.30	55.71	78.62	21.4
10.00	1326.1	2394.1	1068.00	18.41	97.03	3.0
6.3	1360.1	1444	83.90	1.45	98.47	1.53
5.00	1372.6	1457.1	84.50	1.46	99.93	0.1
pan	759.1	763.2	4.10	0.07	100.00	0.0
		total	5802.30			



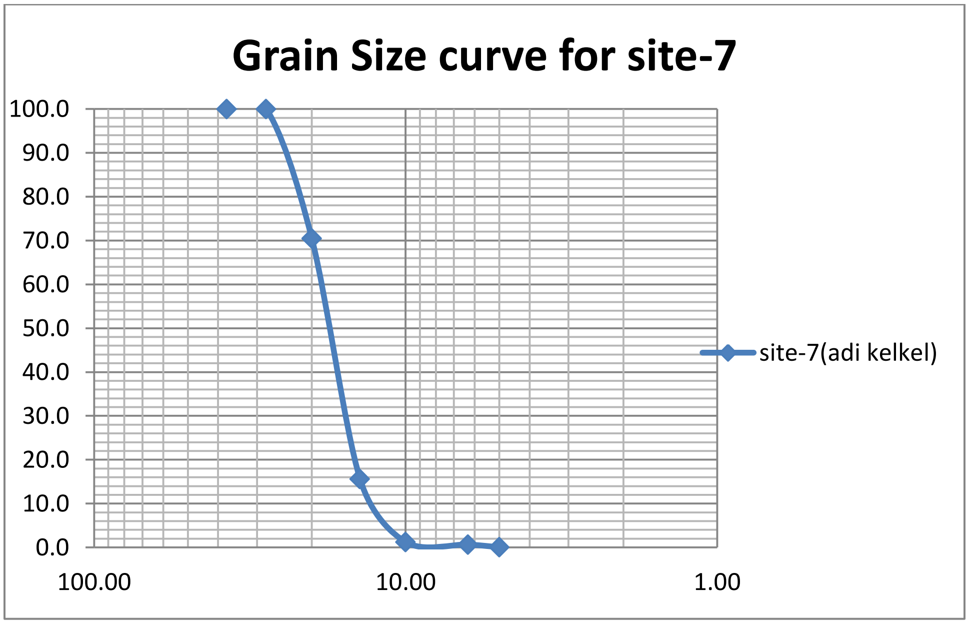
Appendix 2F Site-6 (Emba Awer)

Sieve size (mm)	Weight of sieve	wt of sieve+ retained aggregate	Mass Retained (gm)	Percent retained (%)	Com. % retained	Percentage finer (%)
37.50	1707.9	1770.4	62.50	1.678348	1.68	98.3
28.00	1730.2	1802.6	72.40	1.94	3.62	96.4
20.00	1616.8	2565.8	949.00	25.48	29.11	70.9
14.00	1358.1	2863.5	1505.40	40.43	69.53	30.5
10.00	1326.1	2000.4	674.30	18.11	87.64	12.4
6.3	1360.1	1577.6	217.50	5.84	93.48	6.52
5.00	1372.6	1602	229.40	6.16	99.64	0.4
pan	759.1	772.5	13.40	0.36	100.00	0.0
		total	3723.90			



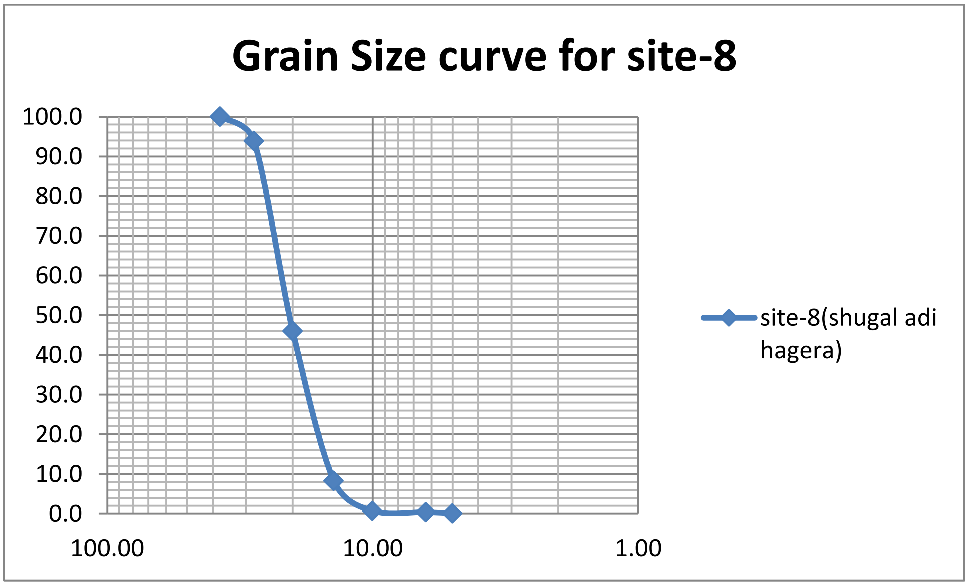
Appendix 2G site-7 (Adi Kelkel)

