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THE NEED FOR STANDARDIZATION OF AGGREGATES FOR CONCRETE PRODUCTION IN ETHIOPIAN CONSTRUCTION INDUSTRY

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Abstract

Concrete is one of the versatile and widely used building material 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. This calls for a critical identification and classification of aggregates so that they are used to meet the intended purpose.

In this article, the physical, mechanical, and chemical properties of aggregates are reviewed. The sources and modes of production of coarse and fine aggregates in the Ethiopian construction industry are assessed. The properties of some aggregate samples, which are mainly quarried from around the city of Addis Ababa, where the major share of construction works are taking place, are discussed. The test results are compared with the standard requirements and concrete compressive strength data's obtained using different aggregate qualities are evaluated. Based on the findings, conclusions are drawn and recommendations are forwarded.

Keywords

Aggregates, Alkali-silica reaction, Basalt, Cement, Concrete, Pumice, Rock, Scoria

INTRODUCTION

Concrete is a versatile and most popular construction material in the world. It is produced by mixing fine and coarse aggregates, cement, water and additives in a certain prescribed proportion. 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 parent materials of aggregates are derived mainly from volcanic activity. 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 riverbeds.

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 dependant on the aggregate, which in turn depends on strength of parent rock, purity, surface texture, gradation and so on.

Basically three classes of aggregates are identified depending on their weight: light weight, normal weight and heavy weight. Lightweight aggregates are aggregates whose maximum dry loose bulk density is about 880kg/m^3 for coarse aggregates and 1040kg/m^3 for all-in aggregates [1]. Lightweight aggregates are classified as *natural* and *artificial* depending on how they are secured. The main natural lightweight aggregates are diatomite, pumice, scoria, volcanic cinder, and tuff. Except for diatomite, all are volcanic in origin. Pumice and scoria are more widely used for hollow and solid concrete block production in Ethiopia.

Normal weight aggregate is generally produced in Ethiopia by crushing parent rocks using mechanical crushers or traditional methods. Basaltic rock is a good example of parent rock, which is used mainly for coarse aggregate production in and around Addis Ababa.

The main focus of this article 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.

ORIGIN AND CLASSIFICATION OF AGGREGATE

Aggregates can be classified as natural or artificial depending on their sources. Natural aggregates are obtained from quarries by processing crushed rocks or from riverbeds while artificial aggregates are obtained from industrial by products such as blast furnace

slag. Natural aggregates are most commonly obtained and are relevant for Ethiopian construction sector since artificial aggregates are hardly produced in the country.

It is an accepted fact that the physical and mechanical properties of aggregates are inherited from parent materials, while the properties of the parent material intern depend on its geological formation. Geologically rocks are classified into three major divisions based on their origin, namely Igneous, Sedimentary and Metamorphic. Igneous rocks are rocks formed from the solidification of molten matter (magma) either at or below the earth’s surface. Igneous rocks are divided into two: plutonic or intrusive, those having cooled slowly with in the earth (e.g. granite, diorite, gabro, etc) and volcanic or extrusive, those which are formed from quick cooled lava (eg. volcanic rock, volcanic glass, felsites, basalt, etc). Plutonic rocks usually have grain sizes larger than 1mm and classified as course or medium grained while volcanic rocks have grain sizes less than 1mm and are classified as fine-grained. These grains are, however, not visible to the naked eyes [2,3].

The most commonly found aggregate rocks in and around Addis Ababa area are basalt, trachite, and ignimbrite. Basalt is a fine-grained extrusive rock, of which the glass content is generally low. Karstaedt analyzed the chemical composition of basaltic stone by taking samples from a quarry in the vicinity of Addis Ababa Bole International Airport [4]. The quarry was planned for a supply of aggregate for the construction of the new Addis Ababa International Airport and the chemical composition was summarised in Table 1.

Table 1 Chemical composition (%) of Addis Ababa Basalt, Bole area [4].

SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	H ₂ O	LoI	TiO ₂	MnO
49	16.1	13.74	8.2	5.4	3.3	0.9	0.8	0.7	2.4	0.2

Sedimentary rocks are formed as strata as a result of sedimentation from disintegrated products. They are stratified rocks usually laid down under water although they can also be formed by wind and glacial action. The sediments are cemented together or compacted during geologic time with varying degree. Typical examples are sand stone, limestone, and shale.

