ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

FACULTY OF TECHNOLOGY
DEPARTMENT OF CIVIL ENGINEERING

THE USE OF MANUFACTURED SAND IN CONCRETE PRODUCTION: TEST RESULTS AND COST COMPARISON.

A thesis submitted to the School of Graduate Studies of the Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering

(Construction Technology and Management)

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LIST OF ABBREVIATIONS

MS	Manufactured Sand
NS	Natural Sand
ACI	American Concrete Institute
ASTM	American Society for Testing of Materials
BS	British Standard
ES	Ethiopian Standard
OPC	Ordinary Portland Cement
PPC	Portland Pozzolana Cement
MOPC	Messobo Ordinary Portland cement
MPPC	Mugher Portland Pozzolana cement
FM	Fineness Modulus
W/C	Water to cement ratio
FA	Fine aggregate
CA	Coarse aggregate
NSC	Normal strength concrete
ISC	Intermediate strength concrete
HSC	High strength concrete
PSD	Particle size distribution
gm	gram
Kg	Kilo gram
KN	Kilo Newton
lt	liter
m	meter

m^3	meter cube
mm	millimeter
MPa	Mega Pascal
SSD	Saturated Surface Dry
LAA	Los Angeles Abrasion
FI	Flakiness index
DoE	Department of the Environment
%	Percentage
ETB	Ethiopian Birr
Kg/m^3	Kilogram per meter cube
Fig.	Figure

ABSTRACT

Manufactured sand is a term used for aggregate materials less than 4.75mm and which are processed from crushed rock or gravel. Due to booming of construction activities in our country, natural sand resources are increasingly depleted and its cost is becoming increasingly high. This research was, therefore, conducted to study the influence that manufactured sand have in compressive strength of concrete, to compare the cost of different mix compositions and to assess the prospects of using manufactured sand as replacement of natural sand in Ethiopia.

Initially, different natural and manufactured sand samples to be used in the concrete mixes were collected and their physical properties were studied. Fifteen different concrete mixes having five mix proportions for both natural and manufactured sand (i.e. 100%NS+ 0%MS; 75%NS+25%MS; 50%NS+50%MS; 25%NS+75%MS and 0%Ns+100%MS) were prepared for normal strength, intermediate strength and high strength concrete using a water cement ratio and cement contents of 0.54, 370kg/m^3; 0.39, 460kg/m^3; 0.30, 520kg/m^3 respectively. The properties of these mixes have then been assessed both at the fresh and hardened state. In addition, comparison of costs for each concrete mixes based on the price of the concrete material collected from Addis Ababa, Nazareth, Awassa, Mekelle and Jimma towns were made.

The results of the hardened properties of the mixes have shown that concrete mixes with partial proportions of manufactured and natural sand achieved a higher compressive strength at all test ages. The cost comparisons results also have shown that using manufactured sand in partial or full replacement to natural sand doesn't cause any significant cost variation. It has been found also that use of manufactured sand is more suitable for high strength concrete production. It can therefore, be concluded from the findings of this research that when the availability of natural sand is scarce or in cities where the price of natural sand is as expensive as manufactured one, manufactured sand concrete mix is a viable and better alternative to the use of natural sand.

Keywords: aggregate, compressive strength, concrete, cost, manufactured sand, workability.

CHAPTER ONE

INTRODUCTION

1.1 General

It is generally known that, the fundamental requirement for making concrete structures is to produce good quality concrete. Good quality concrete is produced by carefully mixing cement, water, and fine and coarse aggregate and combining admixtures as needed to obtain the optimum product in quality and economy for any use [1].

Good concrete, whether plain, reinforced or prestressed, should be strong enough to carry superimposed loads during its anticipated life. Other essential properties include impermeability, durability, minimum amount of shrinkage, and cracking [1].

The following factors contribute to the production of good quality concrete [1]:

- knowledge of the properties and fundamental characteristics of concrete making materials and the principles of design,
- reliable estimates of site conditions and costs,
- quality of component materials,
- a careful measurement of weigh-batching of cement, water and aggregate,
- proper transport, placement and compaction of the concrete,
- early and thorough curing, and
- competent direction and supervision

Although good concrete costs little more than poor concrete, its performance is vastly superior. 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, unlike water and cement, which do not alter in any particular characteristic except in the quantity, in which they are used, the aggregate component is infinitely variable in terms of shape and grading. These shows the importance of the care that should be taken in processing and supplying aggregates for concrete production.

For the aggregate producer, the concrete aggregates are end products, while for the concrete manufacturer; the aggregates are raw materials to be used for successful concrete production. With the aggregate production, the quality of the aggregate products can be influenced, while raw material –gravel or rock, may have characteristics, which cannot be modified by the production process. However, there is also a limit, whether technical and/or economical, in the mix design modification after which it is useful to select a more suitable aggregate product.

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 our country. However, the intensive construction activity is resulting in a growing shortage and price increase of the natural sand in the country. In addition, the aggregate and concrete industries are presently facing a growing public awareness related to the environmental influence of their activities.

The environmental impact is attributed to the non-renewable character of the natural resources, the environmental impact on neighborhood, land use conflicts, high energy consumption needed for aggregate production and the potential environmental or health impact of materials produced due to leaching of heavy metals, radioactivity and to special mineral suspects to have hazardous health effects. Therefore, due to the above-mentioned facts, looking for viable alternatives to a natural sand is a must.

One possible alternative material that can be used as a replacement for natural sand is the use of 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.

To this effect, this research is carried out to study the prospects of the uses of manufactured sand in our country. The research is divided into two sections, which are experimental study and cost comparison.

In the experimental study different concrete mixes with different percentage of natural and manufactured sands were prepared and the respective fresh and hardened properties of the resulting concrete mixes were determined and analyzed.

In due course of the experimental study, concrete mix designs using higher proportions of manufactured sand to partially or fully replace natural sands in concrete resulted in a concrete mix, which is harsh, difficult and harder to place and finish. To overcome some of these problems an admixture was added. Besides providing water reduction, the use of such an admixture had imparted superior workability to the mix.

Following the experimental analysis, cost comparisons of the different mixes were carried out using material costs collected from the different parts of the country. Finally, from the obtained results conclusions were made and recommendations were forwarded.

CHAPTER TWO

OBJECTIVES AND METHODOLOGY OF THE STUDY

2.1 General

Sand, as one of the most accessible natural resources, has been used mostly as a construction material since the earliest days of civilization. It is defined as "continuously graded unconsolidated material (sediment) present on the earth's surface as a result of the natural disintegration of rocks" [2].

The main natural and cheapest 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.
- 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.

- 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.

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.

2.2 Objectives of the research

The general objective of this research work is

- to study the influence of manufactured sand on the compressive strength development of concrete and compare the result with that of concrete produced using selected river sand.

The specific objectives of this research are, therefore:

- to provide background information on manufactured sand, cements, admixtures, aggregates and mix design processes.
- to assess existing concrete produced using manufactured sand
- to conduct a cost comparison of concrete produced with and without manufactured sand in different proportions.
- to draw conclusions and give recommendations based on the research findings and indicate areas for further study.

2.3 Methodology

The following methodology has been employed to achieve the objectives of the research

Stage 1: literature review

A comprehensive literature review is made to understand the previous efforts, which include the review of textbooks, periodicals and academic journals, seminar, conference and research papers.

Stage 2: main research

The methods followed to achieve the objectives are:

- assessment is made on the existing mix design methods and test results of concrete produced using manufactured sand.
- tests were conducted using river sand, manufactured sand and a combination of both with equal amounts of cement, coarse aggregate and water and with variable amounts of admixtures.
- a cost comparison of concrete produced using partial or full replacement of the natural sand with manufactured sand was made.
- the results were presented in graphical form and interpretation and discussion were made on the research findings.
- based on the findings conclusions are drawn and recommendations are forwarded.

Stage 3: Writing the research report

This stage involves compiling and writing up the thesis.

The results of this theses work will be helpful for:

- educational institutions, which use the information for academic purposes.
- environmental organizations seeking to understand interactions of minerals with the environment.
- concrete producers to focus on manufactured sand in order to produce comparable, even better, quality of concrete.

- private/governmental organizations or construction firms that use the data for construction purposes in order to minimize the use of scarce resource of natural (river) sand.

CHAPTER THREE
LITERATURE REVIEW

3.1 Constituents of concrete

If a concrete is to be suitable for a particular purpose, it is necessary to select the constituent materials and combine them in such a manner as to develop the special qualities required as economical as possible. The selection of materials and choice of method of construction is not easy, since many variables affect the quality of the concrete produced, and both quality and economy must be considered.

The characteristics of concrete should be evaluated in relation to the required quality for any given construction purpose. The closest practicable approach to perfection in every property of the concrete would result in poor economy under many conditions, and the most desirable structure is that in which the concrete has been designed with the correct emphasis on each of the various properties of the concrete, and not solely with a view to obtaining of maximum possible strength [3].

3.1.1 Cement

Cement is a key to infrastructure industry and is used for various purposes and also made in many compositions for a wide variety of uses. Cements may be named after the principal constituents, after the intended purpose, after the object to which they are applied or after their characteristic property.

Cement used in construction are sometimes named after their commonly reported place of origin, such as Roman cement, or for their resemblance to other materials, such as Portland cement, which produces a concrete resembling the Portland stone used for building in Britain.
The term cement is derived from the Latin word Caementum, which is meant stone chippings such as used in Roman mortar not-the binding material itself [4]. Cement, in the general sense of the word, described as a material with adhesive and cohesive properties, which make it capable of bonding mineral fragments in to a compact whole. The first step of reintroduction of cement after decline of the Roman Empire was in about 1790, when an Englishman, J. Smeaton, found that when lime containing a certain amount of clay was burnt, it would set

under water. This cement resembled that which had been made by the Romans. Further investigations by J. Parker in the same decade led to the commercial production of natural hydraulic cement.

Joseph Aspdin, an English mason, made an important advance towards the manufacture of dependable hydraulic cement in 1824. His product was called Portland cement because it resembled a building stone that was quarried on the Isle of Portland off the coast of Dorset, UK. Until the end of the nineteenth century, large quantities of this cement were exported to many parts of the world. The first factories for Portland cement outside the British Isles were opened in France in 1840, Germany in 1855, and the United States in 1871 [1] and in Ethiopia in the twentieth century.

Chemical compounds of Portland cement

The raw material used in the manufactures of Portland cement comprises four principal compounds. These compounds are usually regarded as the major constituents of cement and tabulated with their abbreviated symbols, in Table 3.1.

Table 3.1 Typical composition of ordinary Portland cement

Name of compound	Oxide composition	Abbreviation
Tricalcium Silicate	$3CaO.SiO_2$	C_3S
Dicalcium Silicate	$2CaO.SiO_2$	C_2S
Tricalcium aluminate	$3CaO.Al_2 O_3$	C_3A
Tetracalcium aluminoferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF

These compounds interact with one another in the kiln to form a series of more complex products. Portland cement is varied in type by changing the relative proportions of its four predominant chemical compounds and by the degree of fineness of the clinker grinding. A small variation in the composition or proportion of its raw materials leads to a large variation in compound composition.

Calculation of the potential composition of Portland cement is generally based on the Bogue composition (R.H Bogue). In addition to the main compounds, there exist minor compounds such as MgO, TiO_2, K_2O and Na_2O; they usually amount to not more than a few percent of the mass of the cement. Two of the minor compounds are of particular interest: the oxides of sodium and potassium, K_2O and Na_2O, known as the alkalis. They have been found to react with some aggregates, the products of the reaction causing disintegration of the concrete and have also observed to affect the rate of gain of strength of cement [5].

Present knowledge of cement chemistry indicates that the major cement compounds have the following properties [6].

a) Tricalcium Silicate, C_3S hardens rapidly and is largely responsible for initial set and early strength development. The early strength of Portland cement concrete is higher with increased percentages of C_3S.

b) Dicalcium Silicate, C_2S hardens slowly and contributes largely to strength increase at ages beyond one week.

c) Tricalcium aluminate, C_3A liberates a large amount of heat during the first days of hardening. It also contributes slightly for early strength development. Cements with low percentages of this compound are especially resistant to soils and waters containing sulphates.

Concrete made of Portland cement with C_3A contents as high as 10.0%, and sometimes greater, has shown satisfactory durability, provided the permeability of the concrete is low.

d) Tetracalcium aluminoferrite, C_4AF reduces the clinkering temperature. It acts as a flux in burning the clinker. It hydrates rather rapidly but contributes very little to strength development. Most colour effects are due to C_4AF series and its hydrates [6].

The compounds tricalcium aluminate and tricalcium silicate develop the greatest heat, then follows tetracalcium aluminoferrite, with dicalcium silicate developing the least heat of all.

