Addis Ababa University
Addis Ababa institute of technology
School of civil and environmental engineering
Structural Engineering Stream

Effect of Fines Content on Compressive strength of Concrete with Crushed Stone Sand

By

Abraham Mitiku

A thesis submitted to the School of graduate studies of Addis Ababa University
In partial fulfillment of the requirement for the Degree of
Master of Science
In
Structural Engineering

Advisor
Dr. Esayas Gebreyouhannes

April, 2019

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DECLARATION

I, the undersigned declare that this thesis entitled "Effect of fines content on compressive strength of concrete with crushed stone sand " is my original work, prepared under the guidance of **Esayas Gebreyouhannes (Ph.D)**. All sources of material used for this research have been dually acknowledged. Moreover, this thesis has not been presented by any other person in this or any other university or Higher Educational Institute for an award of a degree.

Abraham Mitiku

Signature _______________

Date_________________

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I would like to pass my deepest thanks for praiseworthy GOD for all the things that happened in my life, especially for giving me strength and endurance to carry out this study. I wish to express my sincere thanks to my advisor **Dr.-Esayas Gebreyouhannes,** for his level of responsibility and for unlimited guidance in the subject matter.

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Abraham Mitiku

ABSTRACT

Crushed rock sand is a term used for fine aggregate passed by 4.75mm and retained on 150μm sieve size which are manufacture in quarry. Because of raped booming of construction industry in Ethiopia, Natural River sand increasingly depleted and its method of production was affect our planet. Concrete is the most dominant building material in construction world. From the given produced volume of concrete more than 70% is aggregate. So, therefore the quality of concrete is strongly influenced by aggregate's physical and mechanical properties. In this research physical properties of aggregates are reviewed, compressive strength of concrete produced from CR sand and River sand were tested to learn the influence of fines content in CR sand on concrete production was investigated.

In very beginning, crushed rock sand and river sand sample to be used in concrete mixes were collected from YENCOMAD construction Plc. crushing site and Alem Tena Area River respectively and their physical property were studied. Twenty-four different concrete mix having three different water to cement ratio (0.4, 0.5 and 0.6) and four different fines content (6%, 9%, 12% and 15%) for both river and crushed sand were prepared using sand to aggregate ratio 0.45 and water content 190kg/m3. The slump was range between 50mm to 90mm for both sand. The average compressive strength of crushed stone sand concrete between 20 and 60 Mpa and for river sand concrete ranging between 15 to 50 Mpa. A total of 144 cube was casted for trial and 216 cube were casted as final laboratory test. Conclusion and recommendation were drown based on laboratory result analysis.

The test results are compared with the standard requirements and specification. Based on the findings, conclusions are drown and recommendations are forwarded.

Keywords: *aggregate, compressive strength, concrete, Crushed rock sand and river sand*

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ABBREVIATIONS AND NOTATION

ACI	American Concrete Institute
ASTM	American Standard for Testing and Measurement
CRS	Crushed Rock Sand
RS	River Sand
EBC	Ethiopian Building Code
Cm2	Square Centimetre
FDRE	Federal Democratic Republic of Ethiopia
FM	Fineness Modulus
G	Gram
KN	Kilo Newton
Gm/cm3	Gram per cubic centimetre
H2O	Water
Kg/m3	Kilogram per cubic meter
Kg	Kilogram
Kip	Kilo pound
Lb/yd3	Pound per cubic
MgO	Magnesium Oxide
MPa	Mega Pascal
N	Newton
OPC	Ordinary Portland cement
PPC	Portland Pozzolana Cement
RC	Reinforced Concrete
SSD	Saturated Surface Saturated
µm	Micrometre
MM	Millimetre
M	Meter
KM	Kilo Meter
AAiT	Addis Ababa Institute of Technology
Dr.	Doctor
Pro.	Profess

CHAPTER ONE
INTRODUCTION

1.1. Background

Cement, sand and aggregate are essential needs for any construction industry. The aggregates are usually coarse and fine aggregates. Sand is a major material used for preparation of mortar and concrete and plays a most important role in mix design. It is considered as fine aggregate.

It is generally known that, building good quality of concrete structure is highly depending up on the good quality of concrete. Good quality of concrete is also produced by carefully mixing of water, cement; fine and Coarse aggregate combining add mixture as needed to obtain the optimum product in quality and economy for any use. Good concrete, whether plain, reinforced or pre-stressed, Should be strong enough to carry superimposed loads during its anticipated life. Other essential properties include permeability, durability, minimum amount of shrinkage, and cracking [1].

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/m3 for coarse aggregates and 1040Kg/m3 for all-in aggregates [2].

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 [3]. In addition to supply necessary material and machinery to produce good quality of concrete the following point is factors contribute to the production of good quality of concrete [1].

a. Knowledge of the properties and fundamental characteristics of concrete making materials and the principles of design
b. Reliable estimates of site conditions.
c. Quality of component materials.
d. A careful measurement of weigh-batching of cement, water and aggregate
e. Proper transport, placement and compaction of the concrete
f. Early and thorough curing, and
g. Competent direction and supervision

The quality of good concrete is dependent mainly on the quality of its constituent materials. It is a known fact that concrete making aggregates constitute the lion share of the total volume of concrete.

In addition to quality, one extremely important factor in concrete production is consistent supply of the coarse and fine aggregates. In this regard, a coarse aggregate is produced by crushing basaltic stone, and river sand is the major natural resource of fine aggregate in Ethiopia. However, the intensive construction activity is resulting in a growing shortage and price increase of the natural sand in Ethiopia. In addition, the aggregate and concrete industries are presently facing a growing public awareness related to the environmental influence of their activities and river sand is also scarce. In general consumption of natural sand is high, due to the large use of concrete and mortar. Hence the demand of natural sand is very high in developing countries to satisfy the rapid infrastructure growth. The developing country will face shortage of good quality of natural river sand. So, therefore the need to find an alternative concrete and mortar aggregate material to river sand in construction works has assumed greater importance now a days. Researcher and Engineers have come out with their own ideas to decrease or fully replace the use of river sand and use recent innovations such as manufactured sand, robot silica or sand, stone crusher dust, filtered sand, treated and sieved silt removed from reservoirs as well as dams besides sand from other water bodies [4].

One possible alternative material that can be used as a replacement for natural river sand is the use of *crushed rock sand (manufactured sand)*. Due to the forecast shortfall in the supply of natural sands and the increased activity in the construction sector, it is apparent that time will come, when manufactured sand may play a significant role as an ingredient in concrete production.

Therefore, the purpose of this study will directly focus on evaluating Crushed Rock Sand from our quarry site in partially or fully replacing river sand in a concrete design. Moreover, and most significantly apart from being a replacing material, the property of crushed rock sand when in use of concrete will be investigated. The very sensitive parameters of concrete in concrete structure design and construction were investigated to evaluate to what extent this material (CR Sand) can contribute to concrete structure construction while still being technically feasible.

To this effect, this research is carried out to study the prospects of the uses of CR sand in Ethiopia.

In the experimental study different concrete mixes with different percentage of manufactured sand and fines were prepared and the respective fresh and hardened properties of the resulting concrete mixes were determined and analysed.

In due Coarse of the experimental study, concrete mix designs using limited proportions of fines varied from 6% up to 15% in concrete, resulted in hardened to sampling and difficult to workability. To overcome such problems an admixture was added. Besides providing water reduction, the use of such an admixture had imparted superior workability to the mix. Finally, from the obtained results conclusions were made and recommendations were forwarded.

1.2. Objective and Scope

1.2.1. Scope

The main and cheapest natural sources of sand are riverbeds and these natural resources are depleting very fast. Due to various reasons good sand is not necessarily readily available and it should be transported from long distances. Transportation is a major factor in the delivered price of construction sand. Moving construction sand to the market increases the sale price of the market significantly, due to the high cost of transportation. The use of specific deposits of sand depends on the performance of these materials in standardized engineering tests, including, but not limited to, grain size distribution, shape and percentage of silt or clay.

It is agreed that natural sand, which is available today, is deficient in many aspects to be used directly for concrete production. Some of the factors include, it doesn't contain fine particles, in the required proportion. It contains an organic and soluble compound that affects the setting time and properties of cement. The presence of impurities such as clay, dust and silt coatings, increase water requirement and impair bond between cement paste and aggregate. The presence of organic materials affects durability of the concrete therefore it shortens the life of the concrete product.

From the environmental point of view, the following are areas of problems in the future.

I. Digging of the sand from riverbeds reduces the water head, so less percolation of rainwater in ground resulting in lower ground water level. In the absence of sand, more water gets evaporated due to direct sunlight. If there is no sand in riverbeds, water will not be filtered.
II. In the future aggregate prices are expected to rise due to decrease in sand deposits, quality and more environmental and land use regulations, which are associated with the rapid urban expansion that contributes to these shortages. Therefore, the importance of finding substitute sources of fine aggregate for concrete production that can be used in place of natural river sand cannot be overemphasized.

Nevertheless, the local construction industry in Ethiopia, like other country, has been using river sand for many decades. In fact, the experience of most concrete/mortar producers in Ethiopia is based mainly on the use of river sand. With river sand changed to river sand substitutes (crushed rock sand), which may have very different characteristics; it takes time for the local construction industry to adapt. Hence, apart from identifying suitable river sand substitutes to supplement or even completely replace river sand, it is important also to evaluate the characteristics of the CR sand and the possible effects of using the CR sand on the performance of the concrete/mortar produced so that the potential users of the substitutes would better understand the major differences between river sand and CR sand. So, therefore the main focus of this thesis is to study the behaviour and quality of crushed rock sand to recommend using crushed rock sand as substitute of river sand in concrete design. The investigation is an attempt to evaluate the characteristics of mortars and concrete using CR sand as fine aggregate. For the comparison purpose characteristics of mortar and concrete with river sand has also been explore.

1.2.2. Experience of the country

The existing fact in Ethiopia is using crushed rock sand very weak, this is happened because government is not provide code and using manual for different actors in the industry. Few private aggregate manufacturers recommended to use crushed rock sand mixing with river sand. When I visit different aggregate manufactures to get sample for laboratory test, I understand that no company produced crushed rock sand for commercial purpose, rather the contractors used by product of other aggregates as sand. The crushers (Jaw Crusher) intentionally install to produce coarse aggregate from 40mm up to 10mm, across the process the crusher disposing less than 10mm size crushed aggregate with quarry dust, now a days the contractors used this disposed rock fragment with dusts as sand mixing with river sand. In my visit I was discussed with aggregate producers on the question of why don't produce crushed rock sand for commercial purpose? The producer was very interested to produce but they didn't get manufacturing and user guide Manuel from government for production, quality control, and designing of concrete by crushed rock sand. Few private construction company like YENCOMAD) starting to use crushed stone sand for their own building (Expansion of Dambal City Centre) under the consultation of higher professionals. And few international contractors like (Saliny) on different dam construction starting to use crushed stone sand by their own or international specification.

Generally, the focus of this research is to produce recommendation alternative sand replacing material for contractors and consultants for concrete design, specifically for Crushed Rock Sand users by aligning the test results obtained from laboratory experiments

1.2.3. Research question

The aim of conducting this research is to find out to what extent the fines affect compressive strength of concrete with crushed rock sand. It questioned, the quality of crushed rock sand for the production of medium and high strength concrete. It is also inquired the allowable percentage of fines to assure the required compressive strength.

1.2.4. General Objective

To study the effect of crushed rock sand and quarry fines on the compressive strength of concrete and compare the result with that of concrete produced using river sand.

1.2.5. Specific Objective

- To study mechanical and physical characteristics of crushed rock sand
- To study the amount of fines required during concrete and mortar production
- Investigate compressive strength of concrete using crushed rock sand and compare with natural river sand
- To assess the effects of fines content on concrete
- To determine the optimum and allowable fines content for medium and high compressive strength of concrete.

1.3. Method Statement

The overall process and methodology that is used in this research is outlined to address both general and specific objectives. Literature review, examination of different building codes, conducting laboratory test, discussion on laboratory finding, compile research report and forward a set of recommendation for all stakeholders are the approaches used for this specific research paper. Depending on the sort of task that was being carried out, the overall phases of study is classified under three stage

1.4. Organization of Thesis

1.4.1. Literature review

A detail and comprehensive literature review is made to understand the previous efforts and finding and to check their methods or the way of approaching during test. Literature review is cover or contains review of textbooks, different country building standard or code of conducts, periodical and academic journals, seminar, conference, electronics library material, different official professionals website, student thesis, different university academician presentation paper, lecturer note, Browsing different and related websites, magazines, organization brochures and video document to grasp and collect the root knowledge to achieve the planed objective of the paper. Previous studies related to this topic were also sorted so as to be used as a review of former studies dealt on this topic.

1.4.2. Materials used for laboratory

Behaviour of the crushed rock sand will be predicted analytically based on the crushed rock sand properties. The prediction will be compared with the experimental or laboratory test results. Crushed rock sand was collected from Addis Ababa area (YENCOMAD crusher site). River sand is also selected from the most common site (Alem Tena Ziway area) that was used for different construction site. After measuring all material property (physical property) prepare mix design by considering water content is 190kg/m3 and water cement ratio was 0.4, 0.5 and 0.6. Fines content was varied with 3% starting from 6% up to 15%. The mixed batch was moulding 15X15X15 cm cube for compressive strength test. Different amount of superplastizier was used get the optimum slump range in between 50 up to 90mm. Coarse aggregate selected from YENCOMAD crushing site that was prepared for 3B+G+32 high rise building.

1.4.3. Conducting Laboratory experiment

In this stage two basic activity was done, the first one is standard tests on concrete ingredients and the second one was mix design and main experiments.

a) **Standard tests on concrete ingredients**: - At this stage the ingredients which involve in concrete production were tested and prepared for concrete making. The property of crushed rock sand and coarse aggregate was assessed in the laboratory. This has involved conducting physical characteristic of crushed rock sand with respect to natural river sand, Grain size distribution, Absorption capacity and cube compressive strength of concrete was conducted. Moreover Fines modules of the fine aggregate and silt content was investigated so as to conduct the experiment with a material that satisfies the required standard and specification.

b) **Mix design and main experiments**: - This has involved the proportioning of ingredients for different grade of concrete. The mix design stage basically defines or determine the amount of ingredients (M3). Concrete material was calculated for one meter cube, and prepare the amount of material used for nine cube casting with standard mix proportion and as relative code guideline. Concrete mix design is batched with W/C ratio (0.4, 0.5 and 0.6) and also it further categorized by the amount of fines content (6%, 9%, 12%, and 15%). The test will performed as using relevant standard codes of practice guide line. Slump of concrete were measured from each mix and cast in 15X15X15 cm cube for 3^{rd}, 7^{th} and 28^{th} day compressive strength test.

