EFFECT OF SUGARCANE BAGASSE ASH ON BAGASSE FIBER REINFORCED CONCRETE PROPERTIES

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EFFECT OF SUGARCANE BAGASSE ASH ON BAGASSE FIBER REINFORCED CONCRETE PROPERTIES

BY

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A Thesis Submitted to the department of Civil engineering for the Partial Fulfilment of the Requirements for the Degree of Master of Science in Civil Engineering (Construction Technology and Management)

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DECEMBER 2020

DECLARATION

I certify that this titled "**Effect of Sugarcane Bagasse Ash on bagasse fiber reinforced concrete properties**" is my own work. The work has not been presented elsewhere for assessment. In compliance with internationally accepted practices, I have dually acknowledged and referred all sources of materials used in this research.

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ABSTRACT

As one of most consumed resources in the planet, different new technologies are highly being implemented recently to enhance both fresh and harden properties of concrete. Insertion of fibers, use of admixtures and utilization of substituting materials are among the technologies being exercised to create special concrete contributing to improve strength and setting time properties which in turn helps to reduce environmental and economic impacts faced while working with concrete. Bagasse fiber-reinforced concrete is one type of special concrete that can be made by way of inserting well-prepared bagasse fiber in to a concrete mix to enhance the tensile properties of concrete. But researchers found that, its utilization reduces compressive strength although the condition might be adjusted using a mineral admixture. The general objective of this study was to assess effects of sugarcane bagasse ash on fresh and harden properties of bagasse fiber-reinforced concrete. This experimental study carried out preparing five different mixes to check compressive, split tensile and flexural strength tests after each 7, 14 and 28 days of curing. For this study, cement replaced by weight with bagasse ash in 5%, 10% and 15%. The effects of each percentage mix have finally been compared with FRC mixture with constant 0.5% sugarcane bagasse and conventional C- 35Mpa concrete. Economic analysis for best mix has also been one of the objectives for study undertaken.

Result of the research shows that, among fiber reinforced concrete mixtures, maximum strength of harden concrete achieved from M2 i.e. a mix with 5% replacement level and incorporation of 0.5% bagasse fiber. based on the investigation, 19.6%, 6.05% and 6.67% more strength have succeeded for computed compressive, split tensile and flexural strength tests respectively at 28 days of curing by this mix relative to control FRC mix with only 0.5% bagasse fiber content. Similarly, the tensile and flexural strength of M2 shows an increment resulting further 15.27% and 13.33% computed value at 28 days of curing with respect to M1 despite a slight reduction in compressive strength as compared with conventional concrete M1. And based on economic comparison, preparation of ordinary concrete mixture takes additional 0.61% increase in price than cost incurred to prepare B.F.R.C. with 5% bagasse ash to replace cement.

Keywords: Bagasse fiber reinforced concrete, Bagasse ash, Fresh property, Harden property, and Economic analysis

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LIST OF ABBREVIATION AND ACRONYMS

AASHTO………………… American Association of State Highway and Transportation Officials

S.B.F.R.C…………………..Sugarcane Bagasse Fiber Reinforced Concrete

ASTM…………………….. American Society for Testing and Material

N.N.P.E……………...…… Nations Nationalities and People of Ethiopia

F.D.R.E............................... Federal Democratic Republic of Ethiopia

B.F.R.C……………………. Bagasse Fiber Reinforced Concrete

S.F.R.C…………………… Steel Fiber Reinforced Concrete

G.F.R.C……………………. Glass Fiber reinforced Concrete

F.R.C………………………. Fiber Reinforced Concrete

S.S.D……………………..... Saturated surface dry condition

OPC……………………...... Ordinary Portland cement

PPC………………………... Pozzolana Portland cement

ACI………………………... American Concrete Institute

ERA……………………….. Ethiopian Road Authority

USD……………………….. United States Dollar

S.B.A………………………. Sugarcane Bagasse Ash

STS………………………... Standards

Mta…………………………..Million Tons Annually

E.C……………………………..Ethiopian calendar

G.C……………………………..Gregorian calendar

Gt.…..…………………………..Giga tone

CHAPTER 1- INTRODUCTION

1.1 Background of the Study

Concrete is the rock-like mass formed from the mixture of cement, water, sand, and gravel, or crushed stone. Its specialty of being cast in any desirable shape, its strength and fire resistance capacity makes it to be the most widely used construction material and the most important element of the construction industry. Besides this known fact, recent technological advancements in the construction sector and growing working methodologies associated with concrete create a tendency to replace stone and brick masonry. Concrete has been the major instrument for providing stable and reliable structures despite the production takes large amounts of natural resources such as sand, aggregate, and water with factory product cement, which contributes to the current environmental complications.

Since durability is among the critical issues to construct reinforced concrete structures with long service life, it is important to produce well-designed concrete as a durable construction material [1]. Moreover, it is well known that concrete is relatively strong in compression but weak in tension and it possesses limited ductility and little resistance to cracking. And these scenarios better be emphasized around reinforced cement concrete.

Micro-cracks present in concrete because of its poor tensile strength and most cracks in concrete are formed during its hardening stage. In this stage for the mentioned and other related problems, the fiber-reinforced concrete becomes an ideal solution to improve the tensile strength, flexural strength, energy absorption capacity, and toughness characteristics of concrete although it is usually used in concrete to control plastic shrinkage, cracking, and drying shrinkage cracking. Some types of fibers produce greater impact and abrasion resistance in concrete. Fiber-reinforced concrete is a composite material consisting of mixtures of cement, fine aggregate, coarse aggregate water, and discontinuous, discrete, uniformly dispersed suitable fibers. The quantity of fiber added to a concrete mix is measured as a percentage of the total volume of the composite termed volume fraction.

The concept of fiber reinforcement is not a new idea and researchers have conducted many studies to check the possibility to incorporate it as a composite construction material for the last two decades. The tendency to reduce strength while using sugarcane bagasse as fiber discreet can even be enhanced using mineral admixtures [2]. In the study, it was mentioned that the percentage reduction in compressive strength was decreasing with an increase in percentage replacement of sugarcane bagasse ash when cured in 5% MgSo4 which concludes that sugarcane bagasse ash (S.B.A.) helps in resisting the concrete towards sulphate attack.

Concerning mineral admixture, the previous research works have identified that concrete made with partial replacement of cement by natural admixture like sugarcane bagasse ash performed better when compared to ordinary concrete up to 10% replacement level due to the presence of a higher amount of silica in S.B.A. Environmental contribution from utilizing fibers in concrete have also been verified [3]. This particular study has a detailed review of the application of waste materials on fiber reinforced concrete production. Thus it can be understood that combined usage of sugarcane bagasse and bagasse ash in concrete would result in better performance.

In this study, utilization of sugarcane bagasse as fiber reinforcement together with the effect of partial replacement of cement with bagasse ash in F.R.C. production has been assessed and strength characteristics of sample specimens were evaluated.

1.2 Statement of the Problem

According to Ethiopian Sugar Corporation, as of this time the country owns 8 operating sugar factories in which each one of them consumes on average 9,327.75 tons of sugarcane per day for their daily sugar production. The government of Ethiopia allocates a substantive amount of budget and irrigable land for this sector. Six years ago, before the kick of the first GTP, 30,397 hectares of irrigable land have been in use for cane plantation which so far has reached more than 130,000 hectares.

Though sugarcane bagasse ash (a by-product from the extraction of sugar) has high silica content and pozzolanic nature, the current trend is to use some of it as compost (soil fertilizer), some of the amount for animal food, and to dispose of the remaining huge amount as waste material. Bagasse ash which possibly proved to be capable of partially replacing cement in many research works worldwide is not yet utilized in Ethiopia, the developing country in which many of its physical infrastructures are still to be constructed using high cost and environmental un-friendly conventional cement.

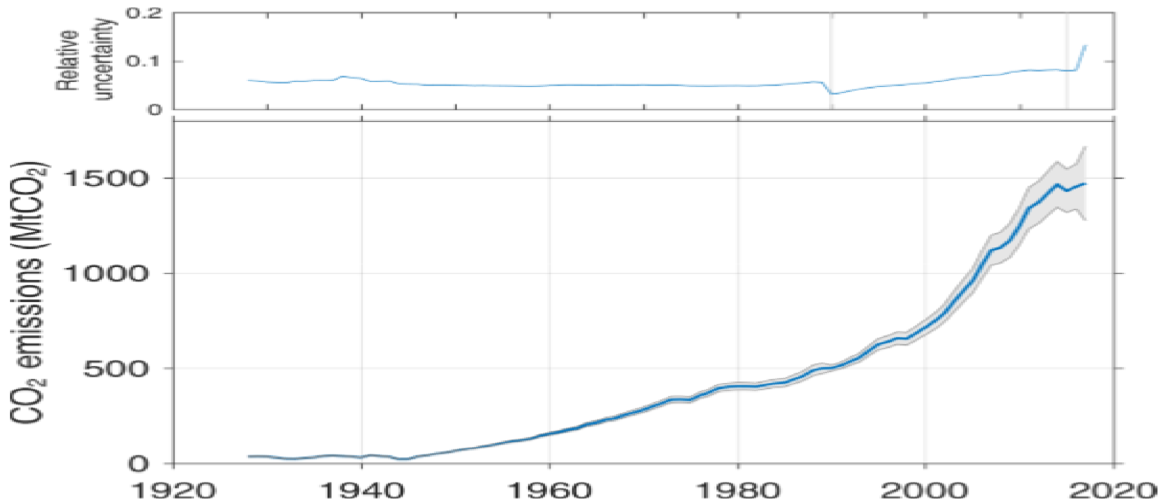

Figure 1.1 – Global process emission from cement production, with a 95% confidence interval. A step-change in uncertainty occurs in 1990. (Adapted from [4])

The significant damaging impacts of cement production on the local environment and its inhabitants have grown as process emissions from cement production reached 1.5± 0.12Gt CO_2 in 2018 [5]. Cumulative emissions from 1928 to 2018 were 38.3 ± 2.4Gt CO_2. The author further emphasized that 71% of which have occurred since 1990G.C.

Moreover, as a result of the growing sugar industries worldwide, the byproduct bagasse and the ash from burned bagasse for energy need is also creating environmental concerns. Ethiopia generates a substantive amount of waste annually from which sugarcane bagasse waste takes a considerable amount contributing to unpleasant highways and walkways. These days, it is not strange to see sugarcane bagasse (a by-product after the juice is extracted) in many locations in the African capital Addis Ababa. The scenario is a daily headache for the people working on city cleaning and significantly contributing to the bad image creation of the city. Addis Ababa city administration, 2010 E.C presented that the city generates a solid waste of 0.4kg/c/day and more than 200,000 tones are collected each year. From these 12,000 tones or 6% is collected from street sweeping [6].

As concrete fibers include steel, glass, synthetic and natural materials, constituting materials are available in pure fabricated or waste generated state. Utilization of materials from the later state gives dual advantage; in strength improvement and material recycling which latter contributes to minimizing environmental pollution.

Sugarcane has two main parts, the internal white part in which the juice is extracted from and the external hard and stiff cover. In previous research works, it has been practiced to utilize both parts of the sugarcane as fiber reinforcement in concrete though the latter part alone believed to have better strength. As F.R.C is a known ancient material that increases structural integrity it is not yet widely applicable especially in Ethiopia. Besides these, the involvement of local researchers in conducting contextual research (based on material availability and importance), introducing the technology, and widening the application is very limited. Published and unpublished researches regarding F.R.C from sugarcane bagasse is not as expected and as needed in Ethiopia, which generates huge amounts of unmanaged and few amounts of managed wastes. So the contribution to Ethiopia's construction industry and national green building strategies is still very low and this indicates in the Ethiopian context, there exists a lack of advanced research about utilizing waste sugarcane bagasse for construction purposes.

1.3 Objective of the study

1.3.1 General objective

The general objective of the study is to investigate the combined effect of bagasse ash and sugarcane bagasse on mechanical properties of bagasse fiber-reinforced concrete.

1.3.2 Specific Objectives

The specific objectives of the study are:

1- To characterize the raw materials: that are used in the study.

2- To investigate the effects of bagasse ash and sugarcane bagasse (the straw or outer hardcover of sugarcane) on mechanical properties of bagasse fiber-reinforced concrete.

3- To undertake economic analysis creating insight on the production cost of bagasse ash and bagasse fiber blended concrete and ordinary concrete mixture.

1.4 Research Questions

This study tries to answer the following questions:

- What are the chemical and physical properties of bagasse ash and ingredients in bagasse fiber reinforced concrete?
- Does utilization of bagasse ash for partial replacement of cement enhance the mechanical properties of bagasse fiber-reinforced concrete?

- What are the economic advantages of replacing cement with bagasse ash in bagasse fiber reinforced concrete?

1.5 Scope of the study

This study focuses only on the utilization of hard external cover of waste sugarcane bagasse as fiber reinforcement in concrete and evaluates the effect of partial replacement of cement with sugarcane bagasse ash on the final result. The study includes workability test, compressive, and split tensile strength tests of prepared F.R.C specimens of different bagasse fiber discreet proportions so that test results can be compared with conventional concrete. Flexural strength of test beams for the mixes is also being conducted.

1.6 Significance of the Study

The output of the study will be an input to the construction industry stakeholders to adopt the technology and it is also important to be a reference material for further studies in higher education. Be able to utilize sugarcane bagasse together with bagasse ash as fiber reinforcement in concrete and cement replacing material respectively, would minimize the cost of construction, reduce CO_2 emissions from cement industries and help a nation significantly providing profitable means of recycling the solid waste which in turn contributes bringing clean and healthy environment. Therefore, the result obtained from the study can be an insight for all stakeholders including sugar industries to take good care of their bi-products and create additional sources of income while providing those materials as a construction input.

1.7 Organization of the Research

The first chapter gives a general background of concrete and fiber reinforcement. The statement of the problem, the objective of the thesis, significance, scope, and methodologies of the study through which the research was conducted are presented.

