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INFLUENCE OF VARIATIONS IN AGGREGATE GRADATIONS ON SELECTED PROPERTIES OF CEMENT CONCRETE

By

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DECLARATION

I, the undersigned, declare that this thesis is my original work performed under the supervision of my research advisor Dr. Alemgena Alene and has not been presented as a thesis for a degree in any other University. All sources of materials used for this thesis have also been properly acknowledged / referred.

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ABSTRACT

Most of the time, natural sands in Ethiopia are failing to meet the standard requirements set in ERA (Ethiopian Roads Authority) standard technical Specification 2013, for gradation for use in cement concrete. Besides, the grading envelop for course aggregate is also very narrow and it is sometimes very difficult to find an aggregate falling within the specification limit. The effect of using aggregates that fall out of specification on properties of concrete and the consequent effect on short and long term performance of concrete is poorly understood. Besides, a rational basis to use or reject concretes made with such aggregates which are out of the gradation requirement is not available.

The goal of this project is to provide guidance and recommendation to the extent that the specification should be revised/relaxed so that concretes made with aggregates which are out of the grading limits set in ERA could be utilized. The main objective of this research paper is to study the influence of variations in aggregate gradations within and out of ERA's Specification on workability, compressive strength, and water absorption of concrete. The methodology used in this research is, deliberately separating the as obtained aggregates into different sieve sizes and recombining them in a range of predetermined proportions to obtain aggregate gradations that fall on the middle, upper limit and lower limit of the specification for both the coarse and fine aggregates, which are called the control mixtures, and some other pre specified mixtures which fall out of the specification beyond the coarser and the finer limits.

Statistical analysis made on the means of the test results shows that, to 95% significant level (alpha value of 0.05) varying fine aggregate gradation from fineness modulus of 1.8 to 3.74 had no impact on the compressive strength of concrete, while the workability is significantly increased as the fine aggregate becomes coarser. To 95% significant level, deviation in aggregate gradation of coarse aggregate up to 10% coarser beyond the coarser limit had no significant impact on compressive strength and workability of concrete, whereas mixtures prepared using 10% more finer and 5% more finer coarse aggregates resulted in significant increase in compressive strength and significant decrease in workability. Water absorption of concrete is not affected by varying both the fine aggregate and the coarse aggregate beyond either the finer or the coarser limit. However, within the specification limit, as the coarseness of either the coarse aggregate or the fine aggregate is increased, the water absorption decreased.

In general, workability of cement concrete is more significantly influenced by deviations in aggregate gradation from the specification limit, while the compressive strength and water absorption are little affected.

In conclusion, it is recommended to relax the upper limit set in the specification for the fine aggregate up to fineness modulus of 2.4, because using more finer fine aggregates with fineness modulus of 1.8, 2.0 and 2.2 resulted in a mixtures with very low workability and high segregation. It is also recommended to relax the lower limit of coarse aggregate up to 10% more coarser because there is no significant variation in concrete properties in between mixtures made with the coarser limit, 5% more coarser, and 10% more coarser coarse aggregates.

Key Words: fine aggregate, coarse aggregate, gradation, aggregate, cement concrete

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LIST OF ABBREVIATIONS / ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
ACI	American Concrete Institution
ACV	Aggregate Crushing Value
DOT	Department of Transport
ERA	Ethiopian Road Authority
FM	Fineness Modulus
IS	Indian Standard
LHS	Left Hand Side
OPC	Ordinary Portland Cement
TFV	Ten Percent Fine Value
SSS	Soundness Loss by Sodium Sulphate

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CHAPTER 1: INTRODUCTION

1.1.Background

Aggregate occupies seventy to seventy five percent in volume of cement concrete. Therefore, the properties of aggregates used to produce the cement concrete have significant effect on the performance of the fresh and hardened concrete. From the varies properties of aggregates, which affect the properties of cement concrete, aggregate gradation has a major role in attaining the desired properties of cement concrete. Aggregate gradation is also known as particle size distribution. (Quiroga P.N and Fowler D.W, 2004) (Steven H. Kosmatka, Beatrix Kerkhoff, and William C. Panarese, 2003)

The void content within the structure of given volume of aggregate and the quantity of cement paste that is needed to fill the voids between aggregates and consequently the workability of the cement concrete is determined by the aggregate gradation. (Quiroga P.N and Fowler D.W, 2004).

Among the constituents of cement concrete, cement is the most expensive one. It is also carbon footprint ingredient in concrete and releases high amount of carbon to the atmosphere during its production. Therefore, it is very crucial to minimize the void content in the aggregates so that the amount of cement paste required which is directly proportional to the amount of cement required will be minimized. This could be achieved by optimization of the aggregate gradation which results in concrete mix that is economical, workable, and environmentally sound. (M Richard, M.D Moya, and D.W Fowler, 2009)

Depending on their size, Aggregates used in concrete are commonly categorized as fine aggregates (which are between 4.75mm and 0.075mm) and coarse aggregate (which are greater than 4.75mm). The presence of material finer than 0.075mm in concrete aggregates is taken as harmful/ deleterious. Deleterious materials affect the quality of concrete in achieving desired mechanical, durability and rheological properties. Hence a limit is set on most of the concrete aggregate specifications on the percent of material passing 0.075mm sieve.

Aggregate gradations for coarse and fine aggregates for cement concrete are separately specified on most of the specifications. For example, ASTM C 33, AASHTO M 6, AASHTO M 43, and

AASHTO M 80 specify fine and coarse aggregate gradations separately. In Ethiopia this practice is accustomed and fine and coarse aggregates are specified separately in ERA Standard Technical Specification 2013 for cement concretes to be used for rigid pavements and for structures.

The boundaries placed on aggregate gradation in ERA standard technical specifications have been established through empirical basis. The qualitative and quantitative effects of utilizing aggregates that do not fulfill the grading requirements on different properties of concrete has not been investigated clearly. Furthermore, quantitative approach on the effect of the extent of deviation from the ERA standard technical specification before which any adverse impacts on concrete properties become critical has not been established.

This research aims to study the sensitivity to variations in aggregate gradations of fine and coarse aggregates which fall both within the limits of the specification and out of the specification limit have on compressive strength, workability and water absorption of cement concrete. The research will attempt to propose the maximum allowable deviations from the gradation of fine and coarse aggregates specified in ERA Standard Technical Specification and the consequences of this deviations on cement concrete in its hardened and plastic state.

1.2.Problem Statement

Aggregates occupy a significant volume fraction of cement concrete and play a key role in defining the properties of concrete in its fresh and hardened form. Aggregate gradation is one of the important aggregate properties that affect the concrete behavior. Most of the time, natural sands in Ethiopia are failing to meet the standard requirements set in ERA standard technical Specification 2013, for gradation for use in cement concrete. Currently, most road projects in Ethiopia are using crushed sand rather than natural sands, because the grading of the natural sands fall out of specification. Besides, the grading envelop for course aggregate is also very narrow and it is sometimes very difficult to find an aggregate falling within the specification limit.

The effect of using aggregates that do not fulfill the gradation requirements on concrete properties and the consequent effect on short and long term performance of the structures are poorly understood. Furthermore, at present time, a rational basis to accept or reject concrete containing such out of specification aggregate is not available.

The research paper will try to investigate the effects of variations in aggregate gradations of fine and course aggregates that fall within and out of the specification on compressive strength, workability, and water absorption and bulk density of cement concrete. In addition, recommendations and guides will be given on the maximum allowable deviations form the specification set in ERA standard technical specification for both coarse and fine aggregates beyond which it would have detrimental impact on the desired quality of the cement concrete.

1.3. Objective

1.3.1. General Objective

The main objective of the research is to investigate the influence of variations in aggregate gradations on compressive strength and workability of concrete.

1.3.2. Specific Objectives

The specific objectives of this research are:

- To determine the influence of variations in the gradation of fine aggregate both within and out of the specification limits on the compressive strength, workability, density and water absorption of cement concrete.
- To determine the influence of variations in the gradation of course aggregate both within and out of the specification limit on the compressive strength, workability, density and water absorption of cement concrete.
- Develop a guide to limit the acceptable deviation in aggregate beyond the specification limits set in ERA Standard Technical Specification.

1.4. Limitations of the Study

The limitations of this research paper are:

- All concrete mixes were proportioned with a constant water cement ratio of 0.48 and cement content of 400 kg/m^3 and no chemical admixtures were used in this investigation. Since only constant water cement ratio 0.48 and fixed quantity of cement which is 400Kg/m^3 is used, the quantitative limits set in the recommendation may not apply for different water-cement ratio and different cement contents.
- Natural sand is used in this study and no crushed sand is employed.
- Due to time and cost limitations, the selected fresh and hardened concrete properties investigated in this study are, the workability using slump test, 7 days and 28 days compressive strength of hardened concrete, density and water absorption of hardened concrete.

1.5. Organization

Chapter one defines the overall importance of the problem areas and provides an introduction into what the research is all about, chapter two deals with literatures on constituents of cement concrete, aggregate gradation and its specification and modern concepts pertaining aggregate gradation and practice of proportioning of aggregates in Ethiopia. Chapter three describes the experimental material and mixtures proportions and, the experimental test method and program. The results are analyzed and discussed in chapter four. Conclusions derived from experimental results and recommendations for this study and other further studies are presented in chapter five.

CHAPTER 2: LITERATURE REVIEW

2.1. Background

Concrete is most utilized substance on the earth next to water and is most widely used man made material in construction in the world. Concrete is made by mixing aggregates, water and cement in appropriate proportions. The mixture of cement, aggregates and water when placed in forms and is allowed to cure, it hardens into a rock mass which is called a concrete. The hardening is the result of hydration reaction between cement and water and concrete gets stronger with time as the reaction goes on for long period of time. (Gambhir, 2010)

Concrete in another words is a hardened artificial stone whereby the voids of coarse aggregates are occupied by the fine aggregates (sand) and the voids of fine aggregates are filled by the cement. Water and cement in a concrete mix, form a water-cement paste which coats on the surface of coarse aggregates and fine aggregates, and binds them together as it cures and cements the aggregates together. (Steven H. Kosmatka, Beatric Kedkhoff, and William C. Panarese, 2003)

2.2. Properties of Concrete

According to Gambhir (2010) making concrete is not just a matter if mixing aggregates and cement with water to produce plastic mass, because good concrete has to satisfy performance requirements in the hardened and plastic state. Concrete shall be workable and free from bleeding and segregation in plastic state. In its hardened state concrete should be durable, impermeable and strong.

According to (James M. Shilstone Sr. and James M Shilstone Jr., 2002) there are four primary performance objectives for concrete mixtures, which are durability, architectural appearance, constructability and Strength.

According to Gambhir (2010), amongst the several properties of cement concrete, its compressive strength is taken to be the most important and is considered as an index of its overall quality. He also stated that “many other properties of concrete appear to be generally related to its compressive strength.”

2.2.1. Fresh Properties of concrete

The diverse requirements of mixability, stability, transportability, placeability, mobility, compactability and finishability of fresh concrete are collectively referred as workability. Indian Standard IS: 6461 (Part-VII)-1973 defines Workability as the property of fresh concrete which determines the ease and homogeneity with which in can be mixed placed, compacted and finished.

The slump test is the Primary workability measuring test applied to this day. The Slump which has been used since 1922 was standardized by ASTM. Because of its simplicity, inexpensiveness and the quickness to perform the test in the field, the slump test has been predominantly used as a measure of workability test.

The slump test shows the performance of concrete under the action of gravity. The test is carried out with the slump cone mound. The slump cone is placed on a horizontal surface and fresh concrete is filled in it in three equal layers and each layer is tamped 25 times with a standard tamping rod. Then the mould is vertically lifted. The dropping of the fresh cement concrete in inches or millimeters is called the slump.

The desired properties of fresh concrete mixture are:

- The mixture should produce a homogeneous fresh concrete from the constituent materials under the action of the mixing forces
- The mix should be stable and free from bleeding. It should not segregate when it is subjected to forces during placing and transportation
- The mix should be able to cast into the required shape without losing continuity or homogeneity under the available techniques of placing the concrete. Also it should be cohesive enough and sufficiently mobile to be placed in the formworks around the reinforcement. This property is termed flowability or mobility of fresh concrete.
- The mix should be suitable to proper compaction into a dense, compact concrete with minimum voids. This property is termed the compactability of concrete
- It should be possible to attain satisfactory surface finish without honeycombing or blowing holes from formwork and on free surface. This capability is termed as finishability of concrete.

2.2.2. Properties of Hardened Concrete

According to Gambhir (2010), The various properties of hardened concrete which are very important are those related with Permiability, shrinkage and creep deformation, response to temperature variation, durability, stress strain characteristics and its strength. Of these properties of hardened concrete, the strength of concrete has the greatest significance because the strength is related to overall picture of the quality of the concrete and the structure of hardened cement paste.

2.3. Aggregate Gradation and its Influence

In 1907 Fuller and Thompson acknowledged the significance of aggregate gradation in concrete proportioning. Based on maximum density they developed an ideal gradation curve. Starting from that time several concepts on aggregate gradation have been proposed like surface area optimization, minimizing particle interference and fineness modulus and also some others.

Different literatures show that aggregate gradations have major effect on the performance of cement concrete in its hardened and fresh form. The particle size distribution of a mass of aggregate should be such that the smaller aggregates filling the voids between the larger ones. The proper particle size distribution of an aggregate produces dense concrete and needs less quantity of fine aggregate and cement paste. To produce quality concrete, it is crucial that the fine and coarse aggregates be well graded. The mortar consisting of the fine aggregate and cement should be somewhat in excess of that just needed to fill the voids in the coarse particle. Too coarse a fine aggregate results in segregation, harshness and bleeding. Also, too fine an aggregate requires too large a water/cement ratio for satisfactory workability. The amount of mixing water and cement required is affected by the surface area. Usually, the water-cement ratio is fixed from strength considerations. Nevertheless, for proper workability and bond the surface of all the aggregates shall sufficiently by covered by cement paste. (Tyler Ley, Daniel Cook, and Grey Fick, 2012), (Prasada Rao Rangaraju, Marcus Balitsaris, Harsh Kizhakkumodom, 2013)

The grading of the aggregate affects the workability which in turn controls the water and cement requirements, segregation, and influences the placing and finishing of concrete. These factors represent the important characteristics of fresh concrete and affect its properties in the hardened state. The key factors governing the desired aggregate particle size distribution are: the surface area of aggregate, the workability of the mix, the tendency to segregation and the relative volume occupied by the aggregate. (M Loseby, MG Alexander, H Beushasuen, 2016)

In general, for a fixed water cement ratio, the smaller the maximum aggregate size, the higher is the cement demand. This is because cement concrete's workability decreases as the maximum size of the aggregate decreases. Larger size aggregates have smaller surface area and the water cement ratio can be decreased which it tern increases the strength of concrete. In practice however, the size of the aggregate is limited based on the volume of equipment used for handling, placing and mixing of the concrete . (Steven H. Kosmatka, Beatric Kedkhoff, and William C. Panarese, 2003)

The compressive strength of cement concrete is affected by the maximum size of aggregate. For a fixed volume of aggregate, with increase of the coarse aggregate, the compressive strength tends to decrease. This happens because larger surface area for bonding with sand-cement paste is provided with smaller size aggregates. Also, with the increase in the maximum size of aggregate the stress concentration in the aggregate-mortar interface increases. Therefore, the nominal size of the coarse aggregate must be as large as possible for concrete with a higher water cement ratio. However, for high strength concretes smaller size coarse aggregates (10mm or 20mm) are much more desirable. . (Tyler Ley, Daniel Cook, and Grey Fick, 2012)

According to (Indian Standard: 456,2000), the maximum nominal size of coarse aggregate should not be greater than one-fourth the minimum thickness of the member. It shall also not be greater than 5mm less than the minimum cover to reinforcement distance or 5mm less than the minimum clear distance between the main bars. For coarse aggregates, the nominal maximum size may be as large as possible within the limits specified here.

According to (Indian Standard: 456,2000), if aggregate is coarser segregation of the mix might take place. If on the other hand, the aggregate is finer more water will be required thus, for a constant water-cement ratio, the quantity of cement demand is increased. Therefore this is uneconomical. An excess of middle size particles in a concrete results in to very harsh mixture.

Total surface area of aggregates is affected by the maximum size of aggregates. The surface area will vary with the shape and texture however it is inversely proportional to the size of the aggregate. The larger the size of aggregate, the lower is the surface area per unit volume. Therefore, the aim of selecting particle size distribution is to have as large a maximum particle size as possible and to grade it down in such a way that the voids in the coarse aggregate are filled with the minimum amount of cement paste and fine aggregate. However, this procedure cannot be applied too far as an aggregate graded in this way would be too harsh and a slight excess of fines is needed to prevent this from happening. Fine aggregates have the greatest contribution in increasing the total surface area compared to the coarse aggregates, therefore particular attention should be given to the proportioning and grading of fine aggregate. For the same workability, the use of finer sand increases the specific surface area, thereby increasing the water required. In the other way, for the same water content, the use of courser fine aggregate in a mix increases the workability. Gambhir (2010),

(Olumide Moses Ogundipe, April 2018) has studied the effect of size of aggregate on the compressive strength of cement concrete. Accordingly to the study, it takes more than 28 day, which is used for specification, for strength development of concrete. It was concluded that compressive strength increases as the aggregate size increases. The study states that there is a particular size of aggregate which gives the best performance and utilizing aggregate size greater than that will not give the desired result. The study concludes that aggregate size of 20mm results in production of cement concrete with the highest compressive strength. It also recommends to give careful attention in selecting of aggregate size used in the concrete production for structures.

Study made by (Ekwulo E.o.& Eme D.B., 2017) on the effect aggregate size and gradation on the fresh and hardened properties of concrete concluded that compressive strength and workability are affected by aggregate size and gradation. Workability decreases as the aggregate size increases for concrete made from uniform size aggregates while the compressive strength increases with increase in size of aggregate for concrete made from uniform aggregate size.

Studies have been made by (Rozalija Kozul & David Darwin, 1997) to understand effects of aggregate size and type on compressive strength of high strength and normal concrete. On the study crushed limestone and basalt with nominal maximum aggregate size of 12mm and 19mm and water to cement ratios ranging from 0.24 to 0.5 and aggregate volume factors containing course aggregate of 0.75 were used. As per the result, concretes produced using limestone have slightly lower compressive strength than those produced using basalt for high strength concrete.

On contrary normal strength concrete, produced using basalt has resulted in slightly lower compressive strength that that is produced using limestone. For both concretes made using limestone and basalt and for normal and high strength concretes aggregate size has little effect on the compressive strength. For Normal strength concretes produced using limestone or basalt and high strength concretes produced using basalt, higher compressive strength is obtained with increased coarse aggregate contents than with decreased coarse aggregate in the mix.

(Zhou, Barr and Lydon, 1995) Have studied the effect of size of aggregate on the compressive strength of concrete and the results show that compressive strength decreases with a decrease in coarse aggregate size. In the study compressive strengths varying from 80MPa to 115MPa with water to cement ratios of 0.32 and 0.23 were used to study the fracture property of concrete. It was concluded that increase in compressive strength of concrete up to 10% was achieved by increasing the maximum aggregate size from 10mm to 20mm.

On contrary studies by (Bloem, D.L. & Gaynor, R.D, 1963)have concluded that compressive strength of concrete decreases with an increase in aggregate size. The same was also concluded by (Walker, S & Bloem, D.L., 1960). They have concluded that for normal strength concrete, a decrease in aggregate size from 64mm to 10mm resulted in an increase by ten percent of compressive strength of concrete. Flexural strength of concrete is not affected by coarse aggregate size.

(Cook, 1989) has concluded that for a given water to cement ratio and for compressive strength above 69 MPa higher strengths are obtained using small coarse aggregate size. Crushed limestone with maximum aggregate sizes of 25mm and 10mm were used in the study. It was concluded that with increasing test age and with decreasing water to cement ratio, the difference in compressive strength due to aggregate size increases. The flexural strength of concrete is also increased with the smaller coarse aggregate size

Tests by (Bloem, D.L. & Gaynor, R.D, 1963) shows decreasing coarse aggregate size increases aggregate total surface area which results in increasing mixing water demand. Even though the water requirement is reduced with increased aggregate size, concretes made with small aggregate size produce higher compressive strength than those produced with large size aggregates. Aggregate size has high impact on high strength concretes and concretes with smaller size aggregate are preferred. However for low strength concretes the increase in aggregate size is compensated by reduction in mixing water required.

Study made by (Cordon & Gillespie, 1963) shows that there is around 30% reduction in compressive strength by increasing the maximum aggregate size from nineteen (19)mm to thirty eight (38) mm. in the study the water to cement ratio was varied from 0.4 to 0.7. In the same study it was also discussed that failure happens at the interface of the matrix aggregate for normal strength concrete. It was also concluded that the stress which causes failure at the interface could be decreased by lowering the size of aggregate (increasing the surface area of aggregate. For high strength concretes, the compressive strength is highly dependent on the aggregate strength as failure is accompanied by aggregate particles fracture.

In the study made by (Ezeldin, A. S & Aitein, P. C., 1991) on the effects of coarse aggregate size and type on compressive strength of high strength and normal concrete, they have concluded that coarse aggregate size and its type has little effect on normal strength concrete. They have also concluded that coarse aggregate size and type has effect in high strength concretes on their failure mode and strength.

Most of the studies show that coarse aggregate size has very little effect on compressive strength of normal strength concretes while in high strength concretes smaller size aggregate size results in increased compressive strength.

According to (Cartwright, 2011) by including intermediate aggregate size material and applying different optimization methods, up to 16% reduction in cement paste for 35MPa and 50Mpa mix designs cold be achieved for concrete used for bridge decks in Ontario. In the study crushed limestone with nominal maximum aggregate size of 6.7mm and 19.0mm and natural sand were used.

According to (Chirag et. al., 2016), fine aggregate gradation has more detrimental effect on concrete properties than coarse aggregate gradation. The grading of fine aggregate has a much greater effect on workability of concrete than does the grading of the coarse aggregate. Experience has shown that it results in unsatisfactory concrete to use very fine sand or very coarse sand.

According to the study made by (Waterways Experiment Station, 1950), on the effect of sand gradation on the properties of mass concrete, there is a general trend for strength to decrease with decreasing fineness modulus. In the study the fineness modules of natural sand was varied from 1.35 to 3.6 while all the mixtures were designed to have the same consistency, the same workability and 2 inch slump. The cement content was also fixed to be 2.5 bags of cement per cubic yard of concrete. As per the findings, it was noted that the water cement ratio was highest for the finest sand and decreased until a fineness modulus of about 2.5 was reached and then remained constant for the remainder of the series.

In the study made by (Ukala, 2019), as the fineness modulus increases the concrete becomes more workable but weaker. In the study effects of combined aggregate gradation on the workability and compressive strength of concrete using combined aggregates fineness modulus were made.

In study made by (M.A. Islam, M.R.M. Raja, M.S. Mia and M.M. Rahman, 2015) on the effects of gradation of sand on the compressive strength of concrete made with brick chips, it is concluded that the compressive strength of concrete increases with the increase of fineness modulus of sand and they also concluded that the rate of increase in strength is higher for lower fineness modulus than that of higher fineness modulus. In this study eleven sandy from different locations with varying fineness modulus from 1.58 to 2.95 were used. In the study 0.5 water-cement ratio for all the mixes and proportion of 1:2:4 was used.

The grading of fine aggregate is more critical than the grading of coarse aggregate because of their contribution to the total surface area. Still, the proportion of coarse to fines aggregates should be so selected in such a way that as neither to increase the total specific surface area (by excess of fine aggregate) nor to increase the particle interference (by insufficiency in fine aggregate). An overall choice of unsuitable particle size distribution can produce bleeding, segregation, and honeycombing. In normal range of mixtures even though a decrease in fines content increases workability, but in practice there is an optimum fine content for maximum workability, such that either a decrease or increase of fine aggregates decreases workability. Gambhir (2010),

A study made by (Prashant Agrawal, Dr. Y.P. Gupta, and Suryakanta Bal. , 2007) on the effects of fineness of sand on the cost and properties of concrete, shows that there is increase in compressive strength when the fineness modulus is increased. In the study sand with varying fineness modules from 2.0 to 3.0 were used and the result shows that there is faster increase in strength towards coarser side of sand. In the same study it was concluded that fineness modulus of sand has very little impact on permeability coefficient of concrete as the values remain more or less constant. In the study, water to cement ratio is kept constant and workability of mix is also fixed in range of 45mm to 55mm of slump. To adjust workability adjustments in admixture dosages were made. The results show that the demand for admixture increases as the fineness modules of sand decreases. Admixture dosages is considerably reduced as fineness of sand is increases.

Study has been made on all-inclusive review of literature related to aggregate gradation for cement concrete. Modern ideas in relation to aggregate gradation that have evolved include 8-to-18 gradation band, Shilstone method of workability and coarseness charts, and 0.45 power gradation chart (Richardson, 2005). Recently Tarantula curve was developed. Each of the modern concepts that have evolved recently about optimization of aggregate gradation for cement concrete are here discussed in detail.

2.3.1. 0.45 Power Chart

Originally the 0.45 power chart was used to in asphalt mixture designs to obtain uniform gradation. The sieve size verses the percent of aggregates passing each sieve is plotted on the x-y axis. In the 0.45 power chart the sieve sizes raised to the power of 0.45 is plotted on the cumulative percent passing chart. Theoretically, a gradation that lies on the straight line will produce a maximum density. Practically particles with grading on the line produce very harsh mix which is not workable.(Richardson, 2005), (Tayler Lay, Daniel Cook, 2014)

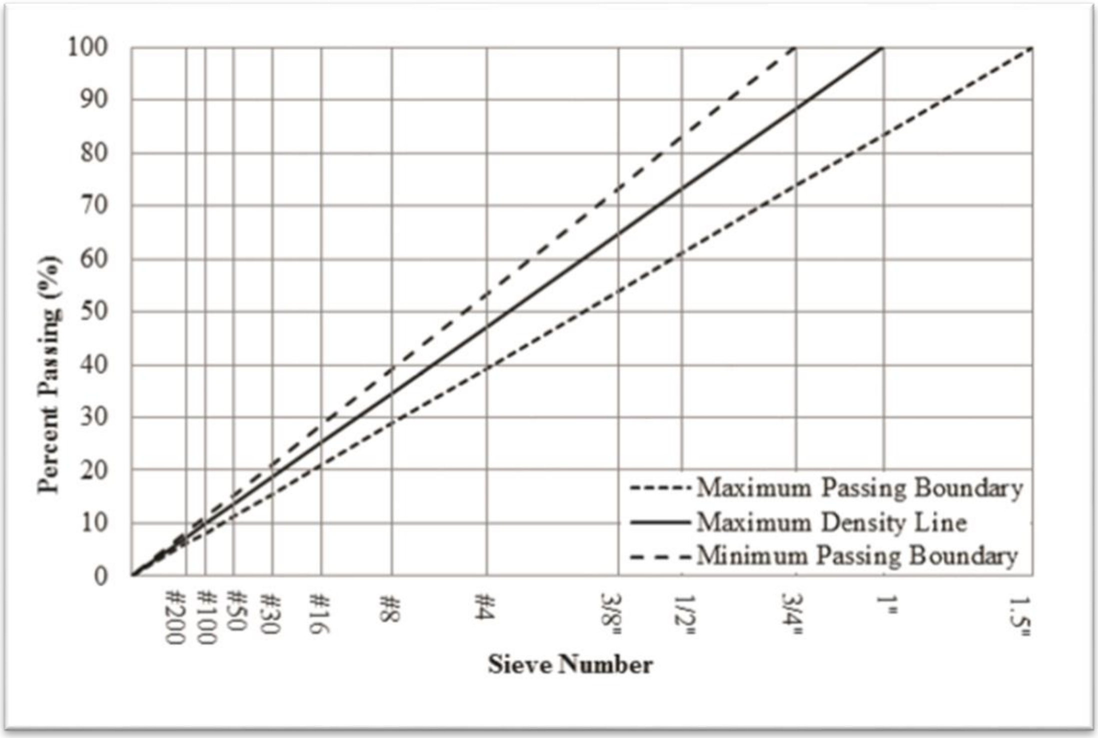


Figure 2. 1 0.45 Power Chart

In the 0.45 power chart, deviations from the straight line are very helpful in identifying the grading problems in the mixture. "Zigzags" across the 0.45 power line result in mixtures that are not workable. Gap-graded aggregate form an S-shape curve. (ACI Committee 302.1R-04, 2004)

2.3.2. Coarseness Factor Chart

The Coarseness Factor Chart was developed by Shilstone (1990). It is a method of evaluating the uniformity and size of the combined aggregate gradation (Figure 2.2). For the Coarseness Factor Chart, instead of considering the fine and coarse aggregate individually, a consideration of the grading of the whole aggregate is made.

The combined aggregate is divided in to 3 portions, which are, fine, W, intermediate, I, and large, Q. Large aggregate is larger than 9.5mm, intermediate aggregate lies between 9.5mm and 4.75mm and fine aggregate is defined as smaller than 4.75mm and larger than 0.075mm. The Coarseness Factor Chart provides the relationship between the coarseness factor which is Q/(Q+I) and the modified workability factor. The modified workability factor is equal to workability (W) corrected when lower than or higher than 6 bags of cement is used per cubic yard. (P.N Quiroga and D.W Fowler, 2004), (Richardson, 2005) (Shilstone, 1990)

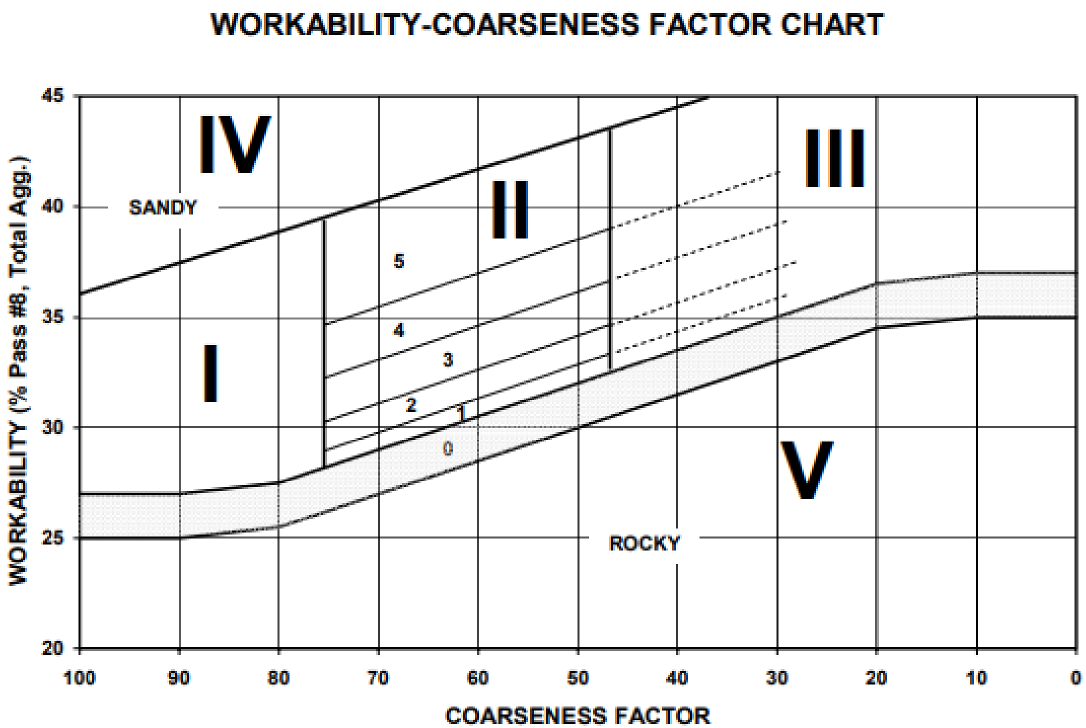


Figure 2. 2 Coarseness Chart Proposed by Shilstone, Source: (Richardson, 2005)

The coarseness factor chart is based on the premises that as the cement content is increased, the fine aggregate content should be decreased to sustain the same workability factor. An increase or decrease in the fine aggregate or cement content without compensation in the other affects the workability of the cement concrete.

Five zones are defined in the chart:

- Zone I – mixtures that fall in this zone are highly gap-graded with are highly susceptible for segregation. They are deficient of intermediate size materials and they are also not cohesive.
- Zone II – mixtures that fall within this zone are produced with aggregate nominal maximum sizes ranging from 37mm to 19mm. The mixtures produce consistent, high quality concrete. Zone II is divided into 5 sub-zones: sub division-1 excellent but needs

caution, sub division-2 excellent for paving and slipform, sub division-3 high quality slab, sub division-4 good general, and sub division-5 varies to material and construction needs

- Zone III – This zone is an extension of Zone II, for which the maximum aggregate size is smaller than 12.5mm.
- Zone IV – These mixtures have too much fines. They have also high potential for segregation in finishing and consolidation and have high permeability and exhibit shrinkage.
- Zone V – Mixtures which fall in this zone are non-plastic and very coarse.

2.3.3. Individual Percent Retained Chart

The current particle size distribution specification of ASTM C 33 specification, has deficiency and excess amount of some size aggregates. This could lead to gap graded and poor workability mixtures with problem of segregation. The individual percent retained chart or with another name of 18-8 band limits the minimum and maximum percent of aggregate proportions in a mixture to 8% and 18% respectively in each sieve so that uniform mixtures will be produced. (P.N Quiroga and D.W Fowler, 2004)

Individual percent retained chart is a graphical method used to evaluate the gradation distribution aggregate particles. It limits minimum 8% and maximum 18% retain on sieves between 25mm and 0.6mm and it is commonly known as 8.-18 chart. It is also called Haystack chart because the chart resembles a stack of hay. (Richardson, 2005) On the graph the amount of material is deficient or excessive in the mixture can easily be identified. Recent researches which were supported by field performance on the Individual Percent Retained Chart has paved the way to the foundation of the Tarantula Curve method of evaluation of gradation distribution.