3.1.1.1 Types of cement

The division of cements into different types is necessarily no more than a broad functional classification, and there may sometimes be wide differences between cements of nominally the same type. Out of the several types of cements, two of them i.e. Portland pozzolana cement and ordinary Portland cements produced in Ethiopia by the Mugher and Messebo cement factories have been used for this research and are briefly discussed below.

3.1.1.1.1 Ordinary Portland cement

Ordinary Portland (Type-I) cement is suitable for general concrete construction when there is no exposure to sulphates in the soil. The standard requires that it is made from 95 to 100 percent of Portland cement clinker and 0 to 5 percent of minor additional constituents. Minor additional constituents are one or more of the other cementitious materials or filler. Filler is defined as any natural or inorganic mineral material other than a cemetitious material [5]. Variations in its composition may produce a difference of up to ±20 % in the compressive strength of concrete that is made with it, but uniform results are obtainable by drawing cement from one source of supply [1].

3.1.1.1.2 Portland Pozzolana cement

Portland Pozzolana cement is manufactured by blending 10-30 percent by weight of pozzolanic material with Portland cement; either by simple mixing or by inter grinding with cement clinker. The calcium hydroxide liberated during the process of hydration of the cement combines slowly with the pozzolana to give it cementitious properties, thereby contributing to water tightness and long, continued gain in strength of the concrete.

Portland pozzolan cement is particularly suitable for use in mass concrete structures (such as in dams and bridge piers), where low heat of hydration is desired; hydraulic structures of all kinds where water tightness is important; structures subject to attack from ground water, sea water or diluted industrial wastes; and under water construction where concrete is deposited by bucket. A pozzolan may be used as a partial replacement of the fines of sand, without a reduction of cement content, where high early strength is required [1].

3.1.1.2 Hydration of Portland cement

Hydration of Portland cement is the chemical reaction it undergoes when brought in contact with water. However, unlike the reaction of the other calcareous cements, hydration of Portland cement is a far more complex phenomenon. This is so because Portland cement is a heterogeneous mixture of several chemical compounds, which are complex in themselves [7].

The most important components of Portland cement from the strength development point of view are C_2S and C_3S which, on hydration, form the same compounds in differing proportions. $C_3S_2H_3$ is the final product of hydration of both C_2S and C_3S, the reactions of hydration can be written for C_3S and C_2S respectively, as follows[5],[20]:

$$2(3CaO.SiO_2) + 6H_2O \rightarrow 3CaO.2SiO_2.3H_2O + 3Ca(OH)_2 \qquad [3.1]$$

$$2(2CaO.SiO_2) + 4H_2O \rightarrow 3CaO.2SiO_2.3H_2O + Ca(OH)_2 \qquad [3.2]$$

3.1.1.2.1 Factors affecting the rate and heat of hydration

The rate of hydration of Portland cement is affected by a number of factors and is briefly discussed as follows [7]:

a) **Cement composition: -**

   The speed with which the chemical reactions proceed depends on the affirmation of the individual compounds to water. The first to react are the aluminates. The rate of hydration of the aluminates can be possibly retarded by varying the percentage of gypsum ($CaSO_4 \cdot 2H_2O$). The amount of gypsum to properly retard the setting varies mainly with the content of C_3A and the fineness of the cement. In very hot countries, cements that are used for making concrete should have reduced proportions of the constituents that hydrate rapidly (C_3A and C_3S) with accompanying high rate of heat liberation. Unchecked rate of hydration accompanied by hot climatic conditions will lead to excessive expansion of the fresh concrete. At later ages, contraction takes place with resulting cracks that will seriously affect the structure. The high heat liberation of the rapid hardening constituents can be put to advantage in very cold regions where freezing and thawing might adversely affect a freshly cast concrete.

b) Fineness of the cement: -

The finer the grinding of the cement, the faster should be the hydration process and vice versa. However, the ultimate degree of hydration is not affected by the fineness of the cement. A finer cement will require not only more water to cover the higher surface area, but also relatively more gypsum to retard the speedy hydration of the decreased number of aluminates particles.

c) Water/cement ratio: -

Both the rate of hydration and the heat evolution are affected by the water/cement ratio. The water/cement ratio has practically no influence on the rate of hydration in the first 24 hours after mixing. Later on, the rate of hydration decreases with a decrease in a water/cement ratio.

d) Age of paste: -

It has been understood that the rate of hydration of cements, and hence the heat evolution, is highest at early age. Depending on the grain size distribution in the cement and the pressure of water, hydration may continue for several years after mixing but at a much-reduced rate as shown typically in Fig.3.1 [7].

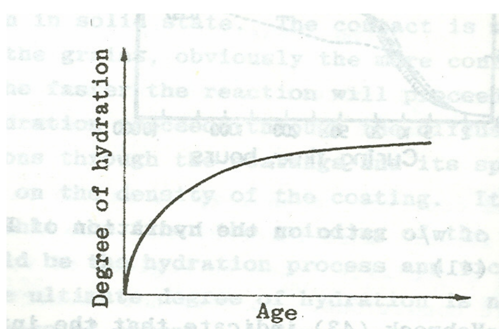

Fig. 3.1 Degree of hydration -vs- age of paste

e) Ambient conditions:-

The rate of hydration of Portland cement is influenced by the ambient temperature, and identical results cannot be expected from specimens that are subjected to different thermal histories. The rate of hydration increases with temperature and this is true only at earlier ages. Ultimately, however, the same degree of hydration is reached irrespective of the curing temperature. The effect of ambient temperature on heat of hydration is shown in Fig. 3.2 [7].

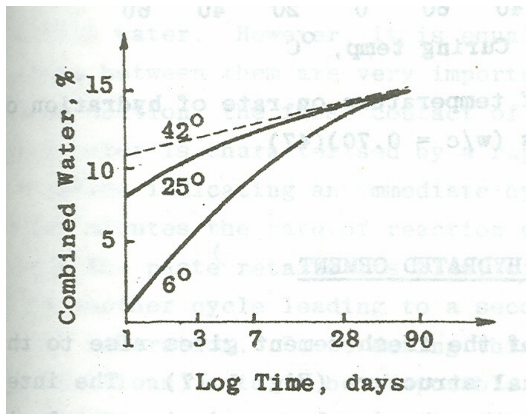

Fig. 3.2 Effect of ambient temperature on rate of hydration of Portland cement

3.1.2 Aggregates

3.1.2.1 General

Aggregates were first considered to simply be filler for concrete to reduce the amount of cement required. However, it is now known that the type of aggregate used for concrete can have considerable effects on the plastic and hardened state properties of concrete. They can form 80% of the concrete mix so their properties are crucial to the properties of concrete. 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 specialist uses, such as nuclear radiation shielding provided by heavyweight concrete and thermal insulation using lightweight concrete [5].

3.1.2.2 Classification of aggregates

The alternative used in the manufacture of good quality concrete, is to obtain the aggregate in at least two size groups, i.e.:

1) fine aggregate often called sand (BS 882; 1992) not larger than 5mm in size[11].

2) course 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. E.g. chemical and mineral composition, petrological 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. It has been found that aggregate may appear to be unsatisfactory on some count but no trouble need be experienced when it is used in concrete.

3.1.2.3 Aggregate properties

By selecting different sizes and types of aggregates and different ratios of aggregate to cement ratios, a wide range of concrete can be produced economically to suit different requirements. Important properties of an aggregate which affect the performance of a concrete are discussed as follows:

3.1.2.3.1 Sampling

Samples shall be representative and certain precautions in sampling have to be made. No detailed procedures can be laid down as the conditions and situations involved in taking samples in the field can vary widely from case to case. Nevertheless, a practitioner can obtain reliable results bearing in mind that the sample taken is to be representative of the bulk of the material. The main sample shall be made up of portions drawn from different parts of the whole. The minimum number of these portions is described in BS 812; part 105; 1990[12]. In the case of stockpiles, the sample obtained is variable or segregated, a large number of increments should be taken and a larger sample should be dispatched for testing [5].

3.1.2.3.2 Particle shape and texture

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].

Surface texture of the aggregate affects its bond to the cement paste and also influences the water demand of the mix, especially in the case of fine aggregate. The shape and surface texture of aggregate influence considerably the strength of concrete. The effects of shape and texture are particularly significant in the case of high strength concrete.

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 it's packing, i.e. by the percentage voids in a loose condition, then the influence on the water requirement is quite definite. The influence of the voids in coarse aggregate is less definite. Flakiness and shape of coarse aggregates have an appreciable effect on the workability of concrete [5].

3.1.2.3.3 Bond of aggregate

Bond between aggregate and cement paste is an important factor in the strength of concrete, but the nature of bond is not fully understood. Bond is to the interlocking of the aggregate and the hydrated cement paste due to the roughness of the surface of the former. A rougher surface, such as that of crushed particles, results in a better bond due to mechanical interlocking; better bond is not usually obtained with softer, porous, and minor logically heterogeneous particles. Bond is affected by the physical and chemical properties of aggregate. For good development of bond, it is necessary that the aggregate surface be clean and free from adhering clay particles [5].

The determination of the quality of bond of aggregate is difficult and no accepted tests exist. Generally, when bond is good, a crushed specimen of normal strength concrete should contain some aggregate particles broken right through, in addition to the more numerous ones pulled out from their sockets. An excess of fractured particles, might suggest that the aggregate is too weak [5].

3.1.2.3.4 Strength of aggregate

The compressive strength of concrete cannot significantly exceed that of the major part of the aggregate contained. If the aggregate under test leads to a lower compressive strength of concrete, and in particular if numerous individual aggregate particles appear fractured after the concrete specimen has been crushed, then the strength of the aggregate is lower than the nominal compressive strength of the concrete mix. Such aggregate can be used only in a concrete of lower strength.

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 a low strength may be due to the weakness of constituent grains or the grains may be strong but not well knit or cemented together.

A test to measure the compressive strength of prepared rock cylinders used to be prescribed. However, the results of such a test are affected by the presence of planes of weakness in the rock that may not be significant once the rock has been comminuted to the size used in concrete.

In essence the crushing strength test measures the quality of the parent rock rather than the quality of the aggregate as used in concrete. For this reason the test is rarely used. Crushing value test BS 812: part 105:1990, measures the resistance to pulverization[12]. The crushing value is a useful guide when dealing with aggregates of unknown performance, when lower strength may be suspected. There is no obvious physical relation between this crushing value and the compressive strength, but the results of the two tests are usually in agreement.

3.1.2.3.5 Deleterious substances of aggregate

For satisfactory performance, concrete aggregates 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.

3.1.2.3.5.1 Organic impurities

Natural aggregates may be sufficiently strong and resistant to wear and yet they may not be satisfactory for concrete making if they contain organic impurities, which interfere with the chemical reactions of hydration. The organic matters are more likely to be present in sand than in coarse aggregate, which is easily washed.

The effects of organic impurities may be only temporary. Results of a research have shown that concrete made with sand containing organic matter had 24-hour strength equal to 53% of the strength of similar concrete made with clean sand. In addition, at 3 days, this ratio rose to 82 percent, then to 92 percent at 7 days, and at 28 days equal strengths were recorded [5].

3.1.2.3.5.2 Clay and other fine materials

Clay may be present in 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 aggregate.

Sand won from the seashore or dredged from the sea or a river estuary, as well as desert sand, contains salt, and has to be processed. Because of the danger of chloride-induced corrosion of steel reinforcement, BS 8110: part 1; 1985 (structural use of concrete) specified the maximum total chloride ion content in the mix [13]. Apart from the danger of corrosion of steel reinforcement, if salt is not removed, it will absorb moisture from the air and cause efflorescence.

3.1.2.3.5.3 Unsound particles

A variety of unsound particles can occur in small quantities in aggregates. Soft particles such as clay lumps, wood, and coal will cause pitting and scaling at the surface. Coal may swell in the presence of moisture or release undesirable organic compounds that interfere with setting and hardening. Weak, friable particles of low density like shale and pumice should be avoided if a good wearing surface is needed.

3.1.2.3.6 Grading of fine and coarse 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.

3.1.2.3.6.1 Maximum aggregate size

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. Experimental results indicated that above the 38.1mm maximum size the gain in strength due to the reduced water requirement is offset by the detrimental effects of lower bond area (so that volume changes in the paste cause larger stresses at interfaces) and of discontinuities introduced by the very large particles [5]. 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.

3.1.3 Manufactured sand

3.1.3.1 General

Aggregate content is a factor, which has direct and far-reaching effects on both the quality and cost of concrete. Unlike water and cement, which do not alter in any particular characteristic except in the quantity in which they are used, the aggregate component is infinitely variable in terms of shape and grading.