The ultimate intention of this laboratory experiment was to find out suitability of CR sand as replacement of river sand for concrete design, to know the maximum and minimum Crushed rock sand size for different concrete production and cement sand past and to know about the effects of fines content in CR sand on the performance of concrete.

1.4.4. Analysis and Evaluation

At this stage, the results from the above laboratory experiments were summarized and discussed. After the test result the points that were discussed is consistence of concrete, compressive strength of concrete and other behaviour concrete which is used to understand the behaviour of crushed rock san. The optimum percentage of fines with respect to percentage of mix involved in this research was selected based on the test result. Appropriate water content for optimum percentage of fines was selected and recommendation was drawn for crushed rock sand users.

Finally, a conclusion was drawn and certain requirements, silt content, mixing ration with river sand were recommended based on the result obtained from the laboratory experiment as well as building code recommendation.

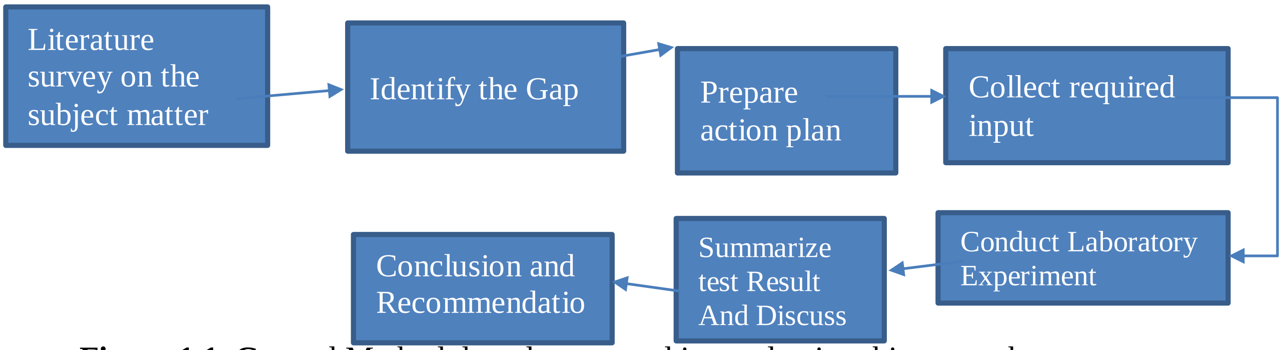


Figure 1.1. General Methodology layout used in conducting this research.

1.4.5. Conclusion and recommendation

Compiling and writing up the research depend up on analytic and laboratory finding. Present the output and finding for end users. The main intension of this section was to draw recommendation for Material Engineers and quality controller, Crushed rock sand manufacturers, concrete designer, material test laboratory technician, educational institutions (which use the information for academic purposes), Researchers for further investigation and come up with alternative idea and Concrete producers to focus on manufacturing of CR sand in order to produce comparable, even better, quality of concrete. The research result will resolve the conflict between client, contractor and consultant on using CR sand and its quality.

CHAPTER TWO
LITERATURE REVIEW

2.1.General

The local construction industry in Ethiopia, like many other country, has been using river sand for many decades. River sand in concrete production, it is used as the fine aggregate whereas in mortar production, it is used as the sole aggregate. Basically, river sand is obtained by dredging from river beds. It has the major characteristics that since it has been subjected to years of abrasion, its particle shape is more or less rounded and smooth, and since it has been subjected to years of washing, it has very low silt and clay contents. These two characteristics of river sand would improve the workability of concrete and mortar. The use of river sand would, given workability requirement, reduce the water demand and/or super plasticizer demand, and thus allow a lower water content and a lower cement content to be adopted in the mix design. To change the river sand by river sand substitutes (Crushed rock sand), which may have different characteristics. Hence, apart from CR sand which may be suitable river sand substitutes, it is important also to evaluate the characteristics of the CR sand and the possible effects of using CR sand on the performance of the concrete produced. So that, the potential users of the substitutes would better understand the major differences between river sand and Crushed rock sand. [1]

Quite obviously, this research paper is mainly focused on Effect of fines on compressive strength of concrete with crushed stone sand. Crushed rock sand (river sand substitute) is expected to be for general usage in the production of normal and high strength concrete, the specification requirements to be established in this study would be the minimum requirements for general applications.

To forward good and reliable recommendation on crushed rock sand, a detailed literature review were conducted. Different country building codes and standards on aggregates for concrete and mortar production was carried. Four new standards published in 2013. Were carried out, focused on aggregates for concrete and mortar design part

a) Hong Kong Construction Standard CS3: 2013 Aggregates for concrete
b) European Standard BS EN 12620: 2013 Aggregates for concrete
c) European Standard BS EN 13139: 2013 Aggregates for mortar
d) American Standard ASTM C33/C33M-13 Standard specification for concrete aggregate

For CS3: 2013, the focuses of the review are on how to maintain compatibility between the requirements for aggregates for concrete and the requirements for aggregates for mortar. For BS EN 12620: 2013 and ASTM C33/C33M-13, the focuses of the review are on grading, fines content and fines quantity requirements in Europe and the US. For BS EN 13139: 2013, the focuses of the review are on grading, fines content and fines quality requirements, and the applicability of these requirements in the country.

2.2.Hong Kong Construction Standard CS3: 2013 – Aggregates for Concrete

This construction standard on aggregates for concrete is the only local standard on aggregates because there is, up to that, no local standard on aggregates for mortar in china. It is largely based on the British Standard BS 882: 1992, which was in use for a long time in Hong Kong,

The standard sieve sizes are: 75 µm, 150 µm, 300 µm, 600 µm, 1.18 mm, 2.36 mm, 5.0 mm, 10.0 mm, 20.0 mm, 37.5 mm and 50.0 mm. Particles finer than 5.0 mm (passing the 5.0 mm

sieve) are regarded as fine aggregate and particles finer than 75 µm (passing the 75 µm sieve) are regarded as fines. These standard sieve sizes and definitions of fine aggregate and fines are the same as those in the British Standard BS 882: 1992 but are totally different from those in the European Standards BS EN 12620: 2013 and BS EN 13139: 2013. [2]
There are, however, two major differences between CS3: 2013 and the British Standard BS 882: 1992. Firstly, the BS 882: 1992 imposes limits on the fines content in fine aggregate as: for use in heavy duty floor finishes, 9%; and for general use, 16%. In contrast, the CS3: 2013 imposes limits on the fines content in fine aggregate as: for Class I (use in heavy duty floor finishes), 10%; and for Class II (general use), 14%. Secondly, the BS 882: 1992 does not require checking of the cleanliness of the fine aggregate. In contrast, the CS3: 2013 imposes the requirement on the cleanliness of the fine aggregate as: if the fines content > 10%, the methylene blue value shall be ≤ 1.4. The lower fines content limit of 14% and the new requirement on cleanliness in the CS3: 2013 are to improve the general quality of the fine aggregate.
The grading limits for the fine aggregate are given in Table 1 below. These grading limits are the same as those in BS 882: 1992.

Table 2.1 Grading limits for fine aggregate in CS3: 2013 and BS 882: 1992

Sieve size	Percentage passing by mass			
	Over all limits	Limits for declared grading		
		C	M	F
10.0 mm	100	–	–	–
5.0 mm	89 – 100	–	–	–
2.36 mm	60 – 100	60 – 100	65 – 100	80 – 100
1.18 mm	30 – 100	30 – 90	45 – 100	70 – 100
600 µm	15 – 100	15 – 54	25 – 80	55 – 100
300 µm	5 – 70	5 – 40	5 – 48	5 – 70
150 µm	0 – 20	–	–	–

2.3.European Standard BS EN 12620: 2013 – Aggregates for Concrete

This is the newest European Standard on aggregates for concrete. It is an update of BS EN 12620: 2002, which has replaced the British Standard BS 882: 1992 in the UK.
As in the 2002 version, the standard sieve sizes are 63 µm, 125 µm, 250 µm, 0.5 mm, 1 mm, 2 mm, 4 mm, 8 mm, 16 mm, 32 mm and 63 mm, which are totally different from those in the British Standards. The demarcation between coarse aggregate and fine aggregate is a particle size of 4 mm (in other words, coarse aggregate is defined as an aggregate comprising of particles larger than 4 mm whereas fine aggregate is defined as an aggregate comprising of particles smaller than 4 mm). Moreover, the definition of fines is the particle size fraction finer than 63 µm (passing the 63 µm sieve).
For fine aggregate with a declared maximum size of D not larger than 4 mm, the following general grading requirements apply: 100% passing the sieve of size 2D, at least 95% passing the sieve of size 1.4D, and 85 to 99 % passing the sieve of size D. So, up to 15% of the fine aggregate is allowed to be larger than the declared maximum size. Apart from these requirements, there are no additional requirements on the grading of fine aggregate.

As in the 2002 version, the aggregate producer is required to declare the typical grading of the fine aggregate produced but tolerance limits are applied to control the variability of the fine aggregate. The tolerance limits to be applied are as given in Table 2. It should, however, be noted that the tolerance limits stipulated in BS EN 12620: 2013 are quite different from the respective tolerance limits stipulated in BS EN 12620: 2002.

Table 2.2 Tolerances on declared typical grading for fine aggregate in BS EN 12620: 2013

Sieve size	Tolerance in percentage passing by mass		
	Category GTC10	Category GTC20	Category GTC25
Da	± 5	± 5	± 7.5
D/2	± 10	± 20	± 25
250 µm	± 20	± 25	± 25
63 µmb	± 3	± 5	± 5
Tolerance further limited by the requirements for percentage passing D. Tolerance further limited by the maximum allowed fines content.			

Were specifies wish to additionally describe the coarseness or fineness of the fine aggregate, so as to impose certain grading limits, the fine aggregate may be described as C (coarse graded), M (medium graded) or F (fine graded). For such descriptions of the fine aggregate, either Table 3 or Table 4, but not both, may be used.

Table 2.3 Coarseness/fineness based on percentage passing in BS EN 12620

Percentage passing 0.5 mm sieve by mass		
CP	MP	FP
5 to 45	30 to 70	55 to 100

Table 2.4 Coarseness/fineness based on fineness modulus in BS EN 12620

Fineness modulus		
CF	MF	FF
4.0 to 2.4	2.8 to 1.5	2.1 to 0.6

Comparing Tables 2.3 and 2.4 to Table 2.1, it can be seen that the coarse graded (CP or CF), medium graded (MP or MF) and fine graded (FP or FF) fine aggregates in the BS EN 12620: 2013 and BS EN 12620: 2002 are similar to the respective coarse graded (C), medium graded (M) and fine graded (F) fine aggregates in the CS3: 2013 and BS 882: 1992. As in the 2002 version, there are no limits imposed on the fines contents in the aggregate. The aggregate producer is allowed to declare the maximum fines content in accordance with specified categories. However, in the 2013 version, one more specified category, the category f6, has been added. In the 2002 version, the categories for maximum values of fines content are: f3 – fines content ≤ 3%; f10 – fines content ≤ 10%; f16 – fines content ≤ 16%; and f22 – fines content ≤ 22%. In the 2013 version, the categories for maximum values of fines content are: f3 – fines content ≤ 3%; f6 – fines content ≤ 6%; f10 – fines content ≤ 10%; f16 – fines content ≤ 16%; and f22 – fines content ≤ 22%. Hence, the fines content categories in BS EN 12620: 2013 are more refined.

As in the 2002 version, unlike the British Standards, provided the aggregate producer declares the maximum fines content in the aggregate and exercise tight control of the fines content, fairly high fines contents are allowed.

Compared to the 2002 version, the requirements on fines quality in the 2013 version are more explicitly spelled out. According to Section 4.5 of BS EN 12620: 2013, the fines shall be considered non-harmful when any of the four following conditions apply:

(1) The fines content in the fine aggregate is not greater than 3%;
(2) The sand equivalent value is higher than a specified limit;
(3) The methylene blue value is lower than a specified limit; or
(4) There is documented evidence of satisfactory use.

No precise limits have been given for the fines content, sand equivalent value and methylene blue value. These limits shall be established from experience of existing requirements of materials in local satisfactory use according to the provisions valid in the place of use of the aggregate.

2.4.European Standard BS EN 13139: 2013 – Aggregates for Mortar

It is an update of BS EN 13139: 2002, which has replaced the British Standards BS 1199 and 1200: 1976 in the UK.

The standard sieve sizes, the definition of fine aggregate as particles smaller than 4 mm, and the definition of fines as particles finer than 63 µm have not changed and remained the same as those in the 2002 version. They are also the same as those in BS EN 12620: 2013.

For fine aggregate with a declared maximum size of D, the following general grading requirements apply: 100% passing sieve of size 2D, at least 95% passing sieve of size 1.4D, and 85 to 99 % passing sieve of size D. So, up to 15% of the fine aggregate is allowed to be larger than the declared maximum size. Apart from these requirements, there are no additional requirements on the grading of fine aggregate. These requirements are the same as those in BS EN 12620: 2013.

As in the 2002 version, the aggregate producer is required to declare the typical grading for each fine aggregate size produced but tolerance limits are applied to control the variability of the fine aggregate. The tolerance limits to be applied are as given in Table 5. It should, however, be noted that the tolerance limits stipulated in BS EN 13139: 2013 are quite different from the respective tolerance limits stipulated in BS EN 13139: 2002.