The second chapter discusses previous works on fiber reinforced concrete in general and sugarcane fiber reinforced concrete in particular. raw materials used in the production of F.R.C, the partial replacement of cement with bagasse ash, mix design considerations and Ethiopian sugar factories with their annual ash and waste bagasse production have also been presented theoretically and empirically.

The third chapter focuses on the experimental program carried out to cast the concrete test specimens. The procedures and methods used in the test specimen preparation including testing concrete constituent materials to determine the physical and chemical material properties, test procedures, material characterization, mix design, casting, and curing are also included.

The fourth chapter discusses test results found out from the experiment. It focuses on the mechanical properties of plain concrete which are compressive strength, split tensile strength, and flexural strength values of the test specimens. Analysis and comparison are also going to be made among various specimens with different bagasse ash and constant fiber content.

The fifth chapter discusses the main findings found out from the study and also this chapter provides conclusions and recommendations. In the last part references and appendix are included.

CHAPTER 2- LITERATURE REVIEW

2.1 Introduction

Under this chapter, the theoretical and empirical subject matter of different works of literature will be discussed. General background about fiber reinforced concrete, possible raw materials to be used as fiber reinforcement, and mix design trends that have been followed by different researchers will be reviewed and at the same time production and performance of cement and bagasse ash worldwide are going to be studied and categorized under the theoretical section of the review. Whereas the empirical section contains research outputs on properties of fiber materials to be utilized in the production of concrete, the effect of bagasse ash, and sugarcane bagasse fiber on mechanical properties of concrete, and the application of fiber reinforcement on building construction.

2.2 Theoretical Review

2.2.1 Background to Fiber Reinforced Concrete

Many researchers describe fiber reinforced concrete in general and S.B.F.R.C. in particular. F.R.C. can be defined as a composite material consisting of a cement-based matrix with random distribution of fiber which can be steel, nylon, polythene, etc. [7]. This definition of fiber reinforced concrete has also been approved by researchers with the same topic of interest [3].

Cementing materials combined with aggregate and reinforcement have great engineering properties. Concrete that includes imbedded metal is called reinforced concrete or Ferro-concrete [8]. Reinforced concrete combines the tensile or bendable strength of metal and the compression strength of concrete to withstand heavy loads. Due to these reasons, the reinforced concrete structure becomes most common, and different structural elements have been built with it. Typically, it is called reinforced cement concrete where different standard grades of steel bars are used as reinforcement. However, reinforcement can be provided in cement concrete in different ways as different types of fibers can be inserted in cement concrete that can provide the functionality of reinforcement. This type of fiber-reinforced cement concrete (F.R.C.C) became more popular in the last two decades.

The study on the use of steel fiber as reinforcement material for concrete pointed out that the fiber is described by a convenient parameter called, aspect ratio. The aspect ratio of the fiber is the ratio of its length to its diameter or thickness [9]. The principal reason behind incorporating fibers into a cement matrix is to upturn tensile strength and toughness of the concrete improving the cracking deformation characteristics of the resultant composite concrete and due to these reasons, it is commonly used in the construction of different civil engineering structures. The authors also point out the continuously growing application of fiber reinforced concrete in various fields. Another study output also supports the improvement of tensile properties of concrete by randomly dispersing discrete fibers to the mixture during the mixing process [10].

Some researchers noticed the destruction of the eco-system as a result of technological advancement [3]. The authors acknowledge the enhancement of human comforts with technology but they have tried to point out the importance of fibers recycled from waste materials and shown how more they contribute to sustainable construction. Obviously, as compared with plain concrete, F.R.C. is able to sustain considerable loads ever at deflection significantly while plain concrete fails abruptly once the deflection corresponding to ultimate flexural strength is surpassed. Fibers also have a natural behavior to reduce fractural deflection associated with plain concrete due to the sewing effect of the fiber thread that controls cracks on the structure.

2.2.2 Raw Materials for Fiber Reinforcement Concrete

Historically, horsehair was used in mortal and straw in mud bricks. According to different works of literature, in the early 1900s asbestos fibers were used in concrete. The experimental study also reads, in the 1950s, the concept of composite materials emerged and fiber reinforced concrete was one of the topics of interest. Then by the 1960s, steel, glass, and synthetic fibers like polypropylene types were used in concrete [11]. Many researchers have tried to classify and describe different fiber raw materials that can successfully combine with the concrete mixture so that F.R.C would be made. The categorization rest on the physical and chemical properties of the fibers, mode of occurrence, and their source [10]. The author describes more than eleven fiber types categorizing them into three basic groups namely, metallic fiber, synthetic fibers, and glass-based fibers.

Fibers may also be categorized as natural fibers and manmade or synthetic fibers [12]. According to the author, natural fibers are 12-29 microns thin hair or wire-like continuous materials that are found in animals or plants and can be used as an element of composite materials. Examples of natural fibers are coconut (coir fibers), human hair, animal hair sisal, elephant grass, jute, sugarcane bagasse, fur, avian fibers; silk fibers, etc. Natural fiber further can be defined as “cellulosic fibers that are produced within the organic tissue of plants” [10]. These cellulosic fibers make up the structural part of plants, meaning they provide the strength and stiffness that plants need to keep their shape and integrity under their weight as well as applied loads like wind and precipitation. The author recognizes them as they warrant consideration for concrete reinforcement. Synthetic fibers are derived from substances that are not present in nature but instead produced from a chemical reaction (synthesis). These fibers may include textile fabrics, steel fabrics, polythene, nylon, etc. [9].

There are some downsides raised associated with natural fibers. The main limitation is when they incorporated in the concrete, they undergo degradation and slight brittle character, especially in the alkali rich cement environment. This degradation is applicable for all types of natural fiber; however, the mechanism of degradation can change based on the form and composition of the fiber. This is due to various features of two or more different fibers especially when they get processed and unprocessed before incorporation. The distinguishing character might be seen in terms of water absorption capacity and alkali-sensitivity causing mineralization of the fibers as these contribute highly to volumetric variability [13].

In related work, the ductility loss characterized by flexural load vs. deflection curves for wood pulp fibers subject to continuous wetting and drying cycles as shown in Figure 2.1 below has been quantified [14]. Due to the mechanisms of degradation recognized in this study and others, research has focused on two approaches to mitigate the degradation of natural fibers, the first is to adjust the cementitious matrix chemistry so that a less reactive environment for fiber mineralization is going to be provided. And the second is the modification of the fibers for improved volumetric and chemical stability.

Previous studies have shown that a fiber treatment technique called fiber hornification helps to improve the volumetric stability of natural fibers. This method involves repeated wetting and drying of the fibers before dispersion in the cementitious matrix. There are cases where after hornification of fibers, flexural strength increases up to 13% and 21% for kraft pulp fibers and cotton linters respectively [15]. Similarly, other authors reported that the pullout resistance increased by roughly 45% while the tensile strain at failure of the hardened composite improved by 39% after the hornification of strand form sisal fibers [16].

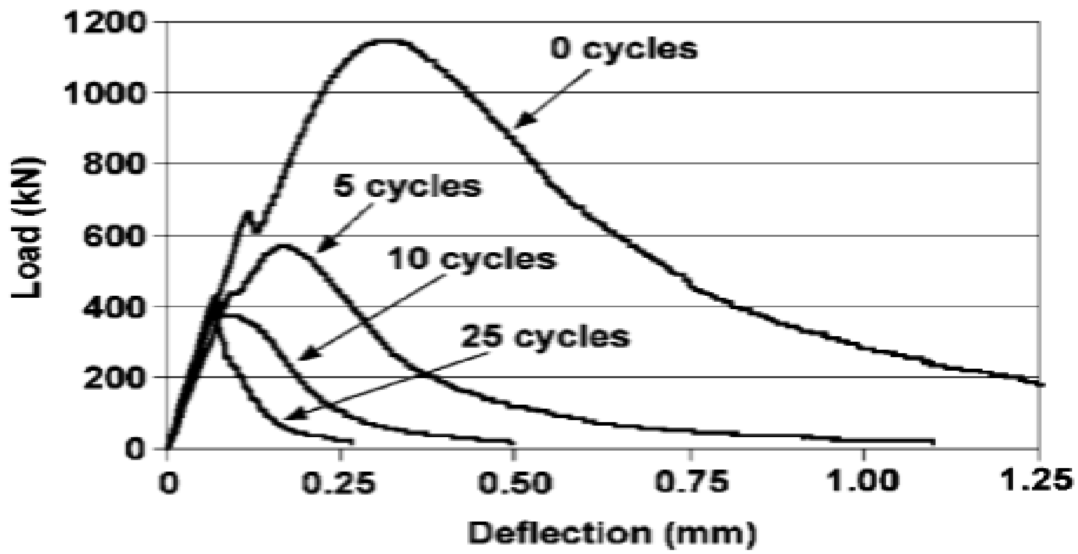

Figure 2.1- Load- deflection curve for pulp fiber composites subjected to cyclic hornification of fibers (adapted from [14])

The other reported natural fiber treatment technique is to immerse the fibers in a silica fume slurry before placement in the cement matrix. This method is testified to significantly improve the long term strength and toughness of the hardened composite by controlling the level of alkalinity at the fiber-matrix interface [17]. More recently, sodium carbonate surface treatment and thermal treatment of sisal fibers has been stated to improve the durability of hardened fiber composites by over 45% and 30% respectively [18] as cited on [10].

Researchers put their effort to investigate the use of different materials to be utilized as fiber reinforcement in concrete. The study which experimentally investigates the effects of incorporating various types of waste metallic fibers (WMF) and waste polypropylene fibers (WPF) on the mechanical properties of fiber Reinforced concrete has evaluated the influence of length, volume, and waste fiber type on compressive strength, flexural strength and toughness of resulting concrete [19]. The results have shown a slight and moderate reduction in compressive strength in both WMF and WPF. On the other hand, the flexural strength, post cracking behavior, and load-carrying capacity were improved while using WPF and hybrid composite from both types. The author generalizes ductility and toughness can significantly be improved when using multimodal composites compared to composites reinforced with the mono- fiber system.

Researchers working on similar discipline would also carry out an experimental study that deals with the behavior of split tensile strength of concrete when mixed with soft drink bottle caps. The incorporation of well-prepared bottle cap fiber can bring a change in the failure mode under compressive deformation from brittle to ductile [20]. Based on the result of the study, the flexural strength of M20 grade concrete has shown a 13.35% increase for 0.25% fiber content. And for M25 grade and similar fiber content, the flexural strength has been increased by 10.49%. The tensile strength of M30 grade concrete has also shown an 11.08% increase for similar 0.25% fiber integration.

2.2.3 Mix Design Considerations for Fiber Reinforced Concrete

There are many types of mix-design methodologies where the choice may be governed by the intended strength, materials to be used, required workability of concrete, durability, and other factors. Fiber as reinforcing material, it's mixtures are characterized by higher cement content, higher fine aggregate content, and decreasing slump with increasing fiber content compared to conventional concrete. Increasing the amount of paste in the mixture will help to provide better workability of concrete [21]. At this point, the author noticed the action requires higher cement content or turning the ratio of fine aggregates to coarse aggregates upwards. Alternatively, admixtures like superplasticizer improve the workability of the concrete but it does not essentially provide the ability to incorporate higher steel fiber content [21]. In the report the author made the mix design considering certain modifications to conventional concrete practice. This includes introducing adequate amount of uniformly distributed fibers in the mixing concrete.

The other experimental study on mix design of fiber reinforced concrete using slag & steel fiber using the IS code method of mix design to prepare M20, M30 &M40 grade of concrete [22]. In the study, the mix design of concrete specimens with various percentages of slag and steel fiber was prepared. From details of several mix proportions for different replacement levels of cement by slag and steel fiber tabulated on the study paper, it is clear that only the amount of cement in (Kg/M^3) increases as an increase in the percentage of fiber whereas, other concrete ingredients remain constant.

Table 2.1: Details of Concrete Mix Proportions for (C20) Grade of Concrete for Slag (Adopted from [22]).

SN	Slag %	W/C Ratio	Mix proportion(Kg/m3)				
			Cement	Slag	Sand	Agg.	Water
1	0	0.5	360	0	584	1224	180.42
2	10	0.5	324	36	584	1224	180.42
3	20	0.5	288	72	584	1224	180.42
4	30	0.5	252	108	584	1224	180.42
5	40	0.5	216	144	584	1224	180.42

Table 2.2: Mix Proportions for (C20) Grade for Steel Fiber (Adopted from [22]).

SN	Steel fiber %	W/C ratio	Mix proportion(Kg/m3)				
			Cement	S.F	Sand	Agg.	Water
1	0	0.5	360	0	584	1224	180.42
2	10	0.5	358.2	1.8	584	1224	180.42
3	20	0.5	356.4	3.6	584	1224	180.42
4	30	0.5	354.6	5.4	584	1224	180.42
5	40	0.5	352.8	7.2	584	1224	180.42

Table 2.3: Mix Proportions for (C20) Grade for Optimum Strength (slag & steel fiber) (Adopted from [22]).

SN	Slag+ S.F %	W/C Ratio	Mix proportion(Kg/m3)				
			Cement	Slag+ S.F	Sand	Agg.	Water
1	0	0.5	360	0	584	1224	180.42
2	20+1	0.5	284.4	72+3.6	584	1224	180.42

2.3 Pozzolans

"Pozzolans are a broad class of siliceous or siliceous and aluminous materials which, in themselves, possess little or no cementitious value but which will, in finely divided form and the presence of water, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties" [23]. There are some materials found naturally or produced artificially which possess pozzolanic activity. According to the author, the commonly used pozzolans today are industrial by-products such as silica fume, fly ash and burned organic matter residues rich in silica like rice husk ash. Bagasse ash which is a by-product of sugar factories found after burning sugarcane bagasse which itself is found after the extraction of the sugar is also a pozzolan proved to be used as supplementary cementitious materials. The production process in general and the potential of sugar factories in Ethiopia relative to bagasse ash production will be discussed below;

2.3.1 Sugar factories in Ethiopia

According to the Africa report news 2011, Ethiopia had been constructing 10 sugar factories with USD$4.6 billion investment following the growth and transformation plan 1 [24]. Even though the plan aims to make the country a self-sufficient sugar producer by the end of 2013 and increase production eightfold to 2.3 million tons by mid-2015, creating a surplus of 1.25 million tons for export, after 5 years it is evaluated lag in the implementation of sugar projects and weak performance of market export during the plan period [25]. However, currently the country owns 8 functional sugar factories with a total estimated production capacity of more than 1.7 million tons per year. Table 2.4 below shows recent sugar factories in Ethiopia and their annual production in tons.