When it is required to construct a major structure, the supply of high quality aggregate for concrete, both coarse and fine, are of extreme importance. The growing shortage and price rise of the natural sand is also a question that a construction industry shall think about. Now looking for viable alternatives to natural sand is a must and not a necessity. Due to short of supply of natural sands and the increased activity in construction sector, the time has come, for manufactured sand to play a significant role as an ingredient in concrete.

3.1.3.2 Definition and functions of manufactured sand

The term-manufactured sand is used for aggregate materials having dimensions less than 5.0mm that are processed from crushed rock or gravel and intended for construction use. The term sand refers to relatively small particles and there are some variations of sand with regard to particle size.

The use of manufactured aggregates (crushed hard rock) in concrete has been known since the Roman time. In modern technology, natural aggregates have proved to be significantly economical in use, for which reason extensive use of manufactured aggregates has been concentrated to regions or projects where the availability of natural aggregates has been limited.

The growing problem of surplus fines from hard rock quarries has, however, in recent times encouraged a development towards more use of manufactured aggregates in many populated areas, and for several concrete applications [8]. Production of excess amounts of fines and depletion of natural aggregate resources are the main problems for aggregate producers. Crushed /manufactured sand has rough surface texture and the particle size distribution curve can be adjusted in the manufacturing of the material.

Another 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 [8].

Manufactured sands are made by crushing aggregate to size appropriate for use as a fine aggregate (< 5.0mm). 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.

3.1.3.3 Properties of manufactured sand

The particle size distribution (PSD) curve of manufactured sand is more often than not tight and the particles are cubic, angular and their surface texture is rough. Properties of aggregates from natural sand and gravel deposits (natural aggregates) differ when compared to aggregates from crushed rock (crushed aggregates). Natural aggregates are weathered and their surface is often smooth and particles are sub angular to round. Crushed aggregates on the other hand have a rough surface texture, particles are angular and, if the production process is high quality, their shape is cubical. This difference in surface texture and shape properties indicates that natural and crushed aggregates are two different types of material and must be treated accordingly, i.e. different requirements apply to the two types. For instance regarding particle size distribution, knowledge and experience for natural aggregates can, for instance, not be used without suitable adjustments [8].

The particle size distribution curve (PSD), for manufactured sand is high in proportions of fines, as opposed to what is normal for natural sand. The best result is expected with a blend of natural and manufactured sand proportions depending on properties for specific production process.

The most important elements in the production of manufactured sand are shown in Fig 3.3. This includes elements related to the raw material, either material parameters that depend on the parent rock or the material type or parameters related to the type of deposit used.

Another important element is the production or crushing process and is divided into three parts: *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].

Finally it is important to know from the start to the intended end - use of the material since the optimal properties vary according to end-use and this may often be controlled during the processing period.

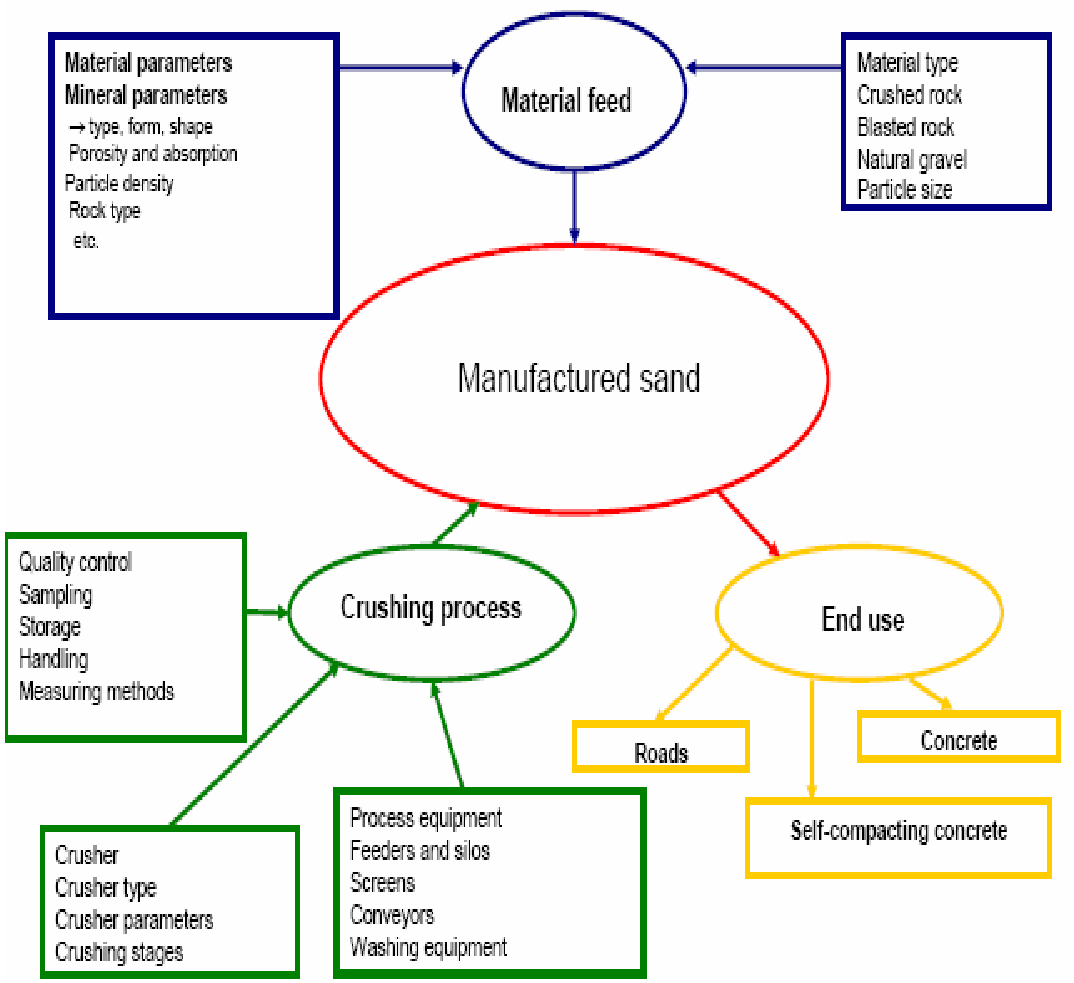

Fig. 3.3 Flow chart for the crushing process and factors affecting quality of manufactured sand [8].

3.1.3.4 Technical and Environmental challenges

3.1.3.4.1 Technical challenges

One of the main challenges in aggregate production, especially when producing crushed aggregates from hard rock quarries 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 manufactured 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.

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. Besides, the sharp angular nature of the crushed materials along with a grading curve different from that of natural sand, calls for precautions in the mix design if the potentials of the material shall be taken to benefit. Table 3.2 shows the difference between natural and manufactured sand.

Table 3.2 Comparison between natural and manufactured sand [8].

Natural sand	Manufactured sand
• Has enough fines	• Has lots of fines
• Has smooth surface	• Provide stable grain distribution
• Has good shape for concrete pumps	• Grains have sharp edges and sometimes irregular
• Need less water for concrete pumps therefore less cement	• Needs more water
• Economical concrete production	• The concrete is more expensive
• Surface is smooth and weathered	• Surface is rough
• Rounded to sub angular in shape	• Particles are angular

3.1.3.4.2 Environmental challenges

Aggregates are important construction materials, both for new constructions and maintenance. Aggregates are a valuable natural resource and it is our obligation to use it sensibly, in particular in highly populated areas where 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. It is further important for authorities to be up to date with locations and details of existing and potential quarries.

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 [8]:

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 neighborhood and society (noise, 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.

3.1.3.5 Production and use of manufactured sand in the Ethiopian construction industry.

Ethiopia has been abundantly supplied with natural aggregates resources for construction purposes due to geographical location of the country. Traditionally most concrete aggregates 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. The under construction 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 is not yet proved.

The resource situation (shortage) of the natural fine aggregate (sand) currently encouraged a development of using manufactured sands in specified road construction sites with foreign contractors, and for several concrete applications. For instance the following structures are made using manufactured sand concrete for a road between Addis Ababa and Jimma by J& P Dragados Joint venture contractors.

- Box culverts;
- Concrete pipes;
- Side drainage ditches and ditch covers;
- Sign posts, Guide posts for reflector, and kilometer posts etc.

Pictures showing the above list and the manufacturing process with the produced stocked material are attached at the end of this thesis.

Some laboratory compressive strength test results of concrete specimens made at Addis-Jimma road project site and the respective mix ratio for concrete mix is shown in Tables 3.3 and 3.4, respectively.

Table 3.3 Density and compressive strength test results of concrete specimens [9].

Class of concrete	Observed slump (mm)	Density (gm/cm^3)		Compressive strength (MPa)		Cement type and quantity
		7th day	28th day	7th day	28th day	
C-25	35	2506	2508	22.90	33.50	OPC-400kg/m^3
C-25	30	2460	2473	13.20	27.70	PPC-400kg/m^3
C-25	35		2481	13.80	28.00	PPC-400kg/m^3
C-25	40	2454	2449	12.20	25.40	PPC-400kg/m^3
C-25	45	2478	2520	23.00	40.30	OPC-400kg/m^3
C-25	25	2454	2477	15.90	29.00	OPC-400kg/m^3
C-25	40	2495	2497	20.50	41.77	OPC-400kg/m^3

Table 3.4 Mix ratios for site batching of concrete mix made at Addis-Jimma road project [9].

Class of concrete	Cement quantity (kg)	Water (Liter)	Crushed sand (0-6 mm) (kg)	Aggregate	
				(6-12 mm) (kg)	(12-23 mm) (kg)
C-25	400	230	770	550	550
C-20	375	220	770	550	550
C-15	350	210	770	550	550

As can be seen from the results of the laboratory and information from the project personnel, the use of manufactured sands in concrete causes the concrete to have poor workability. The irregular particle shape of the manufactured sands contributes for the low workability. The water required for a given degree of workability (slump) is directly related to the void space in the aggregate. When the void space is high, the water requirement necessary for a given workability will also be high. And the strength of the concrete will also be low unless additional cement is added.

In addition, the higher fines content of manufactured sand has significant effects on the workability and strength of concrete. Producing concrete with the above situation leads to uneconomical concretes because of the larger surface area of the finer particles.

3.1.4 Water

Water is a key ingredient in the manufacture of concrete. Water used in concrete mixes has two functions: the first is to react chemically with the cement, which will finally set and harden, and the second function is to lubricate all other materials and make the concrete workable [1]. Although it is an important ingredient of concrete, it has little to do with the quality of concrete [10]. One of the most common causes of poor-quality concrete is the use of too much mixing water. Fundamentally "the strength of concrete is governed by the nature of the weight of water to the weight of cement in a mix, provided that it is plastic and workable, fully compacted, and adequately cured" [1].

It has been said that there is much more bad concrete made through using too much good quality water than there is using the right amount of poor-quality water. The rule of thumb for water quality is "if you can drink it, you can work concrete with it". A large fraction of concrete is made using municipal water supplies. However, good quality concrete can be made with water that would not pass normal standards for drinking water [10].

3.1.5 Admixtures

Admixtures are materials other than cement, aggregate and water that are added to concrete either before or during it's mixing to alter its properties such as workability, curing temperature range, setting time or colour. These days a mix without admixture is an exception. Admixture is a chemical product which is added to the concrete mix in quantities not larger than 5% by mass of cement during mixing or during an additional mixing operation prior to the placing of concrete, for the purpose of achieving a specific modification to the normal properties of concrete [5].

Admixtures are capable of imparting considerable physical and economic benefits with respect to concrete production. It is an established fact that the use of admixtures result in concomitant savings, for example, in the cost of labour required to effect compaction and in improving durability without the use of additional measures [5].

3.1.5.1 Types of admixtures

Based on the function, the classification of admixtures as per ASTM C494-92 is as follows[14]:

i. Type A Water reducing
ii. Type B Retarding
iii. Type C Accelerating
iv. Type D Water reducing and retarding
v. Type E Water reducing and accelerating
vi. Type F High range water reducing or superplasticizing
vii. Type G High range water reducing and retarding, or superplasticizing and retarding.

The chemistry of concrete admixtures is a complex topic requiring in-depth knowledge and experience. A general understanding of the options available for concrete admixtures is necessary for acquiring the right product for the job, based on climatic and job requirements. The specific effect of admixtures must be understood before they are used. Moreover, the specific effects produced may vary with the properties and proportions of the other ingredients of the mix.

The manufacturers recommend the dosage of the various admixtures, usually expressed as a percentage of the mass of cement in the mix, but they are often varied according to circumstances. The effectiveness of any admixture may vary depending on its dosage in the concrete and also on the constituents of the mix, especially the properties of the cement. Some of the characteristics property of superplasticizers, as it is used for this research work, is mentioned in the following section[15].