Metamorphic rocks are formed from pre-existing igneous, sedimentary or metamorphic rocks by the action of heat or pressure or both. The change may be textural, structural or mineralogical accompanied by changes in chemical composition. Typical examples are marble, meta-quartzite, and slate.

Properties of Aggregate

The physical properties like specific gravity, porosity, thermal behaviour, 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.

Aggregate Size, Shape and Surface Texture

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. Secondly, for a given volume of concrete, using larger aggregate results in a smaller volume of paste, thereby providing more restraint to volume changes of the paste. This may induce additional stresses in the paste, creating microcracks prior to application of load, which may be a critical factor in very high strength concretes [5]. 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. The essential requirement of an aggregate for concrete production is such that it remains stable within the concrete and in the particular environment throughout the design life of the concrete without adversely affecting the performance of concrete in either the fresh or hardened state.

Mechanical Properties

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. Rougher texture results in a greater adhesion or bond between the particles and cement matrix. Determination of the quality of bond is rather difficult. When bond is good, a crushed concrete specimen should contain some aggregate particles broken right through, in addition to the more numerous ones separated from the paste matrix. On the other hand, an excess of fractured particles suggest that the aggregate is too weak.

It is generally understood 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 required information about the aggregate particles has to be obtained from indirect tests, such as crushing strength of prepared rock samples, crushing value of bulk aggregate, and performance of aggregate in concrete. 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 failure by impact, and it is usual to determine the aggregate impact value of bulk aggregate based on ASTM standard [1]. Toughness determined in this manner is related to the crushing value, and can, in fact, be used as an alternative test.

Hardness, or resistance to wear, is an important property of concrete used in roads and in floor surfaces subjected to heavy traffic. The aggregate abrasion value of the bulk aggregate is assessed using Los Angeles abrasion machine. 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.

Physical Properties

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.

Chemical Properties: Alkali-Aggregate Reactions

Alkali-aggregate reactions are chemical reactions in concrete involving certain active mineral constituents often present in some aggregates and the sodium and potassium alkali hydroxides from portland cement paste. The reactions are potentially harmful only when they produce significant expansion and hence cracking of concrete, leading to loss of strength and elastic modulus.

Alkali-aggregate reactions occur in two forms: *alkali-silica reaction* (ASR) and *alkali-carbonate reaction* (ACR). Alkali-silica reaction is the reaction between the alkali hydroxide in portland cement and certain siliceous rocks and minerals present in the aggregates, such as opal, chert and chalcedony. The products of this reaction often result in significant expansion and cracking of the concrete and ultimately, failure of the concrete structure. Alkali-carbonate reaction on the other hand is the reaction between the cement hydroxides and certain dolomitic limestone aggregates which can also result in deleterious expansion. Alkali-silica reaction is of more concern than alkali-carbonate reaction because the occurrence of aggregates containing reactive silica minerals is more common. Alkali reactive carbonate aggregates have a specific composition whose occurrence is relatively rare [6,7]. Since the occurrence of dolomitic limestone is very rare in Ethiopia, more emphasis should be given to alkali-silica reactions.

Abebe et al in a recent study reviewed the mechanisms of alkali-silica reactions and discussed the potential of such reactions in Ethiopia by examining: i) the chemical and mineralogical composition of selected rocks, ii) the oxide concentration of silica sand obtained from different localities, iii) the alkali content of cements produced in Ethiopia and iv) the temperature and relative humidity of Ethiopian conditions [9]. The study emphasized the need for laboratory analysis of aggregate samples with a particular focus to those aggregates susceptible to alkali silica reactions.

Deleterious Substances

There are three broad categories of deleterious substances that may be found in aggregates: impurities which interfere with the processes of hydration of cement, coatings preventing the development of good bond between aggregate and cement paste, and certain individual particles which are weak or unsound in themselves. These harmful effects are distinct from those due to the development of chemical reactions between the aggregate and the cement paste. Aggregates may also contain sulphate or chloride salts that can be easily removed by washing in fresh water as otherwise it can have dangerous consequences in reinforced concrete structures resulting in corrosion of steel.