Table 2.4: Annual sugar production of current Ethiopian sugar factories (Source: [26])

Factory	Sugarcane crushing capacity per day per tone	Region	Total land for sugarcane in hectares	Annual production per tone	Remark
Wonjji Shoa	6,250	Oromia	12,800	174,946	
Metahara	5,372	Oromia	10,230	130,000	
Fincha	12,000	Oromia	21,000	270,000	
Tendaho	13,000	Afar	25,000	300,000	
Kessem	6,000	Afar	20,000	153,000	1^{st} phase
Arjo Diddessa	8,000	Oromia	16,000	204,000	w.r.t Kessem

Omo Kuraz Number Two	12,000	South N.N.P.E	20,000	250,000	
Omo Kuraz Number Three	12,000	South N.N.P.E	20,000	250,000	
Total	74,622		145,030	1,731,946	
Average	9,327.75		18,128.75	216,493.25	

According to Ethiopian Sugar Corporation, there are still 5 additional sugar factories under construction namely, Omo Kuraz number 1, Omo Kuraz number 5, Tana beles sugar factory 1, Tana beles sugar factory 2, and Wolkaiyt sugar development project. When these factories become fully operational they are capable of producing a sum of more than 1.7 million tons of sugar per year [26]. The activities indicate after few years Ethiopia will produce twice its production capacity now and nearly 3.5 million tons of sugar is expected from 13 factories found in different regions of the country.

2.3.2 Production potential of bagasse fiber and bagasse ash in Ethiopia

Besides being the main ingredient in the production of sugar, sugarcane consists of about 30% bagasse which is a voluminous by-product in the sugar mills used as a fuel to fire furnaces in the same sugar mill that yields about 8-10% ashes containing high amounts of un-burnt matter, silicon, aluminum, iron, and calcium oxides, and the final sugar produced, estimated to be 10% of the weight of sugarcane crushed [27], [28]. Moreover, from 30% of bagasse produced, 50% is water and above 48% of it accounted to be bagasse fiber whereas the remaining small amount becomes soluble solids [29]. In the discussion above, the flourishing path in Ethiopian sugar industries can be noticed. These boost up in the production of sugar in turn brings a high amount of bagasse fiber and bagasse ash. Table 2.5 below summarizes the calculated bagasse fiber and bagasse ash potential in the country.

Table 2.5- Bagasse fiber and Bagasse ash potential in Ethiopia

Working Factories	Annual sugar production (tons)	Annual bagasse production (tons)	Annual bagasse fiber (tons)	Annual bagasse ash production (tons)	Remark
Wonjji Shoa	174,946	524,838	251,922.21	22,673	From (8-10) % estimated ash content avg. 9% taken for the calculation. NB- amount of sugar produced takes 10% of sugarcane processed
Metahara	130,000	390,000	187,200	16,848	
Fincha	270,000	810,000	388,800	34,992	
Tendaho	300,000	900,000	432,000	38,880	
Kessem	153,000	459,000	220,320	19,828.8	
Arjo Diddessa	204,000	612,000	293,760	26,438.4	
Omo Kuraz Number Two	250,000	750,000	360,000	32,400	
Omo Kuraz Number Three	250,000	750,000	360,000	32,400	
	Total	*5,508,069*	*2,643,873.12*	*237,948.58*	
Ongoing projects					
Omo Kuraz 1	250,000	750,000	360,000	32,400	
Omo Kuraz 5	500,000	1,500,000	720,000	64,800	
Tana beles 1	242,000	726,000	348,480	31,363.2	
Tana beles 2	242,000	726,000	348,480	31,363.2	
Wolkaiyt plant	484,000	1,452,000	696,960	62,726.4	
	Total	*5,154,000*	*2,473,920*	*222,652.8*	

2.3.3 Pozzolanic properties of bagasse ash

As bagasse ash is siliceous material that forms more calcium silicate hydrate gel reacting with free lime during hydration of cement, it possesses a high pozzolanic activity which makes it a valuable component of blended binders in concrete, many researchers put their effort to utilize the material for partial replacement of cement in different scenarios [2], [30], [28], [29], [31]. To understand the relation between cement and pozzolanic nature of bagasse ash better, it is important to discuss the typical composition and hydration process of cement.

2.4 Cement and its Composition

Cement is a fine soft powder manufactured through a closely controlled chemical combination of calcium, silicon, aluminum, iron, and other ingredients. It is made from the mixture of elements that are found in natural materials like limestone, shells, and chalk combined with shale, clay, slate, blast furnace slag, silica sand, and iron ores. Cement is not often used on its own, but rather to bind sand and gravel together. Thus, it can be considered as a binder used for construction that sets, hardens, and adheres to other materials to bind them together. Cement mixed with fine aggregate produces mortar for masonry, or with sand and gravel, produces concrete. There are different types of cement categorized based on their composition, intended purpose, appearance, air entrainment, and setting properties. Among all, ordinary Portland cement is the most widely and commonly used type.

As briefed on these sections above, the raw materials used for the manufacture of cement consist mainly of lime, silica, alumina, and iron oxide. These oxides interact with one another at high temperatures to form more complex compounds. The relative proportions of these oxide compositions together with the rate of cooling and fineness of grinding are factors for influencing the various properties of cement [32].

Table 2.6: Approximate oxide composition limits of ordinary Portland cement.

Oxides	Content in percentage [32]	Average Content in percentage [33]	Remark
CaO	60-67	64.18	Calcium oxide
SiO_2	17-25	21.02	Silicon oxide
Al_2O_3	3.0-8.0	5.04	Aluminum oxide
Fe_2O_3	0.5-6.0	2.85	Ferric oxide
MgO	0.1-4.0	1.67	Magnesium Oxide
K_2O, Na_2O(Alkalies)	0.4-1.3	0.94	Potassium and Sodium Oxide
SO_3	1.3-3.0	2.58	Sulfur trioxide

The more complex four compounds formed when oxides interact with one another at high clinkering temperature usually regarded as major compounds or as a "Bogue's compounds". These are fundamental components of cement that determine the rate of strength, hydration process, and setting. The following table 2.7 below shows major compounds and percentage compound compositions.

Table 2.7: "Bogue's compounds" and percentage compositions from equations suggested by Bogue [32].

Name of compound	Formula	Abbreviated formula	percentage compositions
Tricalcium silicate	$3\ CaO.SiO_2$	C_3S	54.1
Dicalcium silicate	$2\ CaO.Sio_2$	C_2S	16.6
Tricalcium aluminate	$3\ Cao.Al_2O_3$	C_3A	10.8
Tetracalcium Aluminoferrite	$4\ CaO.Al_2O_3.Fe_2O_3$	C_4AF	9.1

2.4.1 Hydration of cement

Cement attains its adhesive property only when mixed with water. And without this adhesive property, the known binding nature is unthinkable. The chemical reactions that take place between cement and water so that the cement can smoothly bind fine aggregate and coarse aggregate is referred to as hydration of cement. During hydration, certain products are formed. These products are vital as they have adhesive value. The major compounds especially C_3S and C_2S in table 2.7 above plays a significant role in the formation of calcium hydroxide $Ca(OH)_2$ and calcium silicate hydrate known as C-S-H gel which is the main element for binding the coarse and fine aggregate together in the concrete paste and makes up 50 to 60 percent of the volume of solid in a completely hydrated cement paste [32]. The gel formation takes place while Tricalcium silicate and Dicalcium silicate in cement chemically reacts with water although the rate at which they react is different.

According to a study conducted on advanced concrete technology constituent materials, only 3 days is enough for approximately half of the C_3S compound will get hydrated and 80% by 28 days. In contrast, the hydration of C_2S does not usually show a significant progress until approximately 14 days [34] as cited in [28]. The rate of hydration in the case of C_3S produces more heat of hydration, the liberation of heat from the exothermic reaction of cement and water [32], and it causes the early strength of concrete. Though too quick to get hydrated, Tricalcium silicate allows concrete to be placed and compacted prior to setting and hardening stage as it will pass through an inactive stage after a rapid initial reaction. The second compound C_2S rather hydrates slowly and produces less heat of hydration resulting the later strength of concrete.

The other hydrated product calcium hydroxide $Ca(OH)_2$ being alkaline naturally, maintains a pH value around 13 in the concrete which resists the corrosion of reinforcements. This product constitutes 20 to 25 percent of the volume of solids in the hydrated paste [32]. But according to the author, it is relevant to reduce the quantity of $Ca(OH)_2$ or (C-H) that is because unlike its importance, calcium hydroxide causes deterioration and durability lose in concrete reacting with sulphates present in soils or water to form calcium sulphate which further reacts with Tricalcium aluminate C_3A bringing sulphate attack. The author further suggests blending materials such as fly ash, silica fume, and such other pozzolanic materials helps to withstand the effect of $Ca(OH)_2$ in concrete. The hydration process of Bogue's compounds has been described in many studies with different chemical equations but the same products. For instance, hydration of C_3S and C_2S compounds in terms of C-H and C-H-S products shown in Eq.2.1 and Eq.2.2 [35] and at the same time in Eq.2.3 and Eq.2.4 [34]:

$2C_3S + 11\ H \rightarrow C_3\ S_2\ H_8$ (C-S- H) + 3CH (Calcium hydroxide)……………. [Eq.2.1]

$2C_2S + 9\ H \rightarrow C_3\ S_2\ H_8$ (C-S- H) + CH (Calcium hydroxide)………………. [Eq.2.2]

$C_3S + 4.3H \rightarrow C_{1.7}\ SH_3 + 1.3CH$ (Calcium hydroxide)……...……….…..….. [Eq.2.3]

$C_2S + 3.3H \rightarrow C_{1.7}\ SH_3 + 0.3CH$ (Calcium hydroxide)……………………… [Eq.2.4]

From the equations above it is understood C_3S is the major contributor to the production of calcium hydroxide. C_2S and C_3S lead to produce a C-S-H gel of about 82 percent and 61 percent, sequentially [35]. Thus, the maximum strength and durability of C_2S cement would be greater than that of cement with a higher proportion of C_3S. Figure 2.2 below shows the heat of hydration of cement paste.

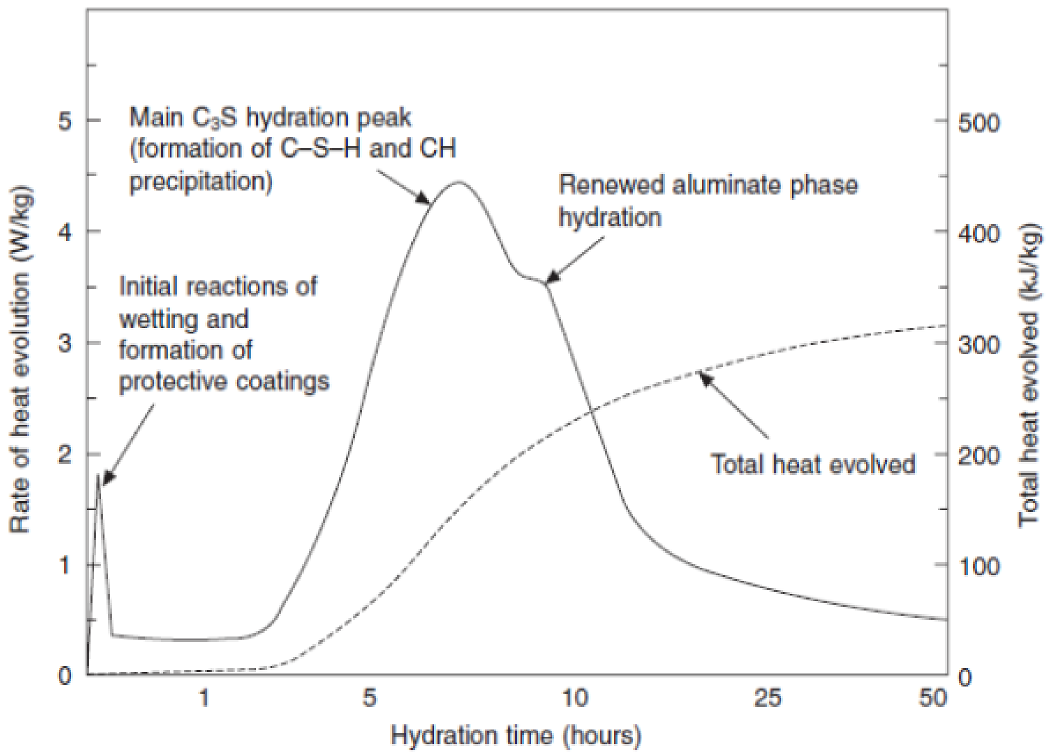

Figure 2.2 - Heat of hydration of a cement paste. (Adapted from [28])

The hydration of (C_3A) is similar to hydration products of Tetracalcium aluminoferrite C_4AF, except the hydration reactions of C_3A are faster and include more heat [35]. This quick interaction with water may lead to flash set and should be delayed with the addition of gypsum. Therefore, the last hydration products alter with the gypsum quantity. The hydration outputs of C_3A have generally created *ettringite*, it is a colorless to yellow hydrous calcium aluminum sulfate mineral with chemical formula $Ca_6Al_2\ (SO_4)_3\ (OH)_{12}\cdot 26H_2O$ and monosulfoaluminate posterior. As a primary constituent of hydration of Portland cement concrete, the formation of ettringite plays an important role in the control of setting though minor amounts of secondary ettringite are often encountered in air voids of hardened concretes, regardless of the type of cement used. The hydrated aluminates do not contribute anything to the strength of concrete.