Superplasticizers

ASTM C 494-92 refers to superplasticizers as "water-reducing, high range admixtures". Compared to what is commonly referred as "water reducer" or "mid-range water reducer" superplasticizers are "high range water reducers"[14]. Superplasticizers are water-soluble organic polymers, which have to be synthesized, using a complex polymerization process, to produce long molecules of high molecular mass, and they are therefore relatively expensive. High range water reducers are admixtures that allow large water reduction or greater flowability without substantially slowing setting time or increasing air entrainment.

Effects of superplasticizers

The main action of the long molecules is to wrap themselves around the cement particles and give them a highly negative charge so that they repel each other. These results in deflocculation and dispersion of cement particles. At a given water/cement ratio and water content in the mix, the dispersing action of superplasticizers increases the workability of concrete.

The second use of superplasticizers is in the production of concrete of normal workability but with an extremely high strength owing to a very substantial reduction in the water/cement ratio. Mechanism of the action of superplasticizers has not been fully explained, it is known that they interact with C_3A whose hydration is retarded.

Dosage of superplasticizers

For increasing the workability of the mix, the normal dosage of superplasticizers is between 1 and 3 liters per cubic meter of concrete, the liquid superplasticizer containing about 40% of the active material. When superplasticizers are used to reduce the water content of the mix, their dosage is much higher, 5 to 20 liters per cubic meter of concrete [5]. The effectiveness of a given dosage of superplasticizer depends on the water/cement ratio of the mix. Specifically, at a given dosage of the superplasticizer, the percentage water reduction, which maintains a constant workability, is much higher at low water/cement ratios than at high water/cement ratios [5].

Use of superplasticizers

The availability of superplasticizers has revolutionized the use of concrete in a number of ways, making it possible to place it, and to do so easily, where it was not possible to do so before. Superplasticizers make it also possible to produce concrete with significantly superior strength and other properties of high strength concrete.

3.2 Concrete mix selection

3.2.1 Mix design

Mix design is a process that consists of two interrelated steps:

1) Selection of the suitable ingredients (cement, aggregate, water and admixtures) of concrete.
2) Determining their relative quantities ('proportioning') to produce, as economically as possible, concrete of the appropriate workability, strength and durability. Although many concrete properties are important, most design procedures are based primarily on achieving a specified compressive strength at some given workability and age [8].

3.2.1.1 Factors governing concrete mix selection

If the designed quality of concrete cannot be achieved it may result in consequences like wastage of material, production of substandard structures, etc. The highest possible strength concrete will seldom be required so that the concrete producer shall select a concrete mix that fulfills all specified requirements [8]. The basic factors in determining the proportions of the concrete mix are discussed as follows.

a) Strength

Strength is one of the important properties of concrete as it influences many other desirable properties of hardened concrete. It usually gives an overall picture of the quality of concrete because it directly related to the structure of the hydrated cement paste.

The mean compressive strength required at a specified age determines the nominal water/cement ratio of the mix. Structural design is based on the assumption of a certain minimum strength of concrete, but the actual strength of concrete produced, whether on site or in the laboratory, is a variable quantity. In selecting a concrete mix we must, therefore, aim at a mean strength higher than a minimum.

b) Durability

Every concrete structure should continue to perform its intended functions that is maintained its required strength and serviceability, during the specified or traditionally expected service life. Concrete must be able to withstand the processes of deterioration to which it can be expected to be exposed. Such concrete is said to be durable. However, there doesn't exist a generally agreed and reliable approach to the selection of mix proportions required for durability under any conditions. Penetrability of concrete, which plays a crucial role in its durability, cannot be directly controlled in the production of concrete. Reliance is necessary on the water/cement ratio, cement content, compressive strength. Whatever the mix proportions are chosen, the concrete must be capable of full compaction using the means available, and that such compaction must be achieved in practice.

c) Water cement ratio

The type of cementitious material used greatly affects the penetrability of the resulting concrete. Strength, type of cement and durability determine between them the water cement ratio required - one of the essential quantities in the calculation of mixes proportions. The nature of cementitious materials to be used is of vital importance also under other conditions of exposure. When concrete is to be subjected to chemical attack, a suitable type of cement must be used but, if resistance to freezing and thawing is the only durability requirement, the choice of the type of cement is governed by other considerations, for instance, the development of early strength or of a high heat of hydration for concreting in cold weather.

d) Economy

The cost of concrete is made up of the costs of materials, labour and equipment. However except for some special concrete, the costs of labour and equipment are largely independent of the type and quality of concrete produced. It is, therefore, the material cost that are most important in determining the relative costs of different mix designs.

Since cement is much more expensive than aggregate, it is clear that minimizing the cement content is the most important single factor in reducing concrete cost. This can, in general, be done by using the lowest slump that will permit adequate placement, by using the largest practical maximum size of aggregate, by using the optimum ratio of coarse to fine aggregates, and, where necessary, by using appropriate admixtures. It should be noted that in addition to cost, there are other benefits to using low cement content; shrinkage will be reduced, and there will be less heat of hydration.

e) Workability

Selection of mix proportions, which do not permit the achievement of appropriate workability, totally defeats the purpose of rational mix proportioning. The workability that is considered desirable depends on two factors:

a) The minimum size of the selection to be concreted and the amount and spacing of reinforcement.
b) Method of compaction to be used.

When the section is narrow and complicated or when there are numerous corners or inaccessible parts, the concrete must have a high workability so that full compaction can be achieved with a reasonable amount of effort. The same applies to steel sections or fixture present or when the amount and spacing of reinforcement make placing and compaction difficult. As these features of the structure are determined during its design, the necessary workability must be ensured in the selection of mix proportions. When no such limitations are present, workability may be chosen within fairly wide limits, but the means of transportation and compaction must be decided upon accordingly. It is important that the prescribed method of compaction is used during the entire progress of construction. Advice on the appropriate values of slump and of means of compaction for various types of construction is given in BS 5328 1997[16]. A properly designed mix must be capable of being placed and compacted properly with the equipment available. Finishability must be adequate and segregation and bleeding should be minimized.

(f) Maximum size of aggregates

In reinforced concrete, the width of the section and the spacing of the reinforcement govern the maximum size of aggregate, which can be used. The improvement in the properties of concrete with an increase in the size of aggregate doesn't extend beyond about 40mm. So that the use of larger sizes may not be advantageous. In particular, in high strength concrete, the use of aggregate larger than 10 to 15 mm is counter productive.

The use of larger maximum size means that a greater number of stockpiles have to be maintained and the batching operators become correspondingly more complicated. The choice of the maximum size may also be governed by the availability of materials and by their cost.

(g) Grading and type of aggregate

Although there are certain good grading curves, no ideal grading exist, and excellent concrete can be made with a wide range of aggregate grading. The grading influences the mix proportions for a desired workability and the water cement ratio: The coarser the grading the leaner the mix which can be used, but this is true with in certain limits only because a very lean mix will not be cohesive without a sufficient amount of fine material.

The influence of the type of aggregate should also be considered because its surface texture, shape and allied properties influence the aggregate/cement ratio for a desired workability and a given water/cement ratio. In selecting a mix it is essential to know what type of aggregate is available. An important feature of satisfactory aggregate is the uniformity of its grading. In the case of coarse aggregate, this is achieved comparatively easily by the use of separate stockpiles for each size fraction. Considerable care is required in maintaining the uniformity of grading of fine aggregate.

A sudden change towards finer grading requires additional water for the workability to be preserved, and this means a lower strength of the batch concerned. Also an excess of fine aggregate may make full compaction impossible and thus lead to a drop in strength. It is essential that the aggregate vary from batch to batch with prescribed limits only.

(h) Cement content

The choice of the cement content is made either on the basis of experience or alternatively from charts and tables prepared from comprehensive laboratory tests. Such tables are no more than a guide to the mix proportions required because they apply fully only to the actual aggregates used in their derivation. Moreover, recommended proportions are usually based on aggregate grading, which have been found to be satisfactory. In comparing various mixes, it is sometimes convenient to convert the aggregate /cement ratio into the cement content or vice versa.

(i) Quality control

Quality control is meant the control of variation in the properties of the mix ingredients and also control of accuracy of all those operations, which affect the strength, or consistency of concrete: batching, mixing, transporting, placing, curing and testing.

(j) Air voids and compaction

The presence of voids in concrete greatly reduces its strength. Voids in concrete are either bubbles of entrapped air or spaces left after excess water has been removed. The latter depends on the water/cement ratio of the mix. The air bubbles, i.e. voids within an originally loose granular material, and governed by the grading of the finest particle in the mix and are more easily expelled from a wetter mix than from a dry one either. For any given method of compaction there may be optimum water content of the mix at which the sum of the volumes of air bubbles and water space will be a minimum. At this optimum water content the highest density ratio of the concrete would be obtained.

3.2.2 Selection of concrete mix proportions and methods of specifying concrete

The selection of mix proportions is simply, the process of choosing suitable ingredients of concrete and determining their relative quantities with the object of producing as economically as possible concrete of certain minimum properties, notably strength and a required consistency. There are four methods to specify concrete mixes. These are: designed mix, prescribed mix, standard mix and designated mix [5].

1) **Designed mix: -** is specified by the designer in terms of strength, cement content, and water cement ratio. Compliance relies on strength testing.

2) **Prescribed mix: -** is specified by the designer in terms of the nature and proportions of mix ingredients. The use of prescribed mixes is advantageous when particular properties of concrete are required.

3) **Standard mix: -** is based on ingredients and proportions fully listed in BS 5328 1997[16]. In Ethiopia standard mix proportions for grade C5 to C30 is specified in EBCS 2-1995 of section 8.2[17].

4) **Designated mix: -** the concrete producer selects the water cement ratio and the minimum cement content. This approach can be used only if the concrete producer holds a special certificate of product conformity based on product testing and surveillance, coupled with certification of quality assurance.

3.2.3 Mix Proportions for high strength concrete

Mix proportions for high strength concrete (HSC) are influenced by many factors, including specified strength properties, locally available materials, local experience, personal preferences, and cost. With the current technology, there are many products available for use in concrete to enhance its properties. Consequently, there are many alternatives for mix proportions that will result in concrete with the desired properties.

The following are important points related to HSC:

- High strength concrete interms of strength will be taken as a compressive strength in excess of 80 MPa [5].
- Concrete tested at an age of 56 or 90 days generally has a higher compressive strength than concrete tested at 28 days. The use of later age makes it easier and more economical to achieve the higher strengths. Proportions of the cementitious materials are usually selected to produce the desired strength at the selected test age [10].
- The most important variable in achieving high-strength concrete is water to cement ratio. As the water cementitious ratio decreases, the concrete compressive strength increases[18].
- Proper selection of the type and sources of cement is one of the most important steps in the production of high strength concrete[19].
- Variation in the chemical composition and physical properties of the cement affect the concrete compressive strength more than variations in any other single material.
- For each concrete strength level, there is an optimum size for the coarse aggregate that will yield the greatest compressive strength per unit mass of cement. In general, a smaller size aggregate will result in a higher compressive strength. On the other hand, the use of largest possible coarse aggregate size is important in increasing the modulus of elasticity or reducing creep and shrinkage[20].
- Fine aggregates with a fineness modulus in the range of 2.5 to 3.2 are preferable for high strength concrete. Concretes with a fineness modulus less than 2.5 may be sticky and result in poor workability and high water requirements [5].
- Water reducers or high-range water reducers are essential in high strength concrete to ensure adequate workability while achieving a low water-cementitious materials ratio[20].

- The optimum dosage of an admixture or a combination of admixtures should be determined by trial mixtures using varying amounts of each additive. It is important to be sure that admixtures are compatible when used in combination.
- There is no standard mix to produce a high strength concrete. Trial mixes are needed to obtain the optimum use of each locally available constituent material [19].

3.3 Workability

Workability is generally defined interms of the amount of mechanical work, or energy, required to produce full compaction of the concrete without segregation, since the final strength of the concrete is in large part a function of the amount of compaction [10].

The ASTM C 125-93 defines workability as "property determining the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogenuity". The ACI given in ACI 116R-90 defines "Property of freshly mixed concrete or mortar which determines the ease and homogenuity with which it can be mixed, placed, consolidated and finished [5].

3.3.1 The need for sufficient workability

The presence of voids in concrete greatly reduces the strength. Five percent of voids can lower strength by as much 30 percent, and even two percent voids can lower strength by as much 10 percent. For hardened concrete to be of an acceptable quality for a given job, the fresh concrete must be capable of satisfying the following requirements [1]:

1) It must be easily mixed and transported;
2) It must be uniform throughout a given batch and between batches;
3) It should have flow properties such that it is capable of completely filling the forms for which it was designed;
4) It must have the ability to be compacted fully without an excessive amount of energy being applied;
5) It must not segregate during placing and consolidation; and
6) It must be capable of being finished properly, either against the forms or by means of troweling or other surface treatment.

