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

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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.

Index Terms— Aggregates crushed value, Concrete aggregates, Rock properties as aggregate materials

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1 INTRODUCTION

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).

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.

2 RESEARCH METHODOLOGY

2.1 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 13026′ to 13036′ North latitudes and 39025′ to 39033′ 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 km2.

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).

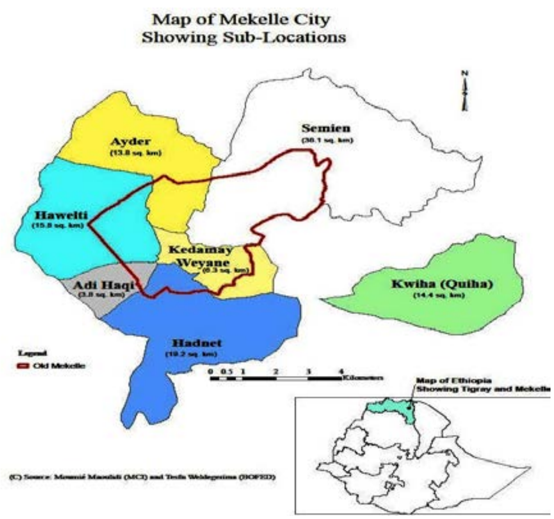

Figure 1: The specific sites (Source: MAO, 2010)

2.2 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 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

2.3 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.

2.3.1 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.

2.3.2 Sample collection and laboratory Testing

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 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 LABORATORY TEST RESULTS AND DISCUSION

3.1 General

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.

3.2 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.

3.2.1 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 3: 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**

3.2.2 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: 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

3.2.3 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 5: 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

3.2.4 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 6: 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

3.2.5 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/m3. This shows that the aggregates from the different sites are with the ASTM standard requirements for normal weight aggregates.

Table7: 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

3.2.6 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 8: 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

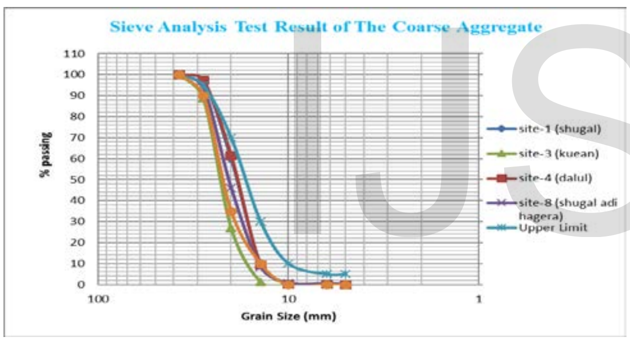

Figure 2: Particle size distribution curve for the different quarry sites

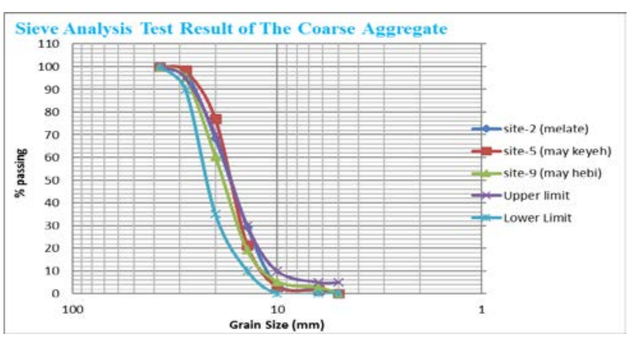

Figure 3: Particle size distribution curve for the different sample

3.2.7 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.

Table9: 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 CONCLUSION

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.

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