LOCALLY AVAILABLE AGGREGATES

The most commonly available local coarse aggregates are obtained from normal weight crushed basaltic stone and lightweight volcanic ash, which are a member of a family of igneous rock (scoria or pumice).

Basalt

Basalts are dark colored, fine-grained extrusive rock. The mineral grains are so fine that they are impossible to distinguish with the naked eye or even with a magnifying glass. They are the most widespread of all the igneous rocks. Most basalts are volcanic in origin and were formed by the rapid cooling and hardening of the lava flows. Some basalts are intrusive having cooled inside the Earth's interior.

Pumice

Pumice is a very light, porous igneous rock that is formed during volcanic eruptions. It is an excessively cellular, glassy lava, usually rhyolite or dacite in composition. It is usually white-gray to yellow in color, but may be red, brown or sometimes black according to the mineral oxides or impurities it contains. Pumice is bubble rich and therefore has very low density. Due to this low density, pumice is very light and can even float in water. It has a bulk density of 500-900kg/m³. The varieties of pumice, which are not too weak structurally, make a satisfactory concrete with a density of 700 to 1400kg/m³ and with good insulating characteristics, but high absorption and high shrinkage characteristics [9-12].

Scoria (red ash)

Scoria is a volcanic cinder which generally has a rough surface and high porous nature, with its pores chiefly in the form of vesicles instead of the more tube like, interconnected pores of the pumice. Scoria vary in color often within the same cone and may be black, red, gray or brown in color. The black color is mostly due to its high iron content while the red color is caused by oxidation of iron in the scoria, which might have happened because of rainfall during the eruption. Scoria aggregate is found extensively in Ethiopia especially in the Great Rift Valley, which crosses the Northeastern part of the country. It is mainly used as a base coarse material in road construction and as an aggregate in the manufacturing of masonry blocks [9-12].

ENGINEERING GEOLOGICAL MAP OF ADDIS ABABA

The geological formation of Addis Ababa soils is dominantly igneous rock. This is due to the volcanic activity the area undergone in geological times. The most abundant rock types are basalt and trachite. The red ash, which is found in the near vicinity of the city, is just an oxidized form of the basalt during eruptions. Figure 1 shows quarries and their distribution in Addis Ababa [13].

The different quarries in Addis Ababa produce crushed aggregates, red ash, stones, clay and selected materials. Basalt stone is used for the production of aggregates on major quarries. The stone is crushed into different aggregate sizes. It is mainly mined around big Akaki and Kilentu rivers, Bole Bulbula and Keranyo which are the areas producing the majority of the city's demand. Red ash (scoria) is mainly used for block making. It is mainly mined around Tullu Dimtu. A reasonable amount of aggregate is also brought from the areas in the vicinity. Scoria and crushed gravel is also brought from Debrezeit area.