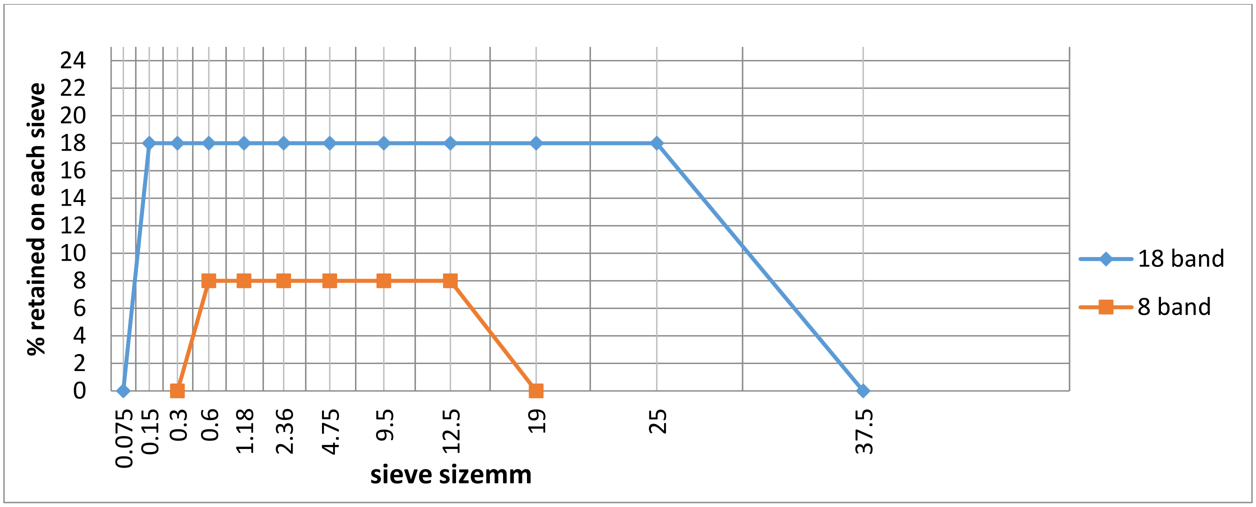


Figure 2. 3 "18-8" Chart

2.3.4. Tarantula Curve

Comparing the aggregate particle distribution and workability of five thousand different mixtures with different aggregates, a new limit on the individual percent retained chart was set. Since the limit set resembles a tarantula, the name tarantula curve was given to it. A new test was developed to evaluate the workability of low flowable mixtures. The test is inexpensive and quick, and it is called the Box Test. (Marlon D. Cook, Ashkan Ghaeezadeh, M. Tyler Ley and Bruce W. Russel, 2013)

The box test shows the response of fresh concrete mixture to vibration. It the test, a fresh concrete mixture is introduced to a wood from which is collapsible and vibrated. After vibration, the wood forms are removed from the side. After that voids made on the sides and edge slumping formed are inspected. Excessive voids on the side show that the vibration is not sufficient and the concrete did not consolidate. (Cook, M.D., A. Ghaeezadah, and Ley, M.T., 2014)

New sets of limits on the Individual Percent Retained Chart were developed based on the comparison made on the workability results obtained by the box test which is called tarantula curve. The tarantula curve provides recommendations for the amount of fine sand for workability which shall be 34% to 24% retained on sieve sizes 0.075mm to 0.6mm. It also provides recommendation of coarse sand needed for cohesion which shall be greater than 15% for the sum materials retained on sieve sizes 2.36mm, 1.18mm and 0.6mm.(Teyler Ley, Daniel Cook, 2014)

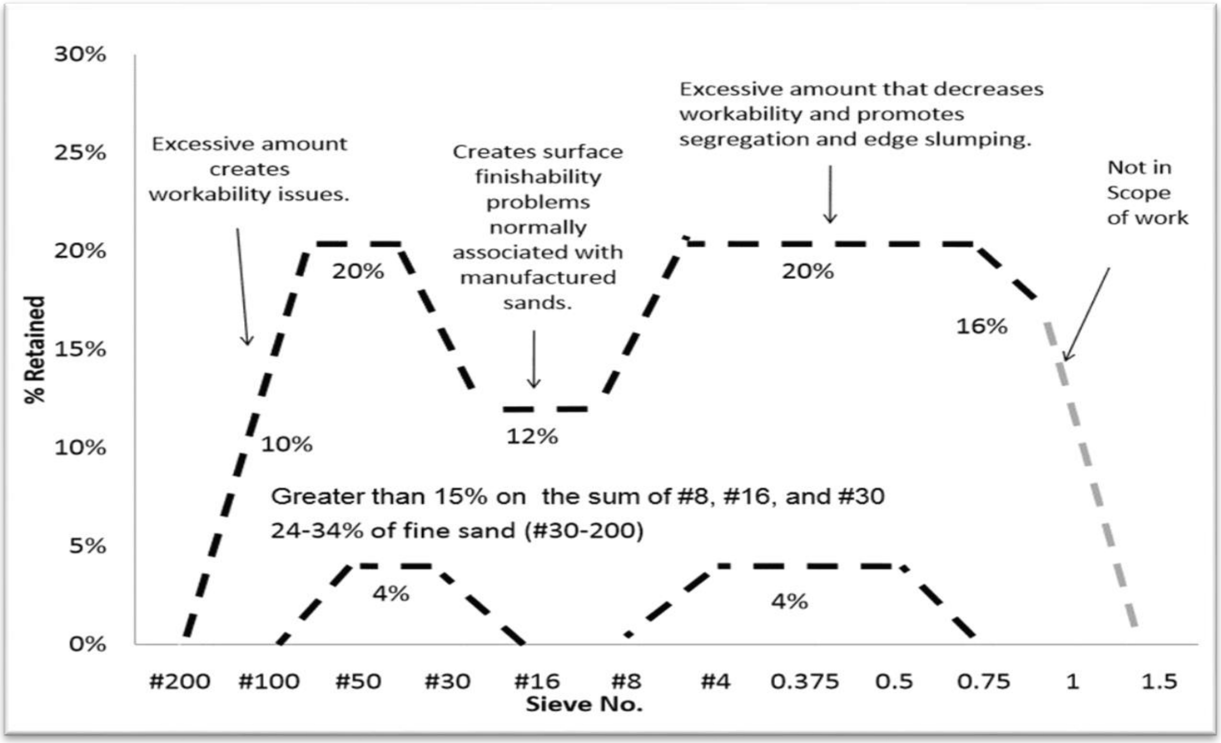


Figure 2. 4 Tarantula Curve, Source (Teyler Ley, Daniel Cook, 2014)

2.4. ACI Mixture Design Method

The ACI 211.1 (ACI Committee , 1991) is cement concrete mix design method which is base empirical formula. The amount of coarse and fine aggregates in a mix are indirectly determined by this method. In the ACI method of mix design the durability and strength are related to the minimum amount of cement needed and the required water cement ratio. With decreasing slump, decreasing aggregate angularity, air entrainment, use of water reducing admixtures and increasing nominal maximum size of aggregate, the quantity of water required decreases.

The volume of coarse aggregate is a function of the fineness modulus of the fine aggregate, the dry-rodded unit weight of the coarse aggregate, and the maximum aggregate size. The volume of fine aggregates depends on the amount of cement, water, coarse aggregate and air entrapment.

One of the drawbacks of the ACI method of mix design is that it over simplifies the proportioning of fine and coarse aggregates by using the fineness modulus of the fine aggregate as a critical factor. Sands with different gradation may have the same fineness modulus.

2.5. Concrete Mix Design Practice in Ethiopia

In Ethiopia, specification for gradation of course and fine aggregates to be used for structural purpose in road construction is set in ERA Standard Technical Specification 2013 Table 8402/02 and Table 8402/03, (see Tables 2.1 and 2.2 below) (ERA, 2013)

Table 8402/2: Grading of Fine Aggregate

Sieve size (mm)	Percentage of total mass passing sieve
10	100
4.76	95-100
2.38	68 - 86
1.19	47 - 65
0.59	27 - 42
0.30	9 - 20
0.15	0 - 7
0.075	0 - 2.5 (4.0)*

*Note: subject to approval by the Engineer.

Table 2. 1 Grading of Fine Aggregate, Source: ERA Standard Technical Specification Table 8402/02

Table 8402/3: Nominal Size and Grading of Coarse Aggregate

Nominal Size (mm)	Percentage of total mass passing sieve						
	Sieve size (mm)						
	31.25	25	19	12.5	10	4.75	0.075
25	90 - 100	-	0 – 20		0 - 2	-	0 - 0.5
20		100	80 – 100	-	10 - 40	0 - 4	0 - 0.5
10			100	90 - 100	40 - 70	0 - 15	0 - 0.5

Table 2. 2 Nominal Size and Grading of Coarse Aggregate, Source: ERA Standard Technical Specification 2013, Table 8402/03

In ERA Standard Technical Specification specific method of proportioning of the constituents of cement concrete for structures is not clearly specified. It is stated in ERA standard technical specification 2013, clause 8404(e) that “concrete mixes for structures shall be designed in accordance with an internationally approved method as approved by the Engineer”. In this regard, the current practice in Ethiopia for proportioning of constituents of cement concrete are made using the ACI 211.1 standard practice for selecting proportions for Normal, Heavy Weight, Mass, and Normal Concrete.

In ACI 211.1, for proportioning of the masses of coarse to fine aggregate, dry rodded unit weight of coarse aggregates and fineness modulus of the fine aggregates and nominal maximum aggregate size is used. In ACI 211.1 bulk volume of oven-dry-rodded coarse aggregate in meter cube is specified for different fineness modulus of fine aggregate ranging from 2.4 to 3.0. ASTM-M6 recommends fine aggregates to have fineness modulus ranging from 2.3 up to 3.1. Refer Table 2.3

TABLE A1.5.3.6 — VOLUME OF COARSE AGGREGATE PER UNIT OF VOLUME OF CONCRETE (SI)

Nominal maximum size of aggregate, mm	Volume of dry-rodded coarse aggregate* per unit volume of concrete for different fineness moduli† of fine aggregate			
	2.40	2.60	2.80	3.00
9.5	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
19	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
75	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

*Volumes are based on aggregates in dry-rodded condition as described in ASTM C 29.

These volumes are selected from empirical relationships toproduce concrete with a degree of workability suitable for usual reinforced construction. For less workable concrete such as required for concrete pavement construction they may be increased about 10 percent. For more workable concrete, such as may sometimes be required when placement is to be by pumping, they may be reduced up to 10 percent.

†See ASTM Method 136 for calculation of fineness modulus.

Table 2. 3 Volume of Coarse Aggregate Per Unit of Volume of concrete, Source: ACI 211.1

The gradation specified in ERA Standard Technical Specification, 2013 Table 8402/02 for fine aggregate has fineness modulus of 2.8 for the finer limit and 3.54 for the coarser limit. The average of the limit specified for the fine aggregate has fineness modulus of 3.17. This implies that the fine aggregates recommended in ERA Standard Technical specification are very coarse compared with the requirements set in ASTM M-6. Even the median of the ERA's specification for fine aggregate is above the limit specified in ASTM M-6. Problem arises very often when trying to proportion coarse to fine aggregate ratio using the mix design procedure specified in ACI 211.1, because in ACI 211.1, bulk volume of oven-dry –rodded coarse aggregate in meter cube is specified for fineness modulus of fine aggregate ranging from 2.4 to 3.0, while the Fineness modulus ranges from 2.8 to 3.54 for fine aggregate gradation specified in ERA standard technical specification. Here it is commonly practiced to extrapolate the results for fineness modulus's that are out of limit.

The fineness modulus concept was first in introduced by Duff Abrams in 1918 for proportioning of coarse and fine aggregates in concrete mix designs. The basis for the fineness modulus concept is that, for aggregates having the same fineness modulus the water demand to produce a mix with the same consistency and the same strength is equal." (Suprenant, 1994).

As stated in the above paragraphs, Fineness modulus is one factor used in proportioning of fine and coarse aggregates in ACI concrete mix design approach. To determine the Fineness Modulus of fine aggregate, the percent retained on specified sieve sizes is added and the sum is divided by 100. The specified sieve sizes are, 9.5mm, 4.75mm, 2.36mm, 1.18mm, 0.6mm, 0.3mm, and 1.5mm (Abrams, 1919). The problem in classifying fine aggregates using their fineness modulus is, the same values of fineness modulus may be attained from several different particle size distributions. In general, a small value of fineness modulus implies a finer sand. Fineness modulus cannot reflect the quality of the grading regions for fine aggregate. Fine aggregate with the same fineness modulus can have different particle size distribution (Zhang, 2011)

The fineness modulus is taken as a weighted average size of a sieve on which the sand is retained, the sieves being counted from the finest (0.150mm sieve).

As per Gambhir (2010), the objective of determining fineness modulus of fine aggregate is to categorize the given aggregates for most economical mix with minimum cement quantity for the required workability and strength. If the fineness modulus value is low it results in uneconomical mix with increased cement demand. If the fineness modulus is high, the mix will be harsh.

Particle size distribution specifications allow aggregates to have a un upper and lower limit of percent passing values on each sieve sizes. The allowable range of percent passing on each of the sieve sizes most often allows different aggregates at different sources to satisfy the specified requirements. The limitations set on the specifications on gradation will ensure that the concrete made with the aggregates satisfying the grading requirement will achieve the desired properties in fresh and hardened state.

However, sometimes natural sands/ fine aggregates falling within the specification limit in terms of grading are not readily available. At least in one or two sieve sizes, the grading is not satisfied. The same is true for coarse aggregates. This is a complex problem and the influences of using such aggregates on hardened and plastic properties of cement concrete might depend on type of mixture and the proportions of ingredients of the concrete mix.

CHAPTER 3: EXPERIMENTAL MATERIALS, TEST METHOD and PROGRAM

3.1. Materials and Mixture Properties

The experimental materials used in this study consist of Ordinary Portland Cement (Dangote), natural fine aggregate from Ataye river, and crushed course aggregate from Ataye - Mehal Meda road project quarry source found at km 46+600 LHS.

3.1.1. Cement

Dangote Ordinary Portland Cement (OPC) with 42.5 R Grade cement is used in all mixtures prepared in this research.

3.1.2. Coarse Aggregates

The Coarse aggregate was obtained from quarry site obtained at km 46+600 LHS of Ataye – Mehal Meda Road Project. Currently, the quarry source is being utilized for construction of major and minor structures in the project. The coarse aggregates were first washed so that the dust particles coated on them will be removed. The washed aggregates were then put in an oven which is kept at a constant temperature of 105 ^{0}C and dried. The quality properties of the coarse aggregate were then determined as per the ASTM and AASHTO standard test procedures.

The aggregate was fresh crushed basalt. The specific gravity and the water absorption of the course aggregate is found to be 2.808 and 1.65% respectively.

Results from the particle size distribution test of the coarse aggregate, is shown in Table 3.1. As this figure shows, the coarse aggregate was of nominal size 19 mm. The summary of the quality tests conducted on the coarse aggregate and the sieve analysis results are shown in Table 3.1 and 3.2 below.

Table 3. 4 Grading of Coarse Aggregate Used (km 46+600 LHS, Quarry Source, Ataye-Mehal Meda Road Project)

Sieve Size (mm)	25	19	10	4.75	0.075
% Pass	100	90.37	36.25	2.83	0.21
Specification Limit (%)	100	80-100	10-40	0-4	0-0.5

Table 3. 5 Quality Test Results of Coarse Aggregate

Station	**Material Description**	**LAA [%]**	**Soundness (NaSO4) [%]**	**Water Absorption [%]**	**Specific Gravity Bulk SSD**
46+600 LHS (Ataye-Mehalmeda	Sound basaltic rock	11.1	1.8	1.65	2.808
ERA's Specification		Max. 40	Max. 12	-	-

Once the quality of the coarse aggregate is checked against ERA's Standard Technical Specification requirements, the aggregates are separated into different fractions of sieve sizes. Then the aggregates were recombined with predetermined proportions so that the desired gradations could be obtained.

3.1.3. Fine Aggregates

The fine aggregates used in this study was natural sand obtained from Ataye River. The qualitative tests were made on the natural sand after washing it and removing the deleterious materials and drying it in oven.

The Bulk saturated surface dry (SSD) specific gravity and water absorption of the sand was found to be 2.58 and 2.51% respectively. The sieve analysis and quality tests performed on the sand is shown in Tables 3.3 and Table 3.4

Table 3. 6 Gradation of Ataye River Sand (Fine Aggregate)

Sieve Size (mm)	Percent Pass	
	Ataye River Sand	Specification
4.75	100	95-100
2.36	80.9	68-86
1.18	53.3	47-65
0.6	18.5	27-42
0.3	4.29	9-20
0.150	0.87	0-7
0.75	0.48	0-2.5

Table 3. 7 Quality Test Results of Fine Aggregate (Ataye River Sand)

	Soundness loss by Sodium Sulphate	Fineness Modulus (%)	Water Absorption (%)	Organic Impurity. Color Standard Plate NO.	Sand Equivalent (%)	Clay Lumps and Friable Particles (%)	Material finer than 0.075mm
Ataye River Sand	2.3	3.42	2.51	1	90	0.44	0.4
ERA's Specification	Max 10		-	<3	Min 75	Max 3%	Max 3%

Once the quality test results are compared against the ERA's Standard Technical Specification, the fine aggregates are separated into different fractions of sieve sizes. Then the aggregates were recombined with predetermined proportions so that the desired specific gradations could be obtained.

(a) Cement Source (Dangote OPC)

(b) Crushed Coarse Aggregate Source

(c) Fine Aggregate Source (Ataye River)

Figure 3. 1 Aggregates and Cement Sources

3.1.4. Mixture Properties

The concrete mixture proportions used in this research paper were made based on ERA specification for concrete for structures, with a target 28-day compressive strength of 30 MPa. The proportions used in this study are, 400 kg/m^3 ordinary Portland cement, and free water cement ratio of 0.48 for all the mixtures. No other chemical admixtures were used. No supplementary cementing materials were employed in this study. For proportioning of the masses of coarse to fine aggregate, dry rodded unit weight of coarse aggregates and fineness modulus of the fine aggregates is used as specified ACI cement concrete mix design manual (ACI 211.1). in ACI 211.1, bulk volume of oven-dry-rodded coarse aggregate in meter cube is specified for different fineness modulus of fine aggregate ranging from 2.4 to 3.0. In this study, for fineness modulus of fine aggregates which are out of the range, I.e., less than 2.4 and greater than 3.0, the bulk volume of oven-dry-rodded coarse aggregate is extrapolated.

3.2. Experimental Test Method

Different tests were conducted to determine the fresh and hardened properties of concrete. The tests conducted include Workability using slump test for determining fresh property of concrete, compressive strength, density and water absorption to determine hardened properties of concrete. The details of these test methods are presented below:

3.2.1. Workability

The workability of fresh concrete was determined using slump test based on ASTM C 143 Test Method.

3.2.2. Compressive strength

The compressive strength test was made on 150mm x 150 mm x 150mm Cubes of concrete. The test was conducted using the BS:1881 part 116 procedure. The effect of variation of fine and coarse aggregates on the rate on development of concrete strength was determined by conducting compressive strength test on the cubes of concrete which were cured for 7 days and 8 days. The concrete cubes are removed from their mold after 24 hours they are casted. After the cast cubes are removed from their mold, they are immediately put in water bath for curing until compressive strength test is conducted.

3.2.3. Water Absorption and Density

To determine the water absorption of concrete, concrete cubes with size of 150mm x 150mm x 150mm and which were cured for 28 days were used as per the test procedures specified in ASTM C 642. On the 28th day the cubes are taken out of bath and are put in an oven for 24 hours at a temperature of $105^0 + 2^0$ C. They were then taken out of oven, their masses were measured and are immersed in water. After 24 hours their masses were measured again. The percentage increase in the mass of the cubes after soaking in water for 24 hours is calculated and reported as the water absorption value of the concrete.

3.3. Experimental Program

To determine the effect of aggregate gradation on the selected properties of concrete, crushed course aggregate from km 46+300 LHS of Efeson (Ataye)-Mehal Meda Project (which is source for crushed aggregate for the project) and natural sand (fine aggregate) obtained from Ataye River were used.

The investigation involved Dangote OPC 42.5R grade Portland cement concrete produced by utilizing the natural sand and crushed coarse aggregates specified above.

To study the effect of variation of gradation of coarse aggregates on the properties of concrete, a standard gradation of fine aggregate was used in the mixtures i.e. middle of gradation specification fine aggregate. Likewise, to study the effect of variation of gradation of fine aggregate on the properties of concrete, a standard gradation of coarse aggregate gradation (middle of gradation for coarse aggregate of Table 8402/03 of ERA Standard Technical Specification) was used. During preparation of the mixtures, the total water and cement content in all the mixtures were held constant and, only either coarse or fine aggregate gradation was varied. ACI 211.1 concrete mix design was followed in proportioning the coarse to fine aggregate ratio.

To determine the influence of variations in aggregate gradation on specific properties of concrete, 20 different concrete mixtures were produced. Among these, 10 mixtures were used to determine the effect of variation of fine aggregate Gradation within and out of specification on selected properties of concrete by fixing the grading of coarse aggregate in the middle of ERA standard Technical specification 2013, Table 8402/03. The gradation of the fine aggregates was varied by varying the fineness modules (FM) from 1.8 to 3.94, i.e., 1.8, 2.0, 2.2, 2.4, 2.6, 2.8, 3.17, 3.54, 3.74, 3.94, of which fineness modules of 2.8, 3.17 and 3.54 represent the finer , middle and coarser margins of the specification (Table 8402/02 of ERA stand Technical specification 2013) for grading of fine aggregate which are used as control mixes. The fineness modules varying from 1.8 to 3.94 were selected because most of the natural sands found in the county fall within this range.

To determine the effect of variation of coarse aggregate gradation on selected properties of concrete, the coarse aggregate gradations are varied from 10% more coarser to 10% more finer by fixing the fine aggregate gradation in the middle of ERA Standard Technical Specification Table 8402/02, grading for fine aggregates, which has fineness modulus of 3.17. seven (7) different mixtures were used here, I.e., 10% more coarser, 5% more coarser, coarser margin of the specification, middle of specification, finer margin of the specification, 5% more finer, and 10% more finer of coarse aggregate grading by fixing the grading of fine aggregate to the middle of specification (FM=3.17). Due to time and cost limitations, in this study, only up to 10% either beyond the finer or the coarser limit of the specification is investigated.

A total of nine mixtures were prepared to determine the effects of aggregate gradations with in the specification limit, and eleven mixtures were prepared to determine the effects of aggregate gradation out of the specification limit.

Beside the aforementioned mixtures, addition 4 mixtures were prepared to determine the effects of aggregate gradation within the specification limit using lower or upper limits fine aggregates with lower or upper limits of course aggregates which barely satisfy the grading requirements set i.e., coarser limit course aggregate with coarser limit fine aggregate, coarser limit coarse aggregate with finer limit fine aggregate, finer limit coarse aggregate with coarser limit fine aggregate, and finer limit course aggregate with finer limit fine aggregate. Beside the four mixtures, among the ten mixtures prepared to determine the effects of the variation of fine aggregate gradation, the ones with FM of 2.8, 3.17 and 3.54, which are the finer limit, middle of limit, and coarser limit of fine aggregate specification are also used to determine the effects of aggregate gradation variation within the specification limit. Among the seven mixtures prepared to determine the effect of coarse aggregate gradation, coarser limit gradation and finer limit gradation of coarse aggregate with the fine aggregate gradation kept on the middle of the specification are once again used to determine the effects of aggregate gradation on selected properties of concrete within the specification limit.

In this paper the words “coarser” and “finer” are used to represent the upper and the lower limits of the grading envelope set in ERA Standard Technical Specification for either coarse or fine aggregate.

For each property of concrete to be investigated three samples were prepared their mean is taken for analysis purpose

The specific tests performed with aggregates and concrete mixtures are shown in Tables 3.5. The laboratory Test Results are attached in Appendix B

Table 3. 8 Type of Tests Conducted

S.No.	**Type of Tests**	**Standards**
1.	Workability	ASTM C143
2.	Density (dry-rodded unit weight) of coarse aggregate	ASTM C 29
3.	Compressive Strength	BS 1881 part 116
4.	Water Absorption and Density of Hardened concrete	ASTM C 642
5.	Water absorption of fine and coarse aggregate	ASTM C 127 and ASTM C 128
6.	Specific Gravity of fine and coarse aggregate	ASTM C 127 and ASTM C 128

3.3.1. Selection of Fine Aggregate gradations

3.3.1.1 Control Gradation for Sand (Fine Aggregate)

The gradations of fine aggregate were selected by considering the ERA Standard Technical Specification 2013, standard fine aggregate gradation specification provided in Table 8402/02. This specification includes standard fine aggregate gradation, with upper and lower limits specified for specific sieve sizes. From ERA standard technical specification, Table 8402/02, the upper limit, the median of the limit and the lower limit were taken as a control gradations. In this way three control gradations are selected for the fine aggregate. A graphical sketch of the upper limit, average (median of the limit) and lower limit values of the fine aggregate gradation with fineness modulus of 2.8, 3.17 and 3.54 respectively is shown in Figure 3.2, refer Table 2.1 for the values of upper and lower limits of fine aggregate gradation.

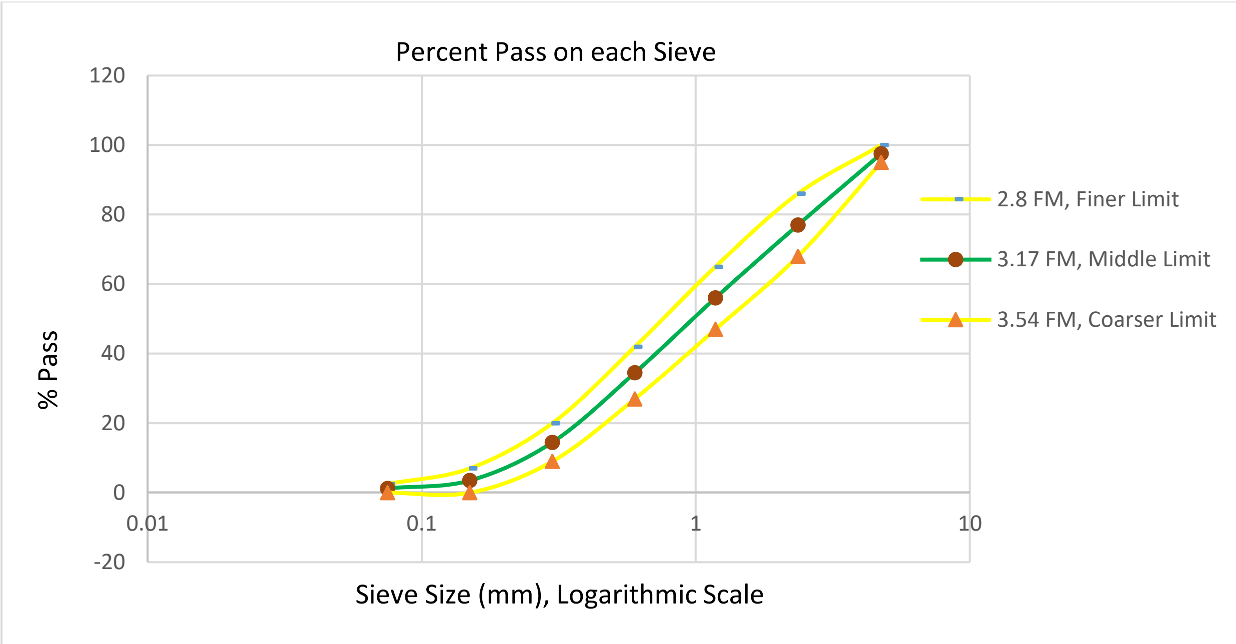


Figure 3. 2 Control Gradations for fine Aggregate

3.3.1.2 Failed Gradation for Fine Aggregate

The failed gradations for fine aggregate are obtained by continuously increasing the percent pass on each sieve beyond the upper limit of the specifications until Fineness modulus of 2.6, 2.4, 2.2, 2.0 and 1.8 are obtained. The percent pass on each sieve beyond the lower limit is also continuously decreased until Fineness modulus of 3.74 and 3.94 are obtained. Here smooth curves are maintained while increasing or decreasing the percent passes beyond the upper and lower limits so that the percent pass curves of each failed gradation do not cross each other. Since Fine aggregates with different gradations may have the same FM value, every effort is made to make the failed gradations well graded as much as possible not to cross each other. The following Table 3.6 and figure 3.3 show the percent pass for each failed gradation.

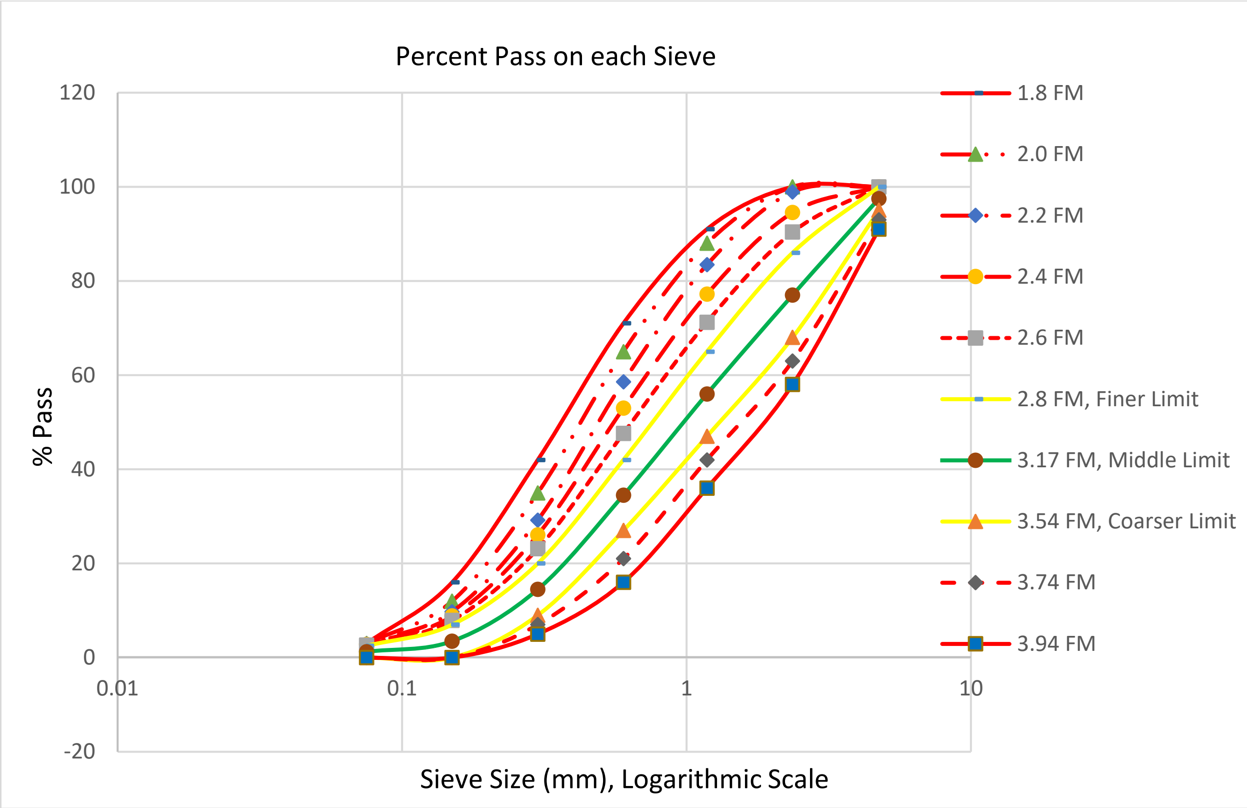


Figure 3. 3 Gradations of Failed and Control Fine Aggregates

Table 3. 9 Gradations of Failed and Control Fine Aggregates

Sieve Size (mm)	Percent Pass									
9.5	100	100	100.0	100.0	100.0	100	100	100	100	100
4.75	100	100	100.0	100.0	100.0	100	97.5	95	93	91
2.36	100	100	98.9	94.5	90.4	86	77	68	63	58
1.18	91	88	83.4	77.2	71.3	65	56	47	42	36
0.6	71	65	58.6	53.0	47.6	42	34.5	27	21	16
0.3	42	35	29.2	26.1	23.1	20	14.5	9	7	5
0.15	16	12	9.8	8.8	7.9	7	3.5	0	0	0
0.075	3	3	3.0	2.8	2.7	2.5	1.25	0	0	0
Fineness Modulus	1.8	2	2.2	2.4	2.6	2.8	3.17	3.54	3.74	3.94

Once the gradations of the fine sand within and out of specification are specified, the proportions of coarse to fine aggregate are set depending on the fineness modulus of the fine aggregates and dry rodded unit weight of middle of coarse aggregate gradation as per ACI 211.1 mix proportion guide. The combined gradation of coarse and fine aggregates on percent retained basis is shown in figure 3.4 and Table 3.7 below.