3.3.2 Factors affecting workability

The workability of concrete is affected by a number of factors, which include the following:

a) Water content of the mix

Increasing the amount of water will increase the ease with which concrete flows and can be compacted. However, apart from reducing the strength, increased water may lead to segregation.

b) Influence of aggregates

For a constant W/C ratio, an increase in the aggregate/cement ratio will decrease the workability; also, more cement is needed when finer aggregate grading is used. A deficiency in fine aggregate results in a mix that is harsh, prone to segregation, and difficult to finish. An excess of fine aggregate will also lead to a rather more permeable and less economical concrete.

The shape and texture of aggregate particles can also affect the workability. The more nearly spherical the particles, the more workable the resulting concrete will be. This is due partly to the fact that the spherical particles will act as "ball bearings" while angular particles will have more mechanical interlock and will therefore need more work to overcome the resulting internal friction. The porosity of the aggregate may also affect workability. If the aggregate can absorb a great deal of water, less will be available to provide workability.

c) Time and temperature: -

With the increase of ambient temperature, the workability decreases since higher temperature will increase both the evaporation rate and the hydration rate. More water may have to be used in very warm weather to maintain the same workability.

d) Characteristics of the cement: -

The increased fineness of the high early strength cements will reduce workability at a given w/c ratio due to their higher specific surface area and also hydrate more rapidly.

e) Admixtures: -

Air-entraining water reducing and set-retarding admixtures will all improve the workability. However, chemical admixtures react differently with different cements and aggregate and can in some circumstances aggravate the loss of workability.

CHAPTER FOUR

MATERIALS PROPERTIES AND MIX PROPORTIONS

4.1 General

As the major objective of the research work is to study the influence of manufactured sand on the properties of concrete produced with it, analyses on the effects of manufactured sand, natural sand and a combination of both were made.

Different mixes targeting at characteristics compressive strength of 25 MPa and higher were also made. The influence of manufactured sand on the compressive strength development was studied, accordingly different values of strengths with variable proportion of manufactured, natural or a combination of the two were obtained.

Physical tests of the materials and compressive strength tests were carried out in the Faculty of Technology (Northern Campus) Construction materials laboratory, whereas flakiness index, elongation and SSD tests of the coarse aggregate materials were carried out in the Highway laboratory of the same Faculty.

4.2 Cements

The locally produced cements, Mugher PPC and Messebo OPC, were used for the preparation of the mix. Mugher PPC was used for the trial mix and normal strength concrete samples. Whereas Messebo OPC was used for the remaining two: intermediate and high strength mix samples. In the beginning of the work, it was planned to cast using Mugher OPC but it wasn't possible to get the product neither in the market nor from the factory. Both Messebo OPC and Mugher PPC, which were used for the mixes, were bought from one of the Addis Ababa's building material shops.

4.3 Aggregates

4.3.1 Natural sand

Natural sand was brought from near Abiata Lake, which is one of the Rift Valley lakes in Ethiopia, located about 210 kms away from Addis Ababa. The area is owned by local farmers who are running the business over the last many years on a family/community basis.

4.3.2 Coarse aggregate

Coarse aggregates used for this research work is brought from Blue Nile construction quarry located at Akaki which is about 25km from Addis Ababa. In order to design and make a concrete mix, the aggregates properties had to be assessed. In order to do this a number of tests were carried out on the above materials. The performed test includes: sieve analysis, bulk and dry density, moisture content, absorption capacity, unit weight, etc. All of the aggregates tests were done in accordance with the Ethiopian standards and conforms to the ASTM requirements. The test findings are shown in Tables 4.1 and 4.2, and Figs 4.1 and 4.2.

As can be seen from the material test results, manufactured sand had higher amounts of fines while lesser amount is seen in the case of natural sand. The silt content of the natural sand was well below the permissible limit, which doesn't necessitate washing of the material. Both fine aggregates materials were sieved and blended so as to achieve a suitable gradation. 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.

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. Then the material was sieved and blended so as to satisfy the graded chart of the Ethiopian standard.

4.3.3 Manufactured sand

To ensure material consistency of aggregates and due to unavailability of materials all of the manufactured fine aggregates have been obtained from Dragados, Addis Ababa-Jimma road project site office located at Welkite, about 210km away from Addis Ababa. This manufactured sand was produced from crushing of basaltic stone where the contractors used for different structures, as discussed in section 3.1.3.5 and shown pictorially in the Annex D.

The physical properties of both fine and coarse aggregates are also shown in Tables 4.1 and 4.2 below.

Table 4.1 Physical properties of fine aggregate.

Item no.	Description		Test result
1	Silt content		
	* Natural sand		0.60%
	* Manufactured sand		13.4%
2	Dry unit weight		
	* Natural sand		1.57%
	* Manufactured sand		1.47%
3	Moisture content		2.25%
4	Absorption capacity		1.83%
5	Specific gravity (gm/cc)	Bulk	2.4
		Bulk(SSD)	2.6
		Apparent	2.6
6	Fineness modulus		
	* Natural sand		3.14
	* Manufactured sand		3.14

Table 4.2 Physical properties of coarse aggregate.

Item no.	Description		Test result
1	Maximum aggregate size		19mm
2	Flakiness Index (FI)		
	* On 14 mm - 6.3mm		29.25%
3	Elongation		39.04%
4	Los Angeles Abrasion (LAA)		10.22%
5	Moisture Content		0.76%
6	Dry unit weight		1.88
7	Absorption capacity		1.39%
8	Specific gravity (gm/cc)	Bulk	2.6
		Bulk(SSD)	2.8
		Apparent	2.7

The summaries of gradation of both natural and manufactured sand before and after blending are shown in Fig 4.1 and 4.2, respectively.

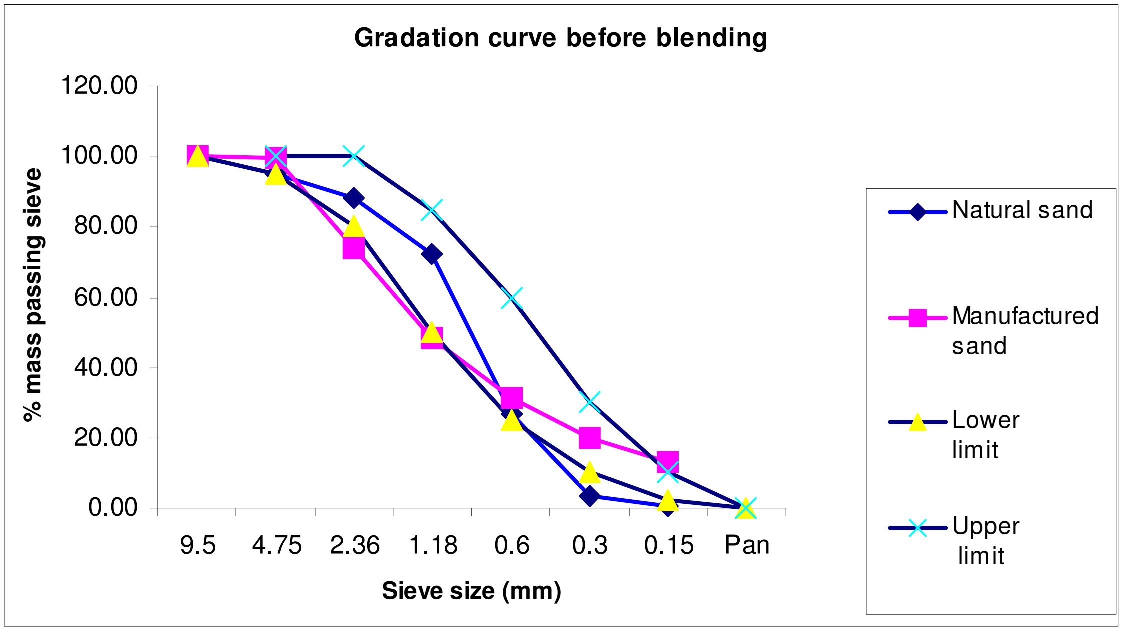

Fig. 4.1 Gradation curve for MS and NS before blending

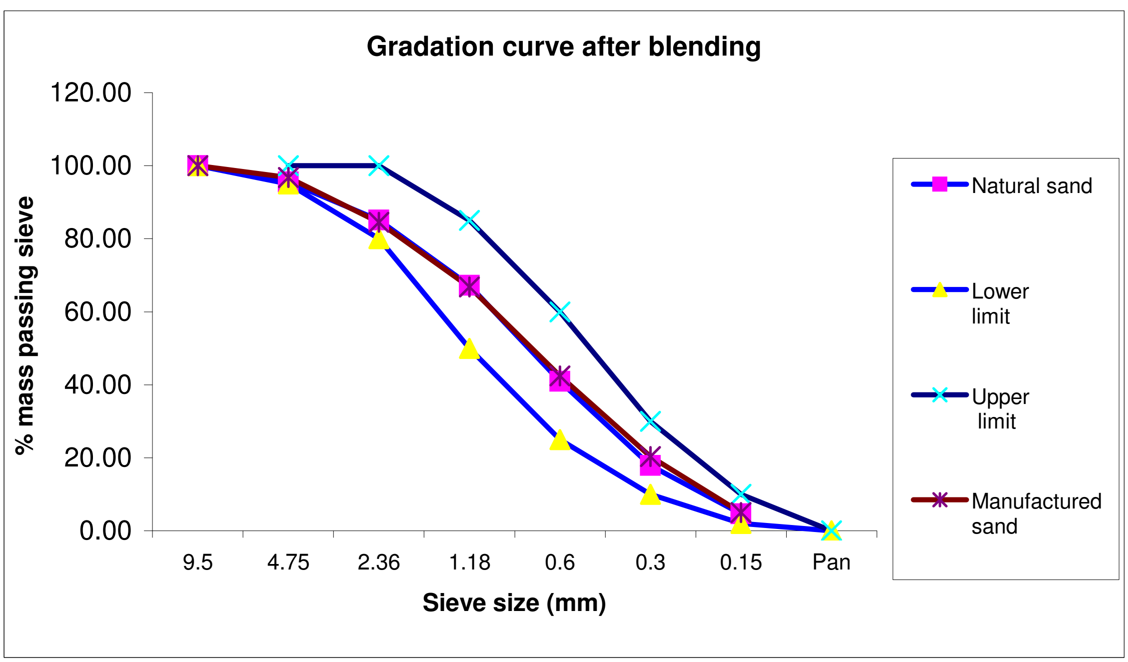

Fig. 4.2 Gradation curve for MS and NS after blending

4.4 Water

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

4.5 Chemical admixtures

The superplasticizer chosen for this research work was SP-430 (Water- reducing) supplied by AB-HAM. This superplasticizer recommended by the supplier catalogue to use from 0.7 to 2 liters per 100 kg of cement. However, it was expected for this research work that larger dosages of superplasticizer would be required to achieve a suitable workability especially in the case of high proportion of manufactured sand to natural ones.

4.6 Mix proportion

In order to analyze the effects of manufactured sand, natural sand and/or a combination of both have on the properties of concrete, different mixes with a characteristic strength ranging from normal strength (C-25) to high strength ones were prepared.

4.6.1 Trial mix

The main objectives of the trial mixes were to:

a) determine if a suitable workability can be achieved in concrete containing manufactured sand as a partial or complete replacement for natural sand.
b) determine what percentage of superplasticizer is required to achieve a suitable workability for concrete with and without manufactured sand.

DoE method of mix design was used in designing the mix proportions. And trial mix was prepared for characteristics strength of 25, 30 and 40 MPa. The mixes were designed with a water cement ratios of 0.54, 0.47, and 0.45 and cement contents of 350, 400, and 425 kg/m^3 respectively. Tables showing concrete mix design using DoE methods are attached at the Annex A.

The same aggregate was used in the preparation of the final specimens, with the following mix proportions 100%NS, 75%NS+25%MS, 50%MS+50%NS, 75%MS+25%NS and 100% MS.

A summary of mix proportion for trial mixes is shown in Table 4.3.

Table 4.3 Mix proportion summary for the trial mixes.