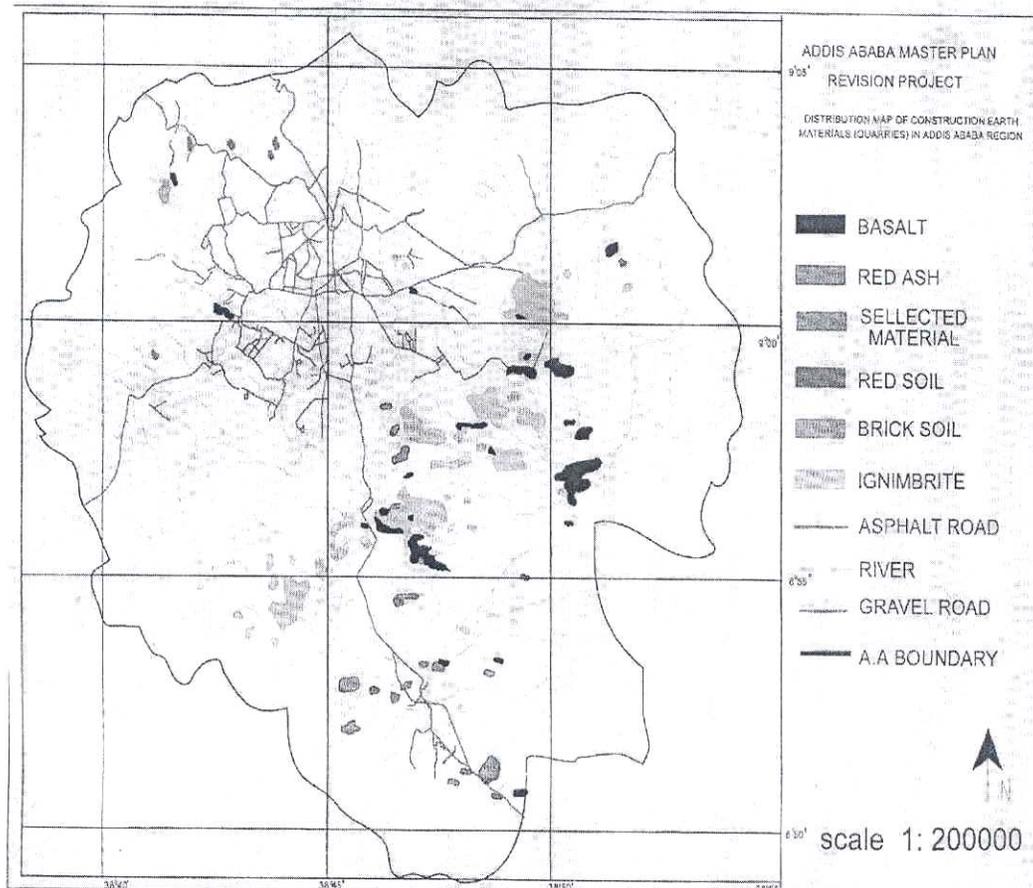


Figure 1 Quarries and their distribution in Addis Ababa [13].

MODE OF AGGREGATE PRODUCTION IN ETHIOPIA

Almost all aggregates used for construction in Ethiopia are natural in origin. The majority of coarse aggregate sources in Addis Ababa are located around rivers within the city, with the exceptions of sources of scoria. The big riverbanks of Akaki River and Matahara river (around bole air port) are the main suppliers of aggregates to the city of Addis Ababa. Scoria is mined from big mountains in areas of flat or rolling terrain. Quarry sites are established at the outskirts of the city on the areas, which were not inhabited until very recently.

Coarse Aggregate Production In Ethiopia

The two dominantly produced aggregates, lightweight (namely pumice and scoria) and the normal weight (basalt), do have different modes of productions. The lightweight aggregate is produced from quarries by simple digging or bulldozing as it is a soft material and the different sizes produced mainly depend on digging or bull dozing.

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 donot 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.

On the other hand, the modern way of aggregate production requires aggregate crushing machines so that the quarry is either drilled, blasted or dug with special mechanisms, fed to crushers, crushed, sieved and separated according to their sizes. The different sizes commonly known as 01, 02, 03 and 04 are stockpiled separately. Size 02 means aggregates having a maximum aggregate size of 20mm, while 01, 03, 04 has a maximum aggregate size of 10, 30 and 40 mm resepectively. This method enables to classify aggregates based on their maximum aggregate sizes and enable engineers to suggest unique mix proportion to arrive at the required concrete quality production. The dust content over the surface of the aggregate, however, is not given adequate emphasis by the producers while creating serious problems during concrete production. Besides, no attempt has been made, so far, to rehabilitate quarry sites after the mining operation is completed. Not even the old mining sites are systematically recorded and marked properly. Typical coarse aggregate manufacturing site around Addis Ababa is shown in Plate 1.



Plate 1 Typical coarse aggregate manufacturing site around Addis Ababa.