Comparing Table 3.5 with Table 3.2, it can be seen that the tolerance limits in BS EN 13139: 2013 are not the same as those in BS EN 12620: 2013. Hence, a fine aggregate, which complies with BS EN 12620: 2013, does not necessarily comply with BS EN 13139: 2013. One major difference is that in BS EN 13139: 2013, the category GTC25, which demands rather lose control on grading, is not allowed. Another major difference is that the D/2 tolerance requirement is applied only to 0/8 mm and 0/2 mm fine aggregates. For 0/4 mm fine aggregate, the D/2 (= 2.0 mm) tolerance limit is replaced by a 1.0 mm sieve tolerance limit with the same tolerance limit value applied.

Table 2.5 Tolerances on declared typical grading for fine aggregate in BS EN 13139: 2013

Sieve size	Tolerance in percentage passing by mass		
	Category GTC10	Category GTC20	Category GTC25
Da D/2c 250 µm 63 µm	± 5 ± 10 ± 20 ± 3	± 5 ± 20 ± 25 ± 5	This category is not allowed
Tolerance further limited by the requirements for percentage passing D. Tolerance further limited by the maximum allowed fines content. For 0/4 mm aggregate, the D/2 sieve shall be replaced by 1.0 mm sieve.			

Were specifies wish to additionally describe the coarseness or fineness of the fine aggregate, so as to impose certain grading limits, the fine aggregate may be described as C (coarse graded), M (medium graded) or F (fine graded). For such descriptions of the fine aggregate, either Table 6 or Table 7, but not both, may be used. Note, however, that while Table 3.6 is identical to Table 3.3, Table 3.7 is slightly different from Table 3.4. Hence, the description of coarseness or fineness in BS EN 13139: 2013 is not exactly the same as that in BS EN 12620: 2013

Table 2.6 Coarseness/fineness based on percentage passing in BS EN 13139

Percentage passing 0.5 mm sieve by mass		
CP	MP	FP
5 to 45	30 to 70	55 to 100

Table 2.7 Coarseness/fineness based on fineness modulus in BS EN 13139

Fineness modulus		
CF	MF	FF
≥ 2.4	2.8 to 1.5	2.1 to 0.6

As in the 2002 version, there are no limits imposed on the fines contents in the fine aggregate. The aggregate producer is allowed to declare the maximum fines content in accordance with specified categories. However, the specified categories in the 2013 version are not the same as the specified categories in the 2002 version, as summarized below.

In the 2002 version, the categories for maximum values of fines content are:

Category 1 – fines content ≤ 3%;

Category 2 – fines content ≤ 5%;

Category 3 – fines content ≤ 8%; and

Category 4 – fines content ≤ 30%.

Furthermore, examples of end uses for the different categories are given as:

Category 1: floor screeds, sprayed, repair mortars, grouts (all aggregates)

Category 2: rendering and plastering mortars (all aggregates)

Category 3: masonry mortars (excluding crushed rock aggregate)

Category 4: masonry mortars (crushed rock aggregate)

In the 2013 version, the categories for maximum values of fines content are:

Category f3 – fines content ≤ 3%;

Category f5 – fines content ≤ 5%;

Category f8 – fines content ≤ 8%; and

Category f22 – fines content ≤ 22%.

Compared to the 2002 version, the requirements on fines quality in the 2013 version are more explicitly spelled out. According to Section 4.5 of BS EN 13139: 2013, the fines shall be considered non-harmful when any of the four following conditions apply:

(1) The fines content in the fine aggregate is not greater than 3%;

(2) The sand equivalent value is higher than a specified limit;

(3) The methylene blue value is lower than a specified limit; or

(4) There is documented evidence of satisfactory use.

No precise limits have been given for the fines content, sand equivalent value and methylene blue value. These limits shall be established from experience of existing requirements of materials in local satisfactory use according to the provisions valid in the place of use of the aggregate. These requirements are exactly the same as those in BS EN 12620: 2013.

2.5.American Standard ASTM C33/C33M-13 – Standard Specification for Concrete Aggregates

In this standard, the standard sieve sizes are 75 µm, 150 µm, 300 µm, 0.6 mm, 1.18 mm, 2.36 mm, 4.75 mm and 9.5 mm, which are similar to those in the British Standard BS 882: 1992 and the Construction Standard CS3: 2013.

The demarcation between coarse aggregate and fine aggregate is a particle size of 4.75 mm (in other words, coarse aggregate is defined as an aggregate comprising of particles larger than 4.75 mm whereas fine aggregate is defined as an aggregate comprising of particles smaller than 4.75 mm). Moreover, the definition of fines is the particle size fraction finer than 75 µm (passing the 75 µm sieve). These are similar to those in the British Standard BS 882: 1992 and the Construction Standard CS3: 2013.

The grading limits for the fine aggregate are given in Table 3.8 below. Unlike BS 882: 1992 and the CS3: 2013, however, only one type of grading is specified. If not stated, the fines content limit shall be 3.0%. For concrete not subjected to abrasion, the fines content limit shall be 5.0% for concrete not subjected to abrasion

Table 2.8 Grading limits for fine aggregate in ASTM C33/C33M-13

Sieve size	Percentage passing by mass
9.5 mm	100
4.75 mm	95 – 100
2.36 mm	80 – 100
1.18 mm	50 – 85
600 µm	25 – 60
300 µm	5 – 30
150 µm	0 – 10
75 µm	0 – 3

For manufactured fine aggregate (i.e. crushed rock fine aggregate), if the fines content consists of dust of fracture, essentially free of clay or shale, the fines content limit shall be 5.0% for concrete subjected to abrasion and 7.0% for concrete not subjected to abrasion. These limits on the fines content are rather low and comparable to those in the Chinese Standards GB/T 14684: 2001 and JGJ 52: 2006.

For manufactured fine aggregate having elevated fines content, evaluation should be carried out to ensure that the fines content is essentially composed of dust of fracture derived from the parent rock in the crushing operation and does not contain an appreciable level of clay mineral or other deleterious constituents. Methylene blue adsorption and hydrometer analyses are accepted as reliable tests for characterizing the fines content and determining the suitability of the fine aggregate for use in concrete. Manufactured fine aggregate with less than 4% by mass finer than 2 µm and with methylene blue adsorption value less than 5 mg/g is considered suitable for use in concrete. However, fine aggregate that exceeds these values also may be considered suitable for use provided that fresh and hardened concrete properties are shown to be acceptable.

2.6.Overview of the Standards on Aggregates for Concrete and Mortar

The above standards are compared among themselves and with the British Standards and with regard to the following aspects.

2.6.1. Standard sieve size

The standard sieve sizes in the British Standards, the Chinese Standards and the American Standards are similar but the standard sieve sizes in the European Standards are totally different.

2.6.2. Demarcation between coarse and fine aggregates

The demarcation between coarse and fine aggregates in the British Standards, Chinese Standards and American Standards are similar but the demarcation in the European Standard is totally different. Demarcation between coarse and fine aggregate is 5.0 mm in the British Standards, Chinese Standards and American Standards but in European standard the demarcation between coarse and fine aggregate is 4.0 mm.

2.6.3. Grading limits for fine aggregate

In the British Standards and Chinese Standards, grading limits for fine aggregates of three different grading classes or zones are specified (the grading zones 1, 2 and 3 in the Chinese Standards are equivalent to the grading C, M and F in the British Standards). In the American Standards, the grading limits for one type of fine aggregate are specified. However, in the European Standards, no grading limits are specified. Instead, the aggregate producer is allowed to declare the typical grading for each fine aggregate size produced but required to control the variability of the fine aggregate such that the grading is within certain tolerance limits. Nevertheless the coarseness/fineness of the fine aggregates may be specified as C, M and F (these grades are actually similar to the respective grades in the British Standards) according to the percentage passing the 0.5 mm sieve or the fineness modulus.

2.6.4. Equivalent grading

In BS 1199: 1976, two grading, namely Type A or Type B, are recommended for external rendering and internal plastering. At the same time, in BS 1200: 1976, another two grading, namely Type S and Type G, are recommended for masonry mortar. The grading of Type A and Type B are compared to the declared grading in CS3: 2013 and BS 882: 1992 in Table 9, whereas the grading of Type S and Type G are compared to the declared grading in CS3: 2013 and BS 882: 1992 in Table 10.

From Table 9, it can be seen that the declared grading C and M in CS3: 2013 and BS 882: 1992 are very similar to the grading Type A in BS 1199: 1976. In fact, apart from the possible slightly higher percentage retained on the 5.0 mm sieve of 11% and the possible slightly higher percentage passing the 150 µm sieve of 20%, the grading C and M would have totally complied with the grading requirements of Type A. In actual practice, such differences in percentage retained on the 5.0 mm sieve and percentage passing the 150 µm sieve are rather small and the grading C and M may be regarded as equivalent to Type A. Furthermore, it can be seen that the declared grading F in CS3: 2013 and BS 882: 1992 is very similar to the grading Type B in BS 1199: 1976. In fact, apart from the possible slightly higher percentage retained on the 5.0 mm sieve of 11%, the grading F would have totally complied with the grading requirements of Type B. In actual practice, such difference in percentage retained on the 5.0 mm sieve is rather small and the grading F may be regarded as equivalent to Type B.

Table 2.9 Comparison of grading in BS 1199: 1976 to those in CS3: 2013 and BS 882: 1992

Sieve size	Grading in BS 1199: 1976		Declared grading in CS3: 2013 and BS 882: 1992		
	Type A	Type B	C	M	F
10.0 mm	100	100	100	100	100
5.0 mm	95 – 100	95 – 100	89 – 100	89 – 100	89 – 100
2.36 mm	60 – 100	80 – 100	60 – 100	65 – 100	80 – 100
1.18 mm	30 – 100	70 – 100	30 – 90	45 – 100	70 – 100
600 µm	15 – 80	55 – 100	15 – 54	25 – 80	55 – 100
300 µm	5 – 50	5 – 75	5 – 40	5 – 48	5 – 70
150 µm	0 – 15	0 – 20	0 – 20	0 – 20	0 – 20

Table 2. 10 Comparison of grading in BS 1200: 1976 to those in CS3: 2013 and BS 882: 1992

Sieve size	Grading in BS 1200: 1976		Declared grading in CS3: 2013 and BS 882: 1992		
	Type S	Type G	C	M	F
10.0 mm	100	100	100	100	100
5.0 mm	98 – 100	98 – 100	89 – 100	89 – 100	89 – 100
2.36 mm	90 – 100	90 – 100	60 – 100	65 – 100	80 – 100
1.18 mm	70 – 100	70 – 100	30 – 90	45 – 100	70 – 100
600 µm	40 – 100	40 – 100	15 – 54	25 – 80	55 – 100
300 µm	5 – 70	20 – 90	5 – 40	5 – 48	5 – 70
150 µm	0 – 15	0 – 25	0 – 20	0 – 20	0 – 20

Table 2.10 shows that the grading Type S and Type G in BS 1200: 1976 are required to have not more than 2% retained on the 5.0 mm sieve and not more than 10% retained on the 2.36 mm sieve. So, Type S and Type G are more like 2.36 mm maximum size aggregates (0/2.36 mm aggregates in European Standard terminology) rather than 5.0 mm maximum size aggregates (0/5.0 mm aggregates in European Standard terminology). On the other hand, the declared grading C, M and F in CS3: 2013 and BS 882: 1992 are all 5.0 mm maximum size aggregates (0/5.0 mm aggregates). Hence, there is no equivalent grading in CS3: 2013 and BS 882: 1992 for Type S and Type G. In fact, the fine aggregates specified

in CS3: 2013 and BS 882: 1992, which all have 5.0 mm maximum aggregate size, are for concrete, not for mortar. In the European Standards BS EN 13139: 2002 and BS EN 13139: 2013, the fine aggregate size 0/2 mm or 0/4 mm.

2.6.5. Definition of fines

The British Standards, Chinese Standards and American Standards define the fines in aggregate as the materials finer than 75 µm or 80 µm, whereas the European Standards define the fines in aggregate as the materials finer than 63 µm. Such slight difference in the definition of fines is not really significant.

2.6.6. Limits on fines content

There are big differences in the maximum allowable limits on the fines content in the various standards.

a. In BS 882: 1992, the fines content in crushed rock sand for concrete is limited to 16% for general use and to 9% for use in heavy duty floor finishes.
b. In CS3: 2013, the fines content is limited to 14% for general use (with the additional requirement that if the fines content > 10%, the methylene blue value shall be ≤ 1.4) and to 10% for use in heavy duty floor finishes.
c. In BS 1199: 1976 and BS 1200: 1976, the fines content in crushed rock sand for mortar is limited to 5% for rendering and plastering, to 10% for Type S sand for masonry mortar, and to 12% for Type G sand for masonry mortar.
d. In ASTM C33/C33M-13, the fines content in manufactured fine aggregate (i.e. crushed rock fine aggregate) is limited to 5% for concrete subjected to abrasion and to 7% for concrete not subjected to abrasion.

In BS EN 12620: 2002 and BS EN 12620: 2013, no limits are imposed on the fines content in fine aggregates for concrete. In BS EN 13139: 2002, it is stipulated that fine aggregates for mortar are to be classified into **four** categories:

1. Category 1 (fines content ≤ 3%) used for floor screeds, sprayed, repair mortars, grout;
2. Category 2 (fines content ≤ 5%), used for rendering and plastering
3. Category 3 (fines content ≤ 8%), used for masonry mortar not using crushed rock aggregate; and
4. Category 4 (fines content ≤ 30%), used for masonry mortar using crushed rock aggregate.

In BS EN 13139: 2013, the categories for maximum fines content are:

Category f3 (fines content ≤ 3%),

Category f5 (fines content ≤ 5%),

Category f8 (fines content ≤ 8%), and

Category f22 (fines content ≤ 22%), and no recommendations of their uses are given anymore. But this does not mean that no limit on the fines content should be specified.