Concrete class and code	Cement type	Cement quantity (kg/m^3)	W/C	Water (liter)	FA (kg/m^3)	CA (kg/m^3)	FA (%)	CA (%)
C-25								
100% MS	Mugher PPC	350	0.54	190	650	1200	35	65
75%NS+25%MS	Mugher PPC	350	0.54	190	650	1200	35	65
75%MS+25%NS	Mugher PPC	350	0.54	190	650	1200	35	65
50%MS+50%NS	Mugher PPC	350	0.54	190	650	1200	35	65
C-30								
100% NS	Mugher PPC	400	0.47	190	630	1165	35	65
100% MS	Mugher PPC	400	0.47	190	630	1165	35	65
75%MS+25%NS	Mugher PPC	400	0.47	190	630	1165	35	65
50%MS+50%NS	Mugher PPC	400	0.47	190	630	1165	35	65
C-40								
100% NS	Mugher PPC	430	0.45	190	800	970	45	55
100% MS	Mugher PPC	430	0.45	190	800	970	45	55
50%MS+50%NS	Mugher PPC	430	0.45	190	800	970	45	55

4.6.2 Final mix

The differences between the trial batches and the final mixes were:

a) based on the results of the trial batches, adjustments and improvement were made for the mix, and
b) higher compressive strength concrete is expected as the water cement ratio is reduced up to 0.3.

The mix proportions were determined based on the DoE method for normal strength concrete and based on literature and trial mix results for intermediate and high strength concrete.

Mix series I. The first final mixes were prepared using Mugher Portland Pozzolana cement (MPPC) for normal concrete strength using a water cement ratio of 0.55 and cement content of 370kg/m^3. Admixtures were used depending on the requirement of the mix when the proportion of the manufactured sand increases. Mix proportions with the amount of coarse and fine aggregates are shown in Table 4.4.

Table 4.4 Mix proportion summary for Normal Strength Concrete.

Concrete class and code	Cement type	Cement quantity (kg/m^3)	W/C	Water (liter)	FA (kg/m^3)	CA (kg/m^3)	Admixture (lt/m^3)	FA (%)	CA (%)
Normal strength									
NSC_1	Mugher PPC	370	0.54	190	650	1200	-	35	65
NSC_2	Mugher PPC	370	0.54	190	650	1200	-	35	65
NSC_3	Mugher PPC	370	0.54	190	650	1200	-	35	65
NSC_4	Mugher PPC	370	0.54	190	650	1200	1.740	35	65
NSC_5	Mugher PPC	370	0.54	190	650	1200	2.900	35	65

Mix series II. The second final mixes were casted using Messebo ordinary Portland cement (MOPC) for intermediate concrete strength using a water cement ratio of 0.39, and a cement content of 460kg/m^3. The amount of admixtures used is also depending on the requirement of the mix and increases with the increased percentage of manufactured sand. The proportion of coarse and fine aggregate with the summary of constituent material is shown in Table 4.5.

Table 4.5 Mix proportion summary for Intermediate Strength Concrete

Concrete class and code	Cement type	Cement quantity (kg/m^3)	W/C	Water (liter)	FA (kg/m^3)	CA (kg/m^3)	Admixture (lt/m^3)	FA (%)	CA (%)
Intermediate Strength									
ISC_1	Messebo OPC	460	0.39	179.4	549	1281	1.371	30.00	70.00
ISC_2	Messebo OPC	460	0.39	179.4	549	1281	5.485	30.00	70.00
ISC_3	Messebo OPC	460	0.39	179.4	549	1281	4.114	30.00	70.00
ISC_4	Messebo OPC	460	0.39	179.4	549	1281	4.663	30.00	70.00
ISC_5	Messebo OPC	460	0.39	179.4	549	1281	5.485	30.00	70.00

Mix series III. The third final mixes were made using Messobo ordinary Portland cement (MOPC) for high concrete strength using a water cement ratio of 0.30, and a cement content of 520kg/m^3. The amount of admixtures used varies from 9 liters to 12 liters per m^3 of concrete depending on the amount of manufactured sand mix. The proportion of coarse and fine aggregate with the summary of constituent material is shown in Table 4.6.

Table 4.6 Mix proportion summary for high strength concrete.

Concrete class and code	Cement type	Cement quantity (kg/m^3)	W/C	Water (liter)	FA (kg/m^3)	CA (kg/m^3)	Admixture (lt/m^3)	FA (%)	CA (%)
High strength									
HSC_1	Messebo OPC	520	0.30	156	486	1314	8.809	27.00	73.00
HSC_2	Messebo OPC	520	0.30	156	486	1314	9.395	27.00	73.00
HSC_3	Messebo OPC	520	0.30	156	486	1314	12.625	27.00	73.00
HSC_4	Messebo OPC	520	0.30	156	486	1314	10.276	27.00	73.00
HSC_5	Messebo OPC	520	0.30	156	486	1314	8.809	27.00	73.00

4.7 Preparation of specimens and mixing procedure

Cement, which were produced locally by Messebo and Mugher cement factory, were used throughout the mixing process. Mugher Portland pozzolanna cement for normal strength concrete and Messebo ordinary Portland cement for Intermediate and High strength concrete were used. Graded aggregate fulfilling Ethiopian standards are also used both for trial and final mix preparation of the samples.

The preparation of the constituent materials was made by using weight measurement. After determining the relative amounts of materials to be used for specimens, the aggregates and cements were mixed dry for one minute. After the addition of water, all the material mixed for another two minutes for normal and intermediate concrete strength and three minutes for high strength concrete. After deducting the amount of admixtures estimated from the weighed water, admixtures added during mixing. Immediately after mixing the concrete, the workability is measured by using a slump cone. The specimens were then put on a firm and level surface of prepared moulds by compacting in two layers using vibrating table. The specimens were vibrated for 45 seconds and 30 seconds for the two steel moulds and one steel moulds, respectively based on past experience. After vibration the top surface is finished using a trowel.

Intermediate and high strength concrete specimens were cured for seven days and exposed to room temperature of the laboratory until the day of testing. Whereas specimens made using Mugher PPC for normal strength concrete, as development of pozzolanic reaction is slow, were cured for 14 days and left the remaining days in room temperature of the laboratory.

CHAPTER FIVE

TEST RESULTS AND DISCUSSION

5.1 General

It was stated above that the main objectives of the laboratory test specimens were to:

- determine if a suitable workability and strength can be achieved in concrete containing manufactured sand as a partial or complete replacement for natural sand.
- determine what percentage of superplasticizer is required to achieve a suitable workability for concrete with or without manufactured sand.
- determine the rate of strength gain for the concrete with and without manufactured sand.

In the following sections, the test results are presented and evaluated in light of the requirements of concrete strength and workability.

5.2 Test results

5.2.1 Sieve analysis

The results of sieve analysis, 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 requiring different aggregate blending. The results of all sieve analysis for all aggregate samples used in the concrete mix are attached in the annex B.

5.2.2 Fresh concrete properties

The results of the slump tests carried out on the fresh concrete gave an indication of the workability of the concrete. As can be seen from the trial mix results shown in Table 5.1 for a water cement ratio of 0.54, 0.47 and 0.45, a maximum slump of 20mm is observed, which is considered as a low workability.

Fresh concrete properties and the 7th day compressive strength data for the trial mixes is shown in Table 5.1

Table 5.1 Fresh concrete properties of trial mixes.

No	Mix code	W/C	Observed slump (mm)	7th day compressive strength (Mpa)
1	100% NS	0.54	13	16.09
2	75%MS+25%NS	0.54	13	14.58
3	50%MS+50%NS	0.54	15	17.29
4	100% MS	0.54	Zero	16.26
5	100% NS	0.47	15	17.11
6	50%MS+50%NS	0.47	12	21.79
7	25%NS+75%MS	0.47	Not measured	20.92
8	100% MS	0.47	20	21.16
9	100% NS	0.45	16	20.76
10	50%MS+50%NS	0.45	12	22.55
11	100% MS	0.45	20	21.86

The first final mix tested had a water cement ratio of 0.55; this mix achieves a workability of 20mm. In the following mix the water cement ratio was reduced to 0.39 to decrease the water amount of the mix and to achieve a higher strength, by using SP-430 superplasticizer. The third final mix had the water cement ratio reduced to 0.30. The recommended dosage of superplasticizer given by the manufacturer is in the range of 0.7 to 2 liters per 100kg of cement. This mix achieved a better slump as additional superplasticizer was added until the concrete reached to a placeable stage.

A lot more difficulty in finishing is observed in both the trial mixes and the final mixes even with the addition of superplasticizer. This difficulty in achieving a smooth finish with the manufactured sand can be attributed to the irregular particle shape of the manufactured sands and more fine contents on the surface of the aggregate.

A summary of the fresh concrete test results of the final mixes is shown in Table 5.2.

Table 5.2 Fresh concrete test results of the mixes.

No	Mix code	Sand proportion	W/C	Admixture (lt/m^3)	Observed slump (mm)
	Normal strength concrete				
1	NSC_1	100% NS	0.55	-	20
2	NSC_2	75%NS+25%MS	0.55	-	17
3	NSC_3	50%MS+50%NS	0.55	-	25
4	NSC_4	25%NS+75%MS	0.55	1.74	15
5	NSC_5	100% MS	0.55	2.9	25
	Intermediate strength concrete				
6	ISC_1	100% NS	0.39	1.37	15
7	ISC_2	75%NS+25%MS	0.39	5.49	100
8	ISC_3	50%MS+50%NS	0.39	4.11	25
9	ISC_4	25%NS+75%MS	0.39	4.66	40
10	ISC_5	100% MS	0.39	5.49	60
	High strength concrete				
11	HSC_1	100% NS	0.3	8.81	50
12	HSC_2	75%NS+25%MS	0.3	8.81	40
13	HSC_3	50%MS+50%NS	0.3	9.4	30
14	HSC_4	25%NS+75%MS	0.3	12.63	120
15	HSC_5	100% MS	0.3	10.28	38

According to the findings of this research, due to the irregular particle shape of the manufactured sand and the reduced amount of water cement ratio, achieving a good workable concrete without admixture was practically impossible. In addition if a high strength concrete mix is required then this can be achieved by lowering the water cement ratio of the concrete mix and using a superplasticizer. However, it should be noted that using large amount of a superplasticizer may cause the concrete mix more expensive than a natural sand mix. G. Tigist [21] also investigates that the use of chemical admixtures has no pronounced effect on the compressive strength of concrete.

5.2.3 Hardened concrete properties

The most common tests carried out on concrete specimens is compressive strength test due to the fact that: a) structural design codes are based mainly on compressive strength of concrete; b) it is assumed that most of the important properties of concrete are directly related to compressive strength, and c) 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 7, 28 and 56 days. At each age a minimum of three specimens were tested to ensure the accuracy of test results. The use of manufactured sand by replacing fully or partially of natural sand had an effect on the compressive strength of concrete. In all the concrete mixes, proportions of natural and manufactured sand except percentage of admixtures are equal in amount. The amount of the superplasticizer is variable depending on the workability of the mix.

The compressive strength of the three different concrete mixes, NSC, ISC and HSC are shown in Fig. 5.1, 5.2 and 5.3 respectively. The figures confirm that the increase in the compressive strength is achieved through the use of manufactured sand.