Fine Aggregate Production In Ethiopia

Fine aggregates (sand), is unconsolidated and highly variable mixtures of different constituents. The construction industry utilizes sand mainly from streambeds, which are commonly derived from quartzo-feldspathic basement rocks, sandy marine sidements and alluvial deposits [14]. The major sand supply for the construction works in and around Addis Ababa is the Awash basin located about 70-120 km southeast of the city. The method of quarrying sand is generally very old and the producers do not attempt to clean and grade the sand right from the source. A sand with a silt content as high as 20% is usually purchased from those quarry sites. Typical method of sand quarrying operations and transporting to the near by loading station using animal transport are shown in Plates 2 and 3, respectively.



Plate 2 Typical sand quarrying practices along the Awash basin.



Plate 3 Transporting of quarried sand to loading trucks.

This sand is then transported to Addis Ababa and sold loaded on a truck, similar to that of coarse aggregates, without further attempt to wash, dry and classify based on physical parameters. 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. Besides, aggregates are normally stored open to the atmosphere, resting on the unprepared ground exposed to extreme temperature variation and possible silt contamination from the earth as shown in Plate 4. Contractors are thus confronted with frequent additional cost of testing for new materials and extra time will thus be required to complete projects, which eventually add to increased cost of the project.



Plate 4 Storage and variation of sand quality in a typical construction site.

Research made in the Addis Ababa University has indicated that a significant increase (about 50%) in compressive strength of concrete is obtained by changing the properties of aggregates keeping the grading limit, cement content and silt content the same [15,16]. This calls for a concerted effort by relevant government agency, concrete producers and professional associations in standardising of aggregate particles interms of size, shape, density, texture and other relevant parameters with the view of producing quality product at a reduced cost.

RESEARCHES ON LOCAL AGGREGATES

Mikyias investigated the concrete making properties of lightweight aggregate made with Ethiopian pumice and scoria [17]. Satisfactory structural capacity has been obtained in addition to reduction of imposed dead loads on structures.

The use of local lightweight aggregate (scoria) as a replacement to crushed rocks has also been studied by Girma ZY [18]. The aggregates used in the tests were a combination of course sand and scoria. The structural properties of lightweight aggregates, which were used with varying proportions to normal weight, have been found to be structurally sound. An increase in the proportion of the lightweight aggregate has, however, showed a gradual decrease in the compressive strength.

Daniel A. studied on the properties of concrete and masonry blocks using pumice and scoria at different proportions. The finding indicated that structural concrete can be produced using locally available light weight aggregates provided the grading, cement content, and other parameters are considered [19,20].

Tigist G. performed tests on potential use of local normal weight aggregates for the production of high strength concrete. The result confirmed that the locally available basalt stone can reasonably be used to produce concrete of higher strength. With the application of super plasticizers, it was demonstarted that concrete strength as high as 90MPa could be obtained [15,16]. This strength was obtained by proper selection of aggregates (removing friable particles), limiting the maximum size of aggregates, washing to remove material finer than No-200 sieve and using higher quantity of cement in combination with limiting the w/c ratio. The research indicated the potential of producing high strength concrete using locally available materials provided the required measures are taken and encouraged the practitioners in the industry to go for a higher quality of concrete rather than the most widely specified class of concrete, which is C-25.

DISCUSSION AND SUMMARY OF LABORATORY TESTS

Particle size distribution of aggregates is important to get the maximum possible close packing of aggregates, which reduces voids and consequently the required paste, and attain economical mix. Close packing also results in stronger mix, as aggregates tend to carry more loads. Thus adequate care should be taken in proper classification and grading of aggregates compatible with standard requirements.

Sample laboratory test results obtained during quality checks for quarry establishment and for concrete mix design preparations in Addis Ababa were gathered from two experienced laboratories, namely CDSCo, and TCDSCo, and are summarised in Tables 2, 3 and 4.

Table 2 Laboratory test results on course aggregate obtained from different crusher sites.

Crusher site	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Sp.Gr. (SSD)	-	2.86	-	-	-	-	-	-	-	3
Absorp. (%)	-	1.2	2	-	-	1.4	1.2	1.6	-	0.9
LAA (%)	15	18	16	19	12	16	16	16	14	12
Sound. (%)	1	1	1	1	10	2	1	1	6	1
ACV (%)	-	15	14	15	-	18	17	14	-	-
AIV (%)	-	-	-	14	-	15	13	-	-	-
FI (%)	24	27	27	-	21	43	29	42	-	-

Source: Transport Construction and Design Share Co. December 2004.