The maximum limits on fines content in fine aggregates for mortar given in the various standards are compared in Table 3.11

Table 2.11 Limits on fines content in fine aggregates for mortar

Standard/ document	Limits on fines content
BS 1199: 1976/ BS 1200: 1976	Crushed rock sand for rendering and plastering: 5% Type S sand for masonry mortar: 10% Type G sand for masonry mortar: 12%
BS EN 13139:2002	Category 1 (floor screeds, sprayed, repair mortars): ≤ 3% Category 2 (rendering and plastering): ≤ 5% Category 3 (masonry with non-crushed aggregate): ≤ 8% Category 4 (masonry with crushed aggregate): ≤ 30%
BS EN 13139: 2013	Category f3 : ≤ 3% Category f5 : ≤ 5% Category f8 : ≤ 8% Category f22 : ≤ 22%
BSI PD 6682-3: 2003	Levelling screed: ≤ 3% Rendering and plastering: ≤ 5% Masonry with Type S sand: ≤ 5% Masonry with Type G sand: ≤ 8%
GB/T 14684: 2001	Natural sand: < 5.0%
	Manufactured sand: If the methylene blue test passes: < 7.0% If the methylene blue test fails: < 5.0%
JGJ 52: 2006	No recommendation

2.6.7. Distinction between aggregates for concrete and aggregates for mortar

In the British Standards and the European Standards, very clear distinction is made between aggregates for concrete and aggregates for mortar but in the Chinese Standards and American Standards, aggregates for concrete and aggregates for mortar are not clearly differentiated. Apparently, the Chinese Standards and American Standards are more for aggregates for concrete rather than for aggregates for mortar.

2.7. Aggregate

More than three-fourth of the volume of concrete were aggregate and the selection and proportioning of both fine and coarse aggregate significantly influence the properties of fresh and hardened concrete. The compressive strength of concrete cannot significantly exceed that of the major part of the aggregate contained. The influence of aggregate on the strength of concrete is not only due to the mechanical strength of the aggregate but also, to a considerable degree, to its absorption and bond characteristics. In general, the strength of aggregate depends on its composition, texture and structure. Thus it is essential that studied the properties of aggregate and should comply with the requirement.

Fig 2.1. Crushing site and stock of coarse aggregate

In the process of preparing an aggregate which fulfil the necessary requirements, both visual and laboratory based inspection must be conducted. Aggregate with impurities should be washed thoroughly until it gets free from it. But if the presence of impurity causes a damage to the chemical and mechanical property of the aggregate, the aggregate shall totally be rejected as this can be a potential for failure on the cohesive nature of the aggregate. In addition, aggregate from single source shall be used in one project so as to arrest variability of characteristics due to variability of ingredient property. Aggregate from various sources will show various property which consequently affect the proportioning of other ingredients of the concrete and finally its strength. Thus aggregate from single source shall be used at a time since there will exist a difficulty and error prone situation in deducing a standard or setting a datum for each sources of the aggregate at a certain project. Aggregates can be broadly classified into four different categories: these are heavyweight, normal weight, lightweight and ultra-lightweight aggregates. However in most concrete practices only normal weight and lightweight aggregates are used. The other types of aggregates are for special uses, such as nuclear radiation shielding provided by heavyweight concrete and thermal insulation using lightweight concrete **[5]**

In the manufacture of good quality concrete the aggregate is categorized in two, in size

1. Fine aggregate often called sand (BS 882; 1992) not larger than 5mm in size
2. Coarse aggregate, which comprises material at least 5mm in size.

All natural aggregate particles originally formed a part of a large mass. This may have been fragmented by natural processes of weathering and abrasion or artificially by crushing. Thus many properties of the aggregate depend entirely on the properties of the parent rock. Chemical and mineral composition, metrological character, specific gravity, hardness, strength, physical and chemical stability, pore structure and colour. On the other hand, there are some properties possessed by the aggregate but absent in the parent rock: particle shape and size, surface texture, and absorption. All these properties have a considerable influence on the quality of the concrete, either in fresh or in the hardened state**. [11]**

Thus considering the above mentioned factors and facts, an aggregate which satisfy the necessary requirement is selected and the entire experiment is conducted in accordance with the required procedure and standard.

2.7.1. Fine Aggregate

Fine aggregates generally consist of natural sand or crushed stone with most particles smaller than 5 mm. Roundness measures the relative sharpness or angularity of the edges and corners of a particle. Roundness is controlled largely by the strength and abrasion resistance of the parent rock and by the amount of wear to which the particle has been subjected. In the case of crushed aggregate, the particle shape depends not only on the nature of the parent rock but also on the type of crusher and its reduction ratio, i.e. the ratio of the size of material fed into the crusher to the size of the finished product. Particles with a high ratio of surface area to volume are also of particular interest for a given workability of the control mix. Elongated and flaky particles are departed from equi-dimensional shape of particles and have a larger surface area and pack in an isotropic manner. Flaky particles affect the durability of concrete, as the particles tend to be oriented in one plane, with bleeding water and air voids forming underneath. The flakiness and elongation tests are useful for general assessment of aggregate but they do not adequately describe the particle shape. The presence of elongated particles in excess of 10 to 15% of the mass of coarse aggregate is generally undesirable, but no recognized limits are laid down [5].

The full role of shape and texture of aggregate in the development of concrete strength is not known, but possibly a rougher texture results in a larger adhesive force between the particles and the cement matrix. Likewise, the larger surface area of angular aggregate means that a larger adhesive force can be developed.

The shape and texture of fine aggregate have a significant effect on the water requirement of the mix made with the given aggregate. If these properties of fine aggregate are expressed indirectly by its packing, i.e. by the percentage voids in a loose condition, then the influence on the water requirement is quite definite [5].

For satisfactory performance, fine aggregate should be free of deleterious materials. There are three categories of deleterious substances that may be found in aggregates: impurities, coatings and weak or unsound particles. Fine aggregates may be sufficiently strong and resistant to wear and yet they may not be satisfactory for concrete making if they contain organic impurities,

Fig 2.2. River Sand from Alem Tenna

Clay may be present in fine aggregate in the form of surface coatings, which interfere with the bond between aggregate and the cement paste. There are two more types of fine material present in aggregate: silt and crusher dust. These material form coatings similar to those of clay. Silt and fine dust increase the amount of water necessary to wet all the particles as they have large surface area. Due to the above cases, it is necessary to control the clay, silt and fine dust contents of fine aggregate.

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

2.7.2. Crushed Rock Sand

The term-manufactured sand is used for aggregate materials having dimensions less than 5.0mm that are processed from crushed rock and intended for construction use. Now a days natural aggregates have proved to be significantly economical in use, for which reason extensive use of manufactured sand has been concentrated to projects were the availability of natural sand has been limited.

One of the advantage in manufactured sand is quarries can be kept in the near vicinity to its place of end use, therefore shortening transport distances, and increased employment opportunities for the locals. In the future it is expected that manufacturing of sand from rock will increase and production from natural deposits will decrease.

Fig 2.3, CRS from YENCOMAD crushing site (After washing)

The crushing process caused the manufactured sand to have an irregular particle shape. These fine particles and irregular shape of the aggregate have detrimental effects on the workability and finish of the concrete. These negative effects have given manufactured sands a poor reputation in the construction industry. However this study reveals that in some other practical areas, these fine particles can be utilized to increase the compressive strength of the concrete.

The most important elements in the production of manufactured sand are quality control, crushing equipment and other processing equipment. As segregation is common in manufactured sand, it is necessary to define procedures for sampling, hardening and testing for quality control purposes to ensure that the 'right' material is being tested.

Crushers are significant in the final outcome when using manufacturing sand; in particular the crusher type, their setting and the number of crushing stages. Other processing equipment includes feeders and silos, screens, conveyor belts and washing equipment [8].

2.7.2.1.Technical Challenges

One of the main challenges in crushed rock sand production is to obtain a satisfactory mass balance. Any excess fraction that has to be kept on stock or even more deposited will create an economic as well as an environmental problem. From the data found from manufacturers of crushed rock sand, the production of crushed aggregate gives a miss balance of particle sizes, as the relative quantity of the sand fraction (0-4.75mm) in most cases exceeds what can be placed on the concrete to be casted. Unless special processing precautions are taken, the crushed sand will end up with a more or less uncontrolled fine content, far in excess of what can be tolerated if the end product is concrete.

Fig 2.4. CRS at YENCOMAD Stock

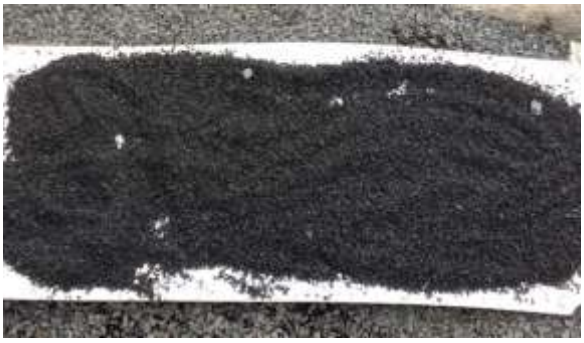


Fig 5.5. CRS after Wash

The surplus fines have traditionally been considered as a waste material at most plants, and have caused considerable deposition costs for the producers as well as being a problem also from an environmental point of view.

2.7.2.2.Environmental challenge

Aggregates are a valuable natural resource and it is our obligation to use it sensibly, in particular in highly populated areas were the demand is great and costs may increase due to long transportation distances. Good understanding of the basic material properties, usage possibilities and quality are significant for sensible use.

In the developed world, the aggregate and concrete industry is presently facing a growing, public awareness relating to the environmental profile of their activities. Important areas of concern are

a. The non-renewable character of the natural resources, especially in regions facing a coming shortage of adequate local materials.
b. The environmental impact on neighbourhood and society (noise, air pollution, etc.) of the quarry and of the materials transport related to the quarrying activities.
c. Land use conflicts between quarries and e.g. agriculture, recreation, building sites, archaeology especially in densely populated regions.
d. A lack of sustainability in production, characterized by inferior mass balance. (i.e. A high percentage of e.g. surplus fines to be deposited) and a high energy consumption needed per ton of aggregate produced. This case might not fully apply in our country case.
e. The potential environmental or health impact of the very materials produced, due to e.g. leaching of heavy metals, radioactivity and to special minerals suspected to have hazardous health properties.

2.8. Experience of Using Crushed Rock Sand in Ethiopia

Ethiopia has been abundantly supplied river sand resources for construction purposes due to geographical location of the country. Traditionally most concrete aggregate have been produced on the basis of glacio-fluvial sand /gravel deposits/ which offer rich but unevenly distributed throughout a country characterized by large transport distances. When conditions require using large quantities of high quality aggregate and sand and even if sufficient quantities of gravel and natural sand are available, concrete made with crushed aggregate and sand is preferred, for this application due to its superior performance. Accordingly few mega projects which is under construction e.g. millennium renascences dam and completed projects e.g. Gilgal Gibe three dam and bridge across the Blue Nile river (Abay bridge) is an example to this effect.

The use of manufactured sand for concrete production in Ethiopia started about a decade ago. This material is being used by foreign contractors for Asphalt and road structures. Extensive uses of manufactured sand have been used in areas where the availability of natural sand is limited. However, in using these materials the benefit of using manufactured sand economically as well as environmentally is not yet proved.

The shortage of the natural sand currently encouraged a development of using manufactured sands in different mega project with foreign contractors. Gradual the problem enforced domestic contractors and clients to use crushed sand for concrete production. Domestic consulting firm show interest to use crushed sand during concrete design and material quality inspection. So, therefore this is the time to develop standard and specification for crushed rock sand. The standard will benefits for all stakeholders in construction industry. Aggregate producers will use as production manual, contractors will use to select quality crushed sand and consultant will use for concrete design and to control the quality of sand on site as well as during production. For instant and to ensure material consistency of aggregates (Fine and Coarse) have been obtained from YENCOMAD Construction PLC. Crushing site, Addis Ababa. The crushing site located at Yerer, about 15km away from Addis Ababa in eastern direction. This crushed rock sand was produced from crushing of basaltic stone, were the contractors used for high rise building which is under construction in Denbel City centre compounds as expansion building.

2.9. Summary of Literature Review

From the above review, it is seen that the standard sieve sizes, demarcation between coarse and fine aggregates, and definition of fines vary from one standard to another standard. Almost all standard take British standard as benchmark so, therefore, it is better to stay with the standard sieve sizes, demarcation between coarse and fine aggregates, and definition of fines in the British Standards.

In general, different requirements are imposed on aggregates for concrete and aggregates for mortar. This is because concrete and mortar have different performance attributes and the quality of fine aggregate has different effects on concrete and mortar. Hence, aggregates for concrete and aggregates for mortar should be clearly differentiated. For both aggregates, (aggregate for concrete and aggregate for mortar), the major issues seem to be the limits to be imposed on the fines content and the assessment of the harmfulness of the fines content. The fines content needs to be limited for the following reasons. In concrete, any harmful substances, such as clay, in the fines would adversely affect the abrasive resistance, maximum achievable strength, and durability of the concrete. Moreover, since the fines content has very large specific surface area, its quantity would affect the water and super plasticizer demands and thus also the workability of the concrete.

The presence of high fines content in the concrete would render the concrete more cohesive, but this has little effect on the concreting operation. In mortar, the presence of clay or excessive fines would adversely affect the abrasive resistance, maximum achievable strength and workability of the mortar. Moreover, the increase in water demand due to higher fines content would force the worker to add more water to improve the workability of the mortar and thus cause the hardened mortar to have a relatively large drying shrinkage and a higher risk of shrinkage cracking. More importantly, the increase in cohesiveness and paste volume due to the presence of excessive fines would render the mortar too sticky and slippery to be properly trowelled because the mortar tends to stick to the trowel and slip

downwards. On the other hand, there are still no established methods for assessing the harmfulness of fines in aggregate and no established acceptance criteria for the non-harmfulness of fines. The BSI PD 6682-3 recommends that aggregates should better be assessed for harmful fines using either a fines content limit or evidence of satisfactory use.
Lastly, whilst the fine aggregates stipulated in BS 1199: 1976, BS 1200: 1976, BS 882: 1992 and CS3: 2013 all have a maximum aggregate size of 5.0 mm, the fine aggregates in BS EN 13139: 2002 and BS EN 13139: 2013 may have a maximum aggregate size of 4.0 mm or 2.0 mm. Although I am not strictly following the European Standards, it seems prudent to follow the practice of having fine aggregates with different maximum aggregate sizes

CHAPTER THREE
MATERIAL PROPERTIES AND EXPERIMENTAL PROGRAM

3.1.General

Before the commencement of the main experiment, the material used in this research were prepared and their concerned property were investigated so as to assure whether prepared materials were complying with the required standard and specification. As this study concerns about Effect of Fines Content on Compressive strength of Concrete with Crushed stone sand, the property of material used in this research need to meet the material requirement.