Table 3. 10 Combined Gradation with Varying FM Value

Sieve Size (mm)	**% Retained for Combined Grading Fixing the Coarse Aggregate Gradation in the Middle of the Limit and Varying the FM Values of Fine Aggregate**									
	1.8 FM	**2.0 FM**	**2.2 FM**	**2.4 FM**	**2.6 FM**	**2.8 FM**	**3.17 FM**	**3.54 FM**	**3.74 FM**	**3.94 FM**
37.5	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0
19	6.5	6.3	6.2	6.0	5.8	5.7	5.3	5.0	4.8	4.6
12.5	27.7	27.0	26.2	25.5	24.8	24.0	22.6	21.2	20.5	19.7
9.5	14.7	14.3	13.9	13.5	13.1	12.7	12.0	11.2	10.8	10.4
4.75	15.0	14.6	14.2	13.8	13.4	13.0	13.4	14.0	14.7	15.5
2.36	1.4	2.3	3.2	4.1	4.7	6.2	9.8	13.8	15.8	18.0
1.18	1.8	2.6	3.5	5.3	7.6	9.3	10.0	10.7	11.1	12.0
0.6	6.5	7.5	8.7	9.0	9.7	10.2	10.3	10.2	11.1	10.9
0.3	10.4	10.9	11.0	11.1	10.9	9.8	9.5	9.2	7.4	6.0
0.15	10.1	9.0	8.7	7.4	6.5	5.8	5.2	4.6	3.7	2.7
0.075	4.7	4.1	3.2	2.9	2.3	2.0	1.1	0.0	0.0	0.0
0.075 Pass	1.2	1.3	1.3	1.3	1.3	1.2	0.7	0.1	0.1	0.1

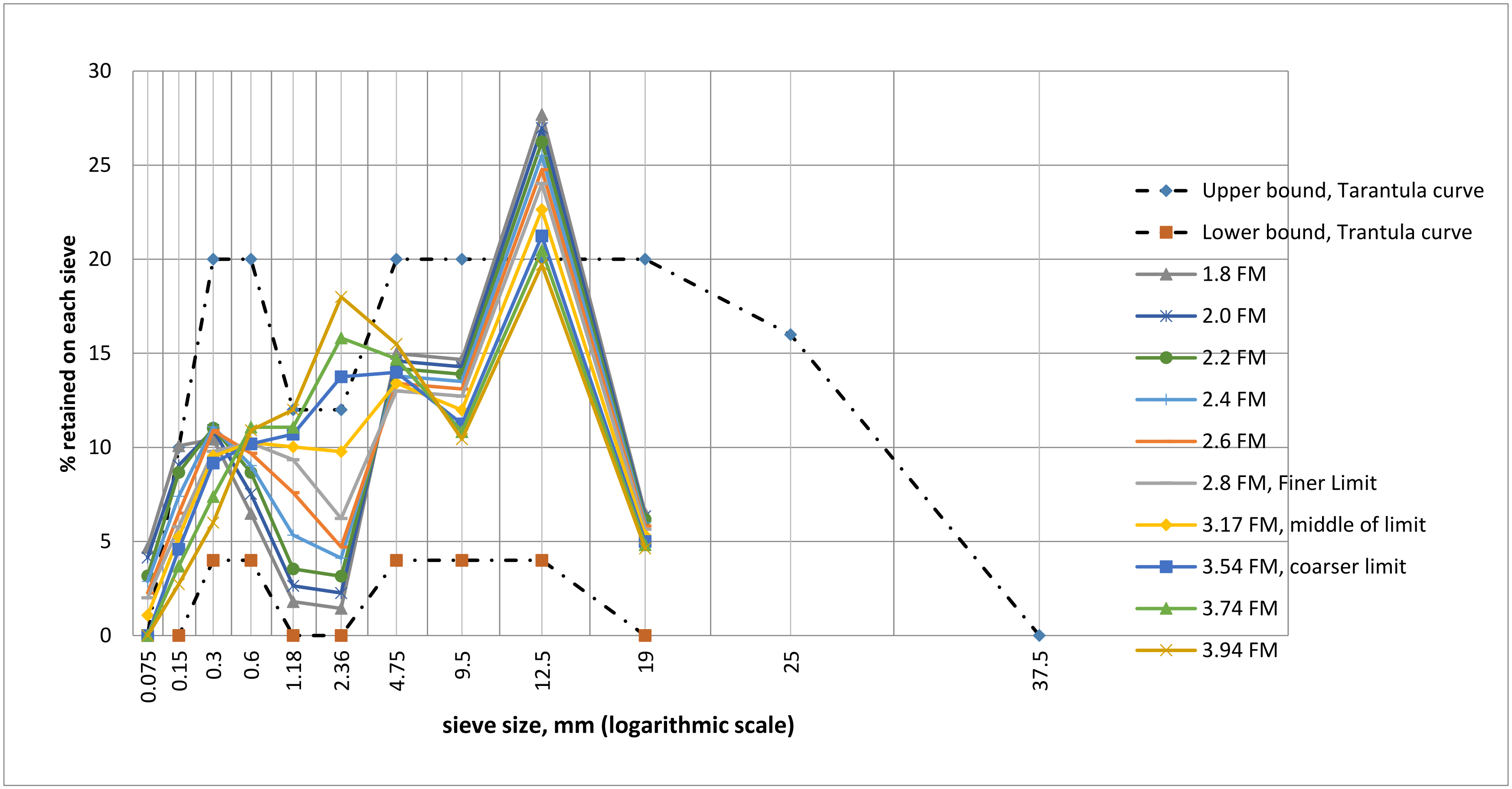


Figure 3. 4 Combined % Retained Gradation with Varying FM Values

3.3.2. Selection of Coarse Aggregate Gradations

3.3.2.1 Control Gradation for Coarse Aggregates

The gradation of coarse aggregate was selected by considering the ERA Standard Technical Specification 2013, standard coarse aggregate gradation for nominal size of 19 mm, as shown in Table 2.2. In this study, beside the sieve sizes specified for 19 mm nominal size, i.e 19 mm, 10 mm, and 4.75 mm one additional sieve size (12.5 mm) is considered in proportioning coarse aggregates. The upper and lower limits for 12.5 mm sieve size are taken from the upper and lower point from a semi-logarithmic curve drawn using the already specified sieve sizes at 12.5 mm (refer figure 3.5). Three control gradations for the coarse aggregate are selected which are the upper limit, average of the limit and lower limit of the gradation specified in Table 8402/03 of the standard technical specification for nominal size of 19mm. the graphical sketch shown in Figure 3.5 is the lower limit, average and upper limit values of the gradation for course aggregate.

Figure 3. 5 Control Gradations of Coarse Aggregate

3.3.2.2 Failed Gradation of Coarse Aggregate

The failed gradations for coarse aggregate are obtained by continuously increasing or decreasing the percent pass on each sieve beyond the upper and lower limit of the specifications by 5% and 10%. Here smooth curves are maintained while increasing or decreasing the percent passes beyond the upper and lower limits so that the percent pass curves of each failed gradation do not cross one other. Every effort is made to make the failed gradations well graded as much as possible. The following Table 3.8 and figure 3.6 show the percent pass for each failed gradations of coarse aggregate.

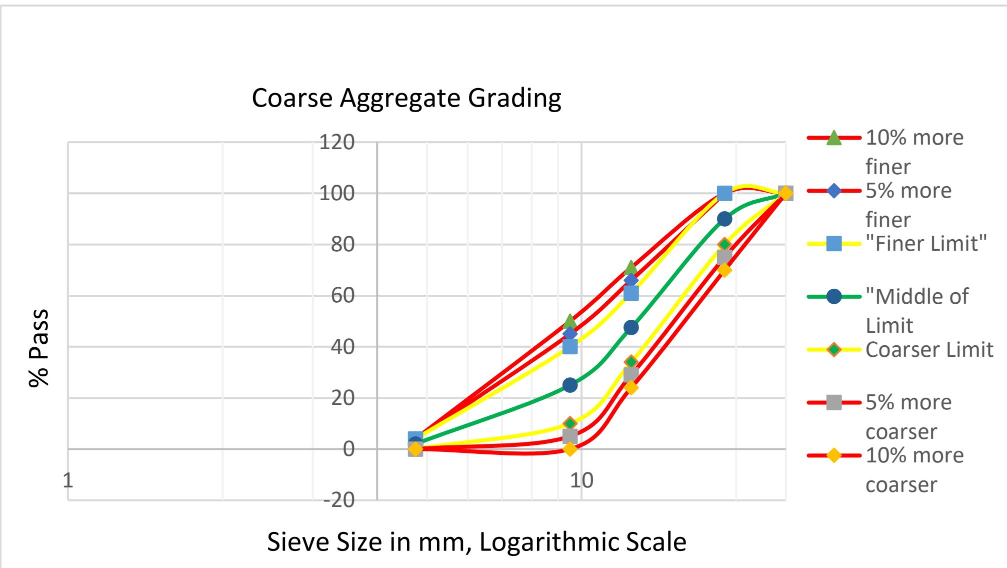


Figure 3. 6 Failed and Control Gradation of Coarse Aggregates

Table 3. 11 Failed and Control Gradation of Coarse Aggregates

Sieve Size (mm)	Percent Pass						
	10% more finer	5% more finer	finer limit	middle of limit	coarser limit	5% more coarser	10% more coarser
25	100	100	100	100	100	100	100
19	100	100	100	90	80	75	70
12.5	71	66	61	47.5	34	29	24
9.5	50	45	40	25	10	5	0
4.75	4	4	4	2	0	0	0
0.075	0.5	0.5	0.5	0.25	0	0	0

Once the gradations of the coarse aggregate within and out of specification are specified, the proportions of coarse to fine aggregate are set depending on the dry-rodded unit weight of different coarse aggregates and fixing the FM value at the middle of ERA Standard Specification for fine aggregate (FM=3.17) as per ACI 211.1 mix proportion guide. The combined gradation of coarse and fine aggregates on percent retained basis is shown in figure 3.7 and Table 3.9 below.

Table 3. 12 Combined Gradation with Varying Coarse Aggregate Gradation

Sieve Size (mm)	% Retained for Combined Grading Fixing the fine Aggregate Gradation in the Middle of the Limit and Varying the Coarse aggregate Gradations						
	10% more Finer	5% more Finer	Finer Limit	Middle of limit	Coarser limit	5% more coarser	10% more coarser
37.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	5.3	10.5	13.1	15.7
12.5	14.6	17.8	21.0	22.6	24.1	24.6	25.1
9.5	11.3	11.3	11.3	12.0	12.5	12.0	11.5
4.75	27.0	23.8	20.6	13.4	6.4	3.8	1.2
2.36	9.9	9.9	9.9	9.8	9.8	9.8	9.8
1.18	10.1	10.1	10.1	10.0	10.0	10.0	10.0
0.6	10.3	10.3	10.3	10.3	10.3	10.3	10.3
0.3	9.6	9.6	9.6	9.5	9.5	9.5	9.5
0.15	5.3	5.3	5.3	5.2	5.2	5.2	5.2
0.075	1.1	1.1	1.1	1.1	1.1	1.1	1.1
0.075 Pass	0.8	0.8	0.8	0.7	0.6	0.6	0.6

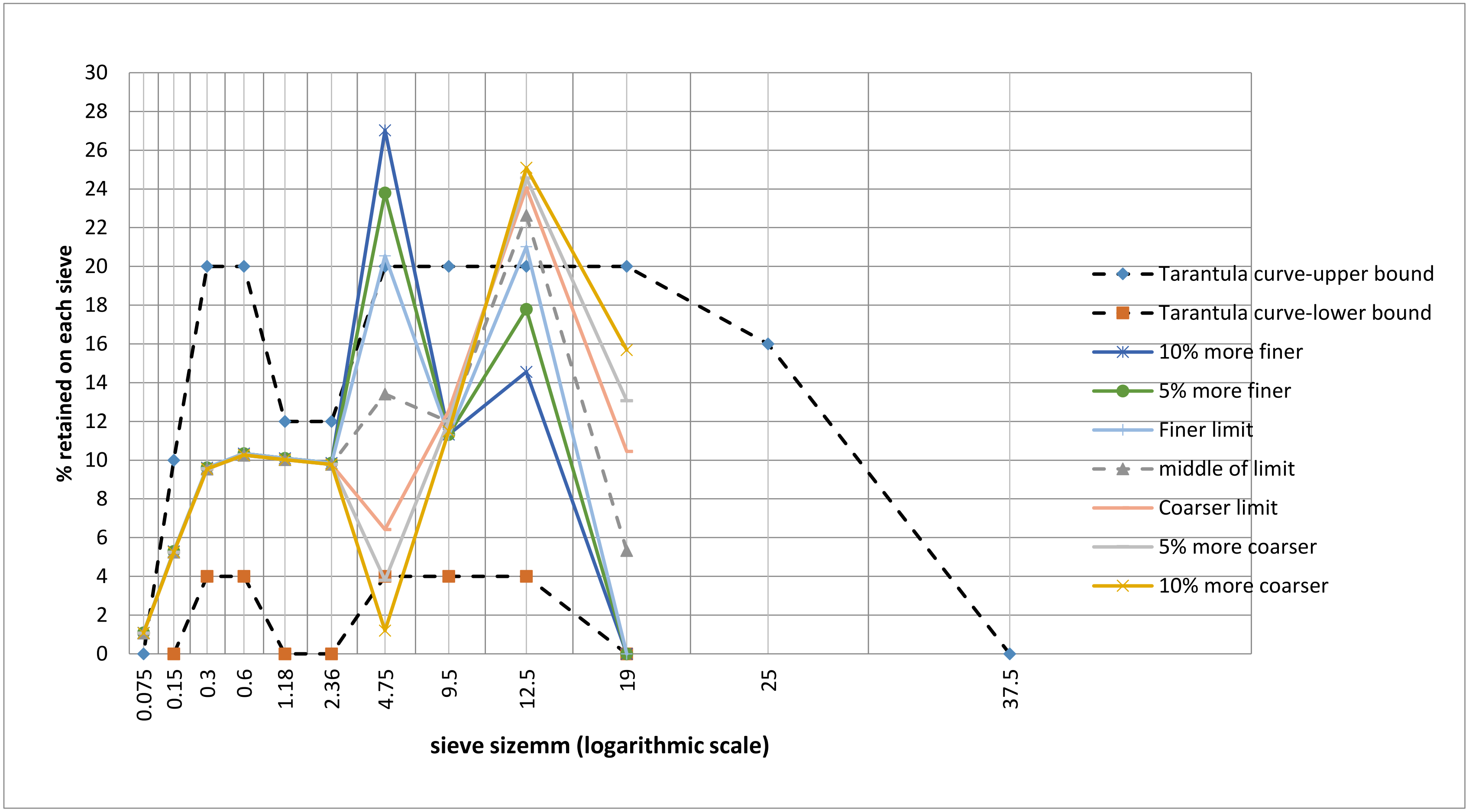


Figure 3. 7 Combined % Retained Gradation with Varying Coarse Aggregate Gradation

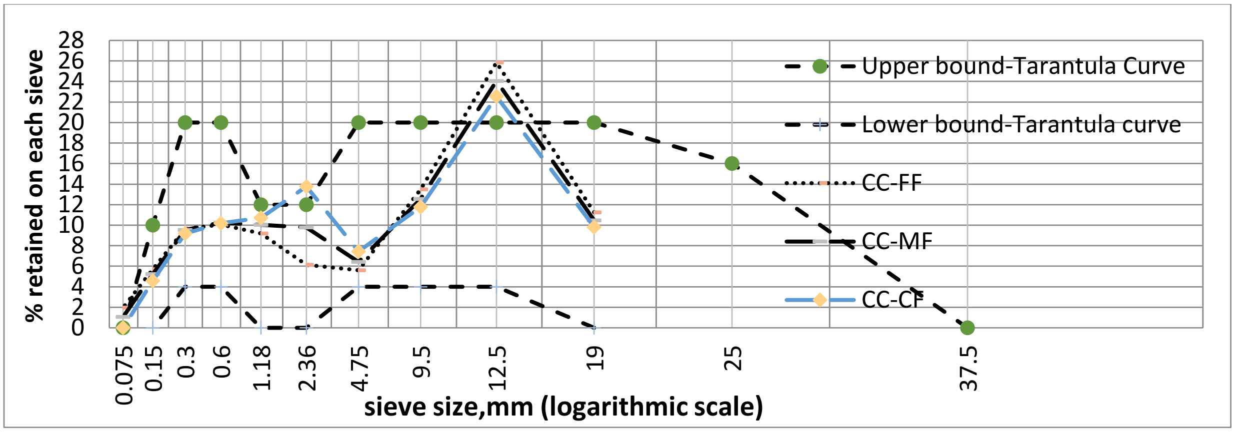
3.3.3. Mix Proportioning for Fine and Coarse Aggregates Within the Specification Limits

To study the effects of variation of gradation within the specification limit of the coarse and fine aggregates, 9 different mixtures are prepared. Three control gradations (finer limit, middle of limit, and coarser limit) of each of the coarse and fine aggregates specification are combined to give 9 different mixtures for analysis of the effect of variation of gradation within the specification limit. The nine(9) combinations are listed below:

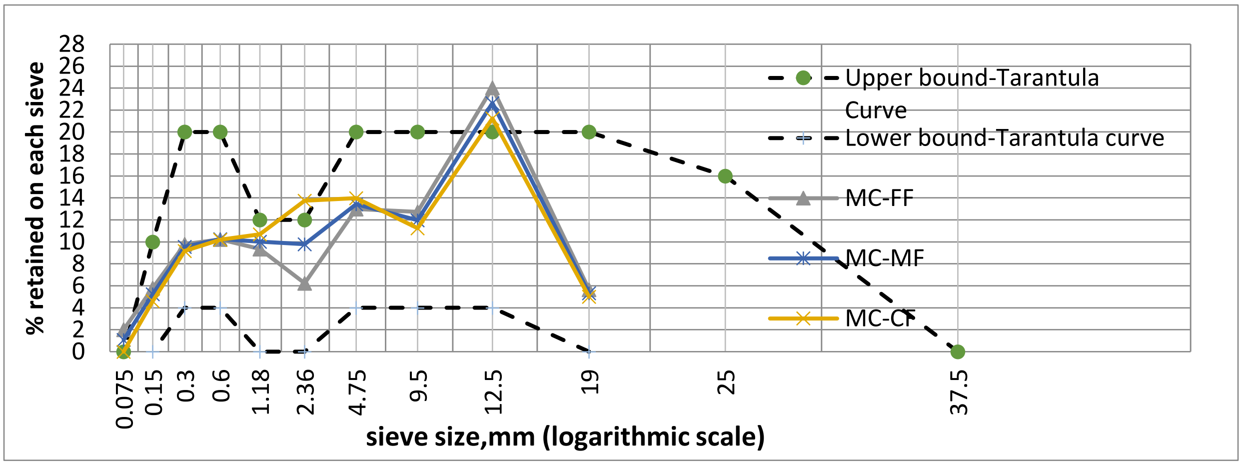
- Coarser limit of coarse aggregate combined with Finer limit of fine aggregate (CC-FF)
- Coarser limit of coarse aggregate combined with middle of limit of fine aggregate (CC-MF)
- Coarser limit of coarse aggregate combined with coarser limit of fine aggregate (CC-CF)
- Middle of limit of coarse aggregate combined with finer limit of fine aggregate (MC-FF)
- Middle of limit of coarse aggregate combined with middle of limit of fine aggregate (MC-MF)
- Middle of limit of coarse aggregate combined with coarser limit of fine aggregate (MC-CF)
- Finer limit coarse aggregate combined with finer limit of fine aggregate (FC-FF)
- Finer limit of coarse aggregate combined with middle of limit of fine aggregate (FC-MF) and
- Finer limit of coarse aggregate combined with coarser limit of fine aggregate (FC-CF)

The grading limits could be referred from Table 2.1 and Table 2.2.

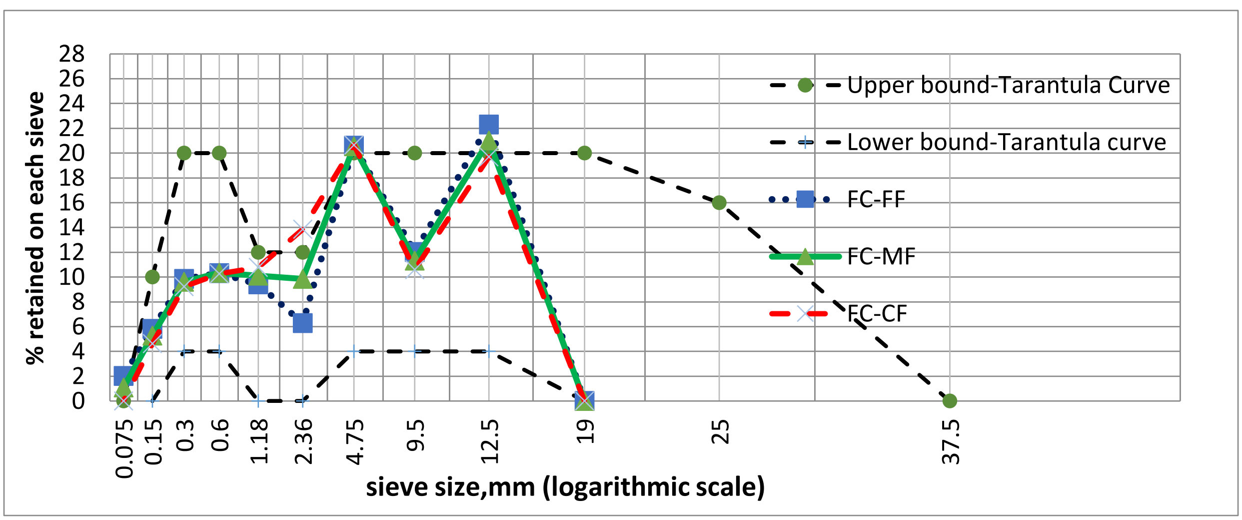
It should be noted that the mixtures prepared as control gradings for fine aggregate are also included here to determine the effect of aggregate gradation within the specification limit. These mixtures are MC-FF, MC-MF and MC-CF which are represented in section 3.3.1.1 as 2.8 FM (finer limit), 3.17 FM (middle of limit) and 3.54 FM (coarser limit) respectively. The mixtures prepared as control gradings for coarse aggregates are also included here to determine the effect of aggregate gradation on selected properties of concrete within the specification limit. These mixtures are FC-MF, MC-MF, and CC-MF which are represented in section 3.3.2.1 as Finer limit, Middle of limit and coarser limit. Here it is worth mentioning that 3.17 FM and Middle of Limit proportions in section 3.3.1.1 and 3.3.2.1 represent the same mixture, that is middle of limit of coarse aggregate gradation combined with middle of limit of fine aggregate gradation (MC-MF). The combined gradation for mixtures prepared within the specification limit in percent retained basis is shown in Figure 3.8 and Table 3.10 below.



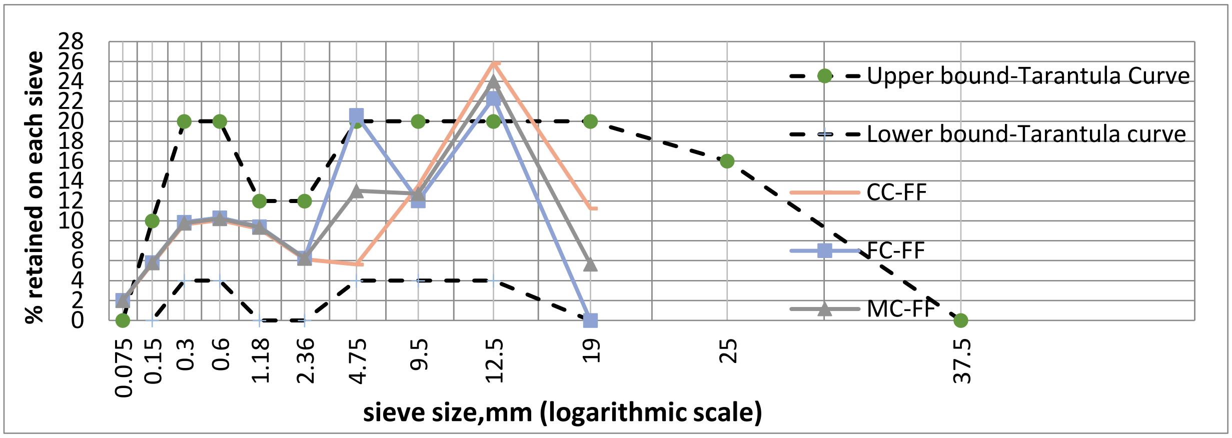
(a) Coarser Coarse Aggregate with Varying Fine Aggregate Gradation



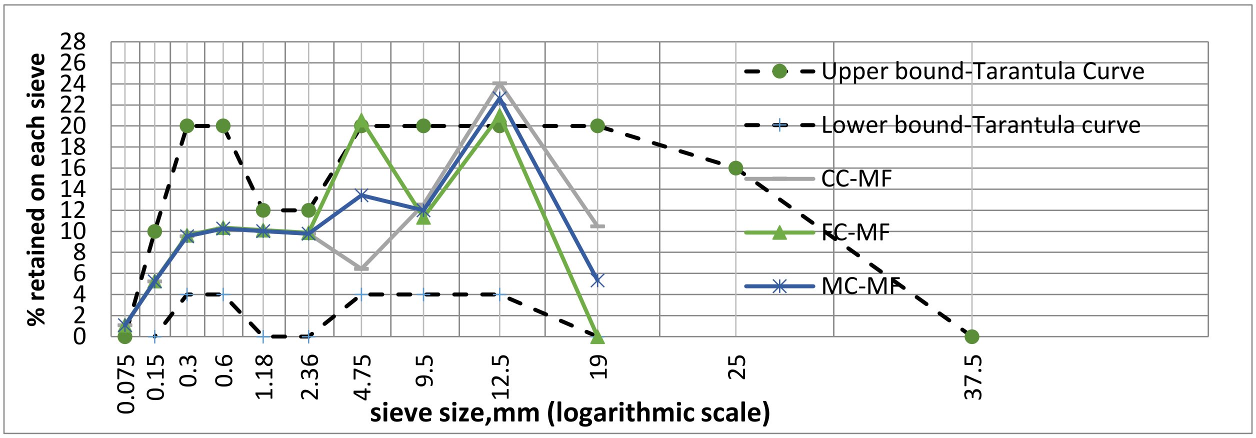
(b) Middle of Coarse Aggregate with Varying Fine Aggregate



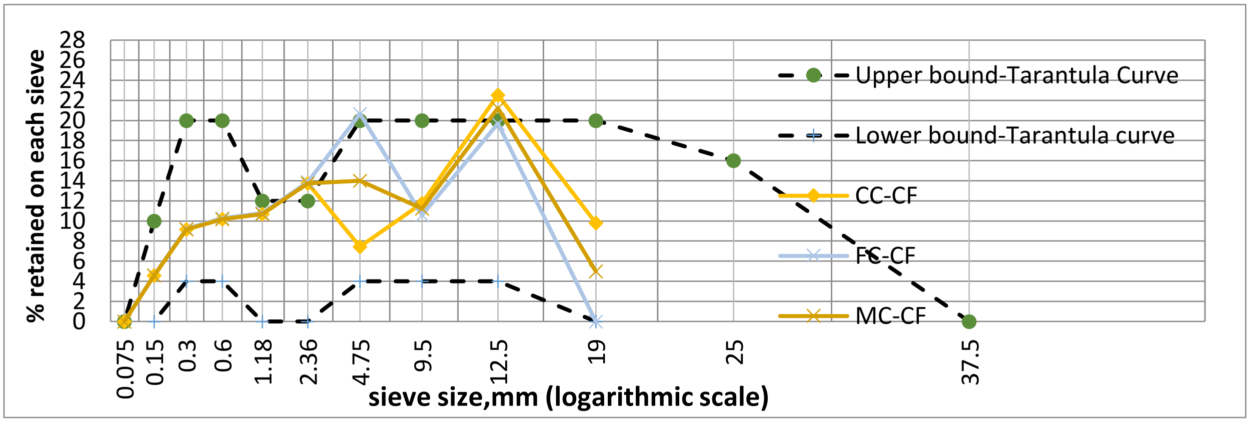
(c) Finer Coarse Aggregate with Varying Fine Aggregate



(d) Finer Fine Aggregate with Varying Coarse Aggregate



(e) Middle of Fine Aggregate with Varying Coarse Aggregate



(f) Coarser Fine Aggregate with Varying coarse Aggregate

Figure 3. 8 Combined Percent Retained Gradation for Fine and Coarse Aggregates within the Specification

Table 3. 13 Combined Grading in Percent Retained for Mixtures within the Specification Limit

Sieve Size (mm)	% Retained for Combined Grading for Different Mixtures within the Specification Limit								
	CC-FF	CC-MF	CC-CF	MC-FF	MC-MF	MC-CF	FC-FF	FC-MF	FC-CF
37.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	11.2	10.5	9.8	5.7	5.3	5.0	0.0	0.0	0.0
12.5	25.8	24.1	22.6	24.0	22.6	21.2	22.3	21.0	19.7
9.5	13.5	12.5	11.8	12.7	12.0	11.2	12.0	11.3	10.6
4.75	5.6	6.4	7.5	13.0	13.4	14.0	20.6	20.6	20.7
2.36	6.1	9.8	13.8	6.2	9.8	13.8	6.3	9.9	13.9
1.18	9.2	10.0	10.7	9.3	10.0	10.7	9.4	10.1	10.8
0.6	10.1	10.3	10.2	10.2	10.3	10.2	10.3	10.3	10.3
0.3	9.6	9.5	9.2	9.8	9.5	9.2	9.9	9.6	9.2
0.15	5.7	5.2	4.6	5.8	5.2	4.6	5.8	5.3	4.6
0.075	2.0	1.1	0.0	2.0	1.1	0.0	2.0	1.1	0.0
0.075 Pass	1.1	0.6	0.0	1.2	0.7	0.1	1.4	0.8	0.3

3.4. Statistical Analysis of Results Using ANOVA

Succeeding the laboratory procedures and data collection, statistical analysis was performed to evaluate the significance of variation of fine and coarse aggregate gradation within and out of specification on workability, compressive strength and water absorption using one-way analysis of variance (ANOVA)

A one-way ANOVA uses two different estimates of sample variance. The first estimate is called the between-group variance, and it involves finding the variance of the means. The second estimate, the within-group variance, is made by computing the variance using all the data and is not affected by differences in the means.

The twenty different mixture proportions were considered. On this research the ANOVA consists of three random samples from each of the independent groups. The null hypothesis (Ho) is that there is no variation in the mean of either the compressive strength, slump or water absorption of different mix proportions. Therefore the null hypothesis is Ho: $\mu 1 = \mu 2 = \mu 3 = \mu 4$ ….

Whereas the alternative hypothesis H1: at least the mean of one group of mixture proportion is different from the rest. The analysis testing of the hypothesis is done at 0.05 level of significance for all the different properties of concrete studied in this research. Every result analysis and discussion made in sections 4.1 to section 4.3 are based on the outputs of ANOVA. The test statistics for one-way ANOVA is the F ratio i.e. the ratio between group variance and the within group variance. The details of ANOVA hypothesis testing are presented in Appendix A of this research Paper.

For results of ANOVA with null hypothesis rejected, to check which samples had different means t-Test was conducted on different combination. Ninety five percent confidence level (alpha value of 0.05) is used in conducting the t-Test.

CHAPTER 4: RESULTS AND DISCUSSION

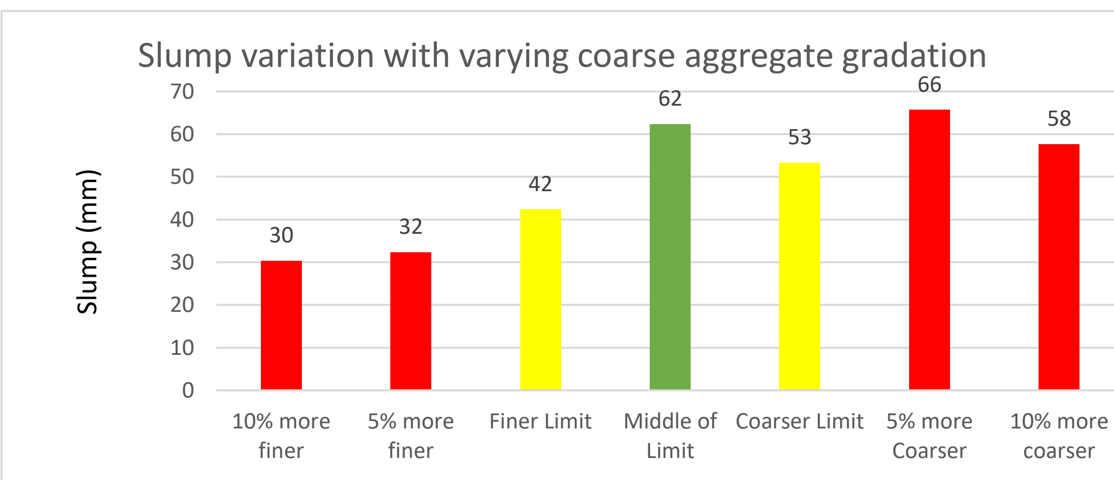
4.1. Effect of Failed Coarse Aggregate Gradation on Slump, Compressive Strength, Water Absorption and Bulk Density of Concrete

To determine the influence variation in gradation of coarse aggregate, the gradation of the coarse aggregate was varied while keeping the gradation of the fine aggregate constant for all the mixtures. The middle of fine aggregate gradation of table 8402/02 of ERA standard technical specification, which has fineness modulus of 3.17, was used in all the mixtures. Since the quantity of all the water content and water-cement and gradation fine aggregate were not variable, the only content varying in the mixture is the gradation of the coarse aggregate. This way, the effect of varying the gradation of coarse aggregate on specific properties of concrete was determined.