On the other hand, the presence of hydrated aluminates is harmful to the durability of concrete particularly where the concrete is likely to be attacked by sulphates. As it hydrates very fast it may contribute a little to the early strength of concrete [32]. Figure 2.3 below shows strength development of major compounds with respect to time.

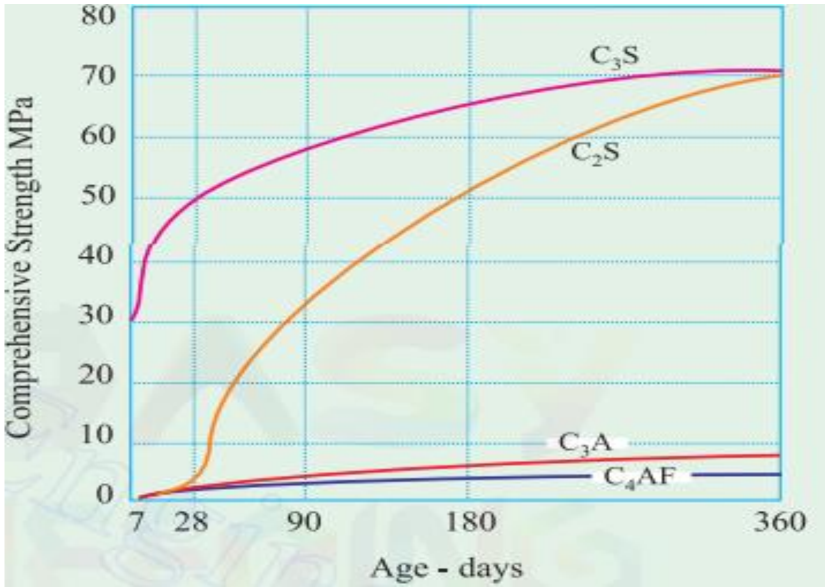

Figure 2.3- strength development of pure compounds. (Adapted from [32])

2.4.2 Global cement production

Cement, the second most consumed material on the planet next to water, is an essential component of infrastructure development and the most important input for the construction industry [36]. This construction industry particularly holds infrastructure development and housing programs, which are necessary for the socio-economic growth of any nation. The need to produce and consume more cement might depend on the nation's economic level, current development situations in GDP, and population size as they drive the demand for housing and infrastructure. Global cement production is expected to increase from 3.27 billion metric tons in 2010 to 4.83 billion metric tons in 2030 [37]. An interesting characteristic of the cement industry is the relatively lower volume of global trade compared to production. The widespread availability of raw materials, the strong correlation of the industry with local economic growth, and high transportation costs incline the balance in favor of domestic production over imports.

According to the global cement review 2013 report, global cement trade represented only 4.5% per annum of global consumption in 2012. Means, on average around 95% of global cement is consumed in the country where it is produced [36]. The statistics depict the developed nation China currently produces over half of the world's cement. Since the development level of a country is a key factor in the consumption of cement, the developing nations with emerging economies in Africa and Middle East Asia would be a point of interest for the industry in the future as more infrastructures are to be built. Figure 2.4 below shows the top 12 nations with the highest cement production worldwide.

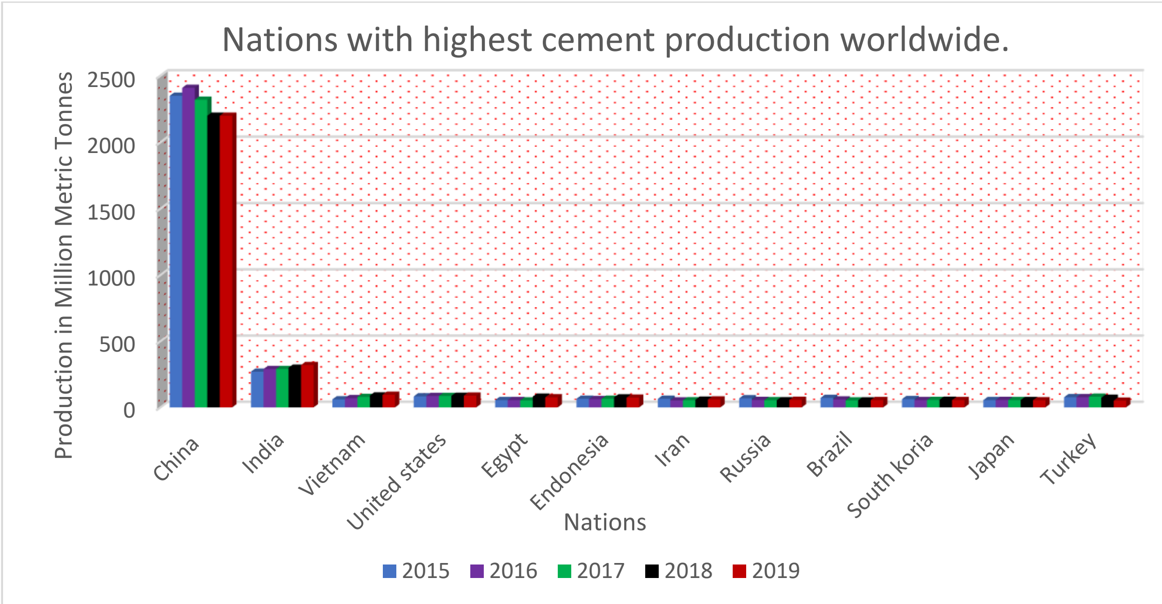

Figure 2.4- Major countries in worldwide cement production from 2015 to 2019(Adapted from [37])

2.4.3 Cement industry in Ethiopia

Ethiopia's Growth and Transformation Plan (GTP II) is a five-year plan approved by the council of ministers endorsed the Parliament to guide development endeavors in the country effective from 2015/16 -2019/20. The major objective is to serve as a foundation towards realizing the national vision of becoming a low middle-income country by 2025 [25]. Among different sectors the plan emphasizes, the major directions in this plan include economic development with accelerated industrialization and increased access to infrastructure through improving the capacity of the construction sector. Given the vast geographical size of the country and massive population, various construction activities are being undertaken by public and private organizations. In this regard, like many other countries, the Ethiopian cement industry is expected to play a significant role in terms of supplying a variety of cement products for the booming construction and infrastructure development.

The written documents tell, Italians are the first to establish cement factory in Ethiopia in 1936 during the five-year fascist occupation of the Country [38]. Since then, concrete construction in

Ethiopia has risen and the demand for cement has been growing. However, the boom in the construction sector following 2004 results severe shortage of cement nationwide According to the report by Ethiopian investment agency, the country had owned four cement plants in 2008 with a combined production capacity of about 2.85 million metric tons per year. Nevertheless, due to the far-reaching growth of the construction sector from 2008-2011 as well as frequent power interruption, cement supply is still significantly found short of meeting demand from domestic production sources. These scenarios forced the government to import around 1.2 million tons of cement in 2008 and 2009 alone [36].

Currently, there are around 26 functional cement factories with a total production capacity of 26.21 million tons annually [38]. Portland cement of both ordinary and pozzolanic types are the major focus of production for factories. Approximately 18 percent of the total production was historically OPC, while 81.1 percent was PPC the remaining 0.9 percent is for Portland lime cement which is currently being produced in a small amount by "Messebo" cement factory. Even though the cement production is extremely being enhanced, it shouldn't be over as the country still has low cement per capita consumption as low as 62 kg in 2016 compared to the Sub-Saharan per capita consumption of 165 kg [39] and the global average of 500 kg/ year [36]. The figure shows as the country has still much to do with housing and infrastructure development.

2.4.4 Cement production and environment

The primary greenhouse gas emitted from cement industries is carbon dioxide. A study on global carbon dioxide emission from cement production reveals this significant extent calculating the process emission which takes 5% of the total anthropogenic gases discharged. The gas emitted is the result of chemical reaction involved in the production of the main component of cement clinker, as carbonates (largely $CaCO_3$, found in limestone) are decomposed into oxides (largely lime, CaO) and CO_2 and emission from the combustion of fossil fuels to generate the significant energy required to heat the raw ingredients to well over 1000°C, and these 'energy' emissions, including those from purchased electricity, could add a further 60% on top of the process emissions. Total emissions from the cement industry could therefore contribute as much as 8% of global CO_2 emissions [5].

In the clinker burning process, to produce 1 ton of cement, 1.52 tons of raw materials are used on average and around 716 Kilograms of CO_2 need to be emitted [40]. Based on the data more than

50% of raw materials are converted mainly to carbon dioxide by processes such as $CaCO_3 \rightarrow CaO + CO_2$. This is a severe global environmental problem since the growing carbon dioxide emission in the atmosphere is causing major climatic changes worldwide and has a direct influence on global warming. Other key polluting substances also emitted to the air by cement industries including specks of dust, nitrogen oxides (NO_xs), a lower amount of carbon monoxide (CO), sulphur oxides (SO_xs), metals, hydrogen chloride, hydrogen fluoride, and some organic compounds which are extremely toxic and hazardous substances that result in acute and chronic human and animal health risks and some of the pollutants are hilariously odorous [41]. The pollutants further jeopardize existing and future vegetation.

Cement is an essential material to think of whenever the national development of any nation is in mind and there is no alternative material for complete substitution of cement in construction yet. As a result, the need for the production of cement is unquestionable. But, at the same time, controlling pollution created by cement industries should also be well-thought-out. To reduce the number of raw materials in the manufacturing of cement, supplementary cementitious materials such as coal fly ash, slag, bagasse ash, and natural pozzolans such as rice husk ash and volcanic ashes are used. These auxiliary materials will have a triple advantage enhancing the strength and durability of the intended structure, reducing the waste materials generated for landfilling, and also the cost of cement production [36].

2.5 Empirical Review

2.5.1 Chemical and Physical Properties of Different Fibers

The two fundamental classifications where different fiber types can be grouped has been described in section 2.2 of this chapter. In this section, chemical and physical Properties of synthetic fiber group and natural fiber group will be presented. Synthetic fibers are man-made fibers resulting from research and development in the petrochemical and textile industries [12]. Currently, there are two different synthetic fiber volumes used in the application, namely low-volume percentage (0.1 to 0.3% by volume) and high-volume percentage (0.4 to 0.8% by volume). Most synthetic fiber applications are at 0.1% by volume level. At this level, the strength of the concrete is considered unaffected, and crack control characteristics are required. Fiber types that have been tried in cement concrete matrix include acrylic, aramid, carbon, nylon, polyester, polyethylene, and polypropylene. Table 2.8 below summarizes the range of physical properties of some synthetic fibers.

Table 2.8: Typical Properties of Synthetic Fibers (Adopted from [12]).

Fibers	Equivalent ø(µm)	Relative density	Tensile strength (MPa)	Elastic modulus (GPa)	Ultimate elongation (%)	Ignition Temperature (°C)	Melt oxidation or decomposition temperature (°C)	Water absorption per ASTM D 570,% by mass
Acrylic	13-104	1.16-1.18	270-1000	14-19	7,5-50,0	-	220-235	1-2.5
Aramid I	12	1.44	2900	60	4.4	High	480	4.3
Aramid II¤	10	1.44	2350	115	2.5	High	480	1.2
Carbon, PAN HM¥	8	1.6-1.7	2500-3000	380	0.5-0.7	High	400	Nil
Carbon, PAN HT§	9	1.6-1.7	3450-4000	230	1-1.1	High	400	Nil
Carbon pitch GP ¤¤	10-13	1.6-1.7	480-790	27-35	2-2.4	High	400	3-7
Carbon pitch HP ΦΦ	9-18	1.8-2.15	1500-3100	150-480	0.5-1.1	high	500	Nil
Nylon¥¥	23	1.14	970	5	20	-	200-220	2.8-5
Polyester	20	1.34-1.39	230-1100	17	12-150	600	260	0.4
Polyethylene¥¥	25-1000	0.92-0.96	75-590	5	3-80	-	130	Nil
polypropylene¥¥	-	0.9-0.91	140-700	3.5-4.8	15	600	165	Nil

Notes
¤ Not all fiber types are currently used for commercial production of FRC
¥ Polyacrylonitrile based, high modulus
§ Polyacrylonitrile, high tensile strength
¤¤ Isotropic pitch based, general-purpose
φφ Mesophase pitch-based, high performance
¥¥ Data listed is only for fibers commercially available for FRC

Natural fibers or natural reinforcing materials can be obtained at low cost and low levels of energy using local manpower and technology. The utilization of natural fibers as a form of concrete reinforcement is of particular interest to less developed regions where conventional construction materials are not easily available or are too expensive. Sisal-fiber reinforced concrete has been used for making roof tiles, corrugated sheets, pipes, silos, and tanks. Elephant-grass-reinforced mortar has been used for low-cost housing projects. Wood-cellulose-fiber reinforced cement has commercial applications in the manufacture of flat and corrugated sheets and non-pressure pipes. Table 2.9 below describes the typical properties of natural fibers.

Table 2.9: Properties of Natural Fiber (Adopted from [12]).

Fiber type	Fiber length[mm]	Fiber ø[mm]	Specific gravity	Modulus of elasticity [10^6Mpa]	Ultimate tensile strength [10^3Mpa]	Elongation at break[%]	Water absorption[%]
coconut	51-102	0.1-0.41	1.12-1.15	19-26	120-200	10-25	130-180
Sisal	N/A	N/A	N/A	13-26	276-568	3-5	60-70
Sugarcane bagasse	N/A	0.2-0.41	1.2-1.3	15-19	184-290	N/A	70-75
Bamboo	N/A	0.05-0.41	1.5	33-40	350-500	N/A	40-45
Jute	178-305	0.1-0.2	1.02-1.04	26-32	250-350	1.5-1.9	N/A
Flax	508	N/A	N/A	100	1000	1.8-2.2	N/A
Elephant grass	N/A	N/A	N/A	4.9	178	3.6	N/A
Water reed	N/A	N/A	N/A	5.2	70	1.2	N/A
Plantain	N/A	N/A	N/A	1.4	92	5.9	N/A
Musamba	N/A	N/A	N/A	0.9	83	9.7	N/A
Wood fiber(craft pulp)	3-5	0.03-0.08	1.5	N/A	700	N/A	50-75
Human hair	0.017-0.1	0.017-0.1	N/A			30	N/A

2.5.2 Effect of sugarcane bagasse and bagasse ash on environment and fiber reinforced concrete

As a natural fiber sugarcane bagasse meant to enhance the mechanical properties of concrete although the material reported having some drawbacks. The reduction in the slump of fresh concrete associated with almost all fiber types incorporated in concrete but higher water absorption capacity and lack of ductile property as needed makes bagasse fiber to contribute less to the strength of concrete. On the other hand, the final residue powder named bagasse ash produced from sugar manufacturing industries is siliceous and aluminous material that in itself possesses little or no cementitious value but in presence of moisture, it reacts chemically with calcium hydroxide at ordinary temperature to form compounds having cementitious properties.