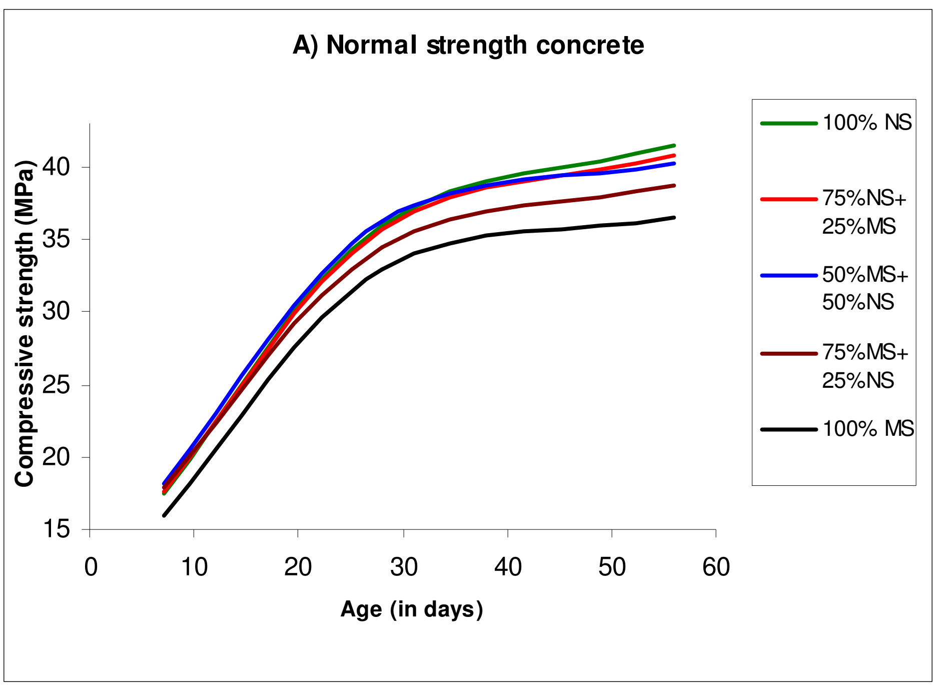

Fig. 5.1 Compressive strength comparison for Normal Strength Concrete

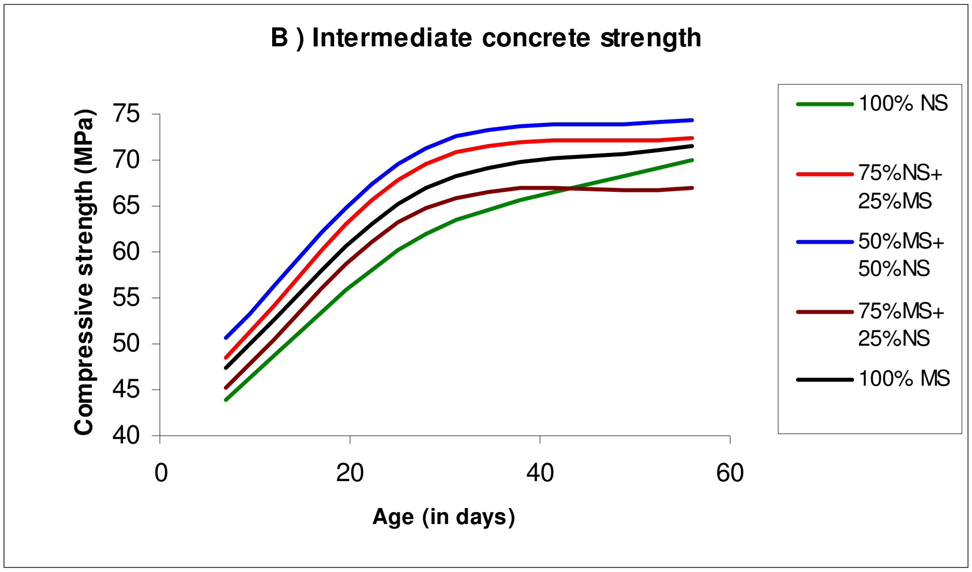

Fig. 5.2 Compressive strength comparison for Intermediate Strength Concrete

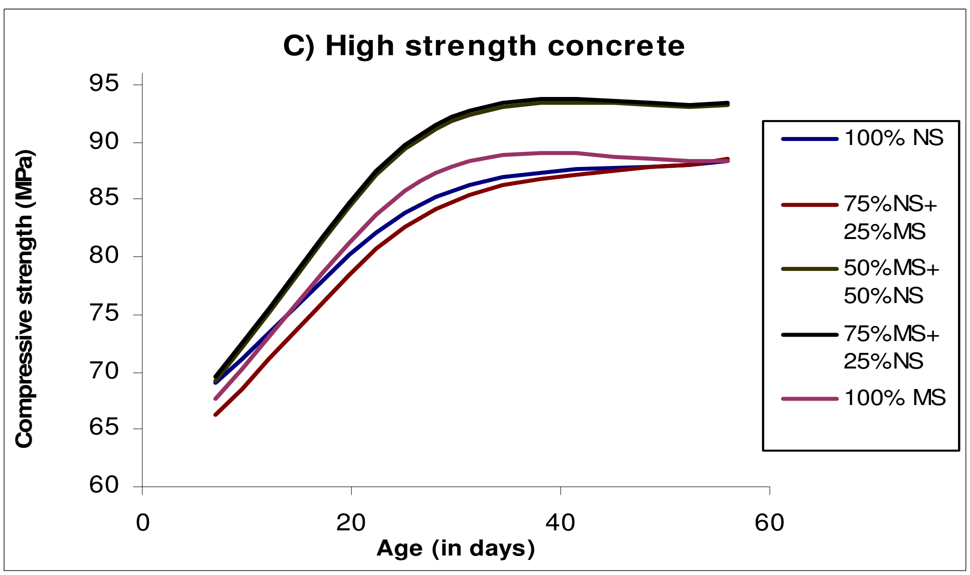

Fig. 5.3 Compressive strength comparison for High Strength Concrete

The concrete test results for NSC at the 7^{th} day showed about 50% of the 28^{th} day compressive strength and about 88% of the 56^{th} day strength at the 28^{th} day. Similarly, for ISC at the 7^{th} day showed about 70% of the 28^{th} day compressive strength and about 95% of the 56^{th} day strength at the 28^{th} day; while HSC at the 7^{th} day showed about 78% of the 28^{th} day compressive strength and about 97% of the 56^{th} day strength at the 28^{th} day.

In general, the addition of manufactured sand resulted in increased compressive strengths. The test results showed that for both, ISC and HSC mix proportion, the manufactured sand with 50%MS+ 50% NS was capable of achieving a higher compressive strength than the natural sand control mix. It can be concluded that the use of manufactured sand for high strength concrete production is more useful. However, special cares have to be taken to ensure that the concrete mix achieves a suitable finish.

Table 5.3 shows the summary of mean compressive strength of concrete made using Mugher PPC and Messobo OPC for NSC, ISC and HSC and tested at the age of 7th, 28th and 56th days of age. The raw data for the compressive strength values are shown in annex A.

Table 5.3 Summary of mean compressive strength of concrete at 7th, 28th and 56th days.

No	Mix code	Sand proportion	7day strength	28day strength	56day strength
	Normal Strength				
1	NSC_1	100% NS	17.52	36.01	41.43
2	NSC_2	75%NS+25%MS	17.68	35.73	40.8
3	NSC_3	50%MS+50%NS	18.11	36.28	40.27
4	NSC_4	75%MS+25%NS	17.94	34.38	38.77
5	NSC_5	100% MS	15.99	32.97	36.51
	Intermediate Strength				
6	ISC_1	100% NS	43.84	61.7	69.65
7	ISC_2	75%NS+25%MS	48.49	69.63	72.96
8	ISC_3	50%MS+50%NS	50.15	71.71	73.43
9	ISC_4	75%MS+25%NS	46.22	67.35	68.56
10	ISC_5	100% MS	47.44	66.44	71.22
	High Strength				
11	HSC_1	100% NS	66.3	85.15	88.4
12	HSC_2	75%NS+25%MS	69.21	84.16	88.57
13	HSC_3	50%MS+50%NS	69.58	91.11	93.25
14	HSC_4	75%MS+25%NS	67.69	91.54	93.39
15	HSC_5	100% MS	69.08	87.23	88.32

CHAPTER SIX

ECONOMIC (COST) ANALYSIS

6.1 General

It can be formulated that aggregate production in Ethiopia has been and will continue to be a local business based on easily accessible natural deposits. Most of the aggregate quarries are owned by the farmers on a private land and they sell their product or lease the quarry to contractors for different works.

These types of quarry are scattered around the country, mainly close to major roads while some are far away from roads. Though aggregates from natural sand and gravel deposits don't contain fine particles in proportion and also have more impurities, the experience of manufactured sand is limited to specific projects. In addition as can be seen from the experience of manufactured sand in Ethiopia, the material properties differ in many ways from those found in natural sand, even though the particles sizes are similar.

The true cost of aggregate material is influenced by various factors, since production and transportation costs play the major role.

6.1.1 Production costs

A survey from the J&P road contractors for the Addis Ababa to Jimma road construction have shown that the production cost for 1 ton of manufactured sand was 50 ETB and it was about 120 ETB per m^3 of manufactured sand. This cost of aggregate was the latest as of March 2006. There are lots of items that have to be considered in the calculation of breakdown of cost for production of aggregates. These include loading, hauling, processing, reclamation, dust control, energy, stripping, maintenance etc. If there were sufficient data for the above processes the figures would have been displayed as proportion of the total cost of the material. In addition environmental issues and quality may alter the outcome of the comparison.

6.1.2 Transportation costs

Information regarding the method of transportation of construction sand from the quarry to the first point of use is not easily available. As all producers don't keep records of cost per m^3 per km, the cost of transport for $1m^3$ of aggregate to a km distance is difficult to estimate or it will take a long process of data collection. It is determined in the preparation of tender for a certain project considering the distance it takes with the respective fuel consumption.

Construction aggregate prices are expected to increase in the future due to the rising cost of fuel used in the production and transporting processes. The rise in fuel cost is expected to affect the delivery prices of construction sand and gravel. These price increases are expected to be more noticeable in and near cities because as nearby resources are used up, more aggregate will have to be transported from distant resources.

6.2 Economic analysis

Several aggregate producers and construction material suppliers cooperated to give information and price on their aggregate products and material they supply to the market. Table 6.1 shows a summary of concrete making materials cost as collected from the respective town's material suppliers and aggregate producers. The costs for the natural sand and coarse aggregate are both with and without transportation cost to the required place. Manufactured sand cost is the production cost and, an approximation is required in order to include cost for transportation. The price shown is ETB per quintal and per m^3 of cement and aggregate, respectively, and the cost of the material was as recent as of June 2006 except for the manufactured sand of March 2006. In addition 18birr/liter was the price of admixture excluding transportation cost.

Table 6.1 Summary of costs for materials used in cost calculation

	Addis Ababa	Nazareth	Awassa	Jimma	Mekelle
Cement					
* Mugher PPC (Birr/qtl)	198	200	206	220	X
* Messebo OPC (Birr/qtl)	195	230	210	215	185
Fine aggregate					
* On own transport (Birr/m^3)		50	44.44		32.35
* Including transport (Birr/m^3)	162.5	75-80	105	156.25	100
Coarse aggregate					
* On own transport (Birr/m^3)		110	130		98
* Including transport (Birr/m^3)	159.38	125	140	185	108

Though the percentage of cement amount per m^3 of concrete is about 15-20%, it's more than 75% of the total concrete cost. Other than the cost of coarse aggregate and admixture, the percentage cost amount of fine aggregate to the total cost of the concrete is well below 12% for all concrete mix types of the specimens.

In the calculation of the concrete mix cost five cities were selected these are: Addis Ababa, Awassa, Jimma, Mekelle and Nazareth. The costs of all materials were taken as it was collected from the respective cities market except the manufactured sand where modification were made due to transportation cost and unavailability of the material outside the locality of Jimma from the selected cities.

The following cost variations of manufactured sand were assumed in the cost analysis

1. production cost and 50% increment to production cost without considering wastage
2. production cost and 250% increment to production cost without considering wastage
3. production cost and 300% increment to production cost and considering 15%wastage for manufactured sand and 5% wastage for natural one.

Percentage of cost for cement, coarse aggregate, fine aggregate and admixture of all concrete mix samples in varying manufactured sand price is shown in the Table 6.2. The proportion is arranged in the order of 100%NS, 25%MS+75%NS, 50%MS+50%NS, 25%NS+75%MS and 100%MS downward in the table.