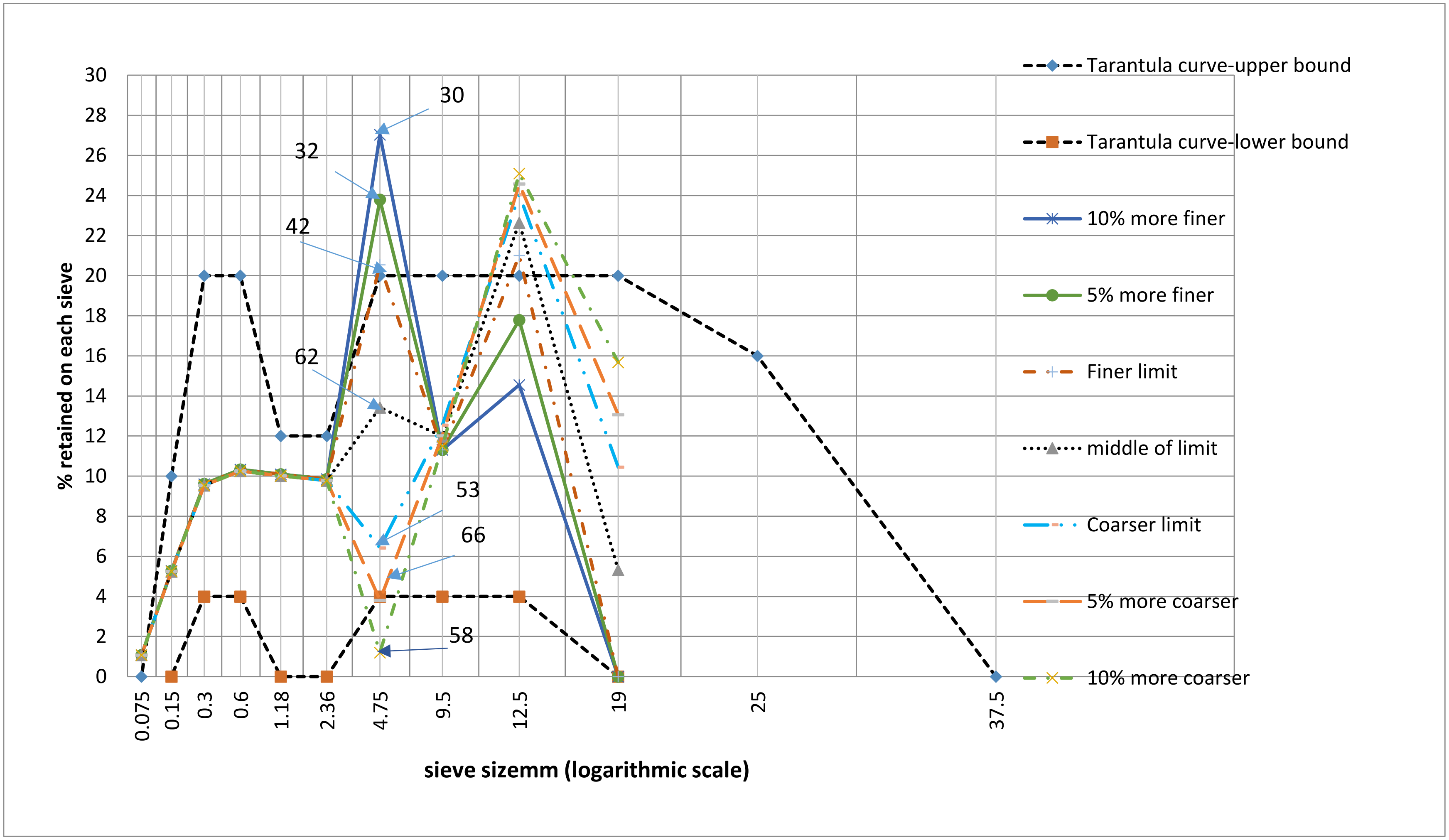
As it is observed from figure 3.7, the variation in coarse aggregate gradations have a pronounced effect on the percent of mass retained on sieve sizes 4.75 mm, 12.5 mm and 19 mm. as the coarseness of the coarse aggregate increases, the percent retained on sieve size 4.75 decreases while the percent retained on sieve size 12.5 and 19 mm increases progressively.

4.1.1. Slump

In figure 4.1 (a) and (b) below, the effect of course aggregate gradation on the slump of concrete is shown. The slump values obtained for all the mixtures are within ERA's specification requirement, which ranges from 25mm to 75mm



(a)



(b)

Figure 4. 1 Effect of Variation of Coarse Aggregate Gradation on Workability of Concrete

The slumps of the control groups, i.e. finer limit, middle of limit and coarser limit, were found to be 42 mm, 62 mm and 53 mm respectively which show high variation. This indicates that major variation in the slump values is resulted when the gradation of the coarse aggregate is varied within the upper and lower margins of the specification limits. The variation in slump between the control mixtures was found to have P value of 4.36E-06 which shows that the variation in slump is highly significant to 95% Confidence level. (Refer Appendix A).

The slumps of more finer courser aggregates, i.e. 5% more finer and 10% more finer were found to be much lower than the control concretes slump. The slumps of coarser aggregates out of specification, i.e. 5% more coarser and 10% more coarser, are found to be more or less similar with their control concrete. There is a general trend of increasing in slump by varying coarse aggregate gradation from 10% more finer up to middle of limit of specification. By varying the gradation of coarse aggregate from middle of limit up to 10% more coarser, no specific trend is observed. As shown in figure 4.1 (a) above, as the percent retained on 4.75mm is decreased and the percent retained on sieve sizes 12.5 and 19mm is increased, the workability shows a general trend of increase. The more finer the coarse aggregate gets, the lower the slump value it has. This may be due to higher surface area to volume ratio of finer coarse aggregates that increase the absorbed water and consequently reduce the free water compared to coarser coarse aggregates.

In general, the slumps obtained using finer coarse aggregate gradation i.e. 10% more finer, 5% more finer and finer limit, with 0% retained on sieve size 19mm are lower compared with slumps obtained using middle of limit, coarser limit, 5% more coarser and 10% more coarser coarse aggregates.

The single ANOVA test conducted on the 7 groups show that F-statistic calculated is more than F-critical for 95% significance level (alpha level of 0.05) and can be conclude that at least one of the seven samples have significantly different means and belongs to different population. To check which samples had different means, t-Test was conducted on different combination, and the results show that only 5% more coarse with 10% more coarser, 5% more finer with 10% more finer and middle of limit with 5% more coarser had p values greater than 0.05 (95% significance level) and showed no significant variation.

4.1.2. Compressive Strength

In Figure 4.2 (a) and (b) below, is shown the effects variations in gradation of coarse aggregate on the rate of development of compressive strength.

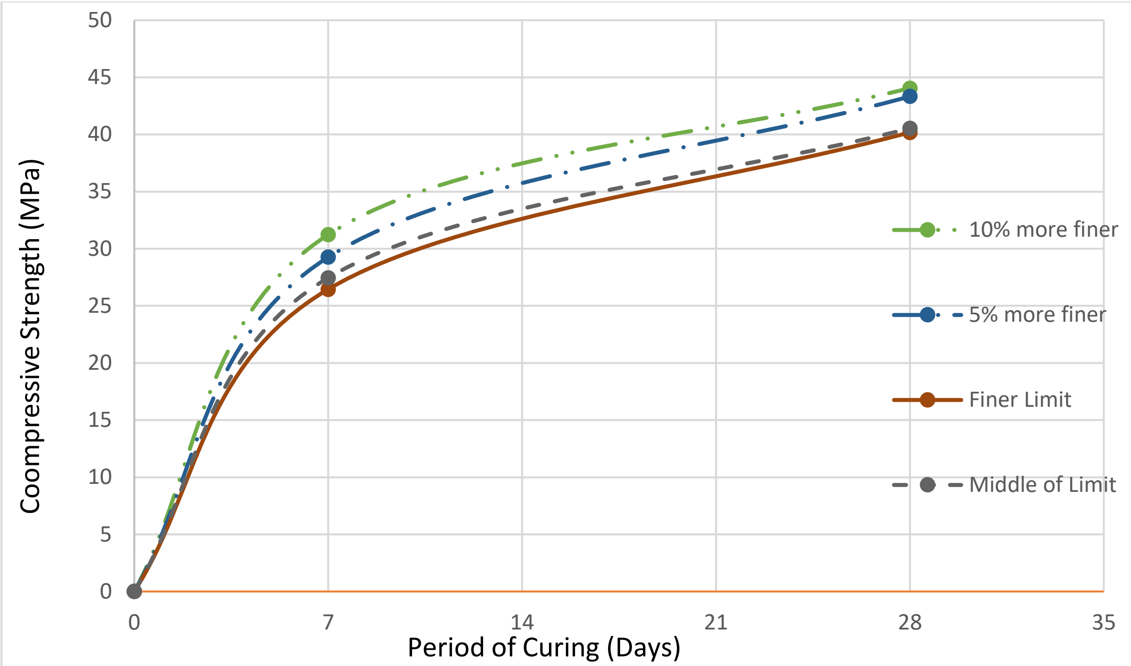
The test results reveals that, by comparing results for the 7 days and 28 days curing of all the mixtures, the compressive strength obviously increases as the days of curing are extended. It can also be witnessed from the results that the rate of compressive strength development is very high for the first 7 days. The rate of compressive strength development is starts to decrease in between the 7 days and 28 days of curing.

As it can be observed from Figure 4.3 (b), the compressive strength at the 7^{th} day of all the mixtures were found to be more or less the same. On the other hand, the early age compressive strength of failed gradation concretes beyond the finer limit, as shown in Figure 4.3 (b), was a found to be higher than the strengths obtained from the control groups. for the failed gradation concretes beyond the coarser limit the early age (7 day) compressive strength are found to be less than the strengths obtained from control groups. The variation of compressive strength for the failed aggregates beyond the coarser limit with the control groups is small compared to the failed aggregates beyond the finer limit.

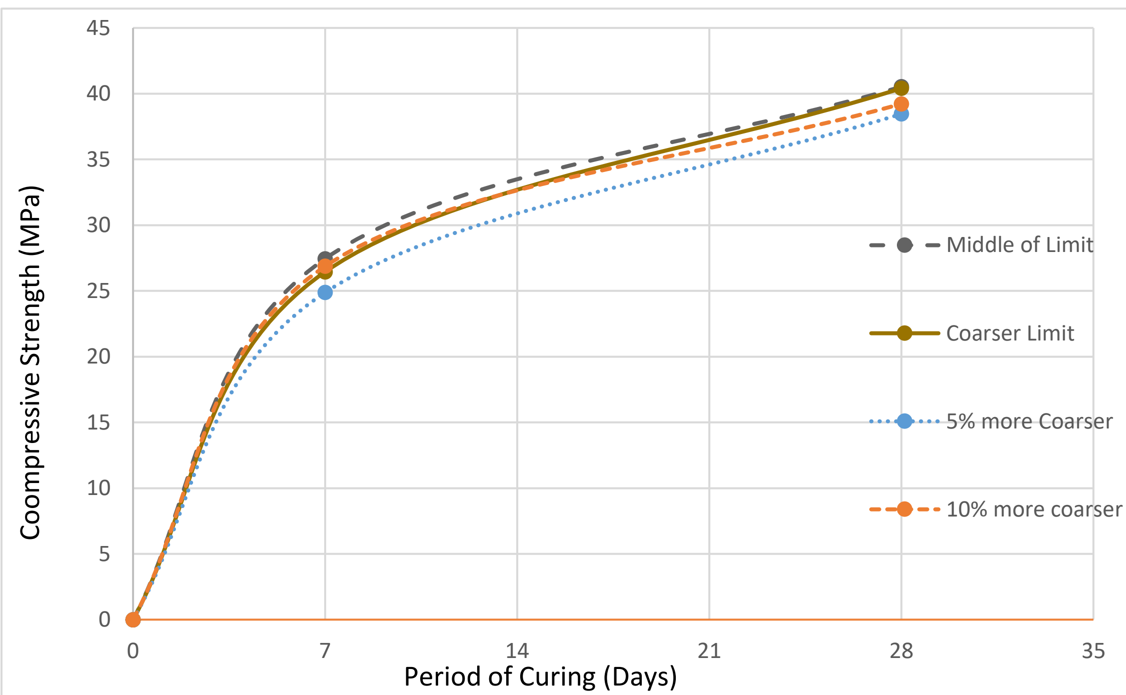
With 7 days of curing time, the compressive strength of all the concrete mixtures are somehow the same for the ranges of finer limit to 10% more coarser. This indicates that compressive strength at the early ages of concrete is only little affected by the variation in the coarse aggregate gradation. However, beyond the finer limit, compressive strength is significantly affected at the early age.

As shown in Figure 4.3(b), the compressive strength at the 28^{th} day was tested for all the mixtures prepared to determine the effect of variation in coarse aggregate gradation at the late ages. The test results show that the 28 days compressive strength of the different mixtures of concrete varied from the highest value of 44.05 MPa to the lowest value of 38.46 MPa. (please refer the figure 4.3.(b). it is also imminent from the results that the 28-days compressive strength varies from 40.18 MPa to 40.53 MPa when only the control gradations(coarser limit, median of the limit and fine limit) are considered which is only 0.87% variation among them. This implies, within the specification limits, variation in coarse aggregate gradation has no significant impact the late compressive strength of cement concrete. The compressive strength of concretes containing more finer failed aggregate gradations was found to be much higher (9.63% and 7.84% higher for 10% more finer, and 5% more finer respectively) than that of finer limit control mix. In the case of coarser failed aggregate gradation concretes, the compressive strength of 5% more coarser concrete was slightly lower (4.8%) than that of Control coarser limit concrete and the compressive strength of 10% more coarser concrete was slightly lower (2.9%) than that of coarser limit control concrete. Increasing trend in compressive strength of concrete is observed when the grading is varied beyond the finer limit. No specific trend is observed on the compressive strength when gradation is varied beyond the coarser limit.

As shown in figure 4.3 (c), the variation in coarse aggregate gradations have a pronounced effect on the percent of mass retained on sieve sizes 4.75mm, 12.5mm and 19mm. As the coarseness of the coarse aggregate increases, the percent retained on sieve size 4.75 decreases while the percent retained on sieve size 12.5 and 19 mm increases progressively. As the percent retained on 4.75mm is decreased and the percent retained on sieve sizes 12.5 and 19mm is increased, the compressive strength shows a general trend of reduction. The more finer the coarser aggregate is the higher compressive strength value the concrete mix has. Single ANOVA analysis conducted among mixtures prepared using finer limit, middle of limit, coarser limit, 5% more coarse and 10% more coarser aggregates resulted in F-statistical value of 0.92 which is very lower than F-critical (3.35 for 95% level of confidence). This showed that the variation in compressive strength among the means of mixtures prepared using finer limit to 10% more coarser gradations of coarse aggregate is not significant. On the other hand, t-Test results show that there is significant variation in compressive strength between concretes made with 10% more finer and 5% more finer gradation compared with the rest of the mixtures.

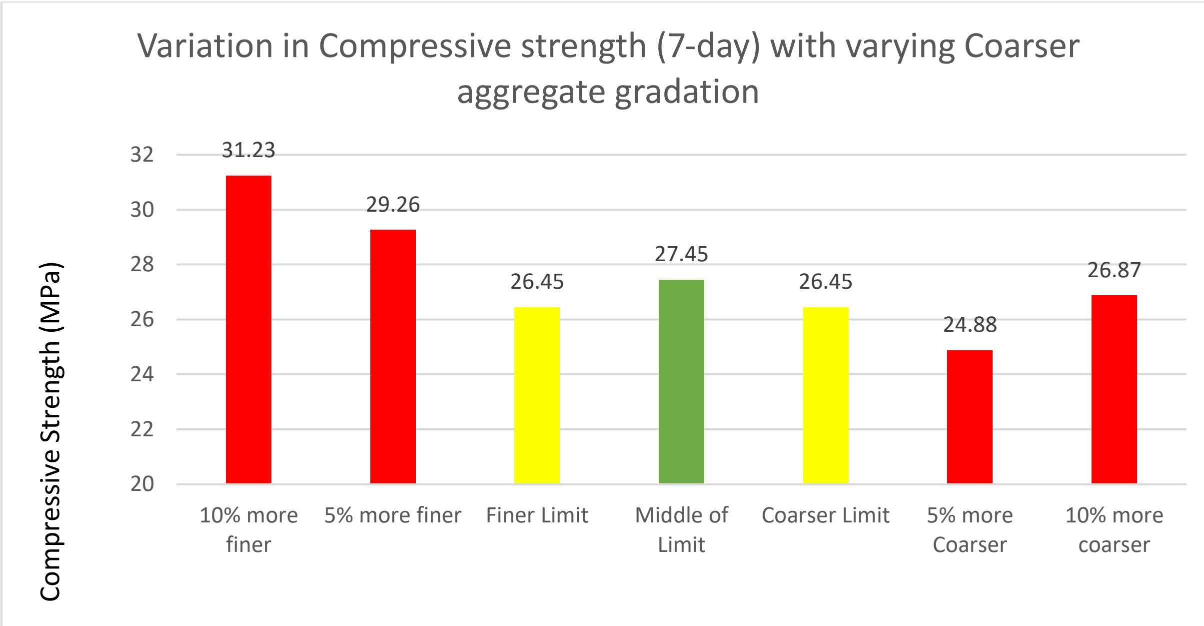


(a) Rate of Compressive Strength Development, Finer Coarse Aggregates

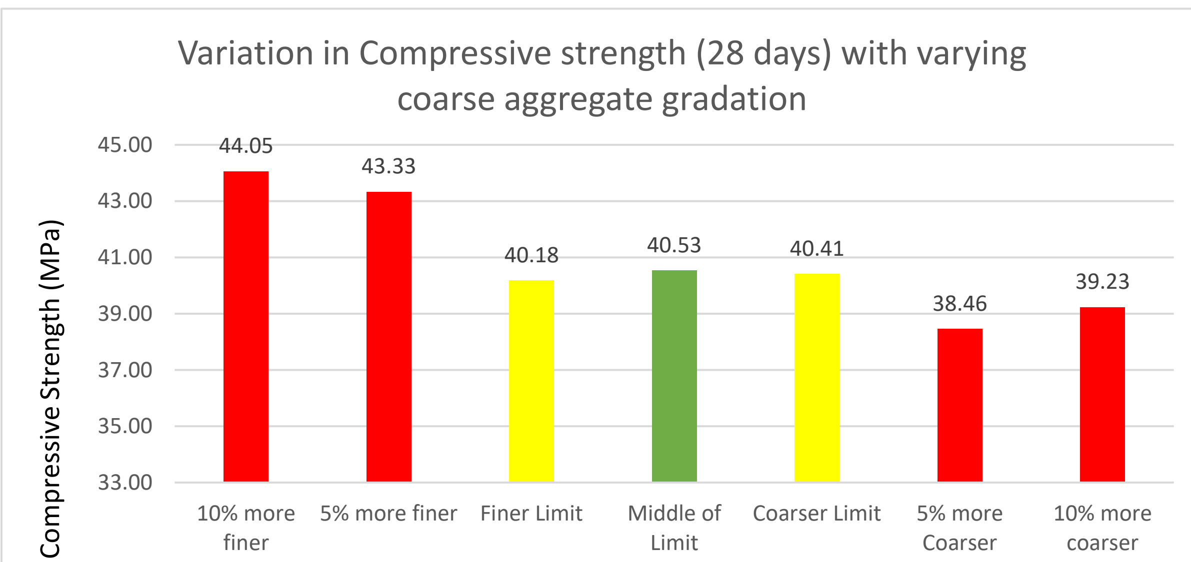


(b) Rate of Compressive Strength Development, Coarser Coarse Aggregates

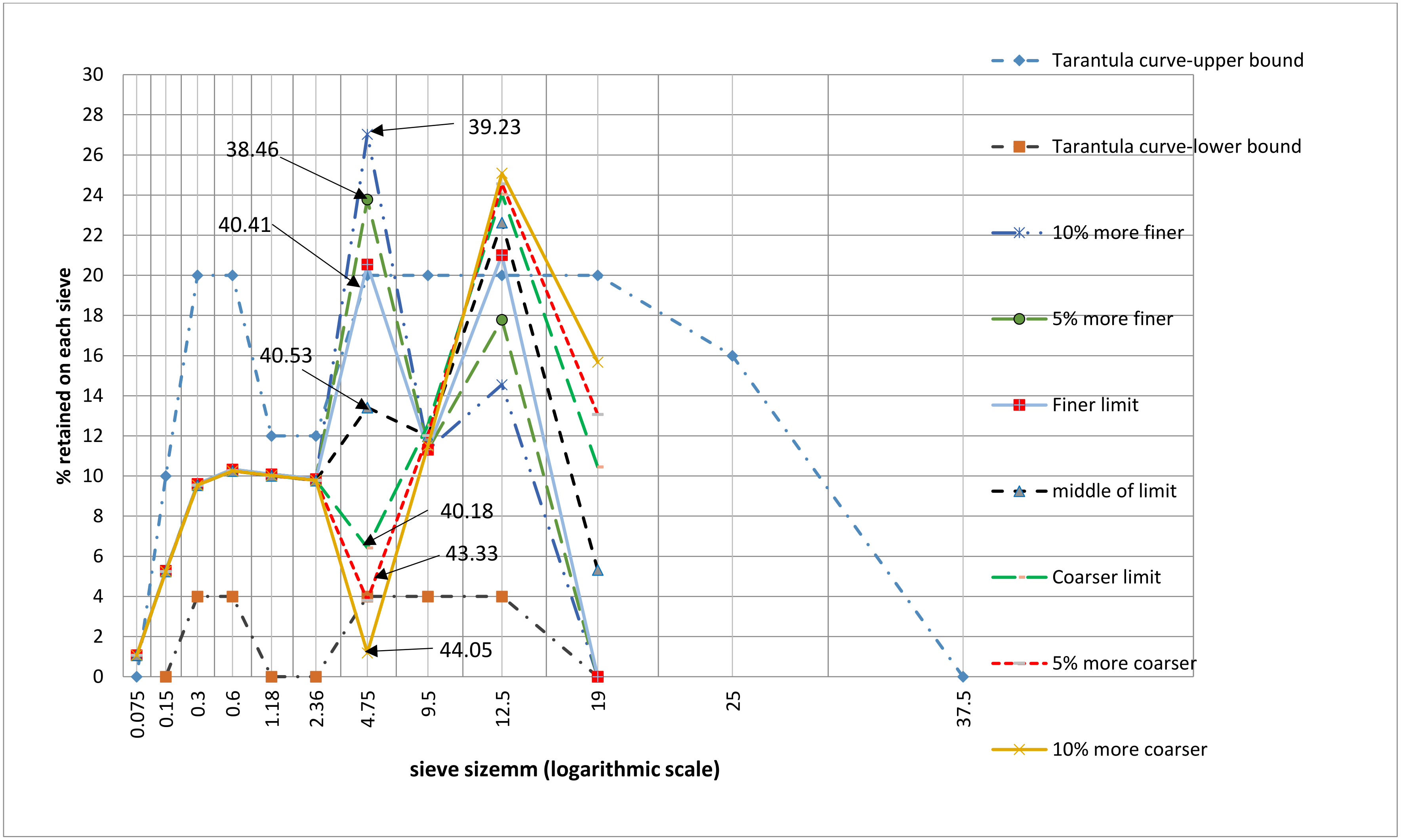
Figure 4. 2 Rate of Compressive Strength Development for Varying Coarse Aggregate Gradation



(a) Variation in Compressive Strength (7-day) with Varying Coarse Aggregate Gradation



(b) Variation in Compressive Strength (28-day) with Varying Coarse Aggregate Gradation



(c) Compressive Strength (28-Day) along with the percent retained curve

Figure 4. 3 Compressive Strength of 28-day and 7-day with Varying Coarse Aggregate Gradation

4.1.3. Water Absorption

Figure 4.4 below shows the effect of gradation of coarse aggregate on the water absorption of concrete after 28 days of casting and curing.

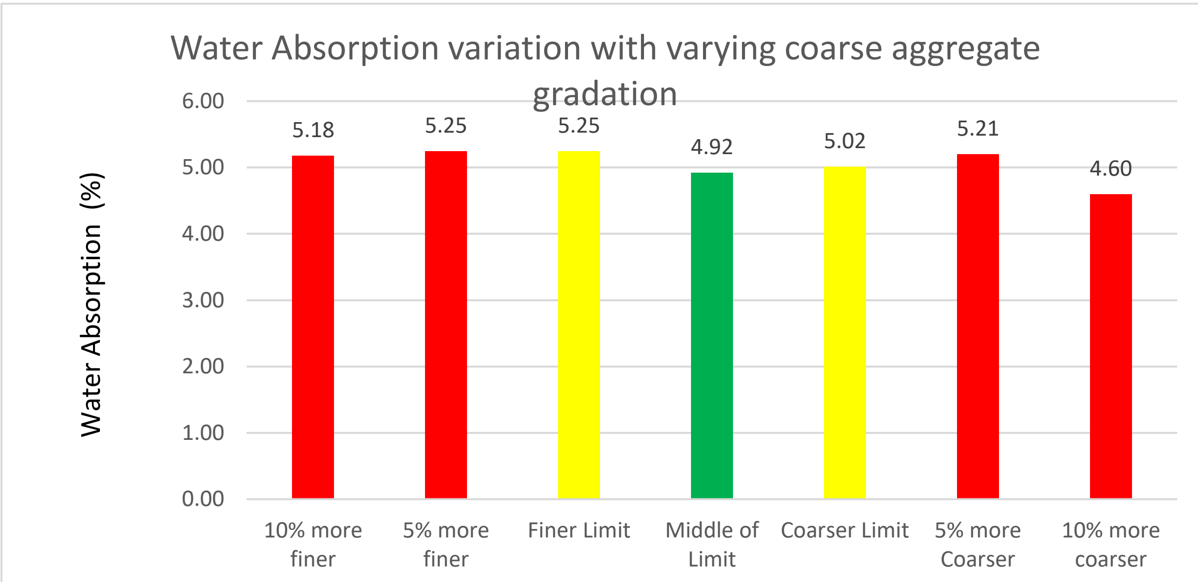


Figure 4. 4 Water Absorption of Concretes Made with Varying Coarse Aggregate

The 28-day water absorption for concrete made with average of the specification of coarse aggregate (middle of limit) is found to be slightly lower than that of the upper limit and lower limit gradation concretes. The water absorption of failed gradations beyond the finer limit had similar water absorption compared with the finer limit. For concretes made with failed gradations beyond the coarser limit, the water absorption has shown slight increase and decrease, compared with the water absorption of coarser limit gradation.

With respect to the control gradation mixtures, water absorption of concretes made with failed gradations showed very minimal variation. There is also no specific trend observed in the water absorption values.

The single ANOVA test conducted among finer limit, 5% more finer, and 10% more finer gradations resulted in P value of 0.87 which show that the variation between the means is very insignificant. T-test conducted between finer limit and middle of limit resulted in P value of 0.04 which shows that there is significant variation in water absorption between finer limit and middle of limit of mix. For the t-Test conducted between middle of limit and coarser limit the P value was found to be 0.29 which show that the variation in water absorption between the two is not significant. The t-Test between coarser limit and 5% more coarser resulted in P value of 0.23 which once again shows that the variation between the means is non-significant.

4.1.4. Bulk Density

The effect of Coarse aggregate gradation on the bulk density of concrete is shown in Figures 4.5

The Bulk Density results for the failed and control gradation concretes varied from 2271 kg/m^3 to 2321 kg/m^3 which is 2.2% only. The bulk density continuously increased with as the grading of coarse aggregate is varied from 10% more finer to 10% more coarser. Compared with density of concrete made with middle of the limit, the bulk densities obtained from concretes made with finer limit grading, 5% more finer and 10% more finer are slightly lower.

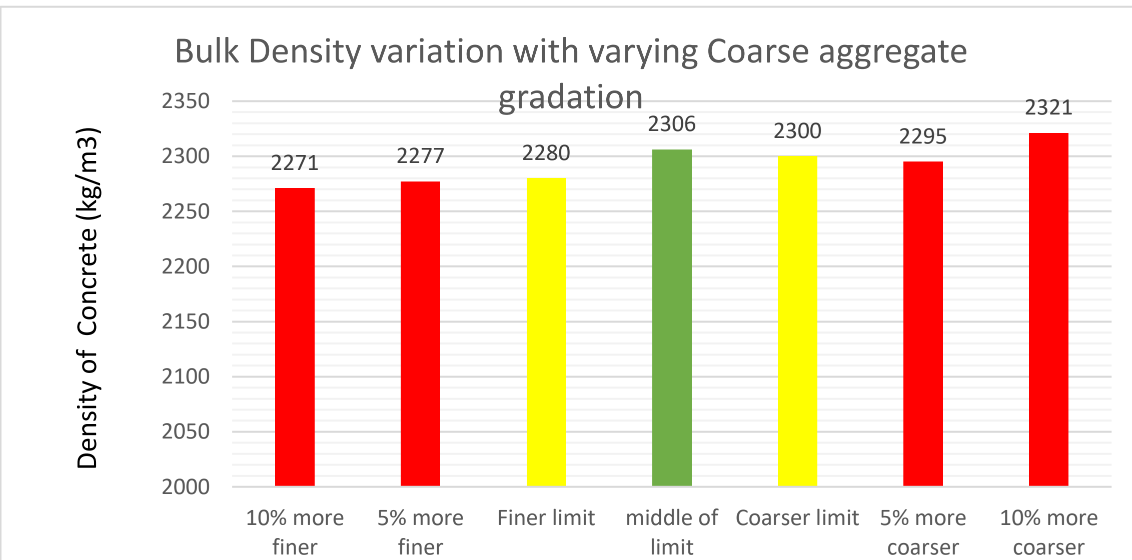


Figure 4. 5 Bulk Density Variation with Varying Coarse Aggregate Gradation

4.2. Effect of Failed Fine Aggregate Gradation on Slump, Compressive Strength, Water Absorption, and Bulk Density of Concrete

To determine the influence variation in gradation of fine aggregate, the gradation of the fine aggregate was varied while keeping the gradation of the coarse aggregate constant for all the mixtures. The middle of coarse aggregate gradation of table 8402/03 of ERA standard technical specification was used in all the mixtures. Since the quantity of all the water content and water-cement and gradation were aggregate were not variable, the only content varying in the mixture is the gradation of the coarse aggregate. This way, the effect of varying the gradation of coarse aggregate on specific properties of concrete was determined.

As it is observed from figure 3.4, the variation in fine aggregate gradations have a pronounced effect on the percent of mass retained on sieve sizes 2.36mm and 1.18mm with minor variation in percent retained on the other sieves.

4.2.1. Slump

In figure 4.7 (a) and (b), the effect of variations of gradation of fine aggregate on the slump of concrete is shown.

As it can be observed, the slump values of control mixes (2.8 FM, 3.17 FM and 3.54 FM which are the finer limit, middle of limit and coarser limit of the specification respectively), increased with increasing FM values. The increase in slump using Finer limit fine aggregate (2.8 FM) with Middle of limit of fine aggregate is not significant (P value of 0.078 which is less than alpha value 0.05 for 95% significance level) but the slump is significantly increased with concrete made with 3.54 FM (coarser limit) compared with middle of limit of fine aggregate (3.17 FM) with P value of 0.0012. The slumps of failed gradation concretes beyond the finer limit continuously decreased with decreased FM values. The slumps of failed gradation concretes beyond the coarser limit also continuously decreased with increased FM values.

The single ANOVA test conducted on the 10 groups show that F-statistic calculated is more than F-critical for 95% significance level (alpha level of 0.05) and can conclude that at least one of the seven samples have significantly different means and belongs to different population. To check which samples had different means, t-Test was conducted on different combination, and the results show that only Middle of limit (3.17 FM) with Finer limit (2.8 FM), Middle of limit (3.17 FM) with 2.6 FM, Finer limit (2.8 FM) with 2.6 FM and 3.74 FM with 3.94 FM had p values greater than 0.05(95% significance level) and showed no significant variation.

As it is observed from figure 4.7, the variation in fine aggregate gradations have a pronounced effect on the percent of mass retained on sieve sizes 2.36mm and 1.18mm with minor variation in percent retained on the other sieves. As the FM of the fine aggregate increases, the percent retained on sieve sizes 2.36 and 1.18mm increases progressively. As shown in figure 4.7, as the percent retained on 2.36 mm and 1.18 mm sieve sizes is increased, the slump shows a general trend of increase up to coarser limit of fine aggregate (3.54 FM). The coarser the fine aggregate is the more the slump value it has up to FM value of 3.54(coarser limit). This may be due to higher surface area to volume ratio of finer fine aggregates that increase the absorbed water and consequently reduce the free water compared to coarser fine aggregates.

Increased coarseness of fine aggregate beyond the coarser limit (3.54 FM) resulted in decreased slump values.

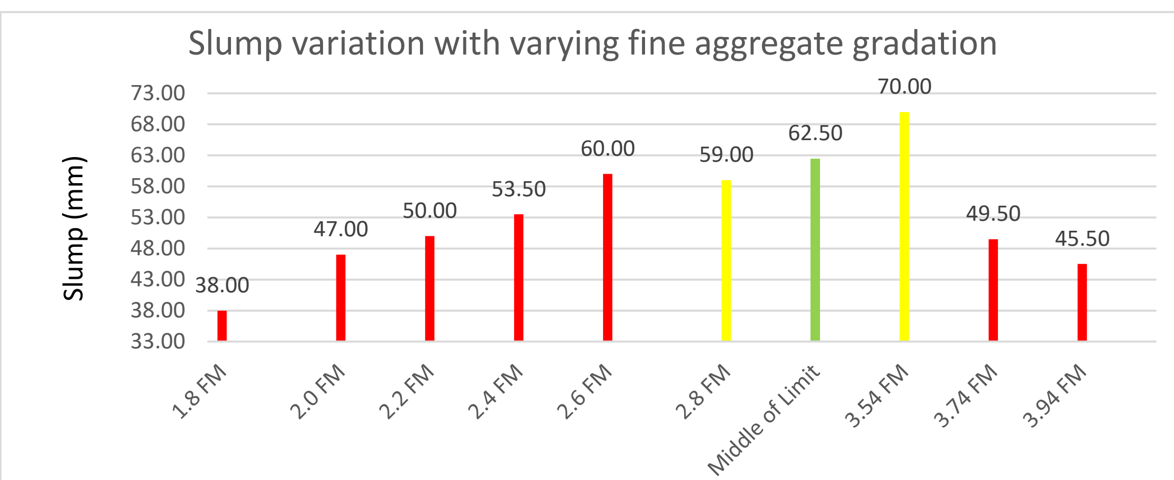
During preparation of the concrete mixtures, it was visually observed that when fine aggregate with FM of 1.8 is used, high segregation problem was observed. The mix has very bad cohesion when visually observed. The mix was also found to be very harsh. Even though the extent was not as with fine aggregate with FM 1.8, the cohesion problem was also observed with mixtures prepared with FM 2.0 and FM 2.2 fine aggregates. Refer figure 3.7 below.