Sugarcane bagasse ash can be used as a cement replacement material to develop quality and reduce the cost of construction material such as mortar and concrete [29]. Moreover, the author recognized that cement manufacturing causes environmental impacts at all stages of the process. Thus, partial replacement bagasse ash in Portland cement would contribute to minimizing environmental pollution as well.

Bagasse ash has also been in use as a mineral admixture for partial replacement of cement in fixed proportions. Analyzing the effect of magnesium sulphate on S.B.A. blended concrete, the concrete mix was designed by varying the proportions of Bagasse ash. The result of the cubes which have been cured in normal water and 5% magnesium sulphate solution shows, the fresh and hardened concrete properties of percentage cement replaced concrete performed better when compared to ordinary concrete up to 10% replacement level of bagasse ash [2].

The effect of sugarcane bagasse ash in combination with steel fiber reinforced concrete has also been investigated. The ash has been partially replaced with cement in the ratio of 0%, 5%, 10%, 15%, and 20% by the weight of cement in M30 grade concrete [31]. From the test results, the optimum percentage of bagasse ash has been achieved on steel fiber reinforced concrete. It is observed that the workability of concrete gets increased as the percentage of bagasse ash increases. This may be due to the increase in the surface area of bagasse ash. After adding SCB, less water is required to wet the cement particles.

At the same time, the Compressive strength, Split tensile strength, and Flexural strength value of concrete goes on increasing rate with an increase in bagasse ash up to the optimum value. The optimum content was found to be 10%. For that concrete, the optimum volume fraction of crimped steel fiber was founded as 1%. According to the result, when compared to conventional concrete compressive strength and split tensile strength increases by 30.6% and 36.2% on steel fiber reinforced concrete with 10% bagasse ash level respectively.

On the other hand, an experimental study carried out on strength characteristics of concrete reinforced with sugarcane bagasse fiber noticed that “The Utilization of fiber in concrete production not only solves the problem of disposing of this solid waste but helps conserve natural resources “ [11]. The investigation uses varying percentages of bagasse fiber from 0% to 1.25% and the required dosage of superplasticizer to improve the workability of the mix. The experimental results after 7, 14, 21, and 28 curing days have shown that plain concrete (0% volume of fiber) had the highest compressive, tensile, and flexural strength. From the test summary of test results, one can notice all strengths characteristics of concrete increase as the number of curing day increases. And the more the increase in the volume of fiber in concrete, the lower the compressive strength of concrete.

It has already been pointed out that flow and workability problems are associated with almost all types of FRC. The use of admixtures and minimizing the volume fraction of fibers to be incorporated in the concrete mix is proved to improve the flow-related problem of FRC which in turn contributes to the strength of hardened concrete. The experimental study on compressive and tensile strength of steel fiber reinforced concrete containing fibers of 0% and 0.5% volume fraction of hook end steel fibers with 50 and 53.85 aspect ratio has revealed that Addition of 0.5% hook end steel fibers having 50mm length increases compressive and split tensile strength of concrete up to 10% and 20% respectively over the mix having 35 mm fiber length. As the addition of 0.5% of steel fiber still reduces the slump value of fresh concrete, the result guides for further reduction of the volume fraction and adjustment on the usage of admixture [42].

2.5.3 Factors influencing the strength results

The rate of application of load has a considerable effect on the apparent strength of concrete; the lower the rate of application of load, the lower will be the recorded strength. The reason for this is probably the effect of creep which will increase the strain. The enhanced strain due to creep will be responsible for the failure of the sample at a lower value of stress applied. The shape and size of the specimen together with the state of moisture content of the specimen also influence the observed strength to a great extent. Higher-strength associates with the dry samples. Although the dry samples may have undergone drying shrinkage which will have ultimately caused some amount of drying shrinkage cracks. Some sort of dilation of cement gel will take place by the adsorbed water which will reduce the forces of cohesion of the solid particles when the sample is wet. And the fall in strength due to the adsorbed water may be more than that of the loss of strength on account of drying shrinkage [32]. Contrary to expectations, a higher modulus of elasticity shown in wet concrete doesn’t contribute to the strength. To have a standard condition for test specimens, the author suggests testing a specimen immediately on removal from the curing water tank.

2.5.4 Application of Fibers on Building Element

As much of the literature discuss how different types of fibers affect the mechanical properties of sample cubes, cylinders, and cast beams, there are also some studies made to investigate the use of these fibers in different types of building elements. There was an experimental study to investigate the effect of fibers on the structural behavior of simply supported two-way slabs, loaded with a point load. In the study, 0.45% moderate fiber content of double hook-end steel fibers have been in use on octagonal slabs spanned 2.2 m in both directions whose reinforcement amount was twice as large in one direction as in the other. Slabs that are conventionally reinforced, steel fiber reinforced and a combination of both types were tested for load redistribution, crack pattern, and load-carrying capacity [43]. The result has shown that steel fibers can provide post cracking ductility and increase the ultimate load-carrying capacity. Fibers also affected load distribution so that more load could be transferred in the weaker direction.

A similar experiment on the applications and prospects of Fiber-reinforced concrete on industrial floors estimated the average cost for flooring installation per square foot of the total size. According to the author, flooring costs may reach 20% of single-story building construction expenditure and the consumption of concrete for floors may come to 40% -50% of the total size of concrete. Upon the view of this work, it was found that fiber reinforcement and fiber meshes have the capacity reduces the thickness of the subfloor about 20% -30% and enable to save 30% -40% of steel respectively hence, permitting to reduce the consumption of cement and fillers [44].

While dealing with the laboratory testing method, the generally accepted and easily performed laboratory testing method of fiber reinforced concrete is the three or four points bending beam tests [45].

2.6 Summary of Research Gaps

A review of the literature shows that even though there are some previous studies on sugarcane bagasse ash and bagasse fiber reinforced concrete which have been done separately, a gap exists in the investigation of the combined effect of these materials in the form of ash and fiber on the properties of concrete. And at the same time, many research works focus usually on the effect of partial replacement of cement with bagasse ash for conventional plain concrete. But it is known that mineral admixtures can enhance both the workability and strength of the fresh and harden concrete properties [31]. This case is very important for FRC in general as pieces of the literature shows that the addition of fibers in concrete significantly reduce the workability of the fresh mixture and SBFRC in particular as it has seen in some literature addition of bagasse fiber reduce the compressive and split tensile strength of hardened concrete [11]. Thus, the gap still exists in the investigation of partial replacement of cement with bagasse ash as a mineral admixture in the case of SBFRC.

The use of both internal and external parts of the sugarcane as bagasse reinforcement in concrete is the previous trend in most of the studies resulting in a loss in strength and reduced slump values. These phenomena show there exists a chance to investigate the effect of utilizing the external hardcover of sugarcane alone as bagasse fiber reinforcement.

This study, therefore, sets to look into not only the effect of waste sugarcane bagasse on FRC but also the effect of Bagasse ash as a partial replacement of cement in fiber reinforced concrete made from utilizing the only external hardcover of sugarcane bagasse on mechanical properties of concrete.

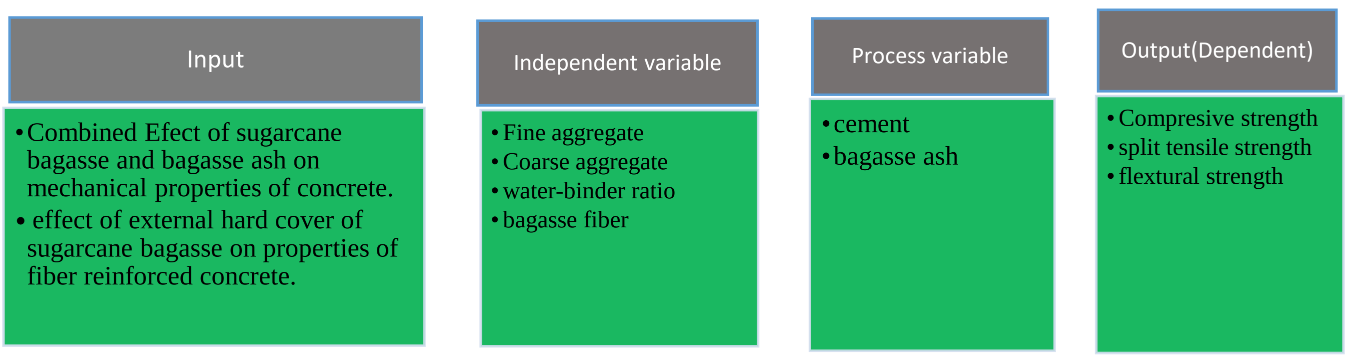

Figure 2.5- Conceptual Framework

As it is presented above the research has been designed to make cement and bagasse ash, the process variables at which any percent change on proportioning will influence all strength value outputs whereas aggregates, bagasse fiber, and water to cement ratio have remained constant throughout the study.

CHAPTER 3- MATERIALS AND METHODS

In this chapter, the materials used for the research and methodologies followed for testing materials and experimental procedures are described concerning their source and relevant physical and chemical properties. All the laboratory investigations on the aggregates, fineness of cement and bagasse ash, and fresh and harden properties of concretes are carried out in Addis Ababa Science and Technology University, Architectural and Civil Engineering Department, material laboratory; whereas the chemical properties of the bagasse ash have been conducted in the Federal Democratic Republic of Ethiopia Ministry of Mines, Petroleum and Natural Gas Geological survey of Ethiopia.

The Experimental study aimed to investigate the compressive strength, split tensile strength, and flexural strength of prepared concrete specimens with the proportion of cement replaced with bagasse ash and bagasse fiber adding to mixing concrete. In the study, the materials used are ordinary Portland cement, fine aggregates, coarse aggregates, bagasse ash, sugarcane bagasse discrete fibers, and water.

3.1 Materials used throughout the experiment

3.1.1 Cement

From the types of cement available commercially in the market, Portland cement is most well-known and can be found in every construction material suppliers working in Addis Ababa. Dangote OPC cement with 42.5 grades has been used for this study.

The physical and chemical properties of cement used should conform to required global and local standards and specifications. The fineness test of cement was undertaken to determine the size of cement particles. According to the Ethiopian Standard, if Blaine air- permeability test can be implemented as an option for Ordinary Portland Cement, a specific surface area can be computed indirectly and shall have a value of not less than 2250 cm2/g. [46], whereas the ASTM C 150 standard recommends a minimum of 2800 cm2/g. in this study, the sieving method of determining the percentage fineness has been implemented as it is commonly used and has easy procedures. The physical properties of the cement used and replaced bagasse ash is presented in table 3.1 below;

Table 3.1: Physical properties of cement and bagasse ash

Materials	Density (g/cm^3)	Average size (µm)
OPC cement	3.15	48.32
Bagasse Ash	2.16	63.5

The average size of both cement and bagasse ash has been computed applying linear interpolation. It can be understood as the sieve size at which 50% of the particles pass.

3.1.2 Fine Aggregate

Locally available "*Metehara*" river sand passing through 4.75mm sieve size and the silt content less than 6mm that conform to the recommended Ethiopian standard have been used for the study.

3.1.2.1 Particle size distribution of fine aggregate

Table 3.2: Particle size distribution of sand as per AASHTO M 6-93 or ASTM C- 136

AASHTO Sieve Size (mm)	Sample taken (gm.)					
	1000					
	Weight Retained (gm.)	Total weight Retained %	Cumulative total weight Retained %	% Passing	AASHTO M-6-93	
					Lower	Upper
9.5	0	0	0	100	100	100
4.75	35	3.5	3.5	96.5	95	100
2.36	85	8.5	12	88	80	100
1.18	160	16	28	72	50	85.0
0.600	270	27	55	45	25	60.0
0.300	340	34	89	11	10	30.0
0.150	80	8	97	3	2	10.0
0.075	20	2	99	1		
Pan	10	1	100	0		
Total sum	1000	100	284.5		Fines modulus(FM)	2.84

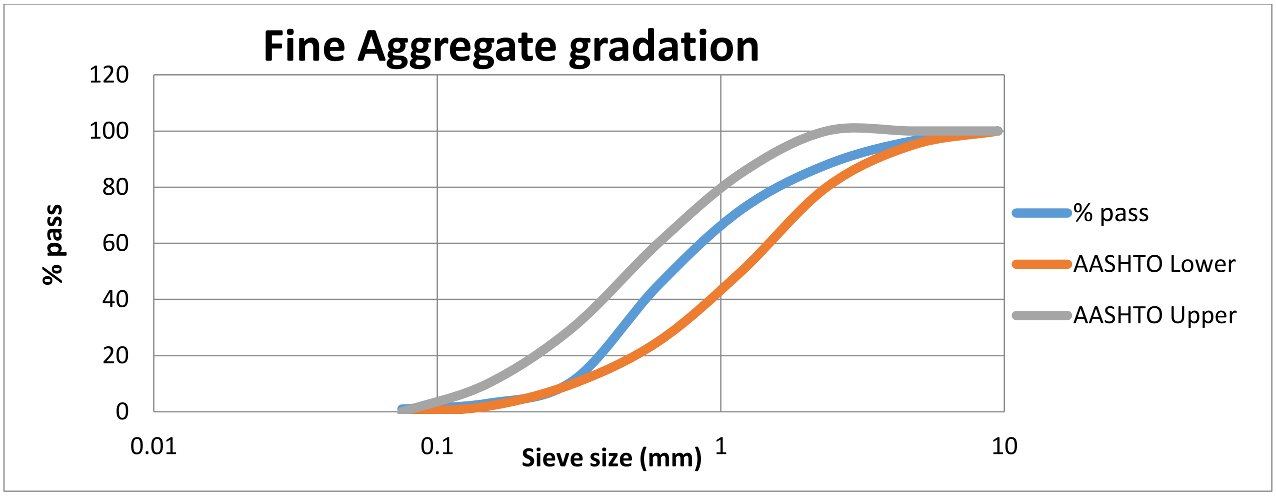

Figure 3.1- Gradation of fine aggregate

3.1.3 Coarse Aggregate

Coarse aggregates used for the production of concrete shall be strong, impermeable, durable & capable of producing a sufficient workable mix to achieve proper strength. The maximum size of the coarse aggregate which has been used for the study was 20mm.