To study the effects of the fines content in fine aggregate on the overall performance of the concrete, a testing program has been worked out. In the testing program, there are three combinations of water/cement (W/C) ratio ((0.40, 0.5 and 0.60), four combinations of fines content ranging from 6% to 15%, with 3% variation and two combinations of superplasticizer (SP) dosage ranging from no SP added to SP added (however, the SP dosage when added varied from 1.43 litter/m^3 of concrete at a W/C ratio of 0.60 to 2.71 litter/m3 of concrete at a W/C ratio of 0.4). Out of the several types of cements, two of them i.e. Portland pozzolana and ordinary Portland cement widely produced in Ethiopia by cement factories. Dangote brand Portland pozzolana cement were used for concrete design.

The influence of manufactured sand and fines content on the compressive strength of the concrete was studied, accordingly different percentage of fines (6%, 9%, 12% and 15%) with different water content were prepared for crushed and river sand mix design.

Normal tap water is used for washing, curing and mixing of concrete. Quarry dust used as fines collected from YENCOMAD quarry site. Physical tests of the materials and compressive strength tests were carried out in Addis Ababa institute of Technology Construction materials laboratory.

3.2.Aggregate

3.2.1. River sand

River sand was brought from Alem Tenna, which is one of the Rift Valley Zone in Ethiopia, located about 110Kms away from Addis Ababa in south east direction. To prepare river sand with the prescribed fines contents of **6%, 9%, 12% & 15%,** fines content in river sad was first removed by washing and dry in SSD level so that the river sand contained a fines content of exactly 0%. Then, the right amount of fines was put back into the fine aggregate so that the fine aggregate contained the prescribed fines content.

Necessary laboratory investigations were carried out in order to ensure compliance of property of the river sand with the required standards and specifications. Gradation, specific gravity and absorption capacity, bulk density, moisture content and silt content were the tested parameters in order to assess the physical properties of the sand.

3.2.1.1.Particle Size Distribution

The actual grading requirements depend on the shape and surface characteristics of the particles. Extending the grading of aggregate to a larger maximum size lowers the water requirement of the mix, so that, for a specified workability and cement content, the water /cement ratio can be lowered with a consequent increase in strength. In structural concrete of usual proportions, there is no advantage in using aggregate with a maximum size greater than about 25 or 40mm when compressive strength is a criterion. Particle size distribution of an aggregate is determined using sieve analysis. Usually the grading and grading limits are expressed in terms of percentage of material passing through each sieve. The particle size distribution and fineness modulus (FM) of the river sand is checked as per the requirement ASTM C 33/ESC.D3.201. After taking two representative samples of the sand, sieve analysis was conducted and an average value of the samples was taken as particle size distribution of the sand.

The 3.1 Summary of grading requirement and the average percentage passing

Sieve Size	Average Percentage passing by Mass	ESC.D3.201 Specification Range
9.5mm	99.01	100
4.75mm	94.45	95 - 100
2.36mm	83.17	80 - 100
1.18mm	61.88	50 - 85
600µm	31.68	25 - 60
300µm	9.41	10 - 30
150µm	3.47	2 - 10
Pan	0.00	

The grain size distribution of fine aggregate along with its limits of specification is depicted in the graph below.

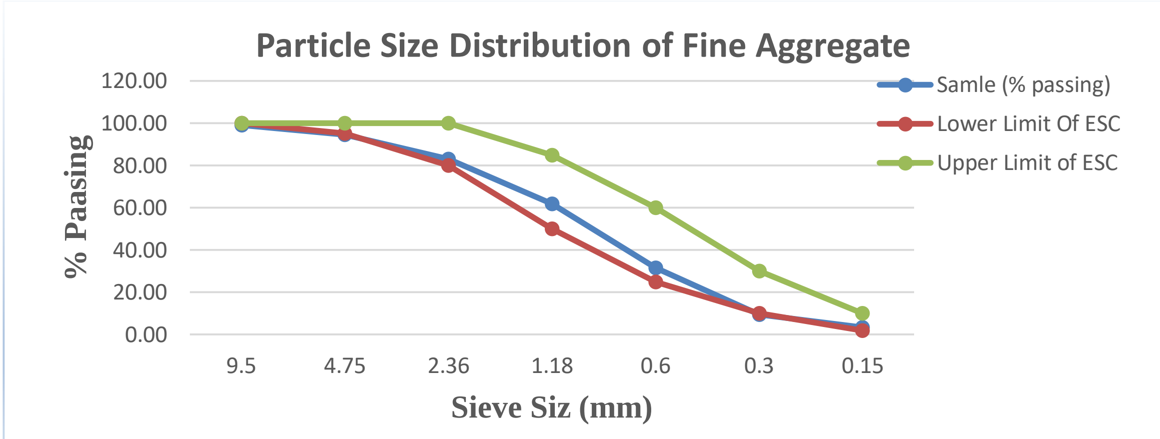


Figure 3.1. Graph for grain size distribution of fine aggregate along with limits of specification.

Using the particle size distribution data, the average fineness modulus (uniformity of grading) also calculated and determined as follows.

FM= (Σ Cumulative Percentage Retained)/100…………………………………….....Eq 3.1

=(100-94.45)+(100-83.17)+(100-61.88)+(100-31.68)+(100-9.41)+(100-3.47))/100 = 3.17

As per the discussed above on table 6 (Coarseness/fineness based on percentage passing) and on table 7, (Coarseness/fineness based on fineness modulus) the FM of the above tested river sand fall into the required range.

3.2.1.2.Specific Gravity and Absorption Capacity

Specific Gravity is important for several reasons. Some deleterious particles are lighter than the "good" aggregates. Tracking specific gravity can sometimes indicate a change of material or possible contamination. Differences in specific gravity may be used to separate the deleterious particles from the good using a heavy media liquid.

Bulk Specific Gravity (also known as Bulk Dry Specific Gravity): The ratio of the weight in air of a unit volume of aggregate at a stated temperature to the weight in air of an equal volume of gas-free distilled water at the stated temperature.

Absorption is the increase in mass due to water in the pores of the material. When the pores are fully filled and there is no surface moisture, the sand will be in a saturated surface dry condition. With this, an increase in moisture (decrease in absorption) will affect the amount of water that will be used in a concrete mix. Thus both parameters need to be defined prior to mix design and subsequent steps in concrete making

3.2.1.3.Moisture content

It is well known to Engineers that water-cement ratio affect the workability and strength of concrete specimens. A design water-cement ratio is usually specified based on the assumption aggregate are inert (neither absorb nor give water to the mixture). But in most case aggregate from different source do not comply with this i.e. wet aggregate give water to the mix and drier aggregates (those with below saturated level moisture content) take water from the mix affecting, in both cases, the design water-cement ratio and therefore workability and strength of the mix. In order to correct for these discrepancies, the moisture content of aggregates has to be determined. This moisture content doesn’t include the moisture that is chemically combined with the minerals in the aggregate. Following the testing procedure and sampling, the moisture content of the river sand is obtained as **1.85%.**

3.2.1.4.Silt content

Sand is a product of natural or artificial disintegration of rocks and minerals. It obtained from glacial, river, lake, residual and wind blow (very fine) deposits. These deposits however, do not provide pure sand. Thy often contain other materials such as dust, loam and clay that are finer than sand. The presence of such materials in sand used to make concrete or mortar decrease the bond between the materials to be bounded together and hence the strength of the mixture. The finer particle do not only decrease the strength but also the quality of the mixture produced resulting in fast deterioration. Therefore it is necessary that one make a test on the silt and checks against permissibility limits. The permissible value of silt content in a sand as per Ethiopian standard is 6% [5]. The sand used for this experiment showed a silt content of 7.7% before it was washed. Since this the value exceeds the permissible range, the sand was washed and tested that its silt content decreased.

Table 3.2 Summary of physical property of River sand used in the experiment

Item No.	Description	Result
1	Bulk specific gravity Bulk specific gravity (SSD state) Apparent specific gravity	2.622 2.703 2.853
2	Absorption (%)	3.093
3	Moisture content (%)	1.85
4	Silt content (%)	1.2

3.2.2. Crushed Rock Sand

When it is required to construct a major structure, the supply of high quality aggregate (Fine and Coarse aggregate) for concrete production is extreme importance. The growing shortage and price rise of the natural sand is a question that a construction industry shall think about. Due to short of supply of natural sand and the increased activity in construction sector, the time has come, for manufactured sand to play a significant role as an ingredient in concrete.

3.2.2.1.Particle Size Distribution

To ensure material consistency of aggregates all of the crushed rock sand have been obtained from YENCOMAD crushing site, located at Addis Ababa-Adama road about 15km away from Addis Ababa. This manufactured sand was produced from crushing of basaltic stone where the manufacturer used for different structures.

After taking two representative samples of crushed rock sand, sieve analysis was conducted and an average value of the two samples was taken as particle size distribution of the sand.

Table 3.3 Sieve analysis of Crushed Rock Sand

Sieve Size	Percentage passing by Mass	ESC.D3.201 Specification Range
9.5mm	100	100
4.75mm	98.5	95 - 100
2.36mm	41.00	80 - 100
1.18mm	13.5	50 - 85
600µm	5.00	25 - 60
300µm	3.00	10 - 30
150µm	2.50	2 - 10
Pan	0.00	

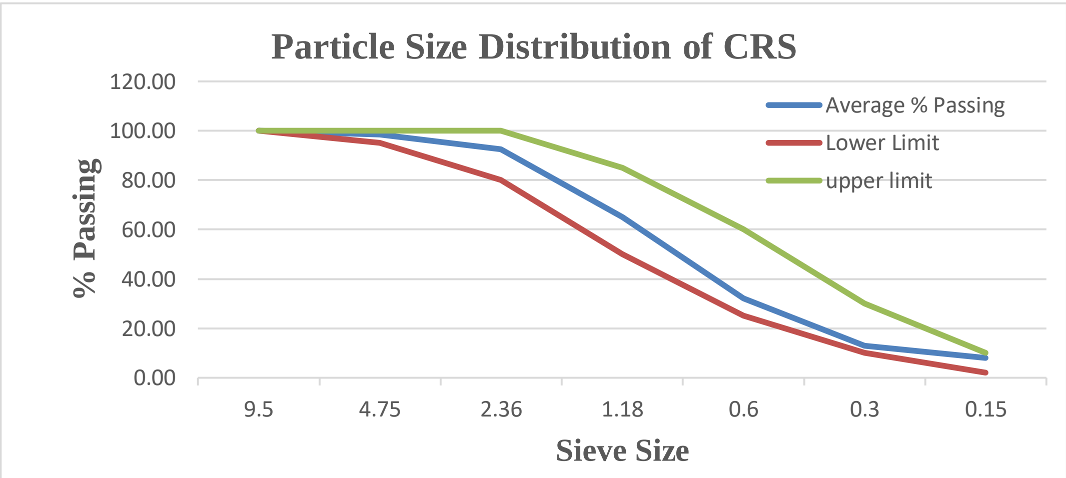


Fig. 3.2. Graph for grain size distribution of fine aggregate along with limits of specification

Using the particle size distribution data, the average fineness modulus (uniformity of grading) also calculated and determined as follows.

FM= (Σ Cumulative Percentage Retained)/100…………………….... Eq 3.1

= (100-98.5)+(100-8)+(100-92.5)+(100-65)+(100-32)+(100-13))/100 = **2.91**

As per the discussed above on table 3.6 (Coarseness/fineness based on percentage passing) and on table 3.7, (Coarseness/fineness based on fineness modulus) the FM of the above tested river sand fall into the required range.

The theory of specific gravity and absorption capacity, moisture content and silt content is the same with river sand test mechanism theory. For instance the following data was the result of river and crushed rock sand.

Table 3.4 Physical Prosperity of fine aggregate

It. No	Description	Test Result		
		River Sand		CR Sand
1	Silt content	1.2%		0.25%
2	Dry unit weight			
3	Absorption capacity	3.09		1.01
4	Specific gravity (gm./cc)	Bulk	2.622	2.878
		Bulk (SSD)	2.703	2.907
		Apparent	2.853	2.964
5	Fineness modulus	3.17		2.91

The summaries of gradation of both river and crushed rock sand are shown in Fig 3.3

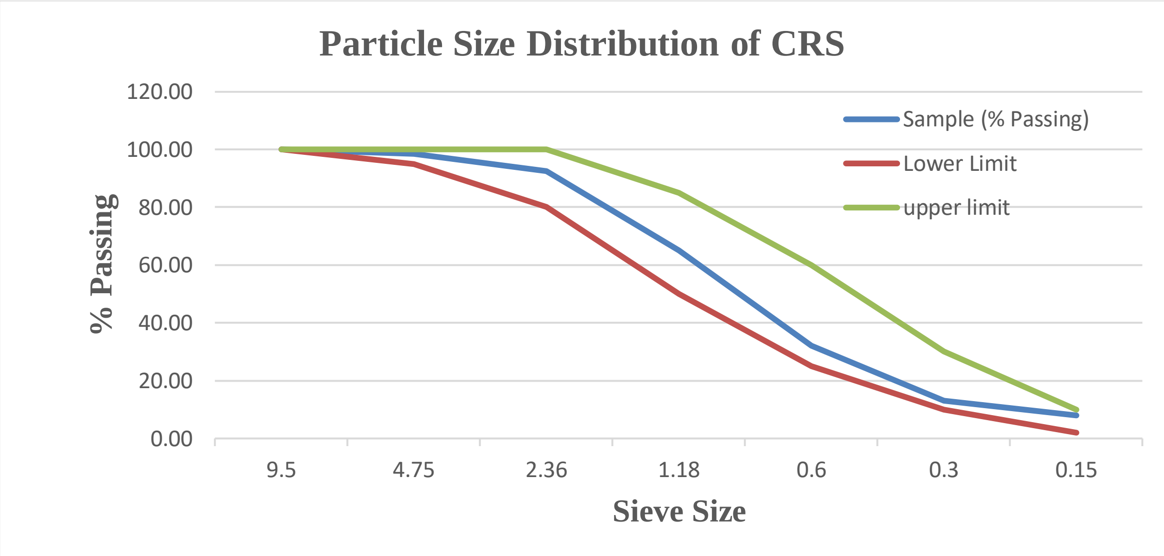


Fig. 3.3 Gradation Curve for RS and CRS

As you can be seen from the material test results, river sand had higher amounts of fines while lesser amount is seen in the case of Crusher rock sand, but the silt content of both type sand was in the permissible limit (silt content result was taken after both sand was washed to remove impurity. Although the particle shape has a negative impact on the workability of the concrete due to increased voids created in the concrete, irregular particle shape may produce a stronger concrete than mix made with rounded particles, as the aggregate will interlock better with the cement paste and other aggregate.