During the mix preparation of the concrete mixtures, it was visually observed that concretes made with FM values of 3.54, 3.74 and 3.94, had finishabilty problem with the coarser sand aggregates tearing across the surface during casting of concrete on the mold. But with equal slump values, the mixtures made with very coarse fine aggregates (3.54 FM, 3.74 FM and 3.94 FM) are very easy on hand (not harsh) compared with mixtures made with very finer fine aggregates (1.8 FM, 2.0 FM and 2.2 FM).

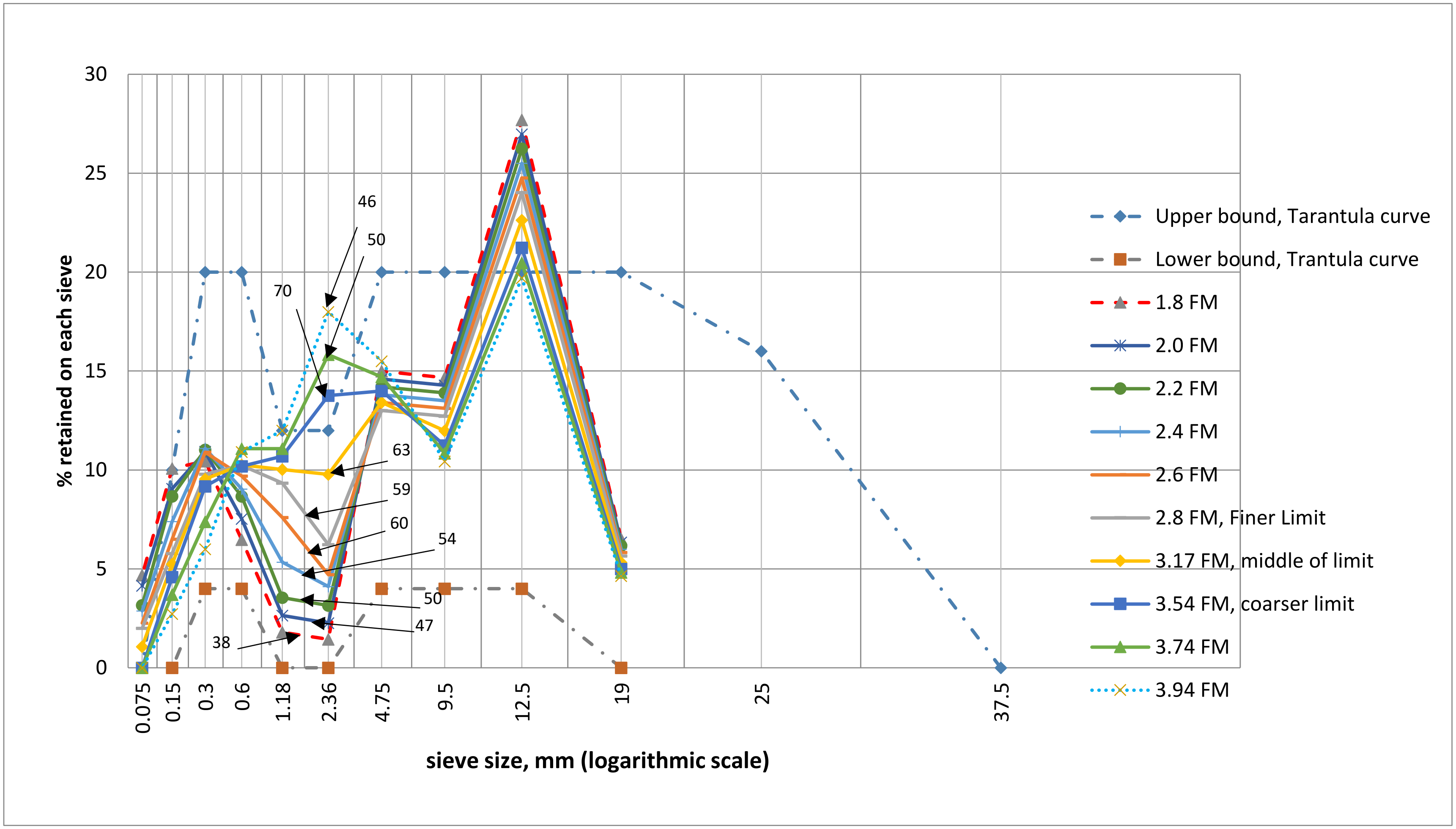
No Finishabilty, segregation or cohesion problem was observed for mixtures prepared using 2.4 FM, 2.6 FM, 2.8 FM and 3.17 FM fine aggregates.

		
1.8 FM mixture	1.8 FM mixture	Slump Test on 1.8 FM
		
2.0 FM Mix	2.2 FM Mix	2.2 FM Mix
		
3.74 FM	3.94 FM	Slump Test for 3.94 FM

Figure 4. 6 Fresh Concrete Appearance for Different FM Values



(a)



(b)

Figure 4. 7 Slump Variation with Varying Fine Aggregate Gradation

4.2.2. Compressive Strength

In figure 4.8 below is shown the rate of compressive strength gain of cement concrete with varying gradation of the fine aggregate.

The test results reveal that, by comparing results for the 7 days and 28 days curing of all the mixtures, the compressive strength obviously increases as the days of curing are extended. It can also be witnessed from the results that the rate of compressive strength development is very high for the first 7 days. The rate of compressive strength development starts to decrease in between the 7 days and 28 days of curing.

As it can be observed from Figure 4.9 (b), the early age (7 days) compressive strength of the control mixtures which are within the specification (finer limit, middle of limit and coarser limit) were found to increase with increased FM values. The finer limit with FM of 2.8 had compressive strength of 25.67 while grading with middle of limit with FM of 3.17 had compressive strength of 27.45 MPa and the coarser limit with FM of 3.54 had compressive strength of 28.29 MPa at the age of 7 - day. On the other hand, the early age compressive strength of failed gradation concretes beyond the finer limit and coarser limit, as shown in Figure 4.9 (b), was a found to be within the ranges of compressive strengths obtained from the control groups. For the failed gradation concretes beyond the coarser limit the early age (7 day) compressive strength are found to be less than the strengths obtained from control groups. The variation of compressive strength for the failed aggregates beyond the coarser limit is small compared to the failed aggregates beyond the finer limit.

At the 7 days curing period the concretes compressive strength for all the mixtures are almost the same for the ranges 1.8 FM to 3.94 FM. This indicates that compressive strength at the early ages of concrete is only little affected by the variation in the fine aggregate gradation. .

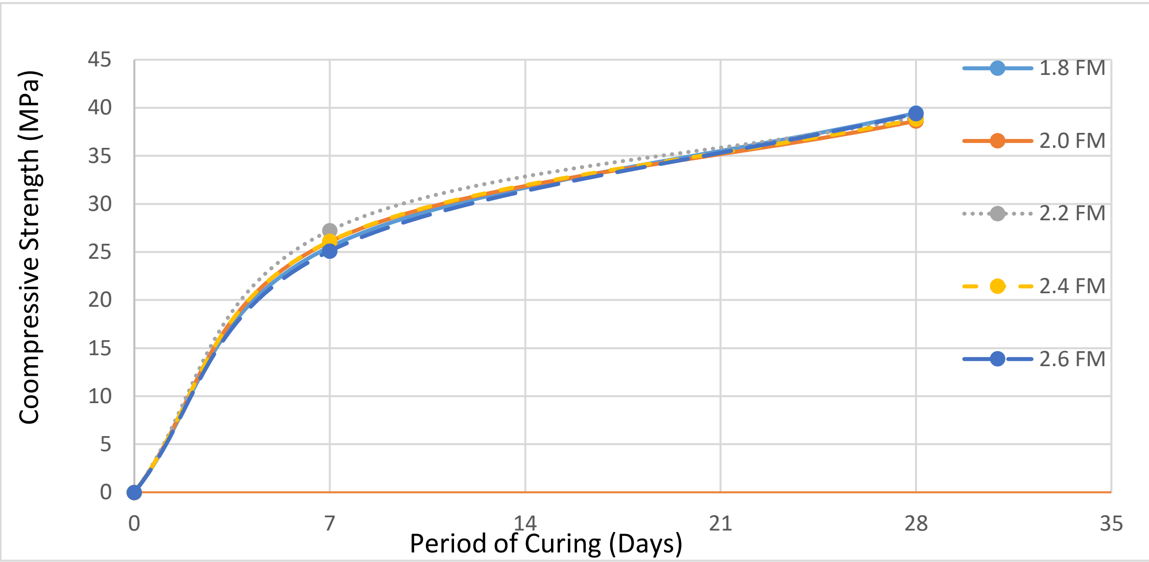
As shown in Figure 4.9(a), the compressive strength at the 28th day was tested for all the mixtures prepared to determine the effect of variation in coarse aggregate gradation at the late ages strength development. The test results show that the 28 days compressive strength of the different mixtures of concrete varied from the highest value of 42.6 MPa to the lowest value of 38.64 MPa.(please refer the figure 4.9.(b). The 28-day compressive strengths ranged between 39.94 for the finer limit and 41.33 MPa for the coarser limit when only the control gradations (coarser limit, median of the limit and fine limit) are considered. For the middle of limit the Compressive strength obtained is 40.53 MPa. This represents a range of 3.48%. This implies, within the specification limits, variation in fine aggregate gradation has slight impact the late compressive strength development of cement concrete with increased strength as the FM is increased. For concretes having more finer failed aggregate gradations, the compressive strength was found to decrease with decreased FM values, except at for FM of 1.8.

for failed aggregate gradations on the coarser side, the compressive strength with FM of 3.74 concrete was slightly lower (2.39%) than that of Control coarser limit concrete and the compressive strength with FM of 3.94 concrete was slightly higher (3.07%) than that of coarser limit control concrete.

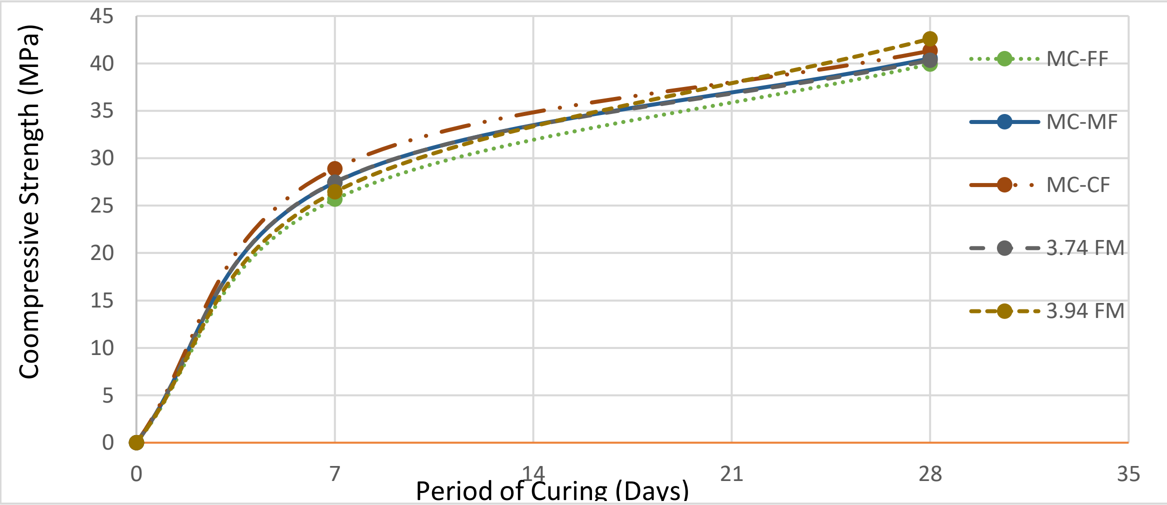
Decreasing trend in compressive strength of concrete is observed when the grading is varied beyond the finer limit. No specific trend is observed on the compressive strength when gradation is varied beyond the coarser limit. In general, the compressive strength results obtained when the grading is varied beyond the finer limit is lower compared to the results of compressive strength of control concretes. The compressive strength results of coarser failed aggregates show no specific trend but are much higher than the results obtained from failed aggregates on the finer side.

As it is observed from figure 4.9 (c), the variation in fine aggregate gradations have a pronounced effect on the percent of mass retained on sieve sizes 2.36mm and 1.18mm with minor variation in percent retained on the other sieves. As the FM of the fine aggregate increases, the percent retained on sieve sizes 2.36 and 1.18mm increases progressively. With increased percent retained of 2.36mm and 1.18mm, no significant variation in compressive strength is observed.

Single ANOVA analysis conducted among mixtures prepared using 1.8 FM to 3.74 FM fine aggregates resulted in F-statistical value of 1.42 which is very lower than F-critical (2.44 for 95% level of confidence) and P value of 0.24. This showed that the variation in compressive strength among the means of mixtures prepared using 1.8 FM to 3.74 FM gradations of fine aggregate is not significant. On the other hand, t-Test results show that there is significant variation in compressive strength between concretes made with 3.94 FM and the rest.

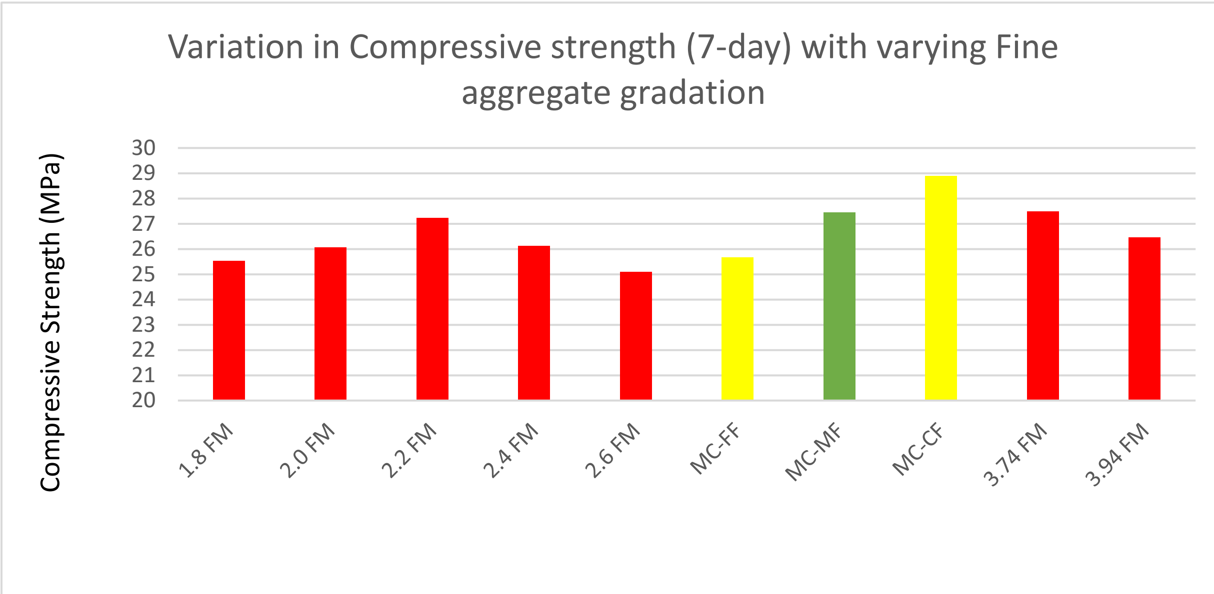


(a) Rate of Compressive Strength Development, Finer Fine Aggregates

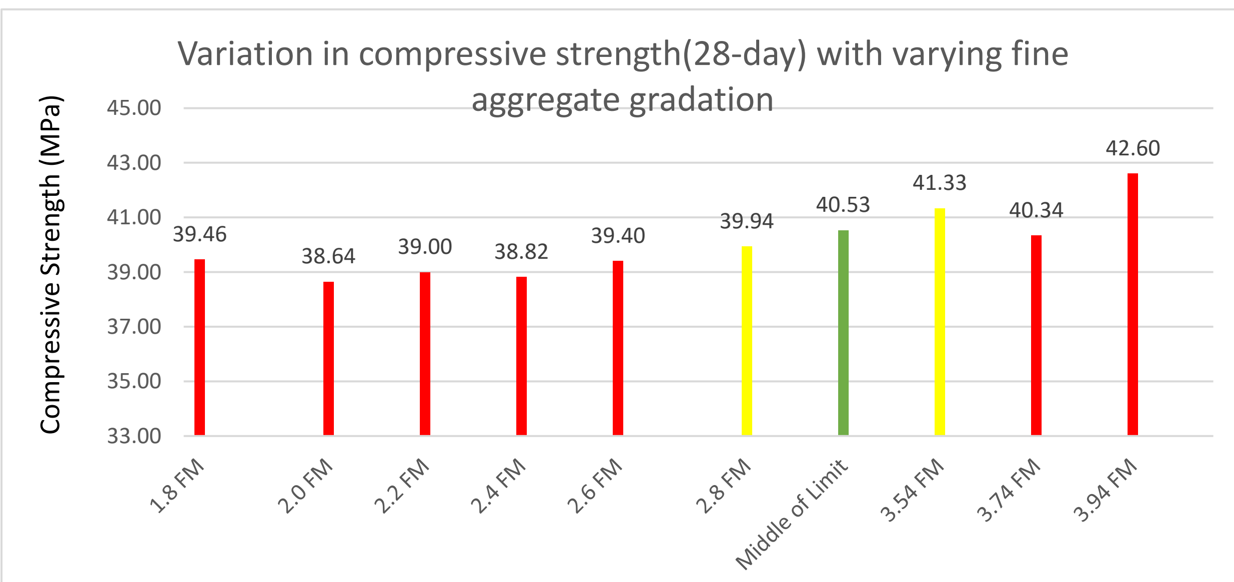


(b) Rate of Compressive Strength Development, Coarser Fine Aggregates

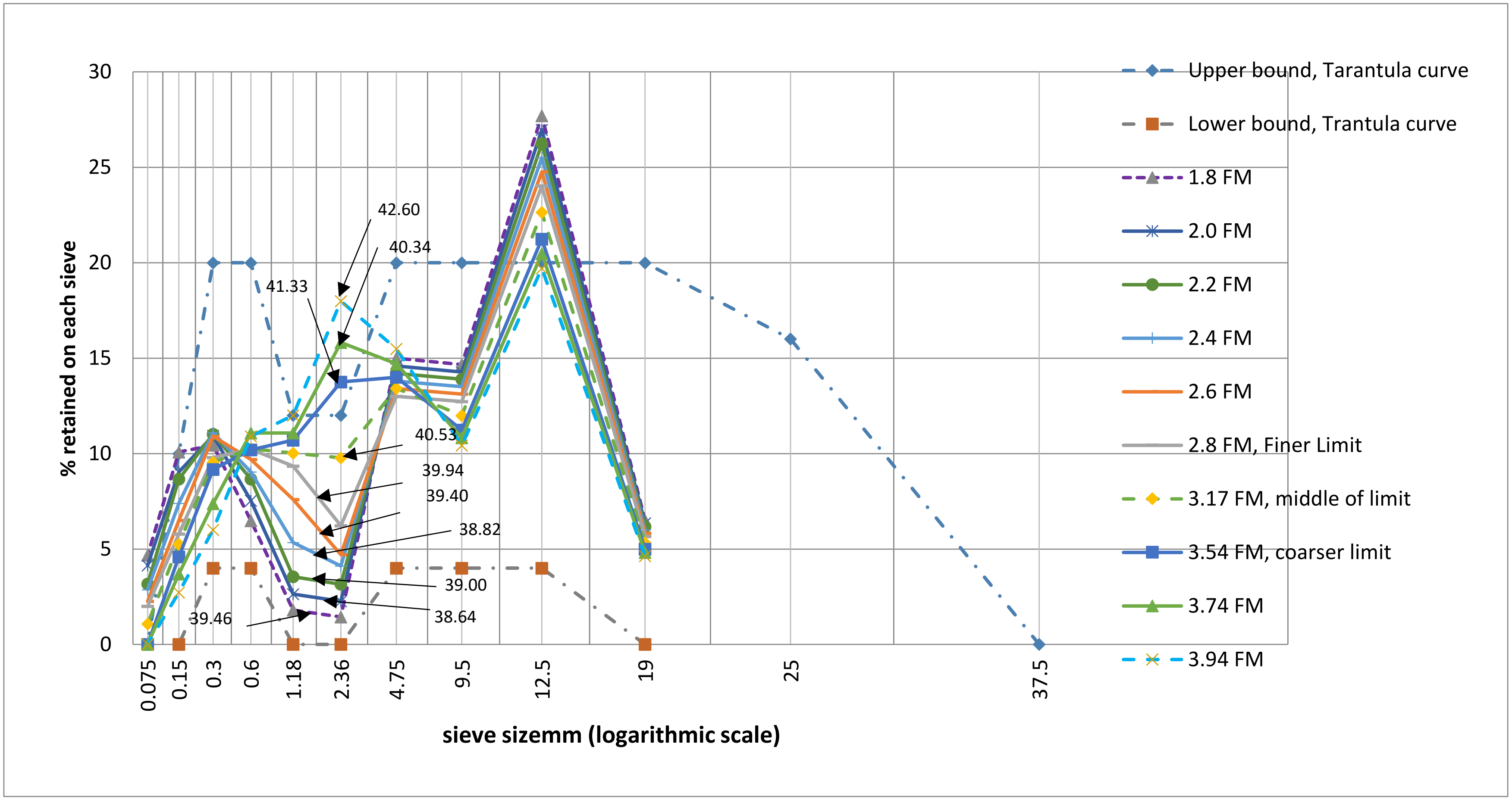
Figure 4. 8 Rate of Compressive Strength Development for Varying Fine Aggregate Gradation



(a) Variation in Compressive Strength (7-day) with Varying Fine Aggregate Gradation



(b) Variation in Compressive Strength (7-day) with Varying Fine Aggregate Gradation



(c) Variation in Compressive Strength (28-day) with Gradation

Figure 4. 9 Compressive Strength of 28-day and 7-day with Varying Fine Aggregate Gradation

4.2.3. Water Absorption

Figure 4.10 below shows the effect variation of gradation of Fine aggregate on water absorption of concrete after 28 days of curing. .

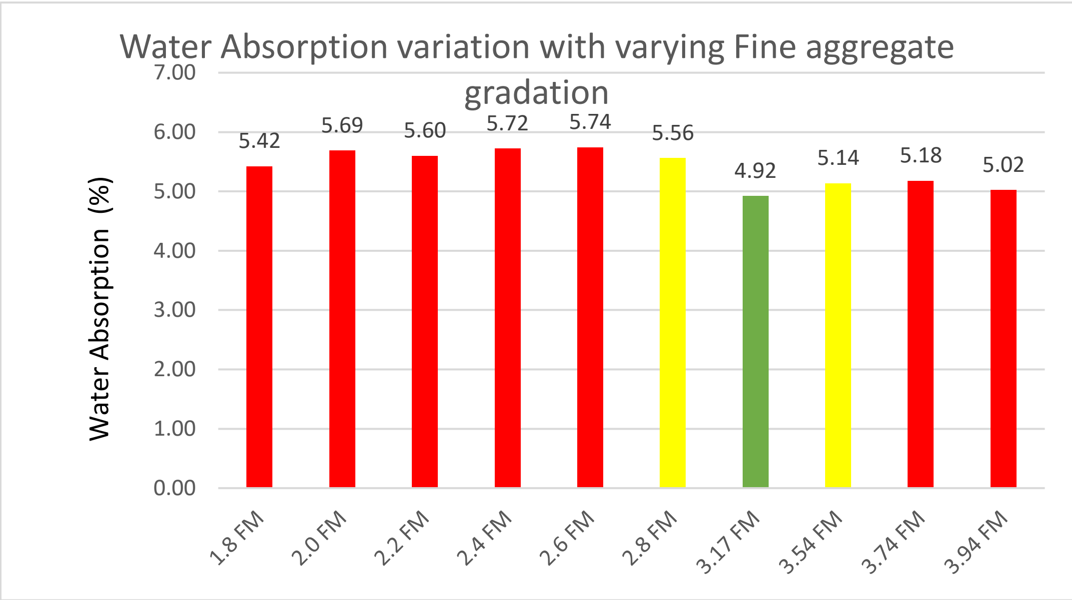


Figure 4. 10 Variation in Water Absorption with Varying Fine Aggregate Gradation

The 28-day water absorption for concrete made with average of the specification (middle of limit) is found to be slightly lower than that of the upper limit and lower limit gradation concretes. Concrete made with middle of the limit (FM=3.17) has the lowest water absorption among the concretes made with gradation within the specification and failed aggregates.

The water absorption of failed gradations beyond the finer limit had similar water absorption compared with the concrete made with the finer limit. For concretes made with failed gradations beyond the coarser limit, the water absorption has shown slight increase and decrease, compared with the water absorption of concrete made with coarser limit gradation.

With respect to the control gradation mixtures, water absorption of concretes made with failed gradations showed very minimal variation. There is also no specific trend observed in the water absorption values.

The single ANOVA test conducted among mixtures prepared using finer limit gradation and failed aggregates beyond the finer limit (1.8 FM to 2.8 FM) resulted in F-Statistical value of 1.06 while the F-critical is 3.1. The P value among the groups was also found to be 0.427. This shows that there is no significant variation in water absorption for concretes prepared using 1.8 FM to finer limit (2.8 FM) fine aggregates.

Likewise, the single ANOVA test conducted among mixtures prepared using middle of limit (3.17 FM), coarser limit (3.54 FM), 3.74 FM and 3.94 FM resulted in F-Statistical value of 0.69 while the F-critical is 4.06. The P value among the groups was also found to be 0.57. This also shows that there is no significant variation in water absorption for concretes prepared using 3.17 FM to 3.94 FM.

Even though the water absorption value increment in percentage for mixtures of concrete made with finer limit gradation (FM=2.8) and failed gradations beyond the finer limit (FM=2.6, 2.4, 2.2, 2.0 and 1.8) are not large compared with water absorption of concrete made with middle of the limit (FM=3.17), the test results show that the water absorptions for mixtures made with FM ranging from 1.8 to 2.6 are likely to be higher than the rest of the mixtures. This implies there is a slightly more durability risk in using fine aggregates that fall out of the specification on the finer side.

The t-Test conducted between 3.17 FM (middle of limit) and 2.8 FM (finer limit) resulted in P value of 0.016 (significant) while between 3.17 FM (middle of limit) and 3.54 FM (coarser limit) is 0.32. The results show much of this observed change in water absorption properties of concrete happened because of the variations in aggregate gradations within the control gradations which are within the specification limits.

4.2.4. Bulk Density

The effect of Fine aggregate gradation on the bulk density of concrete is shown in Figure 4.11. The Bulk Density results for the failed and control gradation concretes varied from 2310 kg/m^3 to 2268 kg/m^3 which is 1.8% only. No specific trend is observed in variation in density of concrete by varying the gradation of fine aggregates within and beyond the specification limits set.

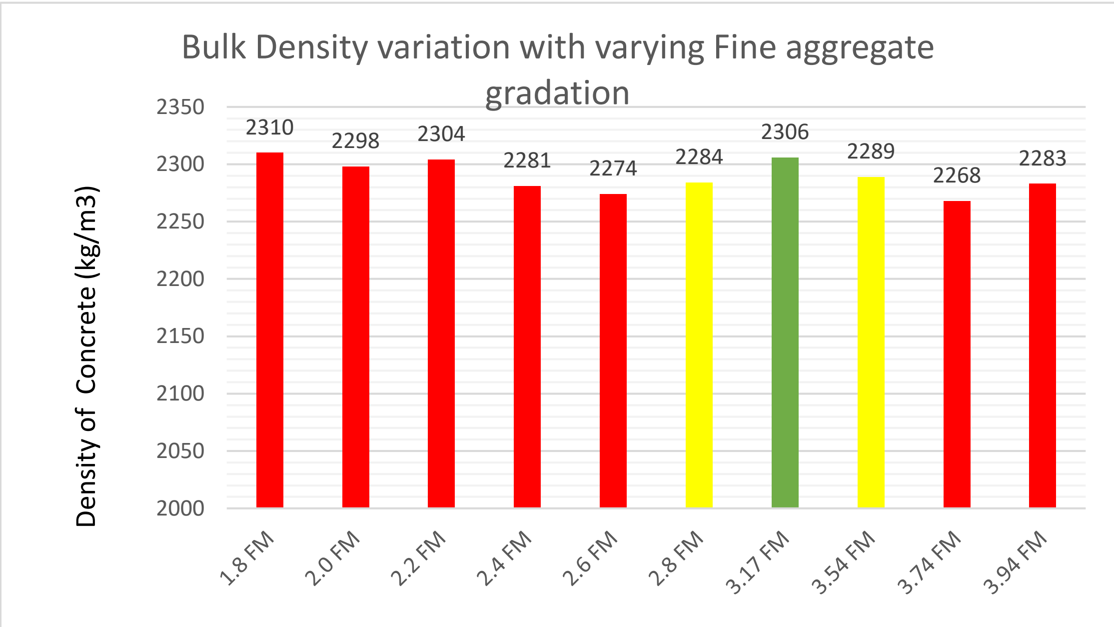


Figure 4. 11 Variation in Bulk Density with Varying Fine Aggregate

4.3. Effects of gradation variations within the specification limit

As stated in section 3.3.3, to study the effects of variation of gradation within the specification limit of the coarse and fine aggregate, 9 different mixtures are prepared. Three control gradations (finer limit, middle of limit, and coarser limit) of each of the coarse and fine aggregates specification are combined to give 9 different mixtures for analysis of the effect of variation of gradation within the specification limit. The nine(9) combinations are:

- Coarser limit of coarse aggregate combined with Finer limit of fine aggregate (CC-FF)
- Coarser limit of coarse aggregate combined with middle of limit of fine aggregate (CC-MF)
- Coarser limit of coarse aggregate combined with coarser limit of fine aggregate (CC-CF)
- Middle of limit of coarse aggregate combined with finer limit of fine aggregate (MC-FF)
- Middle of limit of coarse aggregate combined with middle of limit of fine aggregate (MC-MF)
- Middle of limit of coarse aggregate combined with coarser limit of fine aggregate (MC-CF)
- Finer limit coarse aggregate combined with finer limit of fine aggregate (FC-FF)
- Finer limit of coarse aggregate combined with middle of limit of fine aggregate (FC-MF) and
- Finer limit of coarse aggregate combined with coarser limit of fine aggregate (FC-CF)

4.3.1. Effect of variation of fine Aggregate Gradation within the Specification Limit

As shown in Figure 3.8 (a), (b) and (c) variation of fine aggregate gradation within the specification limit had a pronounced effect on the percent mass retained on sieve size 2.36mm while there is only slight variation in percent retained on sieve sizes 1.18mm and 12.5mm sieves.

4.3.1.1 Compressive Strength

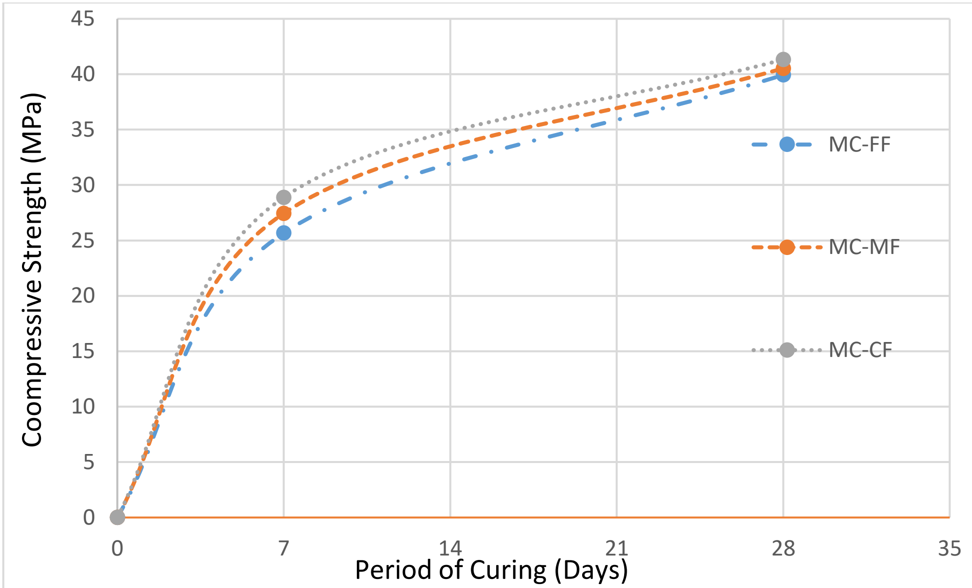
The effect of variation of coarse aggregate gradation on compressive strength is shown in the figure 4.12 (a) to (i), As shown in figure 4.12 (a), (b) and (c), keeping the coarse aggregate gradation within the middle of the specification limit, variation of fine aggregate from the finer to the coarser limit of the specification resulted in increased 7-day and 28-day compressive strength of concrete. The variation in 28-days compressive strength between concretes made with finer limit and coarser limit fine aggregate is 3.48%. refer figure 4.12 (a), (b) and (c). The F-statistical value obtained using one-way ANOVA is 0.966 and the critical F value is 5.14 for 95% confidence level for the three samples. This shows that there is no significant variation on the means when one-way ANOVA is conducted on the three groups. The P-value from the one-way ANOVA analysis for the three groups is also found to be 0.4327 which is very greater than the alpha value selected (0.05 for 95% confidence level)

Keeping the coarse aggregate gradation on finer limit of the specification, varying the fine aggregate gradation from finer limit to the coarser limit of the specification resulted in increased 7-day and 28-day compressive strength of concrete. There is high variation (8.25%) in 28-day compressive strength using the finer limit and coarser limit of fine aggregate gradation. Refer figure 4.12 (d), (e) and (f). The F-statistical value obtained using one-way ANOVA is 2.06 and the critical F value is 4.73 for 95% confidence level for the three groups. This shows that there is no significant variation on the means when one-way ANOVA is conducted on the three groups. The P-value from the one-way ANOVA analysis for the three groups is also found to be 0.196 which is very greater than the alpha value selected (0.05 for 95% confidence level)

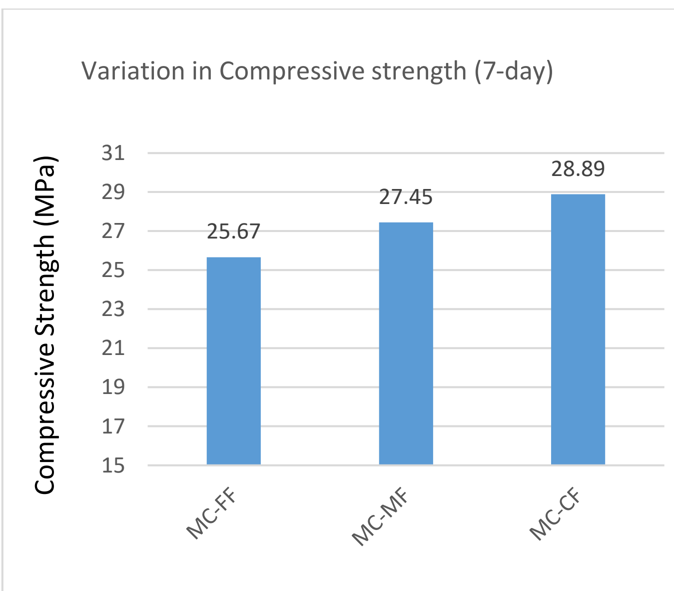
For concrete mixtures prepared keeping coarse aggregate gradation on the coarser limit of the specification and varying the fine aggregate gradation from finer limit to coarser limit, no specific trend is observed and the compressive strength obtained using the middle of limit of fine aggregate is lower compared to strengths obtained using the finer and coarser limit of fine aggregate. (refer figure 4.12 (g) (h) and (i). The F-statistical value obtained using one-way ANOVA is 4.18 and the critical F value is 5.14 for 95% confidence level for the three groups. This shows that there is no significant variation on the means when one-way ANOVA is conducted on the three groups with alpha level of 0.05. But for alpha level of 0.1 (90% confidence level) F-statistical value of 4.18

which is greater than F-critical value which is 3.46 is obtained. This implies that for 90% confidence level there is significant variation in compressive strength obtained using CC-FF, CC-MF, and CC-CF gradation mixtures. The t-Test showed that Signiant variation in compressive strength existed between CC-FF & CC-CF and, CC-MF & CC-CF gradation mixtures with P values of 0.03 and 0.062 respectively. For CC-FF and CC-MF, the P value obtained was 0.46 which show there is no significant variation in compressive strength between the two mixes.