3.1.3.1 Particle size distribution of coarse aggregate

Table 3.3: Particle size distribution of a coarse aggregate as per AASHTO M 43-88/ ASTM C-136 and ERA STS. 8402-3

AASHTO Sieve Size (mm)	Sample taken (gm.)							
	2004							
	Weight Retained (gm.)	Total weight Retained %	Cumulative total weight Retained %	% Passing	AASHTO M43-88 /ASTMC-136		ERA STS. 8402-3	
					Lower	Upper	Lower	Upper
25	0	0	0	100	100	100	100	100
19	172.2	8.46	8.46	91.54	90	100	80	100
9.5	1396.8	68.64	77.1	22.9	20	55	10	40
4.75	466	22.9	100	0	0	10	0	4
Pan	0	0						
Total sum	2035							

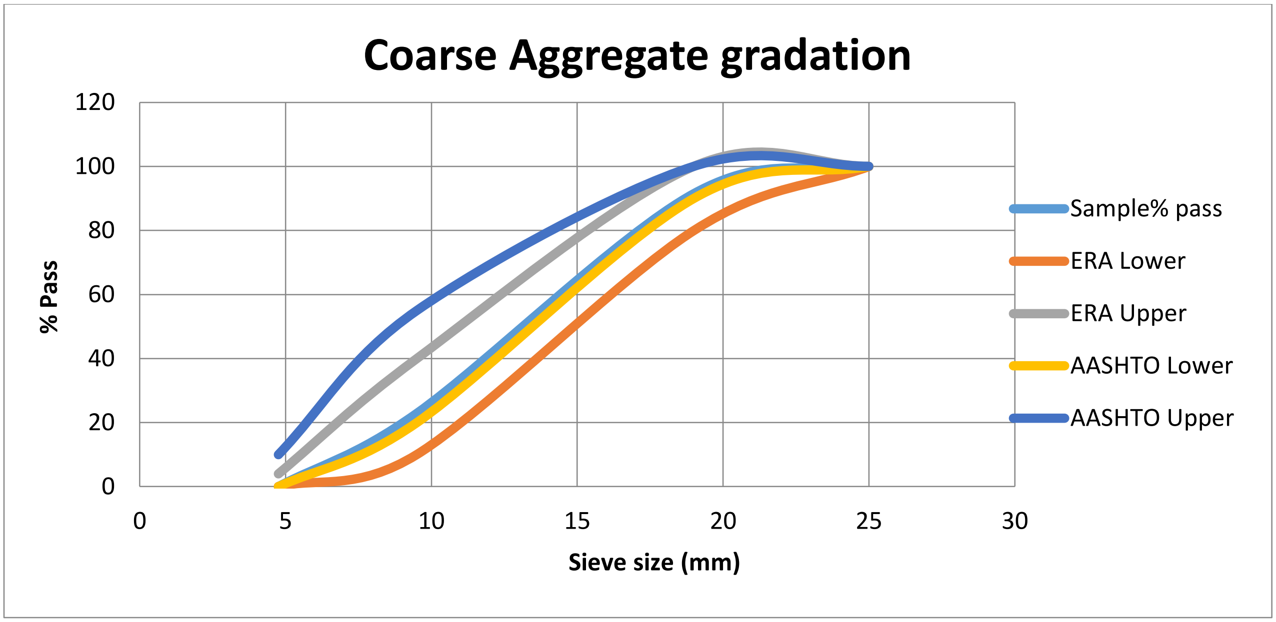

Figure 3.2- Gradation of coarse aggregate

3.1.4 Water

The quantity of mixing water for concrete affects the resulting hardened concrete. Impurities in water may interface with the setting of cement adversely affect the strength and durability of concrete. Fresh and clean potable water which is free from organic matter, silt, and oil as per standard have been used for casting and curing the specimen.

3.1.5 Sugarcane bagasse fiber

Bagasse is the fibrous remain of sugarcane stalks after crushing and extraction of the juice. Like any other biomass, it has the following composition (by weight): 41.8% cellulose, 28.0% hemicelluloses, and 21.8% lignin. It is estimated that approximately 1.25 kg of bagasse is produced per kilogram of sugar produced [47] and [48].

The average bagasse percentage in sugarcane is around 30%. The moisture content is a large determinant of the bagasse percentage in sugarcane since it constitutes about 65 to 75 % of the sugarcane in general or approximately it takes 50 % of bagasse produced in particular. Thus the fiber percentage of sugarcane normally ranges from 8 to 14%. The rest of the bagasse is made up of soluble solids. [48]

The bagasse used for the experiment has been the external hardcover of sugarcane after the moisture is fully removed. For the study, washed and Sundried sample has been used to minimize the effect of remaining sugar on the result and again to protect the specimen from losing its properties if oven-dry is an option. Future sieving using a sieve shaker has been carried out to remove the fine dust particles from the sample. In addition to the sieve, cutting and slicing the bagasse fiber have also been carried out to maintain a constant aspect ratio of 15.

Figure 3.3- Bagasse fiber and it's preparation for constant aspect ratio, separation of nodes, water-absorbent spongy part, and fine dust.

3.1.6 Bagasse ash

The bagasse ash for partial replacement of cement has been the by-product of "Wonjji" sugar factory after the juice is extracted. The factory is located around 90km from the capital Addis Ababa in Oromia Regional State –North-Eastern Ethiopia. No further grinding was necessary except sieving by 300-micron universal sieve size to remove the coarse particles from the sample and make it suitable for blending with the cement. The actual temperature of the furnace was not determined since there was no measuring equipment as long as the furnace. But the production plant section of the company tells the furnace have 800^{o}C for complete combustion of the sugarcane. Regarding this point, a related study noticed that the pozzolanic activity of bagasse ash was reduced due to the occurrence of crystallization of minerals at a temperature around 650^{o}C [28]. The grain size distribution of Dangote OPC cement and bagasse ash is shown in table 3.4 below;

Table 3.4: Grain size distribution for bagasse ash and Dangote OPC cement

Sieve size (μm)	Percent passing (cement)	Percent passing (Bagasse Ash)
300	100	100
150	99.2	80
125	98.5	73.6
75	93.2	61.5
63	82.2	50.5
32	14.4	21.8
Pan	8	12.1

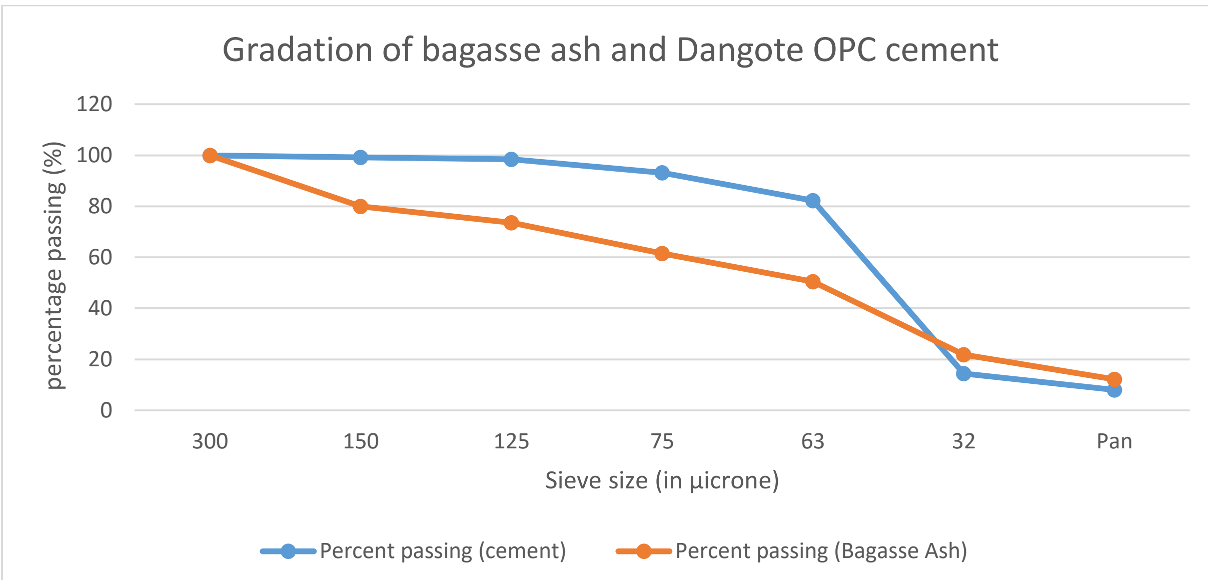

Figure 3.4- Gradation of Dangote OPC cement and sieved bagasse ash (300 μm.)

Major and minor oxide compositions of bagasse ash have been determined by the complete silicate analysis method in a geological survey of Ethiopia geochemical laboratory. According to the laboratory report (attached to the appendix section of this study), the analytical method applied to perform the activity has been $LiBO_2$ FUSION, HF Attack, Gravimetric, Colorimetric, and Atomic absorption spectroscopy (AAS).

Table 3.5: Chemical composition of cement and bagasse ash

Analyzed Major and Minor oxides	Composition in percent (%)		Remark
	Bagasse Ash [Appendix B]	Dangote OPC Cement [30]	
SiO_2	62.30	22.82	Major Oxide
Al_2O_3	9.49	5.41	>>
Fe_2O_3	3.80	3.37	>>
CaO	0.76	66.32	>>
MgO	1.52	1.46	Minor Oxide
Na_2O	1.16	-	>>
K_2O	5.84	-	>>
MnO	0.16	-	>>
P_2O_5	0.84	-	>>
TiO_2	0.37	-	>>
H_2O	2.18	-	>>
LOI (Loss in ignition)	10.71	-	>>
SO_3	-	2.16	
$SiO_2+Al_2O_3+ Fe_2O_3+$ CaO	**76.35**	**97.92**	$\sum Major\ Oxides$

Figure 3.5- Bagasse ash sieved with 300µm standard sieve size.

3.2 Research Methodology

The overall process of the research includes; literature review, a dusk study on different manuals and specifications, material collection, sample preparation, experimental program, and numeric analysis of results so that conclusion and recommendation would be made.

Before all different research journals and articles related to the topic of interest have been studied to learn methodologies with best practices and checked if there exists a gap then, the most widely used international and local manuals and with their material test specifications and design provisions reviewed to help meet the research objectives.

After the desk study is completed, all materials (bagasse ash, bagasse fiber, sand, coarse aggregate, and cement) that help to conduct the research have been collected and prepared per the studied specification. ASTM and AASHTO standards together with ERA manual helps for particle size distribution of aggregates.

Physical tests on materials were the next activity to be undertaken for material characterization so that mix-design could be done with ACI 211.1-91 procedures. Sample preparation has been following the mix design utilizing the results of physical tests on materials.

The research output obtained from laboratory experiments on sample cubes, cylinders and beams has been recorded at 7, 14, and 28 curing days and then discussed. The formulation of conclusions and recommendations drawn based on the results obtained have been the last activity.

3.2.1 Research Design

The designed methodology will be presented in the hierarchical diagram 3.6 below. The figure presents all the necessary procedures followed for the successful completion of the study.