Sieve size (mm)	Weight of sieve	wt of sieve+ retained aggregate	Mass Retained (gm)	Percent retained (%)	Com. % retained	Percentage finer (%)
37.50	1707.9	1707.9	0.00	0	0.00	100.0
28.00	1730.2	1730.2	0.00	0.00	0.00	100.0
20.00	1616.8	2751.4	1134.60	29.51	29.51	70.5
14.00	1358.1	3468.5	2110.40	54.89	84.40	15.6
10.00	1326.1	1877.7	551.60	14.35	98.75	1.3
6.3	1360.1	1383.1	23.00	0.60	99.35	0.65
5.00	1372.6	1395.4	22.80	0.59	99.94	0.1
pan	759.1	761.4	2.30	0.06	100.00	0.0
		total	3844.70			



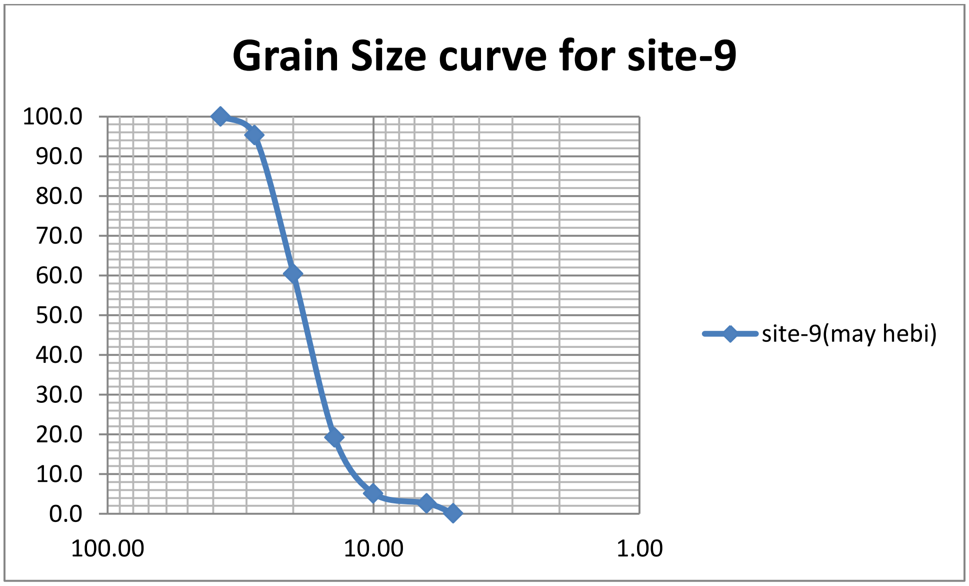
Appendix 2H Site-8 (Shugal Adi Hagera)

Sieve size (mm)	Weight of sieve	wt of sieve+ retained aggregate	Mass Retained (gm)	Percent retained (%)	Com. % retained	Percentage finer (%)
37.50	1707.9	1707.9	0.00	0.00	0.00	100.0
28.00	1730.2	1984	253.80	6.13	6.13	93.9
20.00	1616.8	3597	1980.20	47.84	53.97	46.0
14.00	1358.1	2919.2	1561.10	37.72	91.69	8.3
10.00	1326.1	1640.3	314.20	7.59	99.28	0.7
6.3	1360.1	1373.8	13.70	0.33	99.61	0.39
5.00	1372.6	1386.5	13.90	0.34	99.94	0.1
pan	759.1	761.4	2.30	0.06	100.00	0.0
		total	4139.20			