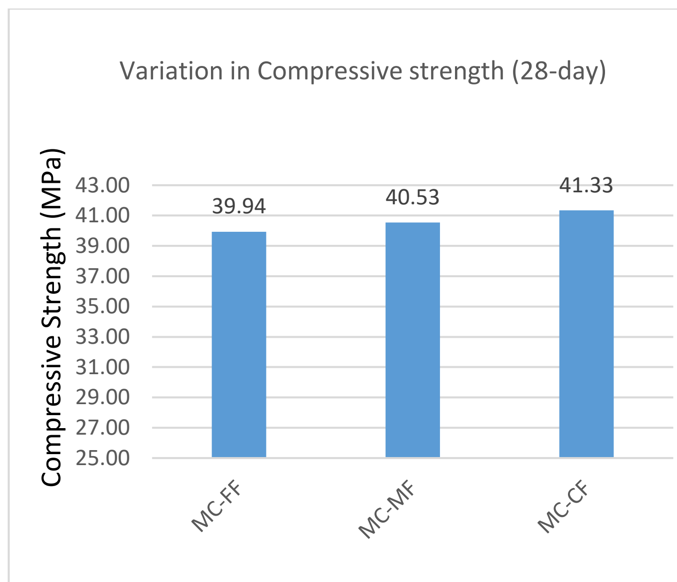
In general, even though the variation is slight, concretes made with coarser fine aggregates (FC-CF, MC-CF, CC-CF) showed increased compressive strength compared with concretes made with finer limit and middle of limit of fine aggregates.



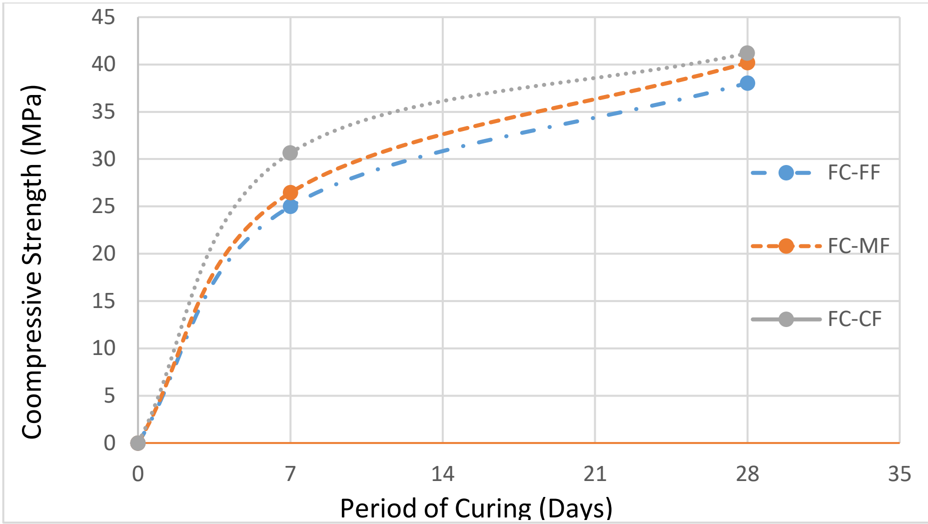
(a) Rate of Compressive Strength Development



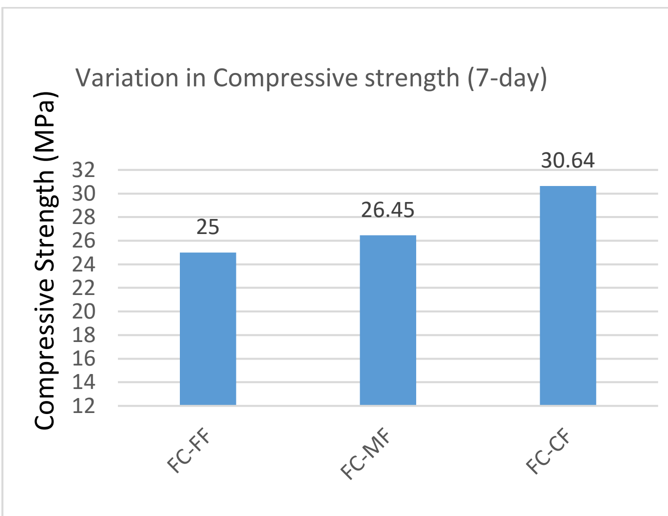
(b) Variation in Compressive strength (7-day) with varying fine aggregate gradation within the specification keeping coarse aggregate in the middle of specification



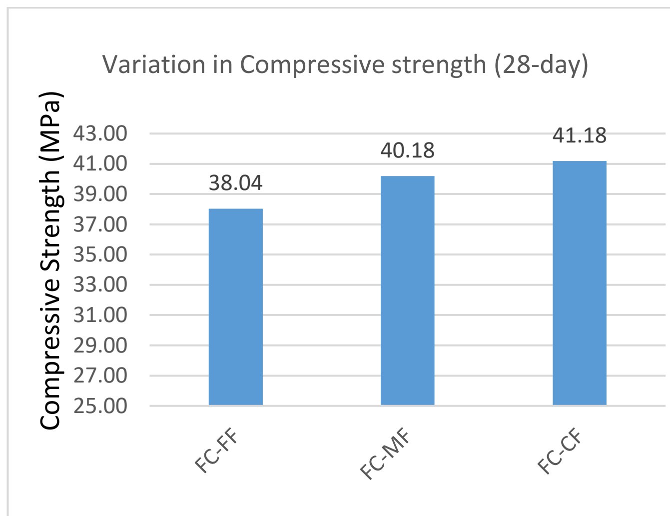
(c) Variation in Compressive strength (28-day) with varying fine aggregate gradation within the specification keeping coarse aggregate in the middle of specification



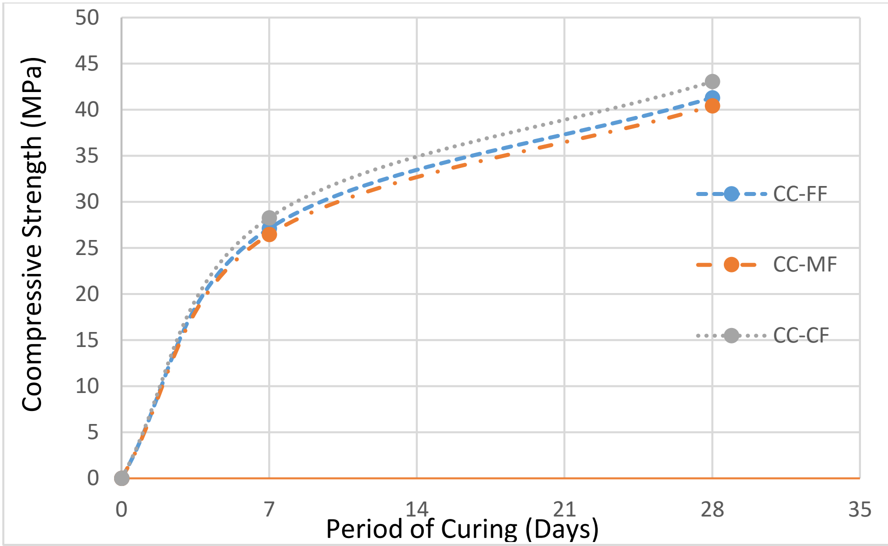
(d) Rate of Compressive Strength Development



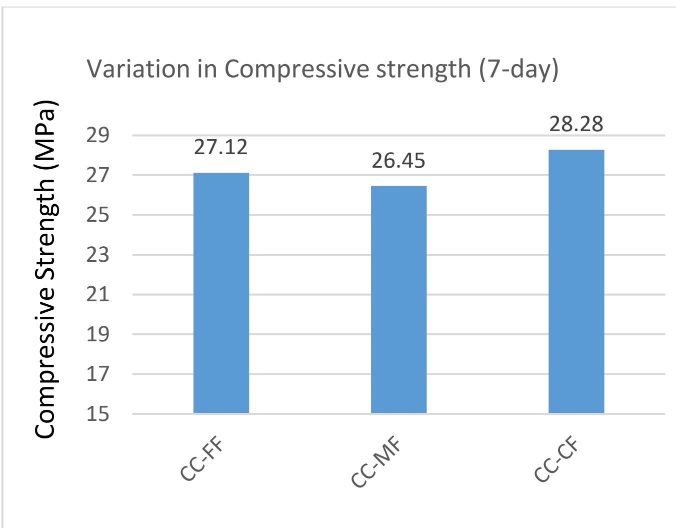
(e) Variation in Compressive strength (7-day) with varying fine aggregate gradation within the specification keeping coarse aggregate in finer limit



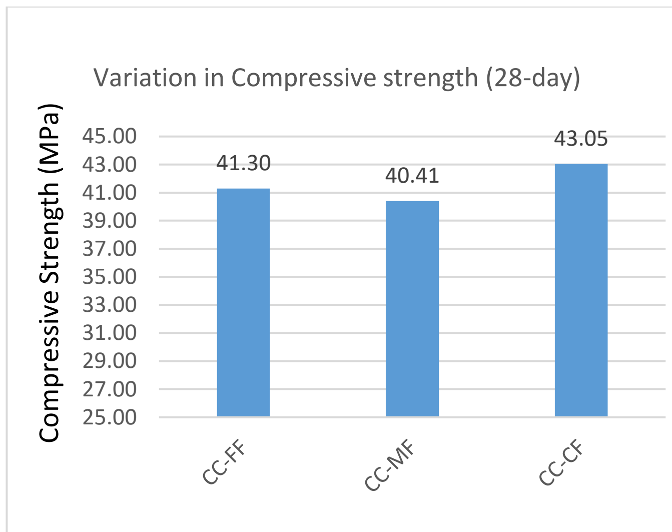
(f) Variation in Compressive strength (28-day) with varying fine aggregate gradation within the specification keeping coarse aggregate in finer limit



(g) Rate of Compressive Strength development



(h) Variation in Compressive strength (7-day) with varying fine aggregate gradation within the specificaiton keeping coarse aggregate in coarser limit



(i) Variation in Compressive strength (28-day) with varying fine aggregate gradation within the specification keeping coarse aggregate in coarser limit

Figure 4. 12 Variation in 28-day and 7-day Compressive Strength with Varying Fine Aggregate Gradation Within the Specification Limit

4.3.1.2 Slump

The effect of variation of fine aggregate gradation within the specification limit are shown in figure 4.13 (a), (b) and (c) below.

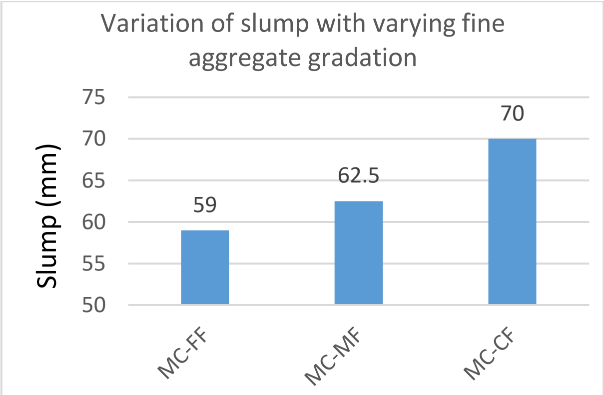
As shown in Figure 3.8 (a), (b) and (c) variation of fine aggregate gradation within the specification limit had a pronounced effect on the percent mass retained on sieve size 2.36mm while there is only slight variation in percent retained on sieve sizes 1.18mm and 12.5mm sieves.

As shown in figure 4.13 the variation of fine aggregate gradation within the specification limit by keeping the coarse aggregate gradation in the middle of the specification resulted in continuous increase in slump when the grading of fine aggregate is varied from finer limit to middle of the limit and to coarser limit. The variation in slump of 18% is observed between concrete made with finer limit and coarser limit fine aggregates. The F-statistical value obtained is 35.148 and the critical F value is 5.14 for 95% confidence level for the three samples. This shows that there is significant variation at least in one of the means when one-way ANOVA is conducted on the three samples. To check which samples had different means, t-Test was conducted on different combination, and the results show that there is significant variation in the means of slumps MC-FF and MC-CF mixtures with P value of 0.001. There is also significant variation in the means of the slumps of MC-MF and MC-CF mixtures. The variation in the means between MC-FF and MC-MF mixtures was found to be non-significant for 95% confidence level with P value of 0.07.

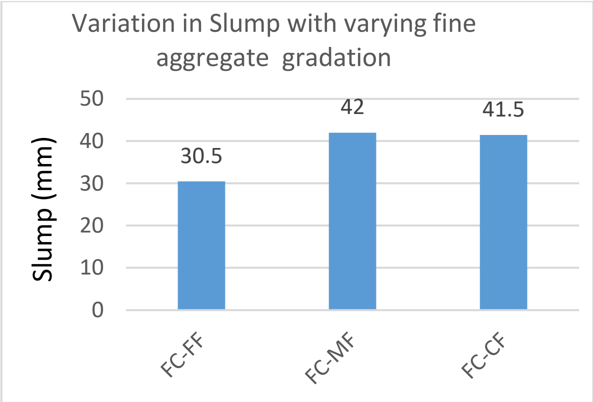
By keeping the coarse aggregate gradation on the finer limit and varying the fine aggregate gradation from finer to coarser limit of the specification no specific trend in slump value is observed. The slump values for coarser limit and middle of fine aggregate gradation are similar. There is significant variation between slump values of mixtures of FC-FF and FC-MF and FC-FF and FC-CF with P values of 0.017 and 0.026 respectively when t-Test is conducted. There is no significant variation in slump between FC-MF and FC-CF mixtures (P value of 0.34)

By keeping the coarse aggregate gradation on the coarser limit and varying the fine aggregate gradation from finer to coarser limit no specific trend in slump value is observed. The slump value obtained using the middle of limit of fine aggregate gradation is found to be slightly lower than that of finer limit and coarser limit gradation concrete slumps. There is significant variation between slump values of mixtures of CC-MF with CC-FF and CC-MF and CC-CF with P values of 0.0022 and 0.020 respectively when t-Test is conducted with alpha level of 0.05. There is no significant variation in slump between CC-FF and CC-CF mixtures (P value of 0.12)

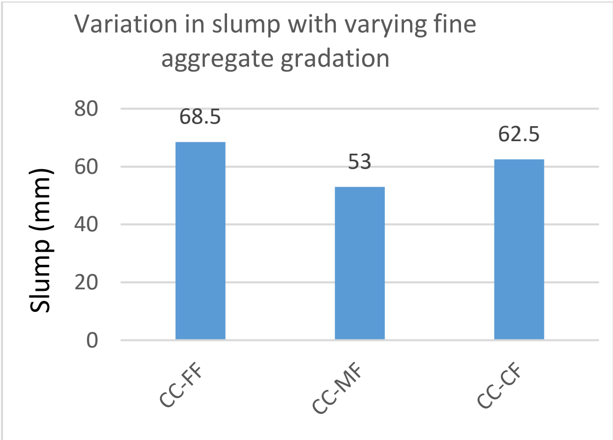
In general, the slumps obtained using finer coarse aggregate gradation with 0% mass retained on sieve size 19mm are lower compared with slumps obtained using middle and coarser limit of coarse aggregate gradation.



(a) Variation of slump with varying fine aggregate gradation within the specification keeping coarse aggregate in the middle of specification



(b) Variation of slump with varying fine aggregate gradation within the specification keeping coarse aggregate in finer limit



(c) Variation in slump with varying fine aggregate gradation within the specification keeping coarse aggregate in coarser limit

Figure 4. 13 Variation in Slump with Varying Fine Aggregate Gradation Within the Specification Limit

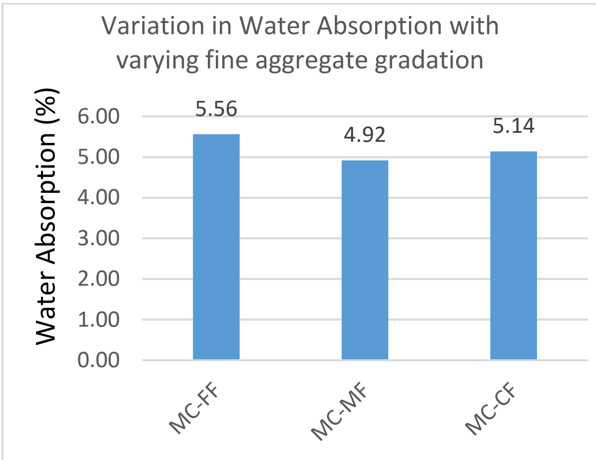
4.3.1.3 Water Absorption

Variation in water absorption with varying fine aggregate gradation within the specification limit and keeping the coarse aggregate gradation in the middle of specification resulted the lowest water absorption when using middle of limit of specification for fine aggregate. The water absorptions for concretes made with finer limit of gradation is high, 13% increased variation from water absorption of concrete made with middle of specification of fine aggregate. For the concrete made with the coarser limit of fine aggregate gradation the variation in water absorption is slight (4.47% increase). T-Test conducted between MC-FF and MC-MF resulted in P value of 0.016 that show there is significant variation between the means of the two, while P value obtained between MC-MF and MC-CF is 0.32 which not significant.

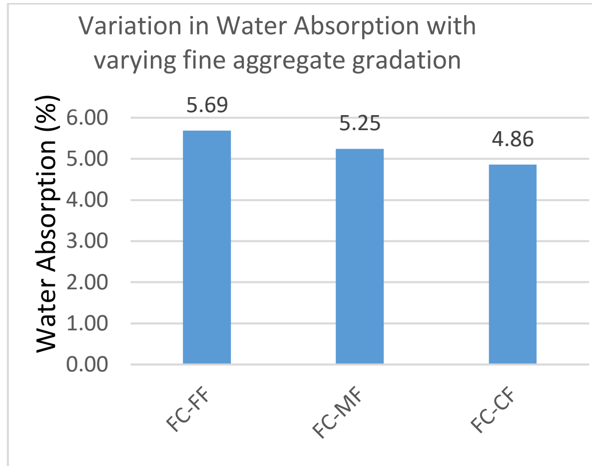
Variation in water absorption with varying fine aggregate gradation within the specification limit and keeping the coarse aggregate gradation in the finer limit resulted in continuous decrease in water absorption with increased coarseness of fine aggregate gradation. Refer Figure 4.14 (b). The variation in water absorption between concretes made with finer limit and coarse limit of fine aggregate is 17.1%. The P values obtained running t-Test between FC-FF & FC-MF, FC-FF & FC-CF, and FC-MF & FC-CF are 0.016, 1.75E-05 and 0.02 respectively. This show that there is significant variation among the means.

Keeping the coarse aggregate gradation in the coarser limit, varying the fine aggregate gradation from the finer limit to the coarser limit resulted in higher water absorption result for concrete made with the finer limit of fine aggregate (9.6% increased water absorption). The water absorption results for concreted made with coarser limit and middle of fine aggregate gradation specification are similar (5.02%). Refer figure 4.14 (c). The P values obtained running t-Test between CC-FF & CC-MF, CC-FF & CC-CF, and CC-MF & CC-CF are 0.02, 0.01 and 0.96 respectively. This show that there is significant variation between the means of CC-FF with CC-MF and CC-FF with CC-CF while there is no significant variation between CC-MF and CC-CF.

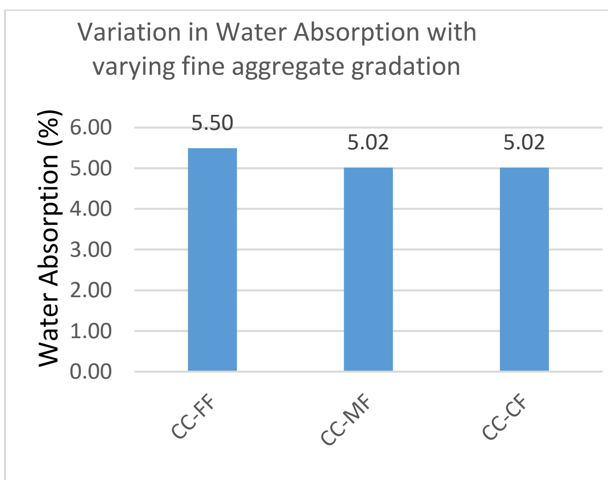
In general, as it could be observed in figure 4.14 (a), (b) and (c), the water absorption results obtained using finer limit of fine sand i.e. (MC-FF, FC-FF and CC-FF), although slight, had higher water absorption compared with the concretes made with coarser limit and middle of limit of fine aggregate gradation, which implies that there is higher risk of durability problem is using finer fine aggregates.



(a) Variation in Water Absorption with varying fine aggregate gradation within the specification keeping coarse aggregate in the middle of specification



(b) Variation in Water Absorption with varying fine aggregate gradation within the specification keeping coarse aggregate in finer limit



(c) Variation in Water Absorption with varying fine aggregate gradation within the specification keeping coarse aggregate in coarser limit

Figure 4. 14 Variation in Water Absorption with Varying Fine Aggregate Gradation Within the Specification Limit

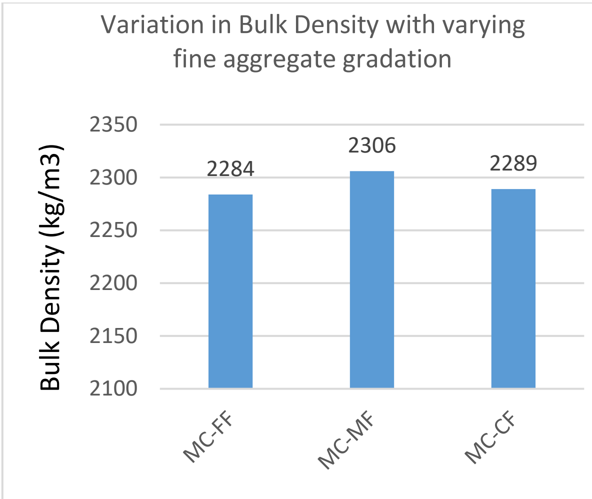
4.3.1.4 Bulk Density

Variation in bulk density with varying fine aggregate gradation within the specification limit and keeping the coarse aggregate gradation in the middle of specification resulted the highest bulk density when using middle of limit of specification for fine aggregate. There is only 0.95% variation in bulk density between concrete made using middle of limit and finer limit of specification. While the variation is only 0.73% between bulk densities for concretes made with middle of the limit and coarser limit.

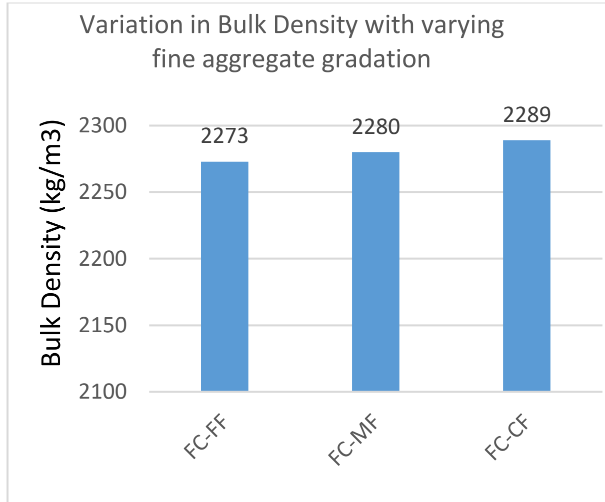
By keeping the coarse aggregate gradation on the finer limit and varying the fine aggregate gradations within the specification limits resulted in, even though very minimal, continuous increase in bulk density as the coarseness of the fine aggregate is increased. The variation in bulk density between coarser limit and finer limit of fine aggregate is only 0.7%

With the coarse aggregate gradation kept on the coarser limit of the specification, varying the fine aggregate gradations within the specification limits resulted in higher bulk density using middle of limit of fine aggregate. There is only 1.69% variation in bulk density between concrete made using middle of limit and finer limit of specification. While the variation is only 0.34% between bulk densities for concretes made with middle of the limit and coarser limit.

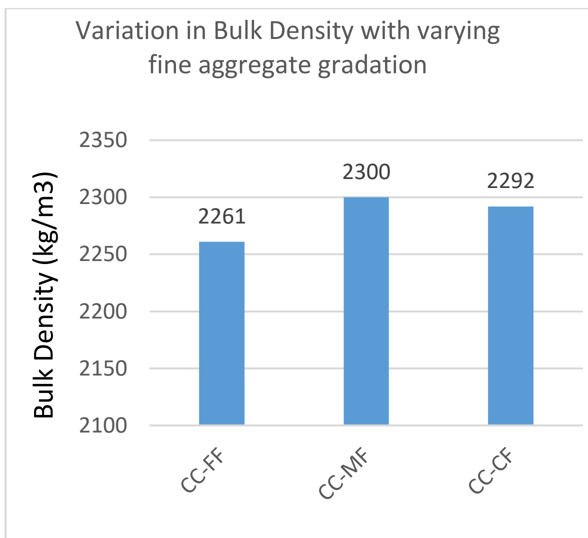
Even though the variation in bulk specific gravity is very minimal, there is a general trend that concretes made with finer limit of fine aggregate gradation (FC-FF, MC-FF, CC-FF) tend to have relatively lower bulk specific gravity (oven dry)



(a) Variation in Bulk Density with varying fine aggregate gradation within the specification keeping coarse aggregate in the middle of specification



(b) Variation in Bulk Density with varying fine aggregate gradation within the specification keeping coarse aggregate in finer limit



(c) Variation in Bulk Density with varying fine aggregate gradation within the specification keeping coarse aggregate in coarser limit

Figure 4. 15 Variation in Bulk Density with Varying Fine Aggregate Gradation Within the Specification Limit

4.3.2. Effect of variation of Coarse Aggregate Gradation within the Specification Limit

As shown in figure 3.8 (d),(e) and (f) the variation of coarse aggregate gradation within the specification limit had a pronounced effect on the percent retained on sieve size 4.75 and 19mm. it had also slight effect on the percent retained on sieve size 12.5mm. As presented in figure 3.8 (d), (e) and (f) as the coarseness of the coarse aggregate is increased the percent retained on sieve size 4.75 decreases while the percent retained on sieve size 19mm increases.

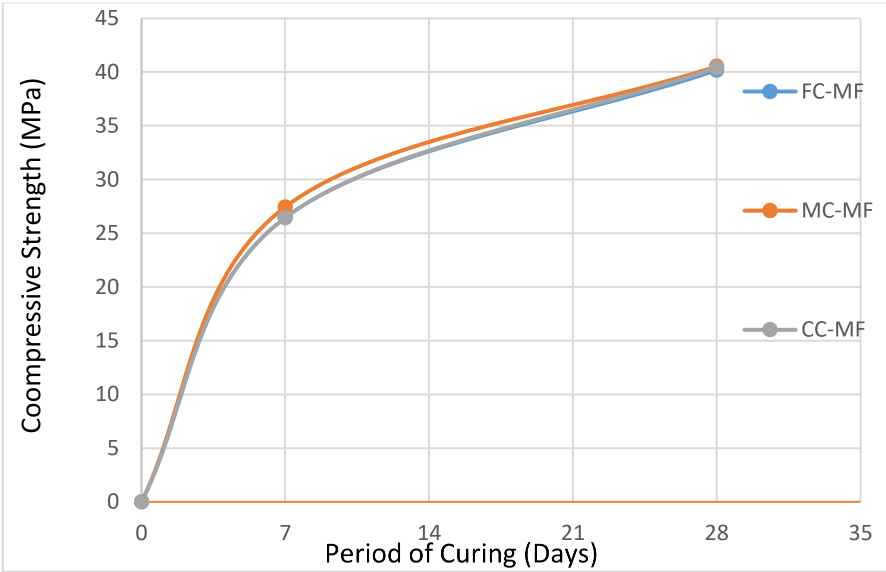
3.3.1.1 Compressive Strength

The effect of variation of coarse aggregate gradation on compressive strength is shown in the figure 4.16. As shown in figure 4.16, (a), keeping the fine aggregate gradation within the middle of the specification limit, no specific trend is observed and the 7-day and 28-day compressive strength obtained using the middle of limit of coarse aggregate gradation is higher compared to strengths obtained using the finer and coarser limit of coarse aggregate. Refer figure 4.16 a, b and c. The variation in 28-days compressive strength between concretes made with finer limit and middle of limit of coarse aggregate is 3.78%. Likewise, the variation is 28-day compressive strength between concretes made with coarser limit and middle of limit of coarse aggregate gradation is 3.78%. The F-statistical value obtained using one-way ANOVA is 0.05 and the critical F value is 5.14 for 95% confidence level for the three groups. This shows that there is no significant variation on the means when one-way ANOVA is conducted on the three groups. The P-value from the one-way ANOVA analysis for the three groups is also found to be 0.94 which is very greater than the alpha value selected (0.05 for 95% confidence level)

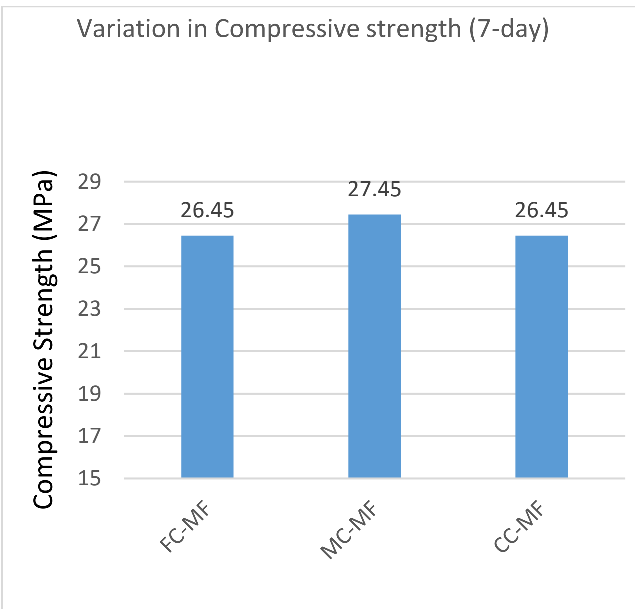
Keeping the fine aggregate gradation on finer limit of the specification varying the coarse aggregate gradation from finer limit to the coarser limit of the specification resulted in increased 7-day and 28-day compressive strength of concrete. There is high variation (8.57%) in 28-day compressive strength using the finer limit and coarser limit of coarse aggregate gradation. Refer figure 4.16 d, e, and f. The F-statistical value obtained using one-way ANOVA is 5.35 and the critical F value is 4.73 for 95% confidence level for the three groups. This shows that there is significant variation at least on one of the means when one-way ANOVA is conducted on the three groups with alpha level of 0.05. The t-Test showed that Signiant variation in compressive strength existed between FC-FF & CC-FF and, MC-FF & CC-FF gradation mixtures with P values of 0.04 and 0.05 respectively. For FC-FF and MC-FF, the P value obtained was 0.15 which show there is no significant variation in compressive strength between the two mixes.