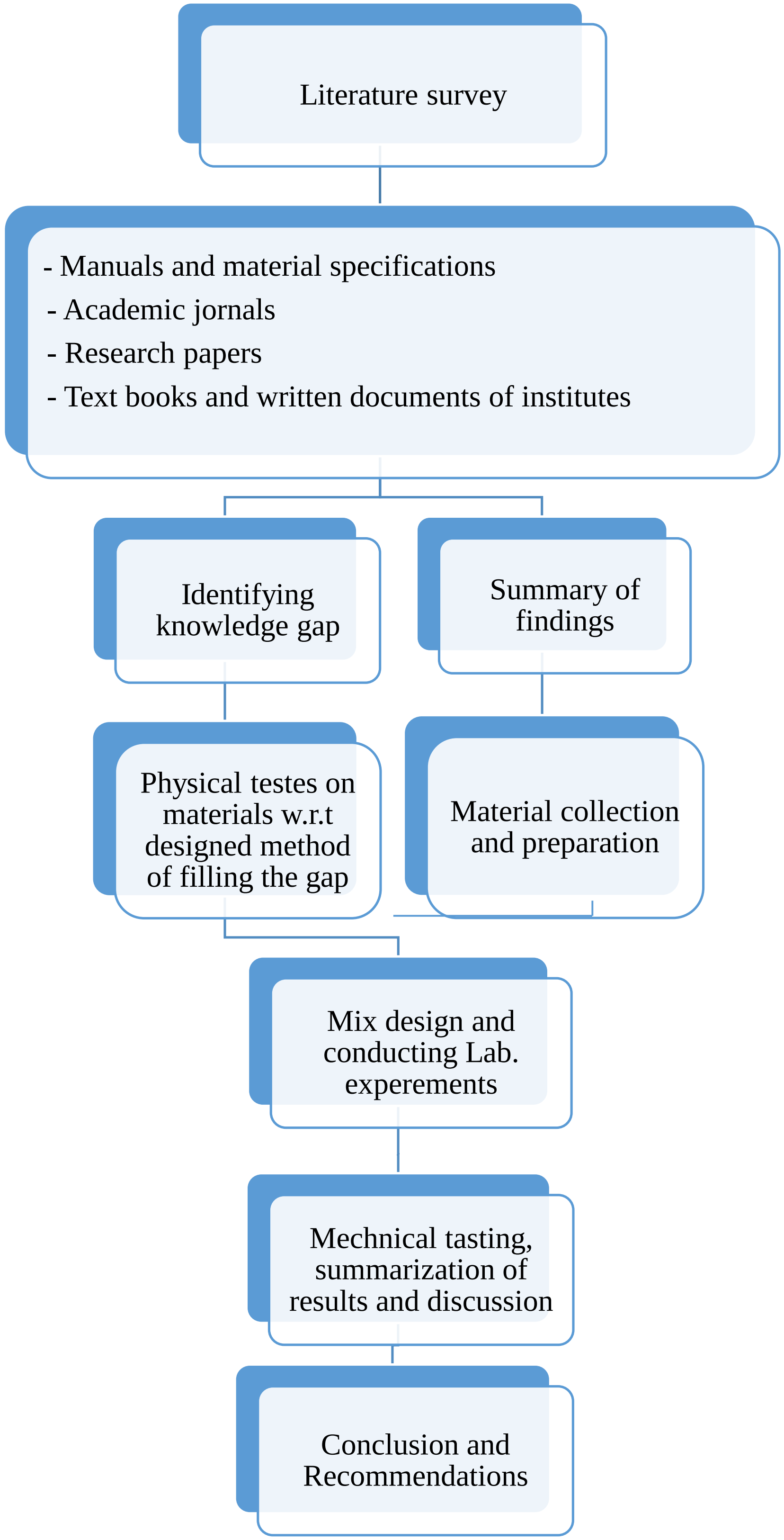

Figure 3.6- General methodology flowchart

3.3 Experimental Program

Under this section, mix design of concrete, trial mix preparation, normal consistency, and setting time tests undertaken for conventional concrete and blended concrete with cement-bagasse ash percentage replacement, all sample preparation techniques followed, and coding and proportioning of different mixes with respective test specimens are going to be presented.

3.3.1 Sample Preparation and Mix Proportion

The compressive strength of C-35 Grade of concrete has been taken as a design strength for the entire investigation. Due to simplicity and common use, the ACI committee (211.1 of 1991) method of mix design has been implemented. After proper preparation of casting molds, mixing, casting of test cubes, cylinders, and flexural beams have been carried out.

3.3.2 Specimen Preparation, Curing, and Testing

The bagasse fiber percentage has been 0.5 and constant throughout the study. Similarly, to keep a constant aspect ratio of 15, the sun-dried fiber has been chopped off using scissors as one can observe in the figure 3.3. For bagasse ash to replace cement 3 percentage variables (5%, 10%, and 15%) have been in use, and mixes were prepared in such a way each variable would have a chance to go together with constant fiber percentage. After preparation and testing of trial mixes, 45 test cubes, 45 test cylinders, and 45 test beams have been prepared and allowed to cure for 7, 14, and 28days. Curing for all test specimens has been carried out after 24 hours of casting. In the mentioned curing days 15 test cubes, 15 test cylinders, and 15 test beams have tested for compressive strength, split tensile strength, and two-point loading flexural strength so that result comparison will be made. The naming of all specimens prepared for different tests clearly stated in the table 3.6 and 3.7 below.

- ✓ Compressive Strength

Compressive strength has been obtained by conducting a compression test on hardened concrete. The test is carried out on cubes which have a nominal size of 15cm x 15cm x 15cm. 15 test cubes in different fiber to ash percentage with 3 samples for each one of them have been prepared. And therefore, a total of 45 cubes have been cast. Loading rate of 0.29MPa/sec used to break the samples. Table 3.6 below shows the naming of sample specimens prepared.

Table 3.6: Concrete Cube Samples Prepared.

Item	Mix code	Description		Casting days			Number of samples
				7	14	28	
1	M1	C-35 MPa conventional concrete cube		3	3	3	9
2	M2	Bagasse fiber %	Percentage (Kg.) cement replaced with bagasse ash	3	3	3	9
		0.5	5%				
3	M3	0.5	10%	3	3	3	9
4	M4	0.5	15%	3	3	3	9
5	M5	0.5% bagasse fiber content only		3	3	3	9
Total number of cube samples							45

- ✓ Split Tensile Strength

Split tensile strength has been obtained by conducting a tensile test on hardened Concrete. Split tensile test is carried out by placing a cylindrical specimen of 30cm x 15cm height to diameter nominal size horizontally in between the loading surfaces of the compression testing machine and the load with rate of 0.16MPa/sec is applied as per ASTM C39/ C39M recommended value until the failure of the cylinder, along with the vertical chamber.

Table 3.7: Concrete Cylinder Samples Prepared.

Item	Mix code	Description		Casting days			Number of samples
				7	14	28	
1	M1	C-35 MPa conventional concrete cylinder		3	3	3	9
2	M2	Bagasse fiber %	Percentage (Kg.) cement replaced with bagasse ash	3	3	3	9
		0.5	5%				
3	M3	0.5	10%	3	3	3	9

4	M4	0.5	15%	3	3	3	9
5	M5	0.5% bagasse fiber content only		3	3	3	9
Total number of cylinder samples							45

- ✓ Flexural strength

The flexural strength of test specimens has been obtained by conducting a two-point loading flexural test on hardened concrete. The test is carried out on test beams which have 50cm length with 10cm * 10cm equal size of breadth and depth. Like the rest of the strength tests, 15 test beams in different fiber to ash percentage with 3 samples for each one of them have been prepared. And therefore, a total of 45 test beams have been cast. The test is conducted referring to British Standard BS 1881-118 (1983) which describes flexural strength determination by letting moment in the central zone using two-point loading and ASTM C 78-94 with recommended load rate of 0.02MPa/sec. The schematic diagram in figure 3.7 below illustrates the specimen, two supports (considered as simply supported), and the loading arrangement [all dimensions are in mm.]

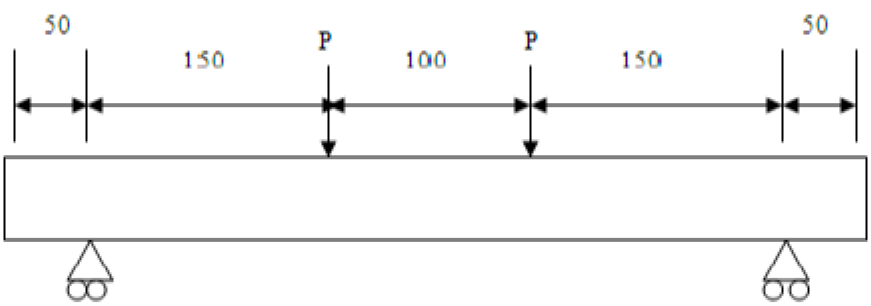

Figure 3.7- Two-point loading test arrangement. (Adapted from: [49])

3.3.3 Mix design of concrete

One of the ultimate aims of studying the various properties of materials of concrete is to design a concrete mix for the desired strength and durability. The design of concrete mix is not a simple task on account of the widely varying properties of constituent materials, the condition that's that prevails at the site of work, in particular the exposure condition, and the conditions that are demanded the particular work for which the mix is designed [32]. The author also suggests that complete knowledge of various properties of these constitute materials with experience of concreting, the implications in case of change on these conditions at the site, the impact of the properties of plastic concrete on hardened concrete, and complicated inter-relationship between the variables are required for the design of concrete mix. Even then the proportion of the materials of concrete found out at the laboratory requires modification and readjustment to suit the field conditions.

Mix design can be defined as "the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible" [32]. Material cost and cost of labor are the two primary factors in which the cost of concrete production depends on; the latter, by way of formworks, batching, mixing, transporting, and curing is nearly the same for good concrete and bad concrete. Therefore, attention is mainly given directed to the cost of materials. Since the cost of cement is many times more than the cost of other ingredients, attention is mainly directed to the use of as little cement as possible consistent with strength and durability.

3.3.4 American Concrete Institute Method of Mix Design

We shall now deal with the latest ACI Committee 211.1 of 1991 method. It has the advantages of simplicity in that it applies equally well, and with a more or less identical procedure to rounded or angular aggregate, to regular or lightweight aggregates, and air-entrained or non-air-entrained concretes.

a) Assuming 5 percent of results are allowed to fall below specified design strength, with a standard deviation 4Mpa.

The mean strength, fm = fmin + ks

$$= 35 + 1.64 \times 4 = 41.56, \text{ Say } 41.6 \text{ MPa.}$$

And from material characterization we have,

Table 3.8: Physical properties of materials.

1. Computation of dry bulk volume of coarse aggregate

Physical properties	Materials		
	Fine aggregate	Coarse aggregate	Unit
Bulk specific gravity in (SSD) condition	2.57	2.71	-
Unit weight	1610	1660	Kg/m^3
Moisture content	2	0.88	%

Absorption capacity	1.09	0.8	%
Fines modulus (FM)	2.84	-	-
Maximum size	4.75	20	Mm

Table 3.9: Dry bulk volume of coarse aggregate per unit volume of concrete as given by (ACI 211.1- 91)

Maximum size of aggregate	Bulk volume of dry rodded coarse aggregate per unit volume of concrete for fineness modulus of sand of			
F.M.	2.40	2.60	2.80	3.00
10	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
20	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65

From the table above, for fines modulus of (2.84) and the maximum size of aggregate (20mm) bulk volume of coarse aggregate can be interpolated and found to be (0.616).

1. Choice of slump

Table 3.10: Recommended values of slumps for various types of construction as given by

(ACI 211.1-91)

Types of construction	Ranges of a slump in (mm)
Reinforced foundation walls & footings	20-80
Plain footings and substructure walls	20-80
Beams and reinforced walls	20-100
Building columns	20-100
Pavements and slabs	20-80
Mass concrete	20-80

From the table above, for mass concrete, the recommended maximum and minimum slumps are 20mm and 80mm respectively. ACI 211.1-91 further suggests the upper limit of slump may be increased by 20 mm for compaction by hand. Now we shall choose 50mm recommended slump so that we can determine approximate mixing water and entrapped air.

2. Estimation of mixing water and entrapped air.

Table 3.11: Approximate requirements for mixing water and air content as given by (ACI 211.1-91)

Workability or air content	Water content, kg/m^3 of concrete for indicated maximum aggregate size							
	10mm	12.5mm	20mm	25mm	40mm	50mm	70mm	150mm
	Non- air-entrained concrete							
Slump								
30-50mm	205	200	185	180	160	155	145	125
80-100mm	225	215	200	195	175	170	160	140
150-180mm	240	230	210	205	185	180	170	-
Approximate entraped air content percent	3	2.5	2	1.5	1	0.5	0.3	0.2

From the ACI standard for slump value 30-50 and maximum size of aggregate 20mm, the water content in 1m^3 concrete is 185kg/m^3. And Approximate entrapped air content would be 2%.

3. Water to cement ratio estimation

Table 3.12: Relation between W/C and average compressive strength of concrete as given by (ACI-211.1-91)

Average compressive strength at 28 days (MPa.)	Effective W/C (by mass)	
	Non- air-entrained concrete	Air entrained concrete
45	0.38	-
40	0.43	-
35	0.48	0.40
30	0.55	0.46
25	0.62	0.53
20	0.70	0.61
15	0.80	0.71

For the compressive strength of 35Mpa non-air-entrained concrete, the recommended W/C ratio from a strength point of view is 0.48. Alternatively, from a durability point of view or special exposure condition ACI-211.1-91 recommends water to cement ratio values so that one can adopt the minimum. In our case, for the concrete exposed to freshwater the given maximum W/C is 0.5. Thus, we shall take 0.48.

4. Cement content estimation

The required cement content can be estimated by dividing the water content by the water to cement ratio. This means for slump value 30mm-50mm the water content is 185kg/m3.

$$\text{Cement (Kg)} = \frac{\text{Water Content}}{\text{W/C}}$$

$$= 185/0.48 = 385.4 kg/m^3$$

5. Coarse aggregate content estimation

From table 1 the dry rodded bulk volume of coarse aggregate per cubic meter of concrete is 0.616. Therefore, the weight of coarse aggregate = 0.616*1660 =*1022.56* kg/m^3

6. Fine aggregate content estimation

Table 3.13: First estimate of the density of fresh concrete for 20mm maximum size of aggregate and non-air entrained concrete as given by (ACI-211.1-91)

Maximum size of aggregate(mm)	The first estimate of density (unit weight) of fresh concrete (Kg/m^3)	
	Non-air entrained concrete	Air-entrained concrete
10	2285	2190
12.5	2315	2235
20	2355	2280
25	2375	2315
40	2420	2355
50	2445	2375
70	2465	2400
150	2505	2435

From the above ACI, the unit weight of concrete for a maximum size of coarse aggregate (20mm) is 2355Kg/m^3. Therefore, using the absolute weight method, the mass of fine aggregate will be;

Fine aggregate (Kg/m^3) = 2355- (the weight of all known ingredients of concrete)

= 2355- 385.4- 185- 1022.56

= 762.04Kg/m^3

Alternatively, the weight of fine aggregate can be found out by the absolute volume method which is more accurate. [32]

Table 3.14: Absolute volume of all the known ingredients.

Item number	ingredients	Weight (Kg/m^3)	Absolute volume cm^3
1.	Cement	385.4	$\frac{385.4}{3.15} * 10^3$=122.3*10^3
2.	Water	185	$\frac{185}{1}$*10^3=185*10^3
3.	Coarse aggregate	1022.56	$\frac{1022.56}{2.71}$*10^3=377.3*10^3
4.	Air		$\frac{2}{100}$*10^6=20*10^3
Total absolute volume			**704.7*10^{3}cm^3**

Therefore, absolute volume of fine aggregate will be;

= (1000-704.7) *10^3

= 295.3*10^3

Weight of fine aggregate = 295.3*2.57

Adopt fine aggregate =759Kg/m^3

Table 3.15: Estimated quantities of materials per cubic meter of concrete.