3.2.3. Coarse aggregate

Coarse aggregates used for this research work is brought from YENCOMAD construction Plc. quarry site, the site and crushing plant of Coarse aggregate is the same with the Crushed rock sand. In the case of coarse aggregates, as there were lots of dusty material and pieces of leaves in it, the material was washed and kept in the laboratory to dry in open air. All tests conducted for the assessment of physical property of the fine aggregate also conducted on the coarse aggregate. Then the material was sieved so as to satisfy the graded chart of the Ethiopian standard. Based on concrete making material, properties and quality was performed. The test includes: sieve analysis, bulk and dry density, absorption capacity and etc. All of the aggregates tests were done in accordance with the Ethiopian standards and conforms to the ASTM requirements.

Table 3.5 physical property of coarse aggregate

Item No	Description		Result
1	Nominal size (mm)		19
2	Specific gravity (gm/cc)	Bulk specific gravity	2.82
		Bulk specific gravity (SSD state)	2.85
		Apparent specific gravity	2.91
		Absorption capacity (%)	1.12

Table 3.6 Sieve analysis of coarse aggregate for particle size distribution

Sieve Size (mm)	Sieve No.	Percentage passing by mass	ASTM code requirement range
25	#1	100	100
19	#3/4	97.1	90-100
12.5	#1/2	40.2	20-55
9.5	#3/8	8.6	0-15
4.75	#4	1.2	0-5
Pan			

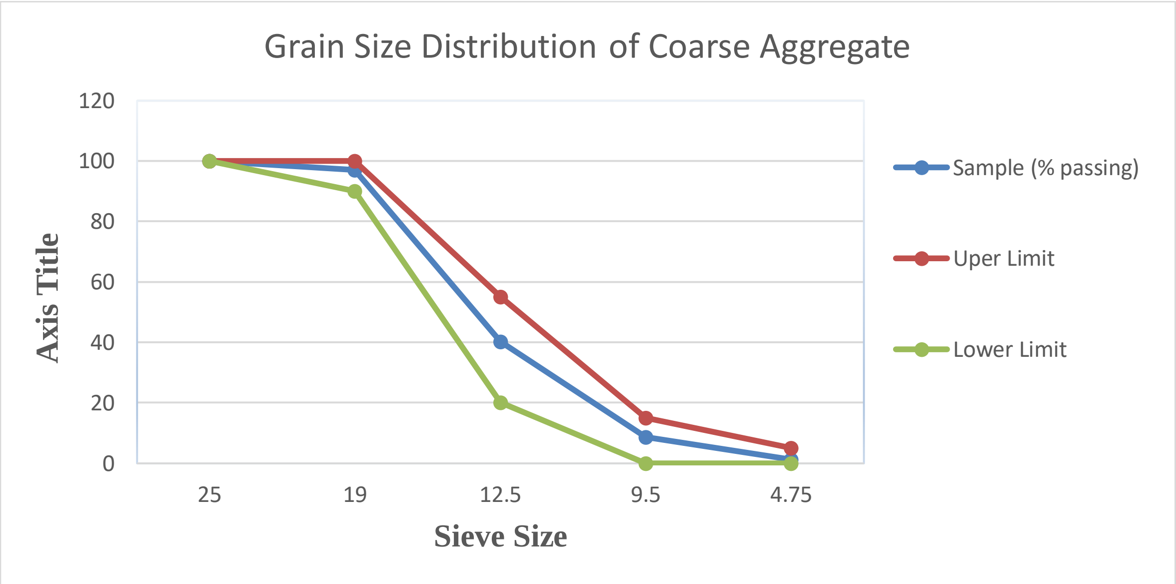


Fig 3.4. Graph for grain size distribution of coarse aggregate

3.3.Water

A tap water, which is supplied from the Addis Ababa water supply and sewerage Authority, is used for all concrete mix, Washing concrete making aggregate and for curing concrete.

3.4.Admixtures

The superplasticizer SP-430 (Water- reducing) supplied by AB-HAM was chosen for this research work. During concrete mix we used from 0.7litter for one meter cube concrete in water content ratio of 0.6 and 2.71 litter per one meter cube for water content ratio of 0.4.

3.5.Cement

The cement used for this research is a Portland Pozzolana cement (PPC) of grade 32.5 with Dangote brand. The cement which were used for the mixes, were bought from one of the Addis Ababa's building material shops.

3.6.Fines

In this research, fines means defined or consider as quarry dust. Particles passed through the size of 75µm sieve size consider as fines. One of the parameter measured the quality of crushed rock sand is the amount of fines contained within the given volume of crushed sand. Compressive strength of concrete and workability is highly affected by uncontrolled amount of fines. Quarry dust used for this research work was brought from YENCOMAD crushing site. The fines was sieved by 75µm sieve size to screen out the material or other impurity bolder than the specified sieve size. After fines prepared add in each mix according to the percentage calculated. The fines was consider as part of sand so the amount was deducted from the amount of sand calculated during mix design preparation. The amount of fines added in each mix vary from 6 % (maximum allowable percentage of fines for concrete) up to 15% (maximum allowable percentage for mortar used for masonry with crushed rock sand).

3.7.Mix Design

Mix design is the process of defining the quantity and proportioning of concrete ingredients so as the concrete be able to satisfy the required grade. The ultimate goal of this experiment is recommending the use of crushed rock sand in concrete design for any structural and non-structural construction. Investigating the impact of crushed rock sand on compressive strength of concrete as well as cement sand pest will be the primary task before the recommendation drown.

Concrete strength with crushed rock sand and with river sand were assessed so as to investigate the contribution of crushed rock sand for compressive strength of concrete and the effect of fines on compressive strength of concrete.

From the literature review, it has been found that the maximum limits imposed on the fines content in aggregate for concrete vary from one standard to another. Whilst no limits are imposed in the European Standards, the limits imposed in the Chinese Standards and American Standards are rather stringent. Up to now, there is no general consensus regarding the effects of the fines content on the performance of the concrete produced and therefore the allowable fines content in fine aggregate for concrete has remained a controversial issue.

3.7.1. Trial Mix

The main objectives of the trial mixes were is to: determine if a suitable workability can be achieved in concrete containing manufactured sand as replacement for natural sand. The mixes were designed with a water cement ratios of 0.4, 0.5, and 0.6, fines contents of 6%, 9%, 12% and 15%, Sand to aggregate ratio is 0.45 and Water Content 190 Kg/m3. From this, it was possible to determine the cement content as follows: -

Cement Content = (190/0.4) = 475 Kg/M^3 for water to cement ratio is 0.4,

Cement content = 190/0.5 = 380 kg/M^3 for water to cement ratio is 0.5 and

Cement content = 190/0.6 = 316 kg/M^3 for water to cement ratio is 0.6
By incorporating other elements of concrete substitute, trial mix design was presented in tables 5.1 and 5.2 her below.

Trial MIX-DESIGN summary

With River Sand

Material		Volume (m^3)	weight (kg)
Cement		0.101	316.667
Water		0.19	190.000
Air		0.03	negligible
Total Aggregate		0.679	-
Sand		0.306	888.850
Coarse aggregate		0.374	1065.071
Admixture		0.0%	0.000
	TOTAL	**1.000**	

Sp.gr of RS	2.7
Sp.gr of C.A	2.85
w/c	0.4,0.5 & 0.6
S/A	0.45

Table 3.7. Trial Mix Design with River Sand (RS)

S/A	Cement (kg/(m^3)	Water (kg/m^3)	RS (kg/m^3)	CA (kg/m^3)	Fines	
					%	kg/m^3
	W/C = 0.4					
0.45	475	190	719.41	986.00	6	43.16
	475	190	696.45	986.00	9	62.68
	475	190	673.49	986.00	12	80.82
	475	190	650.53	986.00	15	97.58
	W/C = 0.5					
0.45	380	190	753.88	1033.56	6	45.23
	380	190	729.82	1033.56	9	65.68
	380	190	705.76	1033.56	12	84.69
	380	190	681.70	1033.56	15	102.26
	W/C = 0.6					
0.45	316	190	776.89	1065.00	6	46.61
	316	190	696.45	1065.00	9	62.68
	316	190	673.49	1065.00	12	80.82
	316	190	650.53	1065.00	15	97.58

Trial MIX-DESIGN summary

With River Sand

Material	Volume (M^3)	weight (kg)
Cement	0.101	316.667
Water	0.19	190.000
Air	0.03	negligible
Total Aggregate	0.679	-
Sand	0.306	888.850
Coarse aggregate	0.374	1065.071
Admixture	0.0%	0.000
TOTAL	**1.000**	

Sp.gr of CRS	2.91
Sp.gr of C.A	2.85
w/c	0.4,0.5 & 0.6
S/A	0.45

Table 3.8. Trial Mix Design with Crushed Rock Sand (CRS)

S/A	Cement (kg/(m^3)	Water (kg/m^3)	CRS (kg/m^3)	CA (kg/m^3)	Fines	
					%	kg/m^3
W/C = 0.4						
0.45	475	190	773.62	986.00	6	46.42
	475	190	748.93	986.00	9	67.40
	475	190	724.24	986.00	12	86.91
	475	190	699.55	986.00	15	104.93
W/C = 0.5						
0.45	380	190	810.28	1033.56	6	48.62
	380	190	784.42	1033.56	9	70.60
	380	190	758.56	1033.56	12	91.03
	380	190	732.70	1033.56	15	109.91
W/C = 0.6						
0.45	316	190	835.52	1065.00	6	50.13
	316	190	808.85	1065.00	9	72.80
	316	190	782.19	1065.00	12	93.86
	316	190	755.52	1065.00	15	113.33

3.7.2. Final mix

This mix were prepared based on the result of trial batch, adjustment and improvement were made for the mix and add-mixtures were considered in Crushed rock sand mix as per requirements for better workability and to get appropriate slump.

The final Mix proportions with the amount of admixture, Coarse and fine aggregates are shown in Table 5.3 and 5.4

Table 3.9. Final Mix Design for River Sand Batch

S/A	Cement (kg/(m^3)	Water (kg/m^3)	RS (kg/m^3)	CA (kg/m^3)	Admixture (lit/m^3)	Fines	
						%	kg/m^3
W/C = 0.4							
0.45	475	190	719.41	986.00		6	43.16
	475	190	696.45	986.00		9	62.68
	475	190	673.49	986.00		12	80.82
	475	190	650.53	986.00		15	97.58
W/C = 0.5							
0.45	380	190	753.88	1033.56		6	45.23
	380	190	729.82	1033.56		9	65.68
	380	190	705.76	1033.56		12	84.69
	380	190	681.70	1033.56		15	102.26
W/C = 0.6							
0.45	316	190	776.89	1065.00		6	46.61
	316	190	696.45	1065.00		9	62.68
	316	190	673.49	1065.00		12	80.82
	316	190	650.53	1065.00		15	97.58

Table 3.10. Final Mix Design for CRS Batch

S/A	Cement (kg/(m^3)	Water kg/m^3)	CRS (kg/m^3)	CA (kg/m^3)	Admixture (lit/m3)	Fines	
						%	kg/m^3
W/C = 0.4							
0.45	475	190	773.62	986.00		6	46.42
	475	190	748.93	986.00		9	67.40
	475	190	724.24	986.00	1.43	12	86.91
	475	190	699.55	986.00	2.71	15	104.93
W/C = 0.5							
0.45	380	190	810.28	1033.56	1.86	6	48.62
	380	190	784.42	1033.56	1.86	9	70.60
	380	190	758.56	1033.56	1.86	12	91.03
	380	190	732.70	1033.56	2.14	15	109.91
W/C = 0.6							
0.45	316	190	835.52	1065.00	1.43	6	50.13
	316	190	808.85	1065.00	1.00	9	72.80
	316	190	782.19	1065.00	1.14	12	93.86
	316	190	755.52	1065.00	1.43	15	113.33

3.8.Mix preparation and specimen

To study the effects of the fines content in fine aggregate on the overall performance of the concrete produced, a testing program has been worked out. In the testing program, there are three combinations of water/cement (W/C) ratio (0.40,0.50 and 0.60), ACI code recommendation water content 190kg/m^3 , sand to aggregate ratio is 0.45, four combinations of fines content ranging from 6% to 15% (the specific fines content values are 6%, 9%, 12% and 15%), and two combinations of superplasticizer (SP) dosage ranging from no SP added to SP added (however, the SP dosage when added varied from 1.0 litre/m^3 of concrete at a W/C ratio of 0.60 to 2.71 litre/m^3 of concrete at a W/C ratio of 0.40).

The crushed rock sand (CRS) and coarse aggregate (CA) used in the tests were crushed granite rock aggregates obtained from the YENCOMAD crushing site. River sand were used in the test obtained from Alem-Tena natural sand quarry site.

To produce fine aggregates with the prescribed fines contents of 6%, 9%, 12% or 15%, the fines content in the fine aggregate was first removed by mechanical sieving so that the fine aggregate contained a fines content of exactly 0%. Then, the right amount of fines was put back into the fine aggregate so that the fine aggregate contained the prescribed fines content.

A pan mixer was used to mix the ingredients in the trial concrete mix. Electronic balances were used to weigh the correct quantities of ingredients to be added to the mixer. During mixing, all the solid ingredients were added at the same time to the mixer. After about one minute of dry mixing, water was added to the mixer and the concrete mix was further mixed for two minutes. If SP was to be added, it was added last and after adding, the concrete mix was further mixed for another two minutes.