For concrete mixtures prepared keeping fine aggregate gradation on the coarser limit of the specification and varying the coarse aggregate gradation from finer limit to coarser limit, resulted in decreased 7-day compressive strength and increased 28-day compressive strength. The results imply that early gain of strength for concretes made with finer limit of coarse aggregate are higher than concretes made with coarser limit and middle of limit of coarse aggregate keeping the fine aggregate gradation on the coarser limit. The 28-day compressive strength for concretes made with coarser limit of coarse aggregate has 4.54% increase compared to concrete made with the finer limit of coarse aggregate. Concrete made with middle of specification of coarse aggregate has almost similar compressive strength with the concrete made with finer limit of coarse aggregate. The F-statistical value obtained using one-way ANOVA is 0.76 and the critical F value is 5.14 for 95% confidence level for the three groups. This shows that there is no significant variation on the means when one-way ANOVA is conducted on the three groups. The P-value from the one-way ANOVA analysis for the three groups is also found to be 0.506 which is very greater than the alpha value selected (0.05 for 95% confidence level)

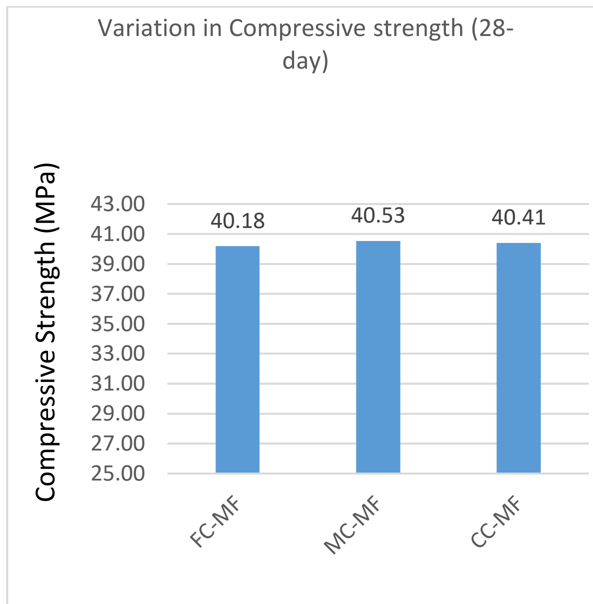
Even though not very significant, in general, concretes made with coarser limit fine aggregate had higher compressive strength compared with concretes made with middle of limit and finer limit of fine aggregate.



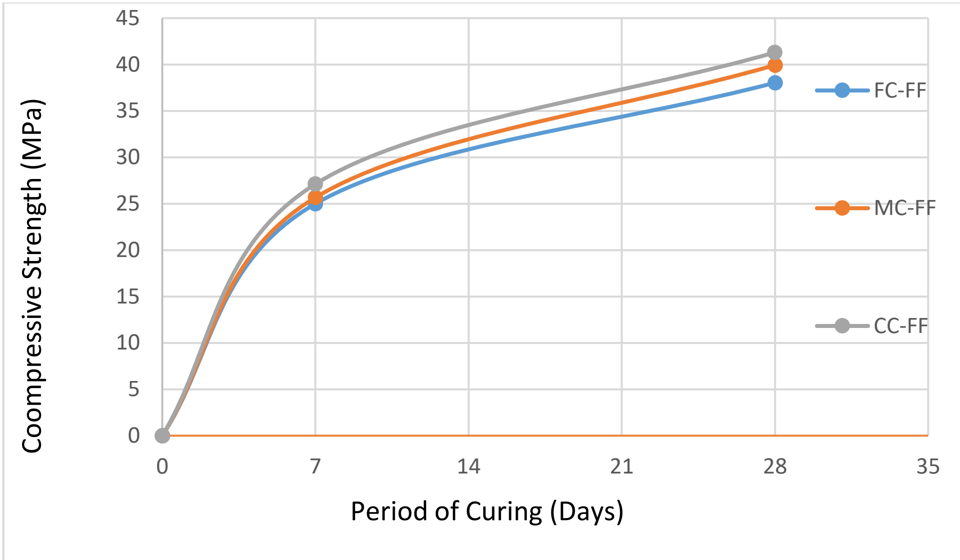
(a) Rate of Compressive strength Development



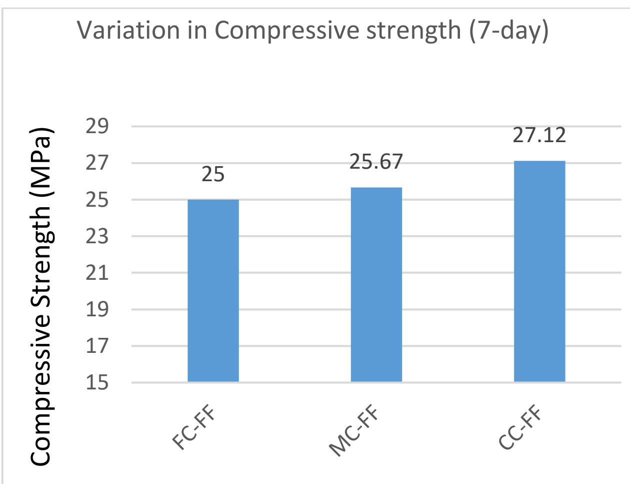
(b) Variation in Compressive strength (7-day) with varying Coarse aggregate gradation within the specification keeping fine aggregate in the middle of specification



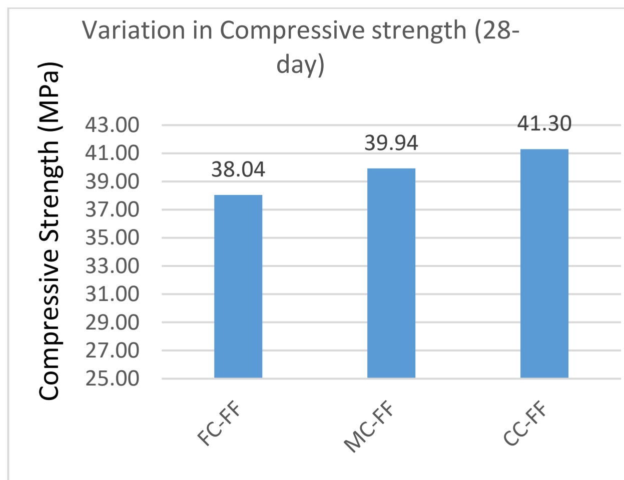
(c) Variation in Compressive strength (28-day) with varying coarse aggregate gradation within the specification keeping fine aggregate in the middle of specification



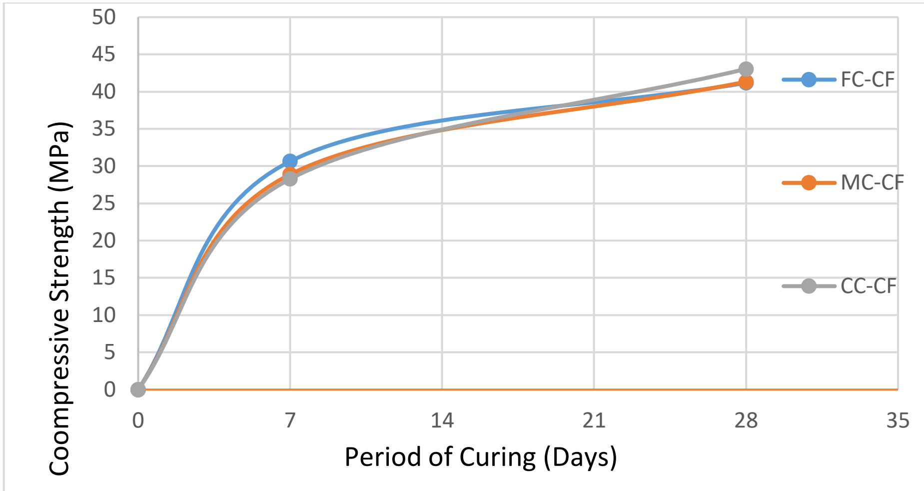
(d) Rate of Compressive Strength Development



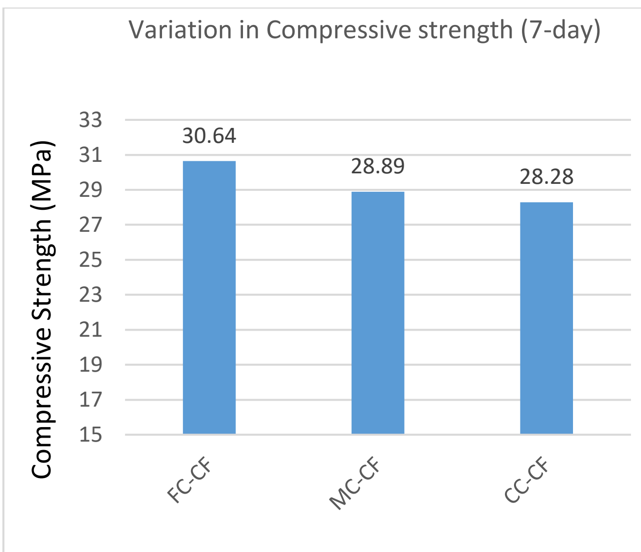
(e) Variation in Compressive strength (7-day) with varying coarse aggregate gradation within the specification keeping fine aggregate in finer limit



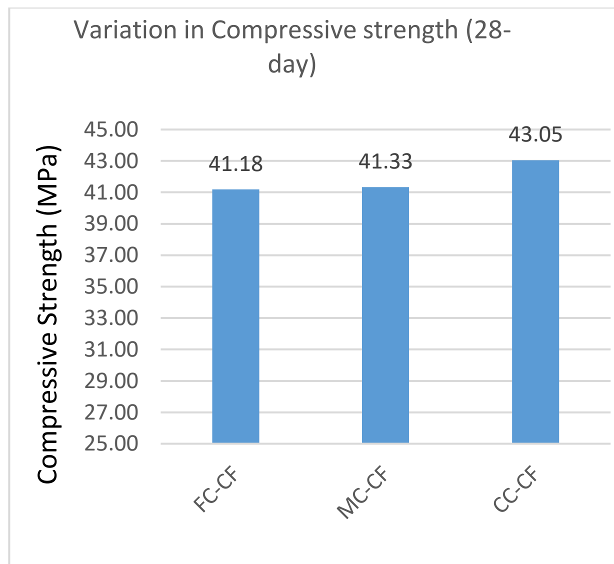
(f) Variation in Compressive strength (28-day) with varying coarse aggregate gradation within the specification keeping fine aggregate in finer limit



(g) Rate of Compressive Strenth Development



(h) Variation in Compressive strength (7-day) with varying coarse aggregate gradation within the specificaiton keeping fine aggregate in coarser limit



(i) Variation in Compressive strength (28-day) with varying coarse aggregate gradation within the specificaiton keeping fine aggregate in coarser limit

Figure 4. 16 Variation in 28-day and 7-day Compressive Strength with Varying Coarse Aggregate Gradation Within the Specification Limit

4.3.2.2 Slump

The effect of variation of coarse aggregate gradation within the specification limit are shown in figure 4.17.

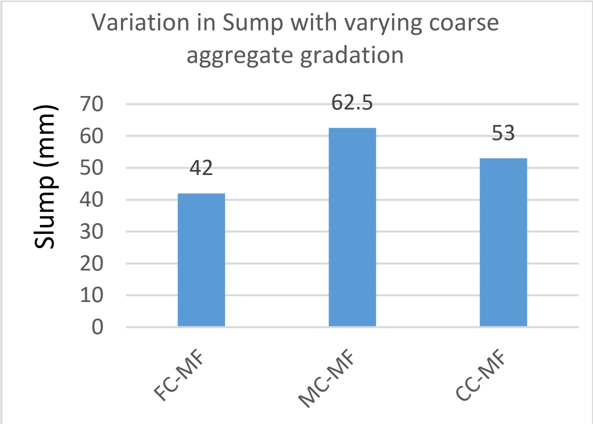
As shown in figure 3.8 (d),(e) and (f) the variation of coarse aggregate gradation within the specification limit had a pronounced effect on the percent retained on sieve size 4.75 and 19mm. it had also minimal effect on the percent retained on sieve size 12.5mm. As presented in figure 3.8 (d), (e) and (f) as the coarseness of the coarse aggregate is increased the percent retained on sieve size 4.75 decreases while the percent retained on sieve size 19mm increases.

As shown in figure 4.17 the variation of coarse aggregate gradation within the specification limit by keeping the fine aggregate gradation in the middle of the specification showed no specific trend in slump value. Concretes made with the middle of limit of gradation for coarse aggregate gradation resulted in higher slump value compared with slumps of concretes made with the finer and coarser limit of the coarse aggregate gradation. Decrease in slump of 32.8% is observed between the slumps of concrete made using the middle of limit and finer limit of specification for coarse aggregate. For the coarser limit concrete there is 15.2% decrease in slump. There is significant variation between slump values of mixtures of CC-MF &MC-MF, CC-MF & FC-MF, and MC-MF & FC-MF with P values of 0.017, 0.00003 and 2.73E-05 respectively when t-Test is conducted.

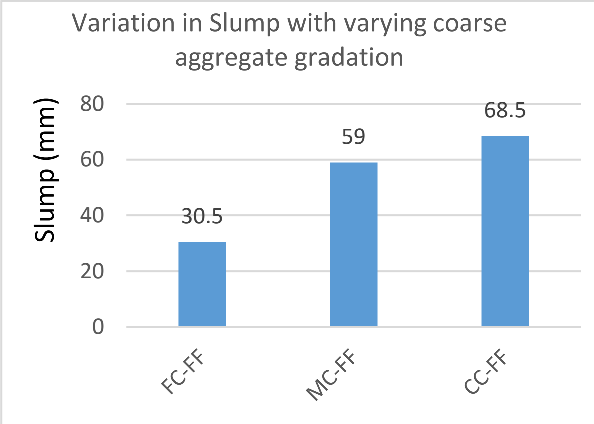
By keeping the fine aggregate gradation on the finer limit and varying the coarse aggregate gradation from finer to coarser limit of the specification resulted in continuous increase in slump value. There is 55% decrease in slump value between concretes made with coarser limit of gradation and finer limit of gradation of coarse aggregate. There is significant variation between slump values of mixtures of CC-FF &MC-FF, CC-FF & FC-FF and MC-FF & FC-FF with P values of 0.016, 0.00045 and 0.001 respectively when t-Test is conducted.

By keeping the fine aggregate gradation on the coarser limit and varying the coarse aggregate gradation from finer to coarser limit, no specific trend in slump value is observed. The slump value obtained using the middle of limit of fine aggregate gradation is found to be higher than that of finer limit and coarser limit gradation concrete slumps. There is significant variation between slump values of mixtures of CC-CF &MC-CF, CC-CF & FC-CF and MC-CF & FC-CF with P values of 0.031, 0.001 and 6.6E-05 respectively when t-Test is conducted.

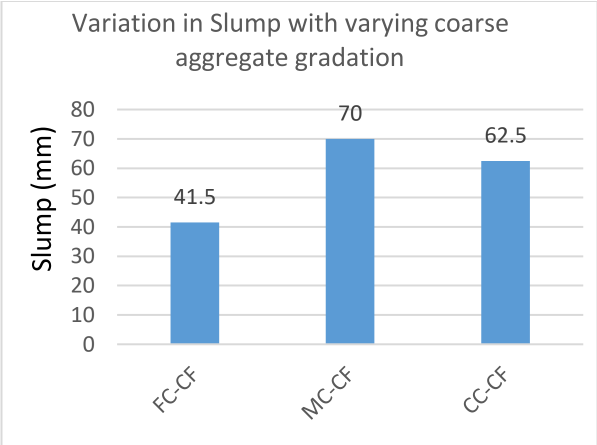
In general, the slumps obtained using finer coarse aggregate gradation with 0% retained on sieve size 19mm are lower compared with slumps obtained using middle and coarser limit of coarse aggregate gradation.



(a) Variation in Sump with varying coarse aggregate gradation within the specification keeping fine aggregate in the middle of specification



(b) Variation in Slump with varying coarse aggregate gradation within the specification keeping fine aggregate in finer limit



(c) Variation in Slump with varying coarse aggregate gradation within the specification keeping fine aggregate in coarser limit

Figure 4. 17 Variation in Slump with Varying Coarse Aggregate Gradation Within the Specification Limit

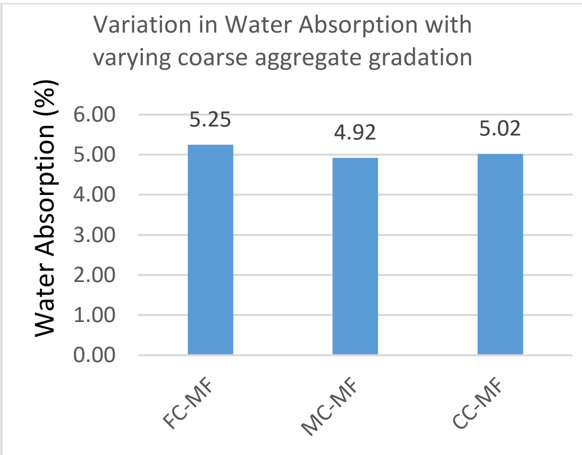
4.3.2.3 Water Absorption

Variation in water absorption with varying coarse aggregate gradation within the specification limit and keeping the fine aggregate gradation in the middle of specification resulted the lowest water absorption when using middle of limit of specification for coarse aggregate. The water absorptions for concretes made with finer limit of gradation is slightly higher, 6.7% increased variation from water absorption of concrete made with middle of specification of coarse aggregate. For the concrete made with the coarser limit of coarse aggregate gradation the variation in water absorption is minimal (2.03% increase). The P values obtained running t-Test between FC-MF & MC-MF, FC-MF & CC-MF, and MC-MF & CC-MF are 0.04, 0.12 and 0.2 respectively. This show that there is significant variation between the means of FC-MF & MC-MF while there is no significant variation between the means of FC-MF & CC-MF, and MC-MF & CC-MF mixtures

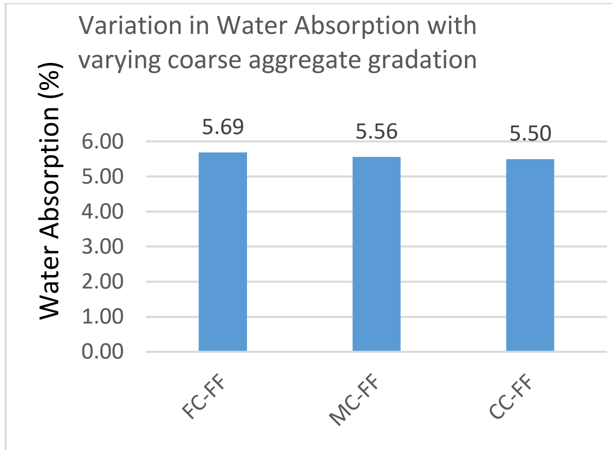
Variation in water absorption with varying coarse aggregate gradation within the specification limit and keeping the fine aggregate gradation in the finer limit resulted in, although minimal, continuous decrease in water absorption with increased coarseness of coarse aggregate gradation. Refer Figure 4.18, (b). The variation in water absorption between concretes made with finer limit and coarse limit of coarse aggregate is only 3.34%. The single ANOVA test conducted on the three groups resulted in P value of 0.5 and F-statistical of 0.76. The critical F value for 95% confidence level is 5.14. This shows that there is no significant variation among the three groups

Keeping the fine aggregate gradation in the coarser limit and varying the coarse aggregate gradation from the finer limit to the coarser limit resulted in higher water absorption result for concrete made with the middle of limit of coarse aggregate. The variation in water absorption results between concrete made with coarser limit and middle of coarse aggregate gradation specification is 2.33% decrease for concrete made with coarser limit. There is 5.44% decrease for concrete made with finer limit of coarse aggregate compared to concrete made with middle of the limit of coarse aggregate. Refer figure 4.18 (c). The single ANOVA test conducted on the three groups resulted in P value of 0.28 and F-statistical of 0.1.55. The critical F value for 95% confidence level is 5.14. This shows that there is no significant variation among the three groups

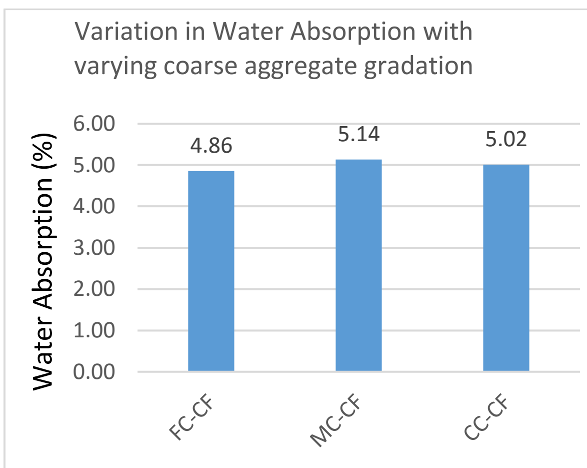
In general, as it could be observed in figure 4.18 a, b and c, the water absorption results obtained using finer limit of fine sand i.e. (FC-FF, MC-FF and CC-FF) although minimal had higher water absorption compared with the concretes made with coarser limit and middle of limit of fine aggregate gradation, which implies that there is higher risk of durability problem is using finer fine aggregates.



(a) Variation in Water Absorption with varying coarse aggregate gradation within the specification keeping fine aggregate in the middle of specification



(b) Variation in Water Absorption with varying coarse aggregate gradation within the specification keeping fine aggregate in finer limit



(c) Variation in Water Absorption with varying coarse aggregate gradation within the specification keeping fine aggregate in coarser limit

Figure 4. 18 Variation in Water Absorption with Varying Coarse Aggregate Gradation Within the Specification Limit

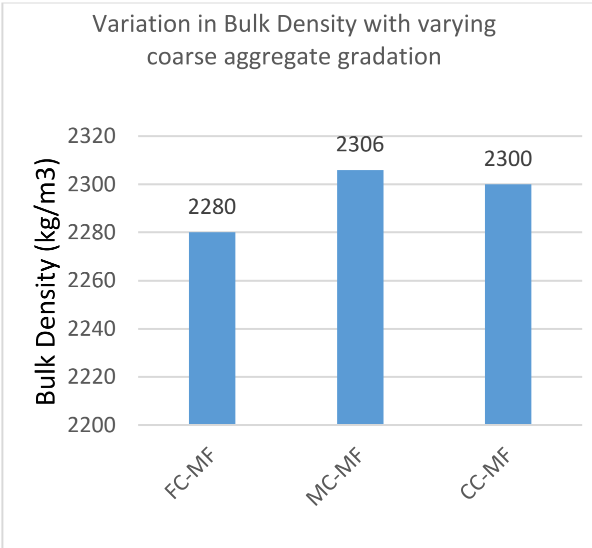
4.3.2.4 Bulk Density

Variation in bulk density with varying coarse aggregate gradation within the specification limit and keeping the fine aggregate gradation in the middle of specification resulted the highest bulk density when using middle of limit of specification for coarse aggregate. There is only 1.12% variation in bulk density between concrete made using middle of limit and finer limit of specification. While the variation is only 0.26% between bulk densities for concretes made with middle of the limit and coarser limit.

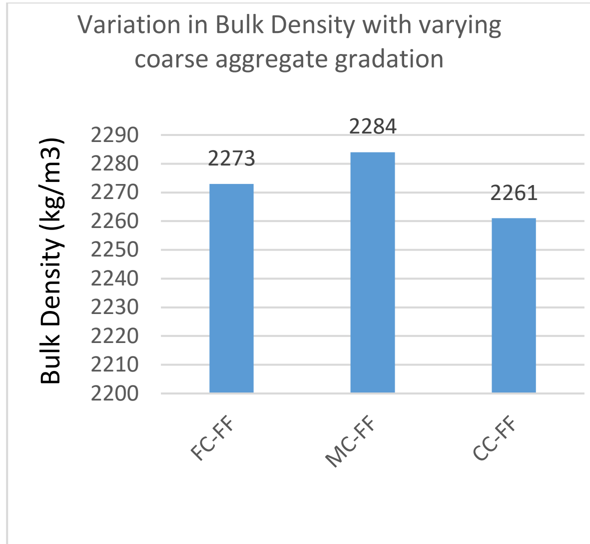
By keeping the fine aggregate gradation on the finer limit and varying the coarse aggregate gradations within the specification limits resulted in highest bulk density when using middle of limit of specification for coarse aggregate. There is only 0.4% variation in bulk density between concrete made using middle of limit and finer limit of specification of coarse aggregate. While the variation is only 1.0% between bulk densities for concretes made with middle of the limit and coarser limit.

With the coarse aggregate gradation kept on the coarser limit of the specification, varying the fine aggregate gradations within the specification limits resulted in almost similar bulk density results. There is only 0.13% variation in bulk density between concrete made using middle of limit and coarse limit of specification for coarse aggregate while the bulk densities of middle of limit and finer limit were found to be equal

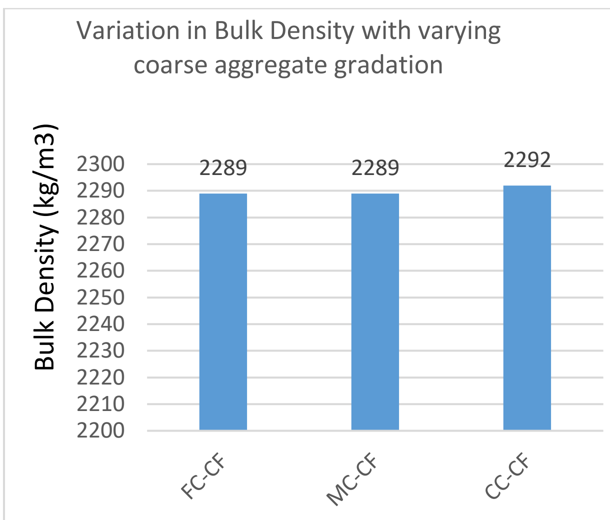
Even though the variation in bulk specific gravity is very minimal, there is a general trend that concretes made with finer limit of fine aggregate gradation (FC-FF, MC-FF, CC-FF) tend to have relatively lower bulk specific gravity (oven dry).



(a) Variation in Bulk Density with varying coarse aggregate gradation within the specification keeping fine aggregate in the middle of specification



(b) Variation in Bulk Density with varying coarse aggregate gradation within the specification keeping fine aggregate in finer limit



(a)Variation in Bulk Density with varying coarse aggregate gradation within the specification keeping fine aggregate in coarser limit

Figure 4. 19 Variation in Bulk Density with Varying Coarse Aggregate Gradation Within the Specification Limit

The following are representative pictures taken during sample preparation and testing of the fresh and hardened properties of cement concrete.

Slump Test

Sample Preparation

Compressive Strength Test and Shape of failed Cube

Failed Cube

Bath for Concrete Cubes

Figure 4. 20 Pictures Showing Tests Conducted on Concrete Mixtures

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

5.1.1. Effect of Failed Coarse Aggregate Gradation on Concrete properties

- Noncompliance to the specification limits of gradation on specific sieves of coarse aggregate beyond the finer limit has significant impact in increasing the compressive strength and decreasing the slump, while failure beyond the coarser limit has no to minimal impact on compressive strength and slump of concrete.
- The slumps obtained using finer coarse aggregate gradation i.e 10% more finer, 5% more finer and finer limit, with 0% retained on sieve size 19mm are much lower and harsh compared with slumps obtained using middle of limit, coarser limit, 5% more coarser and 10% more coarser coarse aggregates. This may be due to higher surface area in finer aggregate that absorbs water.
- Much of the observed change in property of water absorption of concrete was observed because of variations in gradations within the limits set in the specification. Gradations of coarse aggregate that fell out of specification (beyond finer limit and beyond coarse limit) showed minimal change in water absorption of concrete.

5.1.2. Effect of Failed Fine Aggregate Gradations on Concrete Properties.

- Slump of concrete is highly affected by variation in gradation of fine aggregate. Concrete mixtures made with gradations of fine aggregates that are finer than 2.6 FM, showed significantly lower slump. Slumps of failed aggregate gradations beyond the coarser limit (3.54 FM) also showed significant reduction in slump.
- Compared with the control gradations, mixtures with gradation of fine aggregate that were too fine resulted in high reduction in slump. This is the same with findings of other researches that the surface area and the water demand will be highly increased as the fine aggregate gets finer.
- Deviation in fine aggregate gradation had a minimal influence on the compressive strength of concrete. Even though not very significant, the compressive strength tends to increase with increased coarseness (increased FM) of fine aggregate
- Even though the water absorption value increment in percentage for concrete made with finer limit gradation (FM=2.8) and failed gradations beyond the finer limit (FM=2.6, 2.4,

2.2, 2.0 and 1.8) are not large, compared with water absorption of concrete made with middle of the limit (FM=3.17), they are likely to have higher water absorption than the rest of mixtures. This implies there is a slightly more durability risk in using fine aggregates that fall out of the specification on the finer side.

5.1.3. Effect of Variation of Aggregate Gradations within the Specification Limit

- Even though the variations are slight, concretes made with coarser fine aggregates (FC-CF, MC-CF, CC-CF) showed increased compressive strength compared with concretes made with finer limit and middle of limit of fine aggregates.
- The slumps obtained using finer coarse aggregate gradation with 0% retained on sieve size 19mm are lower compared with slumps obtained using middle and coarser limit of coarse aggregate gradation.
- The water absorption results obtained using finer limit of fine sand i.e. (MC-FF, FC-FF and CC-FF), although slight, had higher water absorption compared with the concretes made with coarser limit and middle of limit of fine aggregate gradation, which implies that there is higher risk of durability problem is using finer fine aggregates.

5.2. Recommendations

Based on the findings of this study, the following recommendations are given

To come to a decisive conclusion, additional studies should be conducted by using different cement concrete and water cement ratio than that is incorporated in the study. Also, additional study incorporating crushed sand shall be made as currently crushed sand is being utilized in more quantities than before.

Additional properties of cement concrete like permeability shall be considered in future researches. The finishabilty and response to vibration of concrete mixtures shall also need to be considered in future researches.

Zero percent retained material on sieve size 19 resulted in lower slump values and the mixtures were found to be very harsh. This entails that the gradation of the coarse aggregate shall include up to 10% more coarser aggregates as it has advantage of improving slump and reduction in cost as production of coarser aggregates is relatively easy.

The current gradations provided in ERA Standard Technical Specification for coarse aggregates tend to be gap graded. Even though, in this research 12.5mm sieve size is deliberately incorporated as a specification, the specification does not specify limits for the 12.5mm sieve. In the specification limits are set for 10mm sieve, the next sieve to 10mm is 19mm. The gap between 10mm sieve and 12.5mm sieve is very narrow and normally, much of the aggregates passing 19mm and retained on sieve size 10mm are coarser than 12.5mm sieve size. This intern leads to higher percent retain on sieve size 12.5mm and which may result in poor cohesion.

Concretes made with the upper limit of fine aggregate tended to have cohesion problem and tear across the surface when trying to finish. The gradation of the upper limit allows much percent of 2.36mm and 1.18mm to be retained that resulted in poor cohesion but this problem is not observed on concretes made with middle of limit of specification for fine aggregate (3.17 FM). So, the upper boundary of fine aggregate gradation shall be reduced.

Concretes made with 1.8 FM, 2.0 FM and 2.2 FM tended to have big cohesion problem and there was also segregation observed. The mixes were also found to be very harsh. But for concrete mixtures made with 2.4 FM and 2.6 FM showed no such problem and the specification shall be relaxed to incorporate them.

Gradations based on combined gradations shall be considered in specifying aggregates as strict control on fine and coarse aggregate gradations separately may not provide the desired concrete mix properties.