Table 6.2 Cost comparison of the mixes

NSC				ISC				HSC			
Addis Ababa Case 1											
Cement	CA	FA	Admix.	Cement	CA	FA	Admix.	Cement	CA	FA	Admix.
0.86	0.09	0.05	0.00	0.86	0.08	0.04	0.02	0.79	0.06	0.03	0.12
0.86	0.09	0.05	0.00	0.81	0.07	0.03	0.09	0.78	0.06	0.03	0.13
0.86	0.09	0.05	0.00	0.82	0.07	0.04	0.07	0.75	0.06	0.03	0.17
0.83	0.08	0.05	0.04	0.82	0.07	0.04	0.08	0.77	0.06	0.03	0.14
0.81	0.08	0.05	0.06	0.80	0.07	0.04	0.09	0.79	0.06	0.03	0.12
Addis Ababa Case 2											
Cement	CA	FA	Admix.	Cement	CA	FA	Admix.	Cement	CA	FA	Admix.
0.86	0.09	0.05	0.00	0.86	0.08	0.04	0.02	0.79	0.06	0.03	0.12
0.85	0.09	0.06	0.00	0.80	0.07	0.04	0.09	0.78	0.06	0.03	0.13
0.84	0.08	0.07	0.00	0.81	0.07	0.05	0.07	0.73	0.07	0.03	0.16
0.81	0.08	0.08	0.03	0.80	0.07	0.05	0.07	0.76	0.06	0.04	0.14
0.78	0.08	0.09	0.06	0.78	0.07	0.06	0.09	0.77	0.06	0.05	0.12
Addis Ababa Case 3											
Cement	CA	FA	Admix.	Cement	CA	FA	Admix.	Cement	CA	FA	Admix.
0.86	0.09	0.05	0.00	0.86	0.08	0.04	0.02	0.79	0.06	0.03	0.12
0.84	0.08	0.07	0.00	0.80	0.07	0.05	0.09	0.77	0.06	0.04	0.13
0.83	0.08	0.09	0.00	0.80	0.07	0.06	0.07	0.73	0.06	0.04	0.16
0.78	0.08	0.10	0.03	0.79	0.07	0.07	0.07	0.75	0.06	0.05	0.14
0.75	0.08	0.12	0.05	0.77	0.07	0.08	0.08	0.76	0.06	0.06	0.12
Awass*a* Case 1											
Cement	CA	FA	Admix.	Cement	CA	FA	Admix.	Cement	CA	FA	Admix.
0.89	0.08	0.03	0.00	0.89	0.06	0.02	0.02	0.81	0.05	0.02	0.12
0.89	0.08	0.04	0.00	0.83	0.06	0.02	0.09	0.80	0.05	0.02	0.13
0.88	0.07	0.04	0.00	0.84	0.06	0.03	0.07	0.76	0.05	0.02	0.17
0.84	0.07	0.05	0.04	0.83	0.06	0.03	0.08	0.79	0.05	0.02	0.14
0.82	0.07	0.05	0.06	0.82	0.06	0.03	0.09	0.80	0.05	0.03	0.12
Awassa Case 2											
Cement	CA	FA	Admix.	Cement	CA	FA	Admix.	Cement	CA	FA	Admix.
0.89	0.08	0.03	0.00	0.89	0.06	0.02	0.02	0.81	0.05	0.02	0.12
0.88	0.07	0.05	0.00	0.82	0.06	0.03	0.09	0.80	0.05	0.02	0.13
0.86	0.07	0.06	0.00	0.83	0.06	0.04	0.07	0.74	0.07	0.03	0.16
0.82	0.07	0.07	0.04	0.82	0.06	0.05	0.08	0.78	0.05	0.04	0.14
0.79	0.07	0.08	0.06	0.80	0.06	0.06	0.09	0.79	0.05	0.04	0.12
Awassa Case 3											
Cement	CA	FA	Admix.	Cement	CA	FA	Admix.	Cement	CA	FA	Admix.
0.89	0.08	0.03	0.00	0.89	0.06	0.02	0.02	0.81	0.05	0.02	0.12
0.87	0.07	0.06	0.00	0.82	0.06	0.04	0.09	0.79	0.05	0.03	0.13
0.85	0.07	0.08	0.00	0.82	0.06	0.05	0.07	0.75	0.05	0.04	0.16
0.80	0.07	0.10	0.03	0.81	0.06	0.06	0.07	0.77	0.05	0.05	0.14
0.77	0.07	0.11	0.06	0.78	0.06	0.08	0.08	0.77	0.05	0.06	0.12

NSC				ISC				HSC			

Nazareth **Case 1**

Cement	CA	FA	Admix.	Cement	CA	FA	Admix.	Cement	CA	FA	Admix.
0.90	0.08	0.03	0.00	0.90	0.06	0.02	0.02	0.83	0.05	0.01	0.11
0.89	0.08	0.03	0.00	0.84	0.06	0.02	0.08	0.82	0.05	0.01	0.12
0.88	0.08	0.04	0.00	0.86	0.06	0.02	0.06	0.78	0.05	0.02	0.15
0.84	0.07	0.05	0.04	0.85	0.06	0.03	0.07	0.80	0.05	0.02	0.13
0.82	0.07	0.05	0.06	0.83	0.05	0.03	0.08	0.82	0.05	0.02	0.11

Nazareth **Case 2**

Cement	CA	FA	Admix.	Cement	CA	FA	Admix.	Cement	CA	FA	Admix.
0.90	0.07	0.03	0.00	0.89	0.06	0.02	0.03	0.81	0.05	0.01	0.13
0.89	0.07	0.04	0.00	0.82	0.06	0.03	0.09	0.79	0.05	0.02	0.14
0.87	0.07	0.06	0.00	0.83	0.06	0.04	0.07	0.75	0.05	0.03	0.17
0.82	0.06	0.07	0.04	0.81	0.06	0.05	0.08	0.77	0.05	0.04	0.14
0.79	0.06	0.09	0.06	0.79	0.05	0.06	0.09	0.78	0.05	0.05	0.13

Nazareth **Case 3**

Cement	CA	FA	Admix.	Cement	CA	FA	Admix.	Cement	CA	FA	Admix.
0.90	0.07	0.03	0.00	0.89	0.06	0.02	0.03	0.81	0.05	0.01	0.13
0.88	0.07	0.05	0.00	0.82	0.06	0.03	0.09	0.79	0.05	0.03	0.14
0.85	0.07	0.08	0.00	0.82	0.06	0.05	0.07	0.74	0.05	0.04	0.17
0.80	0.06	0.10	0.04	0.80	0.05	0.07	0.08	0.76	0.05	0.05	0.14
0.77	0.06	0.12	0.06	0.78	0.05	0.08	0.09	0.77	0.05	0.06	0.12

Jimma **Case 1**

Cement	CA	FA	Admix.	Cement	CA	FA	Admix.	Cement	CA	FA	Admix.
0.86	0.09	0.04	0.00	0.87	0.08	0.03	0.02	0.79	0.07	0.02	0.12
0.86	0.09	0.05	0.00	0.81	0.07	0.03	0.09	0.78	0.07	0.02	0.13
0.86	0.09	0.05	0.00	0.82	0.08	0.03	0.07	0.75	0.06	0.02	0.17
0.83	0.09	0.05	0.03	0.82	0.08	0.03	0.08	0.77	0.06	0.02	0.14
0.81	0.09	0.05	0.05	0.81	0.07	0.03	0.09	0.79	0.07	0.03	0.12

Jimma **Case 2**

Cement	CA	FA	Admix.	Cement	CA	FA	Admix.	Cement	CA	FA	Admix.
0.86	0.09	0.04	0.00	0.87	0.08	0.03	0.02	0.79	0.07	0.02	0.12
0.86	0.09	0.05	0.00	0.80	0.07	0.04	0.09	0.78	0.07	0.03	0.13
0.85	0.09	0.06	0.00	0.82	0.08	0.04	0.07	0.74	0.06	0.03	0.16
0.81	0.08	0.07	0.03	0.80	0.07	0.05	0.07	0.76	0.06	0.04	0.14
0.78	0.08	0.08	0.05	0.79	0.07	0.05	0.09	0.77	0.06	0.04	0.12

Jimma **Case 3**

Cement	CA	FA	Admix.	Cement	CA	FA	Admix.	Cement	CA	FA	Admix.
0.86	0.09	0.05	0.00	0.86	0.08	0.03	0.02	0.79	0.07	0.02	0.12
0.85	0.09	0.06	0.00	0.80	0.07	0.04	0.09	0.78	0.06	0.03	0.13
0.83	0.09	0.08	0.00	0.81	0.07	0.05	0.07	0.74	0.06	0.04	0.16
0.79	0.08	0.09	0.03	0.79	0.07	0.06	0.07	0.75	0.06	0.05	0.14
0.76	0.08	0.10	0.05	0.77	0.07	0.07	0.08	0.76	0.06	0.06	0.12

ISC				HSC			
Mekelle		**Case 1**					
Cement	CA	FA	Admix.	Cement	CA	FA	Admix.
0.89	0.06	0.02	0.03	0.79	0.04	0.02	0.15
0.82	0.05	0.03	0.11	0.78	0.04	0.02	0.15
0.84	0.05	0.03	0.08	0.74	0.04	0.02	0.19
0.82	0.05	0.04	0.09	0.77	0.04	0.03	0.16
0.81	0.05	0.04	0.10	0.78	0.04	0.03	0.14
Mekelle		**Case 2**					
Cement	CA	FA	Admix.	Cement	CA	FA	Admix.
0.89	0.06	0.02	0.03	0.79	0.04	0.02	0.15
0.81	0.05	0.03	0.10	0.78	0.04	0.02	0.15
0.82	0.05	0.04	0.08	0.73	0.04	0.03	0.19
0.81	0.05	0.05	0.09	0.76	0.04	0.04	0.16
0.79	0.05	0.06	0.10	0.77	0.04	0.05	0.14
Mekelle		**Case 3**					
Cement	CA	FA	Admix.	Cement	CA	FA	Admix.
0.89	0.06	0.03	0.03	0.79	0.04	0.02	0.15
0.81	0.05	0.04	0.10	0.77	0.04	0.03	0.15
0.81	0.05	0.06	0.08	0.73	0.04	0.04	0.19
0.79	0.05	0.07	0.09	0.75	0.04	0.05	0.16
0.77	0.05	0.09	0.10	0.75	0.04	0.07	0.14

In the cost analysis of the material of case 1, the maximum percentage cost difference between 100% MS and 100% NS is about 2.8% in the case of Nazareth of NSC and the minimum percentage cost difference between 100% MS and 100% NS is about 0.1% and 0.3% in the cases of Addis Ababa and Jimma of ISC and HSC, respectively.

In the cost analysis of the material of case 2 the maximum percentage cost difference between 100% MS and 100% NS is about 6.1% in the case of Nazareth of NSC and the minimum percentage cost difference between 100% MS and 100% NS is about 2.1% and 2.3% in the cases of Addis Ababa and Jimma of HSC and ISC, respectively.

In the cost analysis of the material of case 3, the maximum percentage cost difference between 100% MS and 100% NS is about 8.9% in the case of Nazareth of NSC and the minimum percentage cost difference between 100% MS and 100% NS is about 3.6% and 3.2% in the cases of Addis Ababa and Jimma of both HSC.

As can be easily seen from Table 6.2, the minimum purchasing cost of the natural sand is observed in Nazareth, which has a direct impact in the cost calculation of the concrete mix. This also assures that the lesser price of the natural sand in the locality, the lesser the need of manufactured sand. In addition the higher the compressive strength the lesser fine aggregate content of the concrete mix. This also reveals that as the compressive strength goes from NSC to ISC to HSC the amount of fine aggregate decreases and the percentage cost difference of the two MS and NS also decreases from NSC.

In the case of Addis Ababa and Jimma the purchase price of natural sand is increasing, implying that there will not be much difference between the use of manufactured and natural sand.

In general by using manufactured sand in partial or full replacement to natural sand, it is possible to achieve a better strength than the natural sand mix alone without significant cost variation.

CHAPTER SEVEN

CONCLUSIONS

The use of manufactured sand in producing concrete for normal strength, intermediate strength and high strength were studied and after the research work is done, the following conclusions are made and recommendations are forwarded.

1. The results of the hardened properties of the mix have shown that the concrete mix for ISC and HSC with proportion of manufactured and natural sand achieved a higher compressive strength almost at all tested age of concrete.

2. A mean compressive strength of 93MPa, which is about C-75 concrete were produced using a 50% proportion of both natural and manufactured sand whereas with the same proportion of constituent material, a mean compressive strength of 88MPa was achieved on 100%NS and 100%MS indicating that the suitable proportion of NS and MS would result in improved compressive strength.

3. Manufactured sands are made by crushing aggregate to sizes appropriate for use as a fine aggregate. During the crushing process the manufactured sand have irregular shapes and more fine particles contributing to improved compressive strength, compared to natural sand control mix.

4. Due to the irregular particle shape of the manufactured sand, in addition to the reduced amount of water cement ratio, manufactured sand is more important for high strength concrete mixes.

5. Analysis made on the influence of manufactured sand in the cost of the concrete revealed that no significant cost variation is observed for mixes with fully or partial replacement of the manufactured sand with natural one.

6. Manufactured sand offers important economic advantages in regions where the availability of natural sand is scarce or in cities where transportation cost is high as in the case of Addis Ababa and Jimma.

7. The use of manufactured sand in the construction industry helps to prevent unnecessary damages to the environment and provide optimum exploitation of the resources.

8. Manufactured sand offers a viable alternative to the natural sand if the problems associated with the workability of the concrete mix can be resolved by using superplasticizer. The addition of superplasticizer to a concrete mix with manufactured sand allows the mix to have a better workability.

RECOMMENDATIONS

1. To minimize cost of manufactured sand transportation more advanced mobile plants might be a solution.

2. In order for a manufactured sand mix containing super plasticizer to be more economical, the maximum dosage of the super plasticizer should be made optimum by reducing the volume of admixture and to get the required consistency.

3. As the amounts of fines depend on the characteristics and on the strength of individual minerals, control over the selection of the raw material has to be made.

4. 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 and cost too.

5. Concerned authorities have up-to-date information about the locations and details of existing quarries in addition with the potential of available quarries.

6. Designers, specifiers, contractors and material suppliers need to understand the effects of manufactured sand angularity as well as fines content on concrete water demand and concrete durability.

Further research is proposed in the following areas.

1. The effects that have on digging for natural sand on environment shall be studied.
2. More research and investigations need to be carried out to assess the scope for saving through optimization of both natural and manufactured sand.
3. Guide lines, mix design proposals and specifications shall be prepared using manufactured sand to establish acceptable mixes for concrete producers, contractors and their clients.

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ANNEXES

DECLARATION

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

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