Upon completion of mixing, a fresh sample was taken from the mixer for the slump-flow test. The slump-flow test was carried out using the standard slump cone. After placing the fresh concrete into the slump cone and lifting the slump cone vertically upwards, the drop in height of the concrete was taken as the slump (a measure of deformability).

Finally, after completion of the slump test, all the concrete samples were put back into the mixer and remixed. Then, Nine 150 mm concrete cubes were cast from the remixed fresh concrete. After casting, the concrete cubes, together with their moulds, were covered and stored in the laboratory for 24 hours after casting. The cubes were de-moulded and put into water curing tank controlled at a temperature of 27 ± 2 °C. Three of the cubes were tested at the age of 3 days, three of the cubes tested at the age of 7 days and the remaining three of the cubes were tested at the age of 28 days. The average value of the measured strengths of the three cubes tested at the age of 7 days was taken as the 3-day cube strength while the average value of the measured strengths of the three cubes tested at the age of 7 days was taken as the 7-day cube strength. The 28^{th} day was taken in the same way.

CHAPTER FOUR
TEST RESULTS AND DISCUSSION

4.1. General

In this research paper “Effect of Fines Content on Compressive strength of Concrete with Crushed Stone Sand ’’ laboratory tests are required to study:

(1) The effects of fines content in fine aggregate on the performance of concrete
(2) The suitable, workability and strength of concrete containing manufactured sand with optimum amount of fines so to use as river substitute.

For the above required studies, the laboratory testing program was designed and it reported in the following sections.

4.2. Test Result

The results of sieve analysis for fines modules as expected, have shown that manufactured sand has larger amount of fine materials than the natural sand. The grading of the natural and manufactured sand is dissimilar. The fines modules of river and crushed rock sand were measured as 3.17 and 2.91 respectively.

The results and computation table of all sieve analysis for all aggregate samples used in the concrete mix are attached in Annex

The most common tests carried out on concrete specimens is compressive strength test due to the fact that:

(1) Structural design codes are based mainly on compressive strength of concrete;
(2) It is assumed that most of the important properties of concrete are directly related to compressive strength, and
(3) The test is easy and relatively inexpensive to carry out.

The compressive strength of the concrete specimens was determined by testing concrete cubes of size 150mm. All specimens were weighed and measured to determine the area of the cube and density of the concrete. The hardened properties of the concrete have been determined at the ages of 3, 7 and 28 days. At each age a minimum of three specimens were tested to ensure the accuracy of test results.

Concrete cubes were prepared for testing the compressive strength of a concrete in each percentage of fines and at each water to cement ration. The average compressive strength value of the concrete is summarized as shown in the table below. The detail of the compressive strength test result of concrete samples are attached in the appendix section of this report.

Table 4.1 Average compressive strength of RS and CRS

Test Result For Average Compressive Strength of River Sand				
W/C	Fines (in %)	Test Day		
		3rd	7th	28th
0.4	6	11.67	17.67	29.46
	9	10.21	16.34	26.13
	12	11.55	18.23	32.28
	15	17.90	21.45	31.63
0.5	6	12.96	21.08	25.24
	9	16.84	17.77	21.21
	12	16.28	16.94	22.25
	15	17.45	18.01	23.90
0.6	6	9.29	9.67	16.40
	9	11.04	10.10	16.20
	12	9.72	9.91	17.45
	15	11.52	12.85	20.43

Test Result For Average Compressive Strength of Crushed Rock Sand				
W/C	**Fines (in %)**	**Test Day**		
		3rd	**7th**	**28th**
0.4	6	21.90	22.03	50.23
	9	27.51	28.57	44.12
	12	28.88	31.84	50.41
	15	28.56	33.31	55.95
0.5	6	35.80	33.83	39.98
	9	27.99	28.76	35.65
	12	24.34	26.36	35.86
	15	24.29	28.22	39.75
0.6	6	20.99	20.11	29.00
	9	20.43	18.83	26.56
	12	15.42	15.17	21.56
	15	18.57	20.68	27.78

RS , W/C = 0.4

	SLUMP = 70		**SLUMP = 65**		**SLUMP = 70**		**SLUMP = 60**	
Date	**Fines = 6%**		**Fines = 9%**		**Fines = 12%**		**Fines = 15%**	
	Failure Load [kN]	**Compressive Strength [MPa]**	**Failure Load [kN]**	**Compressive Strength [MPa]**	**Failure Load [kN]**	**Compressive Strength [MPa]**	**Failure Load [kN]**	**Compressive Strength [MPa]**
3rd	254.8	11.32	243.1	10.80	262.3	11.66	408.8	18.17
	261.6	11.63	218.0	9.69	253.5	11.27	396.9	17.64
	271.3	12.06	228.3	10.15	264.0	11.73	402.8	17.90
7th	383.8	17.06	372.2	16.54	408.0	18.13	382.8	17.01
	415.1	18.45	378.4	16.82	408.1	18.14	496.1	22.05
	393.7	17.50	352.1	15.65	414.2	18.41	569.1	25.29
28th	660.2	29.34	618.8	27.50	726.5	32.29	695.6	30.92
	670.4	29.80	588.8	26.17	716.8	31.86	725.2	32.23
	657.8	29.24	556.0	24.71	735.6	32.69	714.1	31.74

Table 4.2 Test result of River Sand with W/C = 0.4

RS, W/C = 0.5

Date	SLUMP = 80		SLUMP = 90		SLUMP = 70		SLUMP = 70	
	Fines = 6%		**Fines = 9%**		**Fines = 12%**		**Fines = 15%**	
	Failure Load [kN]	**Compressive Strength [MPa]**	**Failure Load [kN]**	**Compressive Strength [MPa]**	**Failure Load [kN]**	**Compressive Strength [MPa]**	**Failure Load [kN]**	**Compressive Strength [MPa]**
3rd	288.10	12.80	363.5	16.16	371.80	16.52	407.90	18.13
	298.00	13.24	395.9	17.60	346.50	15.40	361.30	16.06
	288.50	12.82	377.2	16.76	380.80	16.92	408.60	18.16
7th	477.40	21.22	402.5	17.89	364.50	16.20	395.70	17.59
	461.60	20.52	388.6	17.27	393.00	17.47	416.10	18.49
	484.20	21.52	408.2	18.14	385.90	17.15	404.20	17.96
28th	571.60	25.40	477.0	21.20	506.00	22.49	553.80	24.61
	565.80	25.15	473.3	21.04	513.80	22.84	534.10	23.74
	566.20	25.16	481.6	21.40	482.30	21.44	525.10	23.34

Table 4.3 Test Result of River sand with W/C = 0.5

RS W/C = 0.6

Date	SLUMP = 100		SLUMP = 70		SLUMP = 70		SLUMP = 55	
	Fines = 6%		**Fines = 9%**		**Fines = 12%**		**Fines = 15%**	
	Failure Load [kN]	**Compressive Strength [MPa]**	**Failure Load [kN]**	**Compressive Strength [MPa]**	**Failure Load [kN]**	**Compressive Strength [MPa]**	**Failure Load [kN]**	**Compressive Strength [MPa]**
3rd	202.10	8.98	244.70	10.88	228.50	10.16	277.70	13.44
	202.20	8.99	262.40	11.66	232.70	10.34	246.60	13.67
	222.60	9.89	237.90	10.57	195.10	8.67	253.20	11.44
7th	210.00	9.33	237.60	10.56	224.20	9.96	302.40	12.34
	232.40	10.33	223.70	9.94	224.20	9.96	307.50	10.96
	210.10	9.34	220.60	9.80	220.80	9.81	257.30	11.25
28th	363.00	16.13	347.60	15.45	371.70	16.52	475.10	21.12
	355.30	15.79	356.50	15.84	409.60	18.20	468.50	20.82
	388.40	17.26	389.60	17.32	396.40	17.62	435.60	19.36

Table 4.4 Test Result of River Sand with W/C = 0.6

CRS W/C = 0.4

Date	SP = 0, SLUMP = 50, Fines = 6%		SP = 0, SLUMP = 85, Fines = 9%		SP = 50, SLUMP = 50, Fines = 12%		SP = 95, SLUMP = 70, Fines = 15%	
	Failure Load [kN]	Compressive Strength [MPa]	Failure Load [kN]	Compressive Strength [MPa]	Failure Load [kN]	Compressive Strength [MPa]	Failure Load [kN]	Compressive Strength [MPa]
3rd	493.6	21.94	594.1	26.40	646.0	28.71	647.0	28.76
	488.8	21.72	643.8	28.61	656.1	29.16	653.6	29.05
	495.7	22.03	618.8	27.50	647.0	28.76	627.0	27.87
7th	510.8	22.70	628.0	27.91	778.4	34.60	747.5	33.22
	500.6	22.25	647.0	28.76	737.4	32.77	751.4	33.40
	475.3	21.12	653.2	29.03	633.5	28.16	749.8	33.32
28th	989.7	43.99	685.4	30.46	1158.8	51.50	1273.6	56.60
	1189.6	52.87	1184.1	52.63	1134.3	50.41	1247.2	55.43
	1211.2	53.83	1108.8	49.28	1109.8	49.32	1255.6	55.80

Table 4.5 Test Result of Crushed Rock Sand with W/C = 0.4

CRS W/C = 0.5

Date	SP = 65, SLUMP = 70, Fines = 6%		SP = 65, SLUMP = 70, Fines = 9%		SP = 65, SLUMP = 75, Fines = 12%		SP = 60, SLUMP = 70, Fines = 15%	
	Failure Load [kN]	**Compressive Strength [MPa]**	**Failure Load [kN]**	**Compressive Strength [MPa]**	**Failure Load [kN]**	**Compressive Strength [MPa]**	**Failure Load [kN]**	**Compressive Strength [MPa]**
3rd	813.50	36.16	622.50	27.67	529.2	23.52	560.8	24.92
	805.90	35.82	617.60	27.45	552.4	24.55	531.7	23.63
	797.20	35.43	649.10	28.85	561.1	24.94	547.4	24.33
7th	754.20	33.52	647.60	28.78	593.6	26.38	637.8	28.35
	807.70	35.90	655.30	29.12	576.2	25.61	639.9	28.44
	721.30	32.06	638.60	28.38	609.3	27.08	627.4	27.88
28th	896.10	39.83	794.70	35.32	814.6	36.20	808.2	35.92
	920.50	40.91	798.20	35.48	806.7	35.85	952.1	42.32
	881.90	39.20	813.60	36.16	799.1	35.52	923.1	41.03

Table 4.6 Test Result for Crushed Rock Sand with W/C = 0.5

CRS W/C = 0.6

Date	SP = 50 SLUMP = 100 Fines = 6%		SP = 35 SLUMP = 70 Fines = 9%		SP = 40 SLUMP = 70 Fines = 12%		SP = 50 SLUMP = 50 Fines = 15%	
	Failure Load [kN]	Compressive Strength [MPa]	Failure Load [kN]	Compressive Strength [MPa]	Failure Load [kN]	Compressive Strength [MPa]	Failure Load [kN]	Compressive Strength [MPa]
3rd	473.10	21.03	465.10	20.67	337.40	15.00	449.50	19.98
	485.60	21.58	472.90	21.02	361.00	16.04	453.30	20.15
	458.20	20.36	440.70	19.59	342.70	15.23	350.50	15.58
7th	475.20	21.12	400.40	17.80	326.40	14.51	461.30	20.50
	450.60	20.03	413.80	18.39	326.70	14.52	466.70	20.74
	431.60	19.18	456.70	20.30	370.60	16.47	468.00	20.80
28th	650.20	28.90	570.60	25.36	473.50	21.04	632.10	28.09
	671.80	29.86	617.30	27.44	505.00	22.44	655.60	29.14
	635.70	28.25	605.00	26.89	476.80	21.19	587.50	26.11