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APPENDICES

APPENDIX A

ANOVA AND t-TEST STATISTICAL ANALYSIS

APPENDIX A - Statistical Analysis Using Single ANOVA and t-Test

Statistical anaysis using ANOVA for 28-day Compressive Strength				
Varying Coarse aggregate Gradation within and beyond the specification keeping the fine aggregate in the middle of specification(3.17FM)				
Groups	*F*	*P-value*	*F crit*	*Remark*
10% more finer	6.18184231	0.001982278	2.790464997	Reject the null hypothesis
5% more finer				
Finer Limit				
Middle of Limit				
Coarser Limit				
5% more Coarser				
10% more coarser				

Statistical anaysis using ANOVA for 28-day Compressive Strength				
Varying Coarse aggregate Gradation within and beyond the specification keeping the fine aggregate in the middle of specification(3.17FM)				
Groups	*F*	*P-value*	*F crit*	*Remark*
Finer limit	0.920598893	0.486124638	3.356690021	Accept the null hypothesis
Middle of Limit				
Coarser limit				
5% more Coarser				
10% more coarser				

t-Test: Two-Sample Assuming Equal Variances for 28-day Compressive Strength			
Varying Coarse aggregate Gradation within and beyond the specification keeping the fine aggregate in the middle of specification(3.17FM)			
Groups		P(T<=t) two-tail	Remark
10% more finer	*10% more finer*	0.338816137	Accept
	Finer limit	0.005279804	Reject
	Middle of Limit	0.010818518	Reject
	Coarser limit	0.026938848	Reject
	5% more Coarser	0.001062245	Reject
	10% more coarser	0.021911506	Reject
5% more finer	*Finer limit*	0.014777634	Reject
	Middle of Limit	0.029193096	Reject
	Coarser limit	0.05837986	Accept
	5% more Coarser	0.00259207	Reject
	10% more coarser	0.040493011	Reject

APPENDIX A - Statistical Analysis Using Single ANOVA and t-Test

Statistical anaysis using ANOVA for 28-day Compressive Strength				
Varying fine aggregate Gradation within and beyond the specification and keeping the coarse aggregate in the middle of specification				
Groups	*F*	*P-value*	*F crit*	*Remark*
1.8 FM	2.827995203	0.022506142	2.341937328	Reject the null hypothesis
2.0 FM				
2.2 FM				
2.4 FM				
2.6 FM				
2.8 FM				
Middle of Limit				
3.54 FM				
3.74 FM				
3.94 FM				

Statistical anaysis using ANOVA for 28-day Compressive Strength				
Varying fine aggregate Gradation within and beyond the specification and keeping the coarse aggregate in the middle of specification				
Groups	*F*	*P-value*	*F crit*	*Remark*
1.8 FM	1.422247455	0.247326545	2.447063748	Accept the null hypothesis
2.0 FM				
2.2 FM				
2.4 FM				
2.6 FM				
2.8 FM (finer limit)				
3.17 FM(middle of limit)				
3.54 FM(coarser limit)				
3.74 FM				

t-Test: Two-Sample Assuming Equal Variances for 28-day Compressive Strength			
Varying fine aggregate Gradation within and beyond the specification and keeping the			
Groups		P(T<=t) two-tail	Remark
3.94 FM	*3.74 FM*	0.038177252	Reject
	3.54 FM	0.360055521	Accept
	Middle of Limit	0.091505701	Accept
	2.8 FM	0.017318646	Reject
	2.6 FM	0.028755985	Reject
	2.4 FM	0.010229832	Reject
	2.2 FM	0.009628593	Reject
	2.0 FM	0.01106565	Reject
	1.8 FM	0.065450681	Accept

APPENDIX A - Statistical Analysis Using Single ANOVA and t-Test

Statistical anaysis using ANOVA for 28-day Compressive Strength				
Varying fine aggregate Gradation within the specification and keeping the coarse aggregate in the middle of specification				
Groups	*F*	*P-value*	*F crit*	*Remark*
MC-FF	0.966340754	0.432706777	5.14325285	Accept
MC-MF				
MC-CF				

Statistical anaysis using ANOVA for 28-day Compressive Strength				
Varying fine aggregate Gradation within the specification and keeping the coarse aggregate in the finer limit of specification				
Groups	*F*	*P-value*	*F crit*	*Remark*
FC-FF	2.069892075	0.196686442	4.737414128	Accept
FC-MF				
FC-CF				

Statistical anaysis using ANOVA for 28-day Compressive Strength				
Varying fine aggregate Gradation within the specification and keeping the coarse aggregate in the coarser limit of specification				
Groups	*F*	*P-value*	*F crit*	*Remark*
CC-FF	4.182311931	0.072873726	5.14325285	Accept for alpha 0.05 but reject for alpha 0.1
CC-MF				
CC-CF				

t-Test: Two-Sample Assuming Equal Variances for 28-day Compressive Strength			
Varying fine aggregate Gradation within the specification and keeping the coarse aggregate in the coarser limit of specification			
Groups		P(T<=t) two-tail	Remark
CC-FF	*CC-MF*	0.460612532	Accept
CC-FF	*CC-CF*	0.038343723	Reject
CC-MF	*CC-CF*	0.062195945	Accept for alpha 0.05 but reject for alpha 0.1

APPENDIX A - Statistical Analysis Using Single ANOVA and t-Test

Statistical anaysis using ANOVA for 28-day Compressive Strength				
Varying Coarse aggregate Gradation within the specification and keeping the Fine aggregate in the Middle of limit of specification (3.17FM)				
Groups	*F*	*P-value*	*F crit*	*Remark*
CC-MF	0.055007125	0.946950073	5.14325285	Accept
MC-MF				
FC-MF				

Statistical anaysis using ANOVA for 28-day Compressive Strength				
Varying Coarse aggregate Gradation within the specification and keeping the Fine aggregate in the finer limit of specification (2.8 FM)				
Groups	*F*	*P-value*	*F crit*	*Remark*
CC-FF	5.359512639	0.038752859	4.737414128	Reject
MC-FF				
FC-FF				

t-Test: Two-Sample Assuming Equal Variances for 28-day Compressive Strength			
Varying Coarse aggregate Gradation within the specification and keeping the Fine aggregate in the finer limit of specification (2.8 FM)			
Groups		P(T<=t) two-tail	Remark
CC-FF	*MC-FF*	0.054209396	Accept for alpha 0.05 but reject for alpha 0.1
CC-FF	*FC-FF*	0.040670684	Reject
MC-FF	*FC-FF*	0.152451247	Accept

Statistical anaysis using ANOVA for 28-day Compressive Strength				
Varying Coarse aggregate Gradation within the specification and keeping the Fine aggregate in the coarser limit of specification (2.8 FM)				
Groups	*F*	*P-value*	*F crit*	*Remark*
CC-CF	0.762769549	0.506805013	5.14325285	Accept
MC-CF				
FC-CF				

APPENDIX A - Statistical Analysis Using Single ANOVA and t-Test

Statistical anaysis using ANOVA for Slump				
Varying Coarse aggregate Gradation within and beyond the specification keeping the fine aggregate in the middle of specification(3.17FM)				
Groups	*F*	*P-value*	*F crit*	*Remark*
10% more finer	61.5849359	2.91458E-09	2.847725996	Reject the null hypothesis
5% more finer				
Finer Limit				
Middle of Limit				
Coarser Limit				
5% more Coarser				
10% more coarser				

t-Test: Two-Sample Assuming Equal Variances For Slump			
Varying Coarse aggregate Gradation within and beyond the specification keeping the fine aggregate in the middle of specification(3.17FM)			
Groups		P(T<=t) two-tail	Remark
Middle of Limit	*Finer Limit*	2.91957E-05	Reject
	5% more finer	0.000589165	Reject
	10% more finer	4.49508E-06	Reject
	Coarser Limit	0.001955686	Reject
	5% more Coarser	0.405715488	Accept
	10% more coarser	0.020092107	Reject
Finer Limit	*5% more finer*	0.026809276	Reject
	10% more finer	1.41432E-05	Reject
	Coarser Limit	0.000308532	Reject
	5% more Coarser	0.002619332	Reject
	10% more coarser	8.36435E-05	Reject
Coarser Limit	*10% more finer*	1.67527E-05	Reject
	5% more finer	0.002294565	Reject
	5% more Coarser	0.026405565	Reject
	10% more coarser	0.025481481	Reject
5% more finer	*10% more finer*	0.531679758	Accept
5% more Coarser	*10% more coarser*	0.089775871	Accept

APPENDIX A - Statistical Analysis Using Single ANOVA and t-Test

Statistical anaysis using ANOVA for Slump				
Varying fine aggregate Gradation within and beyond the specification and keeping the coarse aggregate in the middle of specification				
Groups	*F*	*P-value*	*F crit*	*Remark*
1.8 FM	70.0531401	3.7407E-13	2.392814108	Reject the null hypothesis
2.0 FM				
2.2 FM				
2.4 FM				
2.6 FM				
2.8 FM				
Middle of Limit				
3.54 FM				
3.74 FM				
3.94 FM				

t-Test: Two-Sample Assuming Equal Variances for Slump			
Varying fine aggregate Gradation within and beyond the specification and keeping the coarse aggregate in the middle of specification			
Groups		P(T<=t) two-tail	Remark
Middle of Limit (3.17 FM)	*2.8 FM*	0.078224885	Accept
	3.54 FM	0.001244101	Reject
	1.8 FM	0.000247865	Reject
	2.0 FM	0.000212839	Reject
	2.2 FM	0.000197148	Reject
	2.4 FM	0.000672594	Reject
	2.6 FM	0.134701935	Accept
	3.74 FM	0.000433759	Reject
	3.94 FM	0.001539283	Reject
Finer Limit (2.8 FM)	*3.94 FM*	0.006464559	Reject
	3.74 FM	0.005358819	Reject
	3.54 FM	0.00143909	Reject
	1.8 FM	0.000881687	Reject
	2.0 FM	0.002122883	Reject
	2.2 FM	0.005023998	Reject
	2.4 FM	0.023215158	Reject
	2.6 FM	0.382319325	Accept
3.54 FM	*1.8 FM*	5.81843E-05	Reject
	2.0 FM	1.49526E-05	Reject
	2.2 FM	1.84501E-06	Reject
	2.4 FM	3.81961E-06	Reject
	2.6 FM	0.000447238	Reject
	3.74 FM	2.40522E-05	Reject
	3.94 FM	0.000276034	Reject
2.6 FM	*2.4 FM*	0.002110646	Reject
	2.2 FM	0.000447238	Reject
	2.0 FM	0.000394036	Reject
	1.8 FM	0.000367451	Reject
2.4 FM	*2.2 FM*	0.002110646	Reject
	2.0 FM	0.001756611	Reject
	1.8 FM	0.00103096	Reject
2.2 FM	*2.0 FM*	0.017704299	Reject
	1.8 FM	0.002603614	Reject
2.0 FM	*1.8 FM*	0.013415402	Reject
3.74 FM	*3.94 FM*	0.172593857	Accept

APPENDIX A - Statistical Analysis Using Single ANOVA and t-Test

Statistical anaysis using ANOVA for Slump				
Varying fine aggregate Gradation within the specification and keeping the coarse aggregate in the middle of specification				
Groups	*F*	*P-value*	*F crit*	*Remark*
MC-FF	35.14814815	0.000486344	5.14325285	Reject
MC-MF				
MC-CF				

t-Test: Two-Sample Assuming Equal Variances for Slump			
Varying fine aggregate Gradation within the specification and keeping the coarse aggregate in the middle of specification			
Groups		P(T<=t) two-tail	Remark
MC-FF	*MC-MF*	0.078224885	Accept
MC-FF	*MC-CF*	0.00143909	Reject
MC-MF	*MC-CF*	0.001244101	Reject

Statistical anaysis using ANOVA for Slump				
Varying fine aggregate Gradation within the specification and keeping the coarse aggregate in the finer limit of specification				
Groups	*F*	*P-value*	*F crit*	*Remark*
FC-FF	12.97701149	0.006620292	5.14325285	Reject
FC-MF				
FC-CF				

t-Test: Two-Sample Assuming Equal Variances			
Varying fine aggregate Gradation within the specification and keeping the coarse aggregate in the finer limit of specification			
Groups		P(T<=t) two-tail	Remark
FC-FF	*FC-MF*	0.017348091	Reject
FC-FF	*FC-CF*	0.026039031	Reject
FC-MF	*FC-CF*	0.348641139	Accept

Statistical anaysis using ANOVA for Slump				
Varying fine aggregate Gradation within the specification and keeping the coarse aggregate in the coarser limit of specification				
Groups	*F*	*P-value*	*F crit*	*Remark*
CC-FF	17.33333333	0.003211723	5.14325285	Reject
CC-MF				
CC-CF				

t-Test: Two-Sample Assuming Equal Variances for Slump			
Varying fine aggregate Gradation within the specification and keeping the coarse aggregate in the coarser limit of specification			
Groups		P(T<=t) two-tail	Remark
CC-FF	*CC-MF*	0.002270372	Reject
CC-FF	*CC-CF*	0.124235982	Accept
CC-MF	*CC-CF*	0.020092107	Reject

APPENDIX A - Statistical Analysis Using Single ANOVA and t-Test

Statistical anaysis using ANOVA for Slump				
Varying Coarse aggregate Gradation within the specification and keeping the Fine aggregate in the Middle of limit of specification (3.17FM)				
Groups	*F*	*P-value*	*F crit*	*Remark*
CC-MF	186.4666667	3.96977E-06	5.14325285	Reject
MC-MF				
FC-MF				

t-Test: Two-Sample Assuming Equal Variances for Slump			
Varying Coarse aggregate Gradation within the specification and keeping the Fine aggregate in the Middle of limit of specification (3.17FM)			
Groups		P(T<=t) two-tail	Remark
CC-MF	*MC-MF*	0.001705157	Reject
CC-MF	*FC-MF*	0.000308532	Reject
MC-MF	*FC-MF*	2.73409E-05	Reject

Statistical anaysis using ANOVA for Slump				
Varying Coarse aggregate Gradation within the specification and keeping the Fine aggregate in the finer limit of specification (2.8 FM)				
Groups	*F*	*P-value*	*F crit*	*Remark*
CC-FF	77.6	5.15654E-05	5.14325285	Reject
MC-FF				
FC-FF				

t-Test: Two-Sample Assuming Equal Variances for Slump			
Varying Coarse aggregate Gradation within the specification and keeping the Fine aggregate in the finer limit of specification (2.8 FM)			
Groups		P(T<=t) two-tail	Remark
CC-FF	*MC-FF*	0.016010966	Reject
CC-FF	*FC-FF*	0.000450855	Reject
MC-FF	*FC-FF*	0.001057565	Reject

Statistical anaysis using ANOVA for Slump				
Varying Coarse aggregate Gradation within the specification and keeping the Fine aggregate in the coarser limit of specification (2.8 FM)				
Groups	*F*	*P-value*	*F crit*	*Remark*
CC-CF	106.9649123	2.03049E-05	5.14325285	Reject
MC-CF				
FC-CF				

t-Test: Two-Sample Assuming Equal Variances for Slump			
Varying Coarse aggregate Gradation within the specification and keeping the Fine aggregate in the finer limit of specification (2.8 FM)			
Groups		P(T<=t) two-tail	Remark
CC-CF	*MC-CF*	0.031296042	Reject
CC-CF	*FC-CF*	0.001026183	Reject
MC-CF	*FC-CF*	6.6558E-06	Reject

APPENDIX A - Statistical Analysis Using Single ANOVA and t-Test

Statistical anaysis using ANOVA for Water Absorption				
Varying Coarse aggregate Gradation within and beyond the specification keeping the fine aggregate in the middle of specification(3.17FM)				
Groups	*F*	*P-value*	*F crit*	*Remark*
10% more finer	0.133895855	0.87722315	5.14325285	Accept the null hypothesis
5% more finer				
finer limit				

t-Test: Two-Sample Assuming Equal Variances For Water Absorption			
Varying Coarse aggregate Gradation within and beyond the specification keeping the fine aggregate in the middle of specification(3.17FM)			
Groups		P(T<=t) two-tail	Remark
Middle of Limit	*Finer Limit*	0.041941771	Reject
	Coarser Limit	0.296290311	Accept
Coarser Limit	*5% more Coarser*	0.231090739	Accept

APPENDIX A - Statistical Analysis Using Single ANOVA and t-Test

Statistical anaysis using ANOVA for Water Absorption				
Varying fine aggregate Gradation within and beyond the specification and keeping the coarse aggregate in the middle of specification				
Groups	*F*	*P-value*	*F crit*	*Remark*
1.8 FM	1.061703728	0.427657502	3.105875239	Accept the null hypothesis
2.0 FM				
2.2 FM				
2.4 FM				
2.6 FM				
2.8 FM (MC-FF)				

Statistical anaysis using ANOVA for Water Absorption				
Varying fine aggregate Gradation within and beyond the specification and keeping the coarse aggregate in the middle of specification				
Groups	*F*	*P-value*	*F crit*	*Remark*
3.17 FM (MC-MF) Middle of limit	0.696993451	0.579537006	4.066180551	Accept the null hypothesis
3.54 FM (MC-CF)				
3.74 FM				
3.94 FM				

t-Test: Two-Sample Assuming Equal Variances For Water Absorption			
Varying fine aggregate Gradation within and beyond the specification and keeping the coarse aggregate in the middle of specification			
Groups		P(T<=t) two-tail	Remark
Middle of Limit (3.17 FM)	*2.8 FM*	0.016304176	Reject
	3.54 FM	0.32124857	Accept

APPENDIX A - Statistical Analysis Using Single ANOVA and t-Test

Statistical anaysis using ANOVA for Water Absorption				
Varying fine aggregate Gradation within the specification and keeping the coarse aggregate in the middle of specification				
Groups	*F*	*P-value*	*F crit*	*Remark*
MC-FF	5.056975145	0.051623529	5.14325285	Accept for alpha 0.05 but reject for alpha 0.1
MC-MF				
MC-CF				

t-Test: Two-Sample Assuming Equal Variances For Water Absorption			
Varying fine aggregate Gradation within the specification and keeping the coarse aggregate in the middle of specification			
Groups		P(T<=t) two-tail	Remark
MC-FF	*MC-MF*	0.016304176	Reject
MC-FF	*MC-CF*	0.166369745	Accept
MC-MF	*MC-CF*	0.32124857	Accept

Statistical anaysis using ANOVA for Water Absorption				
Varying fine aggregate Gradation within the specification and keeping the coarse aggregate in the finer limit of specification				
Groups	*F*	*P-value*	*F crit*	*Remark*
FC-FF	41.42012425	0.000308052	5.14325285	Reject
FC-MF				
FC-CF				

t-Test: Two-Sample Assuming Equal Variances For Water Absorption			
Varying fine aggregate Gradation within the specification and keeping the coarse aggregate in the finer limit of specification			
Groups		P(T<=t) two-tail	Remark
FC-FF	*FC-MF*	0.016691289	Reject
FC-FF	*FC-CF*	1.74805E-05	Reject
FC-MF	*FC-CF*	0.021885126	Reject

Statistical anaysis using ANOVA for Water Absorption				
Varying fine aggregate Gradation within the specification and keeping the coarse aggregate in the coarser limit of specification				
Groups	*F*	*P-value*	*F crit*	*Remark*
CC-FF	12.49218219	0.007261494	5.14325285	Reject
CC-MF				
CC-CF				

t-Test: Two-Sample Assuming Equal Variances For Water Absorption			
Varying fine aggregate Gradation within the specification and keeping the coarse aggregate in the coarser limit of specification			
Groups		P(T<=t) two-tail	Remark
CC-FF	*CC-MF*	0.02106765	Reject
CC-FF	*CC-CF*	0.017810341	Reject
CC-MF	*CC-CF*	0.965203813	Accept

APPENDIX A - Statistical Analysis Using Single ANOVA and t-Test

Statistical anaysis using ANOVA for Water Absorption				
Varying Coarse aggregate Gradation within the specification and keeping the Fine aggregate in the Middle of limit of specification (3.17FM)				
Groups	*F*	*P-value*	*F crit*	*Remark*
CC-MF	5.462874556	0.044546138	5.14325285	Reject
MC-MF				
FC-MF				

t-Test: Two-Sample Assuming Equal Variances For Water Absorption			
Varying Coarse aggregate Gradation within the specification and keeping the Fine aggregate in the Middle of limit of specification (3.17FM)			
Groups		P(T<=t) two-tail	Remark
CC-MF	*MC-MF*	0.206290311	Accept
CC-MF	*FC-MF*	0.129209983	Accept
MC-MF	*FC-MF*	0.041941771	Reject

Statistical anaysis using ANOVA for Water Absorption				
Varying Coarse aggregate Gradation within the specification and keeping the Fine aggregate in the finer limit of specification (2.8 FM)				
Groups	*F*	*P-value*	*F crit*	*Remark*
CC-FF	0.762858891	0.506768915	5.14325285	Accept
MC-FF				
FC-FF				

Statistical anaysis using ANOVA for Water Absorption				
Varying Coarse aggregate Gradation within the specification and keeping the Fine aggregate in the coarser limit of specification (2.8 FM)				
Groups	*F*	*P-value*	*F crit*	*Remark*
CC-CF	1.55861744	0.285012771	5.14325285	Accept
MC-CF				
FC-CF				

APPENDIX B

LABORATORY TEST RESULTS

7 Day's Cube Compressive Strength (15cm*15cm*15cm cube), with Loading Rate of Machine 0.28MPa/s							
Trial Mix	**Cube no.**	**Weight(g)**	**Unit Weight (kg/m3) SSD**	**Crushing Load (kN)**	**Corrected Crushing Load (kN)**	**Compressive Strength (MPa)**	**Average Compressive Strength (MPa)**
1.8 FM	1	8380	2483	594.5	574.2	25.53	25.51
	2	8247	2444	582.6	562.3	24.99	
	3	8275	2452	605.7	585.4	26.02	
2.0 FM	1	8345	2473	598.6	568.2	25.25	26.07
	2	8195	2428	611.5	590.8	26.26	
	3	8396	2488	631.4	600.8	26.70	
2.2 FM	1	8152	2415	637.8	615.8	27.37	27.23
	2	8259	2447	624.1	602.1	26.76	
	3	8248	2444	642.2	620.2	27.56	
2.4 FM	1	8129	2409	616.2	595.4	26.46	26.12
	2	8296	2458	598.9	578.1	25.69	
	3	8235	2440	610.5	589.7	26.21	
2.6 FM	1	8245	2443	575.3	555.2	24.68	25.10
	2	8100	2400	581.6	561.5	24.96	
	3	8269	2450	597.5	577.4	25.66	
2.8 FM (MC-FF)	1	8125	2407	587.5	567.4	25.22	25.67
	2	8245	2443	610.3	590.2	26.23	
	3	8418	2494	595.4	575.0	25.56	
(3.17 FM) (MC-MF) Middle of Limit	1	8036	2381	631.3	609.5	27.09	27.45
	2	8141	2412	648.1	625.5	27.80	
	3	8096	2399	640.9	618.3	27.48	
3.54 FM (MC-CF)	1	8006	2372	683.2	659.4	29.30	28.89
	2	8025	2378	673.8	650.0	28.91	
	3	8105	2401	664.5	640.7	28.47	
3.74 FM	1	8168	2420	641.8	619.5	27.54	27.48
	2	8190	2427	621.4	599.1	26.63	
	3	8059	2388	658.2	635.9	28.26	
3.94 FM	1	8028	2379	625.8	604.7	26.87	26.45
	2	8019	2376	607.1	586.0	26.06	
	3	8004	2372	616.2	595.1	26.43	
CC-FF	1	8285	2455	630.2	608.3	27.04	27.12
	2	8269	2450	639.8	617.9	27.46	
	3	8196	2428	626.1	604.2	26.85	
Coarser Limit (CC-MF)	1	8221	2436	615.7	594.6	26.42	26.45
	2	8205	2431	613.7	592.6	26.34	
	3	8198	2429	619.7	598.6	26.60	
CC-CF	1	8081	2394	655.2	632.1	28.09	28.28
	2	8109	2403	665.5	642.4	28.55	
	3	8088	2396	657.8	634.7	28.21	

7 Day's Cube Compressive Strength (15cm*15cm*15cm cube), with Loading Rate of Machine 0.28MPa/s							
Trial Mix	**Cube no.**	**Weight(g)**	**Unit Weight (kg/m3) SSD**	**Crushing Load (kN)**	**Corrected Crushing Load (kN)**	**Compressive Strength (MPa)**	**Average Compressive Strength (MPa)**
FC-FF	1	8127	2408	586.3	566.3	25.17	25.00
	2	8139	2412	583.2	563.2	25.03	
	3	8112	2404	578.4	558.4	24.82	
Finer Limit (FC-MF)	1	8185	2425	614.1	593.0	26.35	26.45
	2	8067	2390	627.1	606.0	26.93	
	3	8148	2414	607.5	586.4	26.06	
FC-CF	1	8105	2401	707.1	681.4	30.28	30.64
	2	8187	2426	720.4	694.7	30.88	
	3	8158	2417	717.8	692.1	30.76	
5% more Coarser	1	7986	2366	581.8	561.8	24.97	24.88
	2	8015	2375	585.8	565.8	25.15	
	3	7996	2369	571.9	551.9	24.53	
10% more coarser	1	8147	2414	620.4	599.5	26.64	26.88
	2	8160	2418	627.8	606.9	26.97	
	3	8083	2395	628.9	608.0	27.02	
5% more finer	1	8176	2423	691.3	669.3	29.74	29.26
	2	8215	2434	671.3	649.3	28.86	
	3	8199	2429	678.4	656.4	29.17	
10% more finer	1	8167	2420	722.5	699.5	31.09	31.23
	2	8107	2402	724.8	701.8	31.19	
	3	8078	2393	729.5	706.5	31.40	

28 Day's Cube Compressive Strength (15cm*15cm*15cm cube), with Loading Rate of Machine 0.28MPa/s							
Trial Mix	**Cube no.**	**Weight(g)**	**Unit Weight (kg/m3) SSD**	**Crushing Load (kN)**	**Corrected Crushing Load (kN)**	**Compressive Strength (MPa/m2)**	**Average Compressive Strength (MPa/m2)**
1.8 FM	1	8282	2454	855.1	825.17	36.67	39.46
	2	8212	2433	914	883.8	39.28	
	3	8300	2459	964.5	932.82	41.46	
	4	8147	2414	940.4	909.27	40.41	
2.0 FM	1	8439	2500	909.3	878.89	39.06	38.64
	2	8339	2471	873.5	843.46	37.49	
	3	8416	2494	916.6	886.02	39.38	
2.2 FM	1	8250	2444	893.9	863.74	38.39	39.00
	2	8449	2503	925	894.23	39.74	
	3	8213	2433	904.6	874.29	38.86	
2.4 FM	1	8080	2394	882.9	852.81	37.90	38.82
	2	8306	2461	907.3	876.93	38.97	
	3	8091	2397	921.3	890.63	39.58	
2.6 FM	1	8277	2452	939.4	908.3	40.37	39.40
	2	8084	2395	936	904.98	40.22	
	3	8346	2473	866.1	836.11	37.16	
	4	8253	2445	927.7	896.87	39.86	
2.8 FM (MC-FF)	1	8017	2375	928.7	897.84	39.90	39.94
	2	8339	2471	934.7	904.6	40.20	
	3	8115	2404	924	893.25	39.70	
(3.17 FM) (MC-MF) Middle of Limit	1	8387	2485	953.4	921.97	40.98	40.53
	2	8185	2425	962.8	931.16	41.38	
	3	8293	2457	913.3	882.8	39.24	
3.54 FM (MC-CF)	1	7702	2282	918	887.39	39.44	41.33
	2	7986	2366	966.8	935.08	41.56	
	3	7939	2352	906.3	875.96	43.00	
3.74 FM	1	8228	2438	952.1	920.7	40.92	40.34
	2	8181	2424	925.7	894.91	39.77	
	3	8068	2391	938.4	907.32	40.33	
3.94 FM	1	8093	2398	997.9	965.45	42.91	42.60
	2	8087	2396	961.5	929.89	41.33	
	3	8204	2431	1013	980.34	43.57	
CC-FF	1	8065	2390	963.5	931.84	41.42	41.30
	2	8333	2469	978.8	946.79	42.08	
	3	8182	2424	940.4	909.27	40.41	
Coarser Limit (CC-MF)	1	8102	2401	919	888.36	39.48	40.41
	2	8186	2425	916.6	886.02	39.38	
	3	8061	2388	985.5	953.33	42.37	
CC-CF	1	8081	2394	1015	982.31	43.66	43.05
	2	8406	2491	992.9	960.56	42.69	
	3	8061	2388	995.2	962.81	42.79	

28 Day's Cube Compressive Strength (15cm*15cm*15cm cube), with Loading Rate of Machine 0.28MPa/s							
Trial Mix	**Cube no.**	**Weight(g)**	**Unit Weight (kg/m3) SSD**	**Crushing Load (kN)**	**Corrected Crushing Load (kN)**	**Compressive Strength (MPa/m2)**	**Average Compressive Strength (MPa/m2)**
FC-FF	1	8127	2408	936.7	905.66	40.25	38.04
	2	8149	2415	856.4	826.5	36.73	
	3	8112	2404	844.7	814.83	36.21	
	4	8128	2408	906.6	876.25	38.94	
Finer Limit (FC-MF)	1	7791	2308	909.3	878.89	39.06	40.18
	2	8067	2390	948.7	917.38	40.77	
	3	7959	2358	947.4	916.11	40.72	
FC-CF	1	8091	2397	1038	1005.02	44.67	41.18
	2	8208	2432	913	882.5	39.22	
	3	8245	2443	923	892.27	39.66	
5% more Coarser	1	8238	2441	895.6	865.43	38.46	38.46
	2	8147	2414	915.6	885.04	39.34	
	3	8792	2605	875.5	845.45	37.58	
10% more coarser	1	8147	2414	955.8	924.32	41.08	39.23
	2	8122	2407	839	809.2	35.96	
	3	7902	2341	906.6	874.1	38.85	
	4	8224	2437	954.4	922.95	41.02	
5% more finer	1	8176	2423	993.2	960.86	42.70	43.33
	2	7986	2366	1031	998.11	44.36	
	3	7949	2355	998	965.55	42.91	
10% more finer	1	8167	2420	1012	979.35	43.53	44.05
	2	8138	2411	1017	984.29	43.75	
	3	8274	2452	1043	1009.96	44.89	

Slump of Cement Concrete Mixtures (ASTM C-143 Test Method)

Trial Mix	1.8 FM	2.0 FM	2.2 FM	2.4 FM	2.6 FM	2.8 FM (MC-FF)	(3.17 FM) (MC-MF) Middle of Limit
Trial 1 slump	35.00	47.00	50.00	53.00	60.00	61.00	64.00
Trial 2 slump	41	48	50	54	62	59	63
Trial 3 slump	39	45	51	54	59	56	61
Average Slump	**38**	**47**	**50**	**54**	**60**	**59**	**63**

Trial Mix	3.54 FM (MC-CF)	3.74 FM	3.94 FM	CC-FF	Coarser Limit (CC-MF)	CC-CF	FC-FF
Trial 1 slump	70.00	48.00	42.00	65.00	55.00	59.00	25.00
Trial 2 slump	70	51	49	72	53	67	35
Trial 3 slump	71	49	46	69	52	62	32
Average Slump	**70**	**49**	**46**	**69**	**53**	**63**	**31**

Trial Mix	Finer Limit (FC-MF)	FC-CF	5% more Coarser	10% more coarser	5% more finer	10% more finer
Trial 1 slump	42.00	40.00	72.00	56.00	27.00	30.00
Trial 2 slump	42	43	60	59	37	31
Trial 3 slump	43	41	65	58	33	30
Average Slump	**42**	**41**	**66**	**58**	**32**	**30**

Water Absorption and Bulk Density of Concrete

Test method (ASTM C642)

Trial type	1.8 FM			2.0 FM			2.2 FM			2.4 FM			2.6 FM			2.8 FM (MC-FF)		
Sample designation	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Mass of oven dried sample in air, (A)	8202.9	7825.4	7950.4	7705.4	8049.1	7822.6	7826.9	7817.9	7558.1	7713.6	7878.6	7706.1	7649.9	7481.9	7832.0	7650.9	7480.9	8049.1
Mass of surface dry sample in air after 48h soaking , (B)	8647.2	8253.0	8378.4	8147.2	8503.0	8267.9	8255.2	8264.8	7981.3	8185.6	8298.9	8146.9	8088.7	7918.2	8275.4	8055.6	7917.2	8495.7
Mass of surface dry sample in water after 48h soaking , (C)	5096.9	4859.0	4945.0	4785.9	5008.5	4863.5	4866.6	4863.5	4701.3	4832.5	4861.6	4723.4	4724.2	4635.7	4823.1	4719.1	4628.9	4969.5
Absorbsion after immersion, %=((B-C)/C)*100	5.39	5.46	5.38	5.73	5.64	5.69	5.47	5.72	5.58	6.12	5.33	5.69	5.71	5.83	5.66	5.29	5.83	5.53
Average Water Absorption (%)	5.42			5.69			5.60			5.72			5.74			5.56		
Apparent density =(A/(B-C))*ρ	2309	2306	2316	2292	2303	2295	2310	2299	2301	2300	2292	2251	2269	2279	2269	2293	2275	2279
Average Bulk Density (kg/m3)	2311			2298			2304			2281			2274			2284		

Trial type	3.17 FM (MC-MF) Middle of limit			3.54 FM (MC-CF)			CC-FF			CC-MF (Coarser limit)			CC-CF			FC-FF		
Sample designation	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Mass of oven dried sample in air, (B)	7889.1	7824.3	7642.5	7640.4	7786.3	7641.5	7558.1	7706.1	7824.5	7642.4	7805.4	7891.5	7861.5	7854.0	7643.5	7838.5	7821.6	7560.2
Mass of surface dry sample in air after 48h soaking , (C)	8277.3	8213.5	8014.1	8007.5	8212.1	8034.5	7958.3	8145.4	8254.7	8033.1	8189.0	8288.1	8250.7	8252.7	8028.4	8284.8	8271.5	7986.1
Mass of surface dry sample in water after 48h soaking , (D)	4856.1	4835.0	4685.2	4685.0	4793.9	4697.1	4675.0	4675.0	4791.3	4697.1	4809.9	4856.1	4814.9	4831.5	4695.8	4836.5	4855.7	4635.8
Absorbsion after immersion, %=((C-B)/B)*100	4.89	4.97	4.86	4.80	5.47	5.17	5.29	5.70	5.48	5.11	4.92	5.04	4.95	5.08	5.04	5.71	5.75	5.63
Average Water Absorption (%)	4.92			5.14			5.50			5.02			5.02			5.69		
Apparent density =(B/(B-D))*ρ	2308	2316	2296	2300	2278	2290	2302	2221	2259	2291	2310	2298	2288	2296	2294	2269	2290	2257
Average Bulk Density (kg/m3)	2306			2289			2261			2300			2292			2273		

Water Absorption and Bulk Density of Concrete

Test method (ASTM C642)

Trial type	FC-MF(Finer Limit)			FC-CF			3.74 FM			3.94 FM			5% more coarser			10% more coarser		
Sample designation	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Mass of oven dried sample in air, (B)	7665.0	7750.2	7571.6	7921.2	8109.8	7571.6	7569.2	7832.0	7643.8	7569.2	7775.8	7751.5	7784.8	7723.6	7639.5	7956.3	7569.2	7803.6
Mass of surface dry sample in air after 48h soaking , (C)	8081.2	8142.4	7969.5	8305.4	8504.5	7939.5	7967.4	8230.7	8039.9	7923.2	8192.5	8141.5	8173.5	8141.9	8037.9	8321.9	7930.6	8171.0
Mass of surface dry sample in water after 48h soaking , (D)	4716.6	4745.2	4647.0	4836.0	4969.4	4631.8	4629.9	4778.3	4668.0	4615.8	4778.3	4745.2	4790.9	4767.8	4706.9	4894.2	4652.0	4821.9
Absorbsion after immersion, %=((C-B)/B)*100	5.43	5.06	5.27	4.83	4.87	4.86	5.26	5.09	5.20	4.68	5.36	5.04	4.99	5.42	5.24	4.60	4.77	4.71
Average Water Absorption (%)	5.25			4.86			5.18			5.02			5.21			4.69		
Apparent density =(B/(B-D))*ρ	2278	2281	2281	2283	2294	2291	2270	2269	2267	2289	2277	2281	2301	2289	2293	2321	2309	2330
Average Bulk Density (kg/m3)	2279			2289			2268			2283			2295			2320		

Trial type	5% more finer			10% more finer		
Sample designation	A	B	C	A	B	C
Mass of oven dried sample in air, (B)	7742.0	7701.5	7572.9	7781.3	7711.2	7642.9
Mass of surface dry sample in air after 48h soaking , (C)	8156.0	8097.5	7971.4	8170.0	8124.8	8041.2
Mass of surface dry sample in water after 48h soaking , (D)	4753.0	4717.0	4648.0	4756.5	4717.3	4673.4
Absorbsion after immersion, %=((C-B)/B)*100	5.35	5.14	5.27	5.00	5.36	5.21
Average Water Absorption (%)	5.25			5.19		
Apparent density =(B/(B-D))*ρ	2275	2278	2279	2280	2263	2269
Average Bulk Density (kg/m3)	2277			2271		