Table 3 Tests for Trachitic stone on Addis Ababa - Ambo road for crusher sites on course aggregate.

Crusher site	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	
Depth (m)	1.3-15	7.6-15	3.5-15	1.85-15	4.9-15	4-15	0-15	2.4-15	0-15	Mean
Sp Gr.	2.85	2.84	2.85	2.84	2.87	2.84	2.84	2.85	2.87	2.9
Absorp. (%)	1.7	1.7	1.8	1.9	0.8	1.4	1.5	1.5	1.4	1.5
LAA (%)	13	15	15	15	15	17	17	16	15	15.3
Sound. (%)	28	25	40	10	2	2	11	2	2	13.6
ACV (%)	15	17	16	16	18	18	18	17	17	16.9
FI (%)	22	37	30	36	38	42	44	44	47	37.8

Source: Transport Construction and Design Share Co. December 2004.

Table 4 Tests for concrete mixes on coarse aggregate.

Contractor	A	B	C	D	E	F
Crusher site	1	2	3	4	5	6
Specific gr. (SSD)	2.74	2.88	2.68	2.79	2.49	2.67
Absorp. (%)	1.07	3.31	1.79	1.97	2.53	1.2
LAV (%)	12	13	19	1.54	13	21
Gradation	Well graded	Coarser	Finer	Finer	Finer	Good

Source: Construction Design Share Co. December 2004

Since, lightweight aggregates are not commonly used for structural purposes, it was not possible to get sufficient number of test results. The reason for limited application of lightweight aggregates for structural concrete could be due to lack of confidence in using the material for structural purposes. In this regard, researchers should attempt to justify the use of lightweight aggregates for structural concrete and forward recommendations on specific application of lightweight concrete in construction undertakings.

Comparison of test results with standards recommendation

The following general trends have been observed from the analysis of sample laboratory test results.

- i) Los Angel's Abrasion value specified in ASTM C 33 is 50%, which is much higher than the mean value obtained from the sample test results indicating that the basaltic stone of AddisAbaba is of satisfactory toughness. Provided, the necessary gradation and physical identification are made, it should be possible to produce higher strength quality concrete with the available aggregate materials.
- ii) Soundness is one of the quality indicators of course aggregates. A maximum of 18% for magnesium sulfate and 12% for sodium sulfate aggregate source is allowed for concrete according to ASTM 33. The basaltic stone of Addis Ababa has appreciable quality in this respect. However, the variation in soundness obtained from trachitic stone requires further scrutiny. It could be due to intrusion of water and possible weathering that can affect part of the rock, which could bring the aggregate to a state of unfit.
- iii) Unfortunately, it has been found that no attention is given to test parameters such as friable particles, cherts, and material finer than no. 200 sieve.

CONCLUSIONS

The following conclusions are drawn based on the research work:

1. The general quality of Addis Ababa basaltic stone for aggregate production is very good.
2. The quarry sites around Addis Ababa are not systematically selected and not properly rehabilitated after mining. This calls for adequate attention by concerned bodies.
3. Aggregate producers should give proper attention in producing consistent and quality products to the customers, which are compatible with the standard

- requirements. The producers should also be able to guarantee the quality of their products satisfying the required relevant standards.
4. Designers should be courageous to specify higher strength quality concrete, which will have a great saving in space, and improved concrete properties rather than limiting concrete class mainly to C-25.
 5. The capabilities of material laboratories in handling the required standard investigations should be improved, and laboratory test results should be compiled indicating the source, material properties and consumer's identification.
 6. Aggregate, both fine and coarse, identification, quarrying, storage and handling should be done professionally. In addition, a national wide effort has to be made in preparing mix design procedure, which would enable to arrive at the desired quality concrete production without much difficulty.
 7. It has been confirmed that in-depth investigation of aggregate properties is highly important to assure quality against reactivity of aggregates. In this regard, close investigation of geological properties would be easy if engineers and geologists work together.
 8. Quarry sites should be checked periodically, without giving notice, by independent body for satisfying standard requirements.

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