Table 4.7 Test Result for Crushed Rock Sand with W/C = 0.6

Fig 4.1. 28th day compressive Strength of Concrete with **RS**

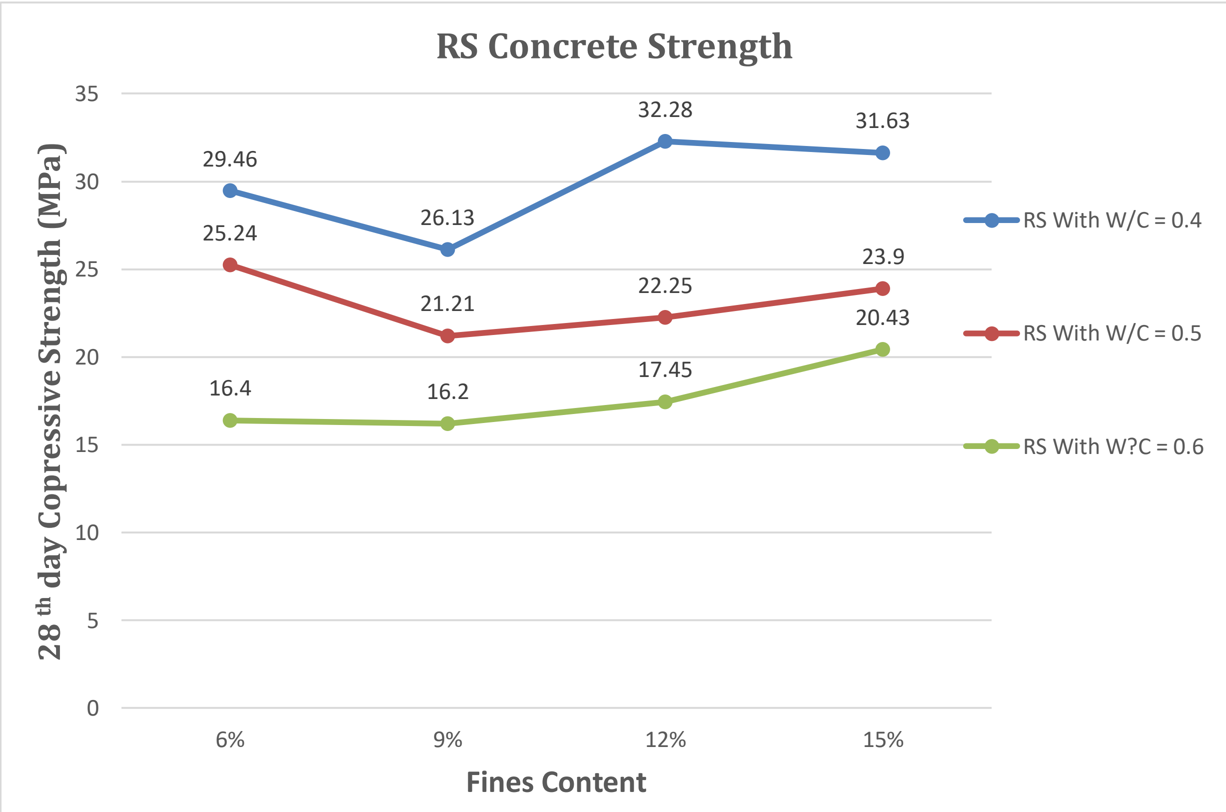
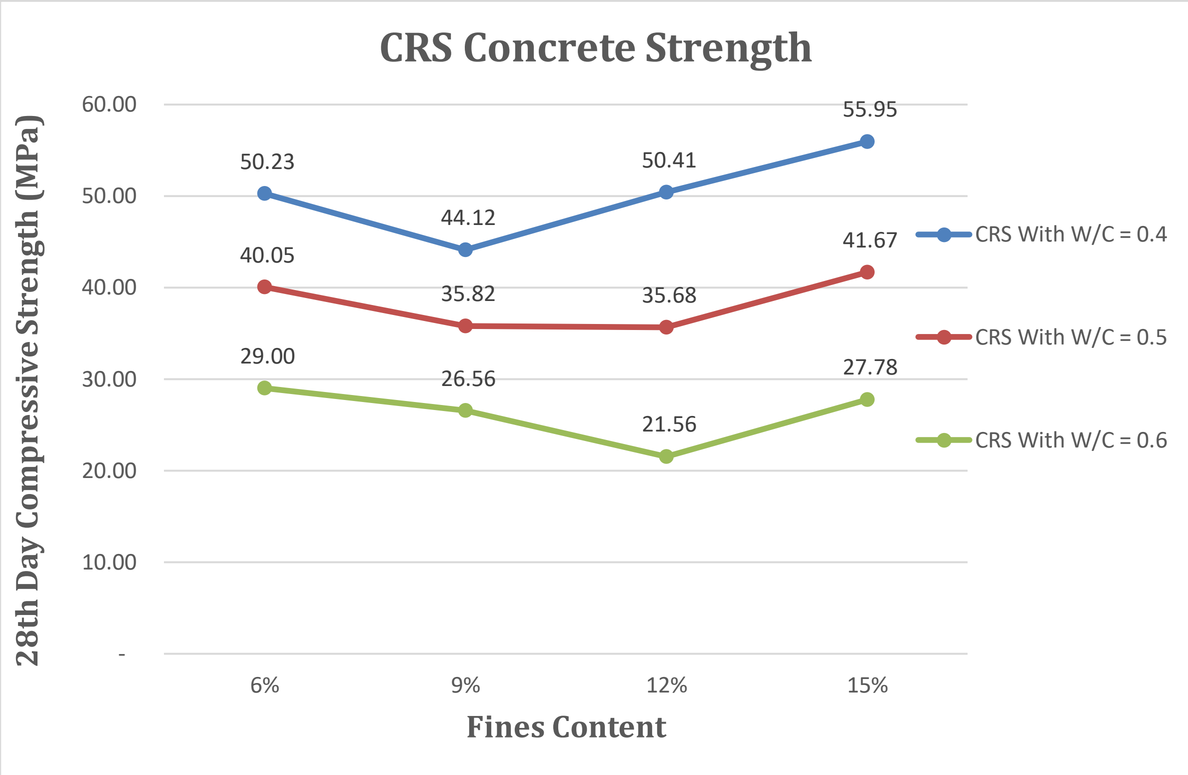


Fig 4.2. 28th Day of compressive Strength of Concrete with **CRS**



4.2.1. Discussion

The laboratory result on effects of fines content on performance of concrete was discussed to justify the suitability of crushed rock sand to replace natural river sand, so as to determine the optimum and allowable fines contents in fine aggregate for concrete production.

There is no doubt that crushed rock sand is the most suitable river sand substitute for concrete and mortar production. River sand, which has been in use for decades, has the major characteristics that since it has been subjected to years of washing, it has a rather low fines content, and since it has been subjected to years of abrasion, it has a more or less rounded and smooth shape. Comparatively, crushed rock sand, has a relatively high fines content and an angular and rough shape. Nevertheless, there are nowadays quarrying technologies for processing crushed rock aggregate to control the fines content and improve the particle shape. Basically, the fines content can be reduced by water washing or air classification and the particle shape can be improved by grinding the aggregate particles in addition to crushing for size reduction.

In fact, the use of manufactured sand as river sand substitute can help to overcome three major shortcomings with river sand. First, since river sand is brought down by river water from upstream, it could have a very complex mineralogy and, as a result, it is generally difficult to ascertain whether its use would lead to any deleterious alkali-aggregate reaction. Second, since river sand is a natural material with no quality control applied, its characteristics could vary widely (in fact river sands dredged from different locations could have different characteristics) whereas manufactured sand is an engineered material with quality control applied to ensure compliance with standards and specifications. Third, river sand dredged from river estuaries close to the sea might have been contaminated with salt, thus causing the concrete/mortar produced to have high chloride content.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.1.Conclusion

The laboratory test results of the concrete mixes reveal the following effects of the fines content on the performance of concrete:

Overall, a higher fines content in the river sand would lead to a lower workability of the concrete produced but if the fines content does exceed 15%, the decrease in workability can be more than compensated by adding more superplasticizer. Hence, it may be said that provided the fines content in the river sand is of good quality and contains little deleterious materials, a fines slightly greater than code limitation (8%) has no adverse effect on compressive strength of concrete.

From laboratory result a fines content increased up to 15%, the compressive strength of concrete getting increase this need further investigation and research to know the root cause. Even then, it is still considered advisable to set a certain maximum limit to the fines content. In CS3: 2013, the fine content is limit to 14% for general use (with the additional requirement that if the fines content > 10%, the methylene blue value shall be ≤ 1.4) and to 10% for use in heavy duty floor finishes. These are very reasonable maximum limits to be imposed. Another reason of setting a maximum limit to the fines content is that in practice, the fines content could fluctuate quite substantially within the specified limit and if the fluctuation in fines content is too large, the workability of the concrete produced would vary from time to time and the concrete producer might find it difficult to adjust the superplasticizer dosage to compensate for the variation in workability.

5.2.Recommendation

5.2.1. Scope

This Recommended Specifications is limited to crushed rock sand and consider as the recommendation of this research paper. It covers aggregates having an oven-dried particle density not less than 2,000 kg/m³, and does not cover lightweight aggregates and heavyweight aggregates. The mortars to be produced are not included in this research and recommendation. Terms and definitions are kept the same with Ethiopian building code.

The recommendation limited on physical and geometrical recommendation only.

5.2.2. Geometrical Requirements

The geometrical properties of aggregates shall be determined with consideration of the application conditions and origin of the aggregates.

5.2.2.1.Aggregate Size

Recommended aggregate size shall be described in terms of aggregate sizes using the designations *d*/*D*, in which *d* is the lower sieve size and *D* is the upper sieve size.

5.2.2.2.Grading

To get good quality of material gradation the grading (i.e. C, M or F) of crushed rock sand it is good to use as per the following table

Table 5.1 - Grading of fine aggregates of size 0/4.75 mm

Sieve size	Percentage by mass passing test sieves (%)			
	Overall limits	Limits for declared grading		
		C	M	F
9.5 mm	100	-	-	-
4.75 mm	89-100	-	-	-
2.36 mm	60-100	60-100	65-100	80-100
1.18 mm	30-100	30-90	45-100	70-100
600 µm	15-100	15-54	25-80	55-100
300 µm	5-70	5-40	5-48	5-70
150 µm	0-20	-	-	-

5.2.2.3.Fines Content

From experiment result and different code recommendation, the amount of material passing the 75µm test sieve, shall not exceed the 15% for general used concrete and 12% for high strength concrete.

5.2.2.4.Other constituents

- Aggregates shall be free of organic substances. The aggregate producer or supplier shall demonstrate that the supplied aggregate is free of organic substances or alternatively the presence of organic substances does not affect the stiffening or hardening of mortar.
- The manufacturing process of manufactured sand requires active production control of all processes, storage should be dry and transportation has to be minimized to prevent segregation
- Concerned government authorities and/or stakeholders have up-to-date information about the locations and details of existing quarries in addition with the potential of available quarries.
- Concerned department should pay special attention and give privileges for crushed rock sand producers and suppliers so as to maximize the benefits of concrete production with CRS.
- Arranging short term training for Consultants, contractors, Designers, and material suppliers to familiarize them on the positive effects of manufactured sand during concrete production as well as it is the best river sand substitute material.

FURTHER RESEARCH IS PROPOSED IN THE FOLLOWING AREAS.

This points or tittles need to investigate further is

1. Recommended specification on crushed rock sand for mortar
2. Guide lines, mix design proposals and specifications shall be prepared using manufactured sand to establish acceptable mixes for concrete producers, contractors, consultants and clients.
3. Environmental effect of natural sand digging

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Annex

DETERMINATION OF SPECIFIC GRAVITY & WATER ABSORPTION OF RIVER SAND

OBSERVATION SHEET

Specific Gravity of River Sand

Take 2000 gram of fine aggregate which passed by 4.75mm sieve size and take one quarter weight of sample (500g)

DESCRIPTION			Sample
a	Weight of sample taken (g)		2000
b	Weight of saturated & surface dray aggregate (g)		500
c	Weight of Oven-Dry sample in air (A) (g)		485
d	Weight of pycnometer + Water (B) (g)		1310
e	Weight of pycnometer + Sample +Water (C) (g)		1625
f	Bulk Specific Gravity	$[\frac{A}{B+500-C}]$ =	2.622
g	Bulk specific Gravity (Saturated - Surface _ Dry Base)	$[\frac{500}{B+500-C}]$ =	2.703
	Apparent Specific Gravity	$[\frac{A}{B+A-C}]$ =	2.853
h	Water Absorption (%)	$[\frac{500-A}{A}] * 100$ =	3.093

DETERMINATION OF SPECIFIC GRAVITY & WATER ABSORPTION OF CRS

OBSERVATION SHEET

	DESCRIPTION		**Sample**
a	Weight of sample taken (g)		2000
b	Weight of saturated & surface dray aggregate (g)		500
c	Weight of Oven-Dry sample in air (A) (g)		495
d	Weight of pycnometer + Water (B) (g)		1310
e	Weight of pycnometer + Sample +Water (C) (g)		1638
	Bulk Specific Gravity	$[\frac{A}{B+500-C}]$ =	2.878
g	Bulk specific Gravity (Saturated - Surface _ Dry Base)	$[\frac{500}{B+500-C}]$ =	2.907
	Apparent Specific Gravity	$[\frac{A}{B+A-C}]$ =	2.964
h	Water Absorption (%)	$[\frac{500-A}{A}] * 100$ =	1.010

DETERMINATION OF SPECIFIC GRAVITY & WATER ABSORPTION OF <u>COARSE AGGREGATE</u>

Specific Gravity and water absorption of Coarse Aggregate Sand

Take 5000 gram of fine aggregate which retained by 4.75mm sieve size and take one quarter weight of sample (500g)

S/N	DESCRIPTION		Sample
a	Weight of Oven-Dry sample in air (A) (g)		4905
b	Weight of Saturated-surface-dry sample in air (B) (g)		4960
c	Weight of Saturated Sample in Water (C) (g)		3219.000
d	Bulk Specific Gravity	$[\frac{A}{B-C}]$ =	2.817
e	Bulk specific Gravity (Saturated - Surface _ Dry Base)	$[\frac{B}{B-C}]$ =	2.849
f	Apparent Specific Gravity	$[\frac{A}{A-C}]$ =	2.909
g	Water Absorption Capacity (%)	$[\frac{B-A}{A}] * 100$ =	1.121

S/A	Cement (Kg/(M$^{3)}$	Water (Kg/M^3	RS (Kg/M$^{3)}$	CA (Kg/M$^{3)}$	Admixture (Lit/M$^{3)}$	Fines	
						%	Kg/M^3
W/C = 0.4							
0.5	475	190	719.41	986.00		6	43.16
	475	190	696.45	986.00		9	62.68
	475	190	673.49	986.00		12	80.82
	475	190	650.53	986.00		15	97.58
W/C = 0.5							
0.5	380	190	753.88	1033.56		6	45.23
	380	190	729.82	1033.56		9	65.68
	380	190	705.76	1033.56		12	84.69
	380	190	681.70	1033.56		15	102.26
W/C = 0.6							
0.5	316	190	776.89	1065.00		6	46.61
	316	190	696.45	1065.00		9	62.68
	316	190	673.49	1065.00		12	80.82
	316	190	650.53	1065.00		15	97.58

S/A	Cement (Kg/(M$^{3)}$	Water (Kg/M^3	CRS (Kg/M$^{3)}$	CA (Kg/M$^{3)}$		Fines	
						%	Kg/M^3
W/C = 0.4							
0.5	475	190	773.62	986.00		6	46.42
	475	190	748.93	986.00		9	67.40
	475	190	724.24	986.00	1.43	12	86.91
	475	190	699.55	986.00	2.71	15	104.93
W/C = 0.5							
0.5	380	190	810.28	1033.56	1.86	6	48.62
	380	190	784.42	1033.56	1.86	9	70.60
	380	190	758.56	1033.56	1.86	12	91.03
	380	190	732.70	1033.56	2.14	15	109.91
W/C = 0.6							
0.5	316	190	835.52	1065.00		6	50.13
	316	190	808.85	1065.00		9	72.80
	316	190	782.19	1065.00		12	93.86
	316	190	755.52	1065.00		15	113.33