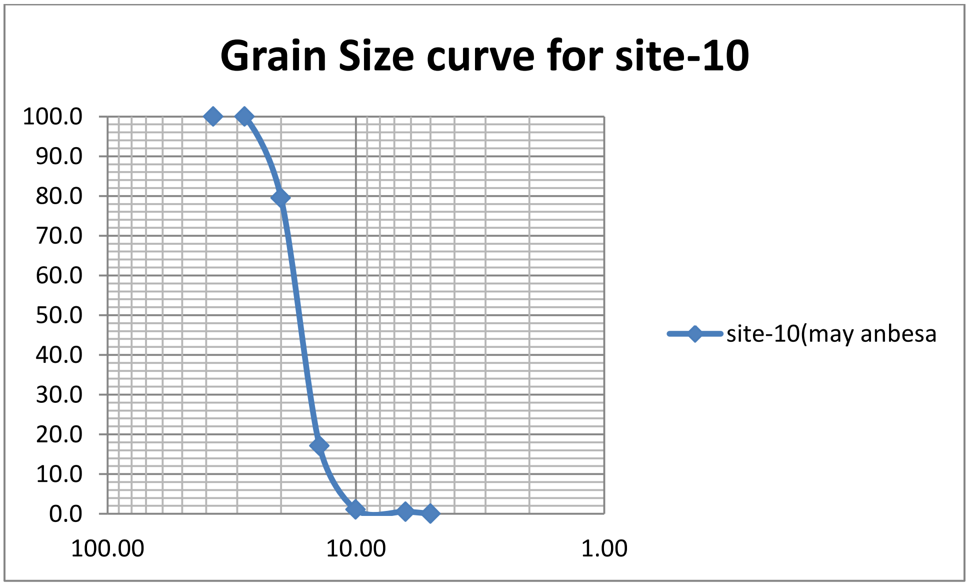
Appendix 2I Site-9 (May Hebei)

Sieve size (mm)	Weight of sieve	wt of sieve+ retained aggregate	Mass Retained (gm)	Percent retained (%)	Com. % retained	Percentage finer (%)
37.50	1707.9	1707.9	0.00	0	0.00	100.0
28.00	1730.2	1936.5	206.30	4.68	4.68	95.3
20.00	1616.8	3153.9	1537.10	34.85	39.53	60.5
14.00	1358.1	3177	1818.90	41.24	80.76	19.2
10.00	1326.1	1946.6	620.50	14.07	94.83	5.2
6.3	1360.1	1470.1	110.00	2.49	97.33	2.67
5.00	1372.6	1484.7	112.10	2.54	99.87	0.1
pan	759.1	764.9	5.80	0.13	100.00	0.0
		total	4410.70			



Appendix 2J Site-10 (May Anbesa)

Sieve size (mm)	Weight of sieve	wt of sieve+ retained aggregate	Mass Retained (gm)	Percent retained (%)	Com. % retained	Percentage finer (%)
37.50	1707.9	1707.9	0.00	0	0.00	100.0
28.00	1730.2	1730.2	0.00	0.00	0.00	100.0
20.00	1616.8	2376.1	759.30	20.44	20.44	79.6
14.00	1358.1	3676.7	2318.60	62.42	82.87	17.1
10.00	1326.1	1922.8	596.70	16.06	98.93	1.1
6.3	1360.1	1379.2	19.10	0.514	99.45	0.55
5.00	1372.6	1391.5	18.90	0.51	99.95	0.0
pan	759.1	760.8	1.70	0.05	100.00	0.0
		total	3714.30			



Appendix A-7: Flakiness index test result of the coarse aggregate

Site-1 (Shugal or Sordo)

Sieve size (mm)	Weight retained (g)	Retained (%)	Passing (%)	Thickness gauge (width of slot) (mm)	Weight of aggregate passed through the gauge (g)
50		100	100	50-37.5	0
37.5	0	0	100	37.5-28	0
28	98.4	2.8	97.2	28-20	281.3
20	1303.9	37.4	59.7	20-14	379.2
14	1744.5	50.1	9.6	14-10	67.4
10	332.8	9.6	16.4	10-6.3	0.6
6.3	3.2	0.1		Total (M1)	728.5
Total (M2)	3482.8	100.0			

Formula: Flakiness Index (F.I.) = $(M1/M1+M_{2)}$ x 100

M1 = Combined weight of all particles passing the gauge

M3 = Total mass retained on 6.3mm sieve and passed 63mm

Calculation:

F.I. = M1 / M1+M2 x 100 = 17.3% round to 17%

N.B. Flakiness Index shall be reported to the nearest whole number

Site name	FLAKINESS
Shugal Sordo	17%
Melate	20%
Kuean	18%
Dalule	21%
May Keyeh	20%
Emba Awuer	20%
Adi Kelkel	26%
Shegul Adi Hagera	20%
May Hebei	21%
May Anbesa	21%

B. Pictures

Appendix B-1: Taking the sample from crushed quarry

Appendix B-2: Air drying of specific gravity

Appendix B-3: Specific gravity balance

Appendix B-4: When out from oven dry the samples

Appendix B-5: LAA machine