Materials	Cement	Fine aggregate	Coarse aggregate	water
Proportions	385.4	759	1022.56	185
Ratio	1	1.97	2.65	0.48

The density of fresh concrete becomes 2352 Kg/m^3 as against 2355Kg/m^3 read from table 5.

The above quantities are on the basis that both fine aggregate and coarse aggregate are in saturated and surface dry condition (SSD conditions).

7. Moisture adjustment

The proportions are required to be adjusted for the field conditions. FA has surface moisture of 2 percent

Therefore, total free surface moisture in FA =

$$2/100 * 759 = 15.18 \text{ kg/m3}$$

Again, absorption of FA would be,

$$1.09/100 * 759 = 8.27 \text{Kg/m}^3$$

$$15.18 - 8.27 = 6.91 \text{Kg/m}^3$$

$$\text{Weight of F.A in field condition} = 759 + 6.91 = 765.91 \text{ Kg/m}^3$$

$$\text{Say } 766 \text{ Kg/m}^3$$

With regard to water, 6.91 kg of water is contributed by F.A.

Similarly, the difference between moisture content and absorption capacity of coarse aggregate can be computed.

$$(0.884 - 0.798)/100 * 1022.56$$

$$= 0.88 \text{ Kg/m}^3$$

$$\text{Weight of C.A in field condition} = 1022.56 + 0.88 = 1023.44 \text{ Kg/m}^3$$

Say 1024 Kg/m^3

Concerning water, 0.88 kg of water is contributed by C.A.

Therefore, from both fine and coarse aggregates, 6.91+0.88 = 7.79 kg of extra water is contributed to the mix. This quantity of water is deducted from Total water i.e., 185.00 – 7.79= 177.21 kg/m3 say 177 kg/m3

8. Quantities of materials to be used in the field duly corrected for free surface moisture in and absorption characteristic of F.A and C.A

Table 3.16: Final compositions of the constituent materials.

Materials	Weight (kg/m^3)	Ratio
Cement	385.4	1
Fine aggregate	766	1.99
Coarse aggregate	1024	2.66
Water	177	0.46
Field density of fresh concrete	2352.4	-

N.B: All calculations made in the entire paper get rounded to the second decimal digit.

3.3.5 Preparation of trial mix and workability of concrete

The trail mix has been prepared following the ACI method of mix design with chosen water to binder ratio of 0.46. the main objective behind trial mix preparation is to check either the selected water to binder ratio would make the prepared fresh concrete within acceptable slump range or not. According to ACI 211.1-91, the recommended maximum and minimum slump values for mass concrete are 20mm and 80mm respectively. The manual further suggests the upper limit of slump may be increased by 20 mm for compaction by hand. Although three mixes namely, M1, M2, and M5 have shown slump values within a limit, the remaining mixes M3 and M4 show a reduction in slump below the recommended minimum value.

Therefore, keeping the cement content constant there has been a slight increment in water to binder ratio to adjust the values. According to [50] cited on [28] an increase or decrease of the water content by 6kg/m^3 will increase or decrease the slump by approximately 25mm. as a result 5kg/m^3 and 6kg/m^3 additional water added for the mixes M3 and M4 respectively. The original calculated required amount of water on the mix design above is 177kg/m^3. Thus, the amount of water taken for M3 is 182 kg/m^3 and 183 kg/m^3 water is taken for M4 accordingly. The detail calculated material proportion for the entire mixes is presented in table 3.17 below;

Table 3.17- Material proportion for the entire mix.

Item	Code	Cement (Kg/m^3)	Bagasse ash (Kg/m^3)	Bagasse fiber (Kg/m^3)	W/C	Water (Kg/m^3)	Fine aggregate		Coarse aggregate	
							(Kg/m^3)	%	(Kg/m^3)	%
1	M1	385.4	-	-	0.46	177	766	33.56	1024	43.53
2	M2	366.13	13.3	11.73	0.46	177	766	32.40	1024	43.31
3	M3	346.86	26.6	11.72	0.49	182	766	32.40	1024	43.31
4	M4	327.59	39.89	11.70	0.50	183	766	32.40	1024	43.31
5	M5	385.4	-	11.76	0.46	177	766	32.40	1024	43.31

Where:

- ✓ M1 is a code standing for conventional concrete mixture with 0% bagasse ash and 0% bagasse fiber.
- ✓ M2 is a code standing for cement-bagasse ash blended concrete mixture with 5% bagasse ash and 0.5% bagasse fiber.[for these mixture water to binder ratio taken is 0.46 as shown in table 3.17 that is due to the fact its slump has been within the acceptable maximum and minimum values]
- ✓ M3 is a code standing for cement-bagasse ash blended concrete mixture with 10% bagasse ash and 0.5% bagasse fiber.
- ✓ M4 is a code standing for cement-bagasse ash blended concrete mixture with 15% bagasse ash and 0.5% bagasse fiber.
- ✓ M5 is a code standing for fiber-reinforced concrete mixture with 0% bagasse ash and 0.5% bagasse fiber.

N.B: For all the coded mixtures, 2% approximate entrapped air shall be taken into consideration**.** And the mixing of all the above-mentioned concrete mixtures has been done using the weight batching technique. But as suggested on [28] for cement- bagasse ash blended concrete the replacement shall not be 1:1. Rather account the lower density of bagasse ash (2.16 g/cm^3), 1Kg of cement has been replaced by 0.69Kg of bagasse ash to keep the fresh concrete paste volume constant.

Table 3.18- Mix proportions for coded Individual batches for the number of test specimens

Code	Total number of test specimens			Cement (Kg)	Bagasse ash (Kg)	Bagasse fiber (Kg)	W/C	Water (Kg)	Fine aggregate (Kg)	Coarse aggregate (Kg)
	Cylinders (15*30) cm	Cubes (15*15*15) cm	Beams (50*10*10) cm							
M1	9	9	9	52.4	-	-	0.46	24.06	104.15	139.22
M2	9	9	9	49.78	1.81	1.59	0.46	24.06	104.15	139.22
M3	9	9	9	47.15	3.62	1.59	0.49	24.74	104.15	139.22
M4	9	9	9	44.54	5.42	1.59	0.50	24.88	104.15	139.22
M5	9	9	9	52.4	-	1.6	0.46	24.06	104.15	139.22

NB: Except mass of bagasse fiber which is computed from the total weight of materials for individual mixture, all material calculation has been done considering allowable wastage of (10%) from the volume of individual mixtures. Thus, the total volume for individual mixture from which materials have been computed becomes 0.13596m^3.

Another important point regarding fiber-reinforced concrete mixture is to make sure all fibers are uniformly distributed entirely throughout the paste to achieve improvements in mechanical properties, keeping the concrete workable to permit proper mixing, placing, and finishing. Moreover, the process helps to prevent the formation of unnecessary balling of fibers in the fresh concrete mixture. Therefore mixing while working with fibers is not just bringing all ingredients together and introducing to the mixer. Rather, it needs dry mixing in a sufficient container so that one can make sure fibers are distributed uniformly in the dry batch of concrete making materials.

Figure 3.8- Materials prepared for dry mixing and balling of fiber in the concrete paste.

3.3.6 Workability of fresh concrete

The workability of fresh concrete for all mixes has been carried out using a standard slump cone having 300mm high with a bottom diameter of 200mm and a top diameter of 100mm. the concrete has been field to the cone in three layers at which each layer would get a rod exactly 25 times using one end rounded steel tamping rod having 16mm diameter and 600mm length.

Figure 3.9- Workability check using slump cone while trial mix preparation

3.3.7 Normal consistency and setting time of hydraulic cement

3.3.7.1 Normal consistency of hydraulic cement

The test was carried out to determine the amount of water required for satisfactory workability. “Vicat apparatus” has been in use to measure the resistance of the concrete paste for a penetration of 300gram needle attached to the middle bottom of the apparatus. The amount of water required for a normal consistency which allows the Vacat needle to penetrate the original surface of the concrete paste to a depth of 9-11mm is then recorded and expressed as a percentage by weight of the dry cement.

$$\% \text{ Water} = \frac{\text{weight of water taken(gm.)}}{weight\ of\ sample\ taken(gm.)}$$

The usual range of water to binder ratio for a normal consistency is between 26% and 33% [46].

Figure 3.10- Normal consistency test on progress for samples prepared using Vicat apparatus.

3.3.8 Setting time of hydraulic cement

This test was carried out to determine the initial and final time that the cement paste takes to form a solid and hard mass when mixed with water upon hydration. Since the setting time of cement is significantly affected by water to binder ratio, the percentage of water need for a normal consistency has been taken to measure both initial and final setting times. The experiment goes for three different Dangote Ordinary Portland cement samples with respectively 5%, 10%, and 15% of individual samples replaced by bagasse ash. Finally, for comparison of test results control

Dangote Ordinary Portland cement of 42.5 grade with no additives checked for its initial and final setting time.

For an initial setting time, "Vicat apparatus" with an attached 1mm diameter needle has been in use and it is determined by recording the period elapsing between the times when water is added to the cement and the time at which the attached needle penetrates 25mm from the surface of the cement paste.

The final setting time has also been determined similarly to the initial setting time determination except for the needle of the "Vicat apparatus" replaced by the needle with annular attachment. And unlike the initial setting time, the final setting time is the time the annular attachment fails to penetrate the surface of the cement paste or when there is no visible penetration.

Figure 3.11- Setting time test on progress for samples prepared using Vicat apparatus.

3.3.9 Fineness of hydraulic cement

A higher rate of strength gain and a higher rate of evolution of heat are directly proportional to the fineness of hydraulic cement as the rate of hydration increases with an increase in fineness. The test was conducted for three samples of Dangote ordinary Portland cement and three bagasse ash samples passed through 300µm sieve size and each having 50gram of total weight. 150µm or No. 100 sieve size has been in use to experiment.

Figure 3.12- Sample of cement and bagasse ash with fineness test on progress

The fineness of samples was calculated from the expression mentioned in a construction laboratory manual [46]. And the average size (μm) of materials is the sieve size through which 50% of the particle passes on the grain size distribution of cement and bagasse ash. [See table 3.4]

$$F= 100-[(\frac{Rs*100}{W})]$$

Where "Rs" is the residue from the sample retained on the sieve and "W" represents the weight of the sample in gram.

CHAPTER 4- RESULTS AND DISCUSSIONS

4.1 Introduction

In this chapter summaries of major laboratory test results of cement and bagasse ash will be analyzed. At the same time, different properties of all bagasse fiber reinforced concrete mixtures and ordinary concrete mix prepared and mentioned in the experimental section of the document are going to be presented and discussed. The following are the main portions to be covered in this section:

4.2 Characterization of raw materials

4.2.1 Fineness of Cement and Bagasse ash

Through the sieving method of determining fineness, the average size of bagasse ash shows a 23.90% higher value as compared to the average size of cement. This is because the bagasse ash did not entertain any type of modification except sieved by 300µm. sieve size. On the gradation of cement and bagasse ash, one can observe when the sieve size gets smaller especially after 63µm, the percentage passing of bagasse ash would get higher. This implies bagasse ash has finer particles than cement when sieved in small-sized sieve i.e. 32µm. The specific surface area of bagasse ash collected from the same source and sieved on 300µm sieve size without any type of modification shows an 8.5% slightly higher value than cement on related research [51]. Similarly, the specific surface area value of bagasse ash pulverized to modify some of its properties gets high with much-inflated value (around 62%) than compared with cement [28]. Table 4.1 below shows materials with average fineness expressed as percentage passing of the sieve and average size;

Table 4.1: Average fineness and size of cement and bagasse ash

Materials	Samples	Original weight (gm.)	Retained weight (gm.)	Fineness (%)	Average size (µm)
OPC cement	A	50	0.43	99.14	48.32
	B	50	0.39	99.22	
	C	50	0.38	99.24	
	Avg.	50	0.40	99.20	
	Ai	50	9.5	81.00	

Bagasse Ash	Bi	50	11.5	77.00	63.5
	Ci	50	9.12	81.76	
	Avg.	50	10	80	

As it can be seen from table 4.1 above the average fineness of the bagasse ash used for partial replacement of cement shows a 24.00% reduction in fineness as compared with cement. The reason is obviously due to lack of certain modification over its physical property like further grinding except sieved with 300µm sieve size. But from the grain size distribution of cement and bagasse ash, it can be understood that there are 51.34% finer particles on the bagasse ash sample relative to the cement below the sieve size 63µm.

4.2.2 Normal consistency and setting time test results

Table 4.2 and table 4.3 under present the normal consistency and setting time of hydraulic cement paste, a paste prepared from cement with percentage replacement of bagasse ash, and cement paste with 0.5% bagasse fiber.

Table 4.2: Normal consistency test results

Trial No:	1	2	3
Normal consistency of OPC hydraulic cement paste (0% BA)			
Weight of cement (gm.)	500	500	500
Weight of water (gm.)	150	140	130
Amount of water (ml.)	150	140	130
Penetration depth(mm)	16	13	10
Normal consistency (%)	30	28	**26**
Normal consistency of cement paste (5% BA)			
Weight of cement (gm.)	475	475	475
Weight of bagasse ash (gm.)	17.25	17.25	17.25
Weight of water (gm.)	152.60	137.83	132.91
Amount of water (ml.)	155	140	135
Penetration depth(mm)	12	11.5	10
Normal consistency (%)	31	28	**27**
Normal consistency of cement paste (10% BA)			

Weight of cement (gm.)	450	450	450
Weight of bagasse ash (gm.)	34.5	34.5	34.5
Weight of water (gm.)	155.04	150.20	145.35
Amount of water (ml.)	160	155	150
Penetration depth(mm)	12.6	11.3	10.6
Normal consistency (%)	32	31	**30**
Normal consistency of cement paste (15% BA)			
Weight of cement (gm.)	425	425	425
Weight of bagasse ash (gm.)	51.75	51.75	51.75
Weight of water (gm.)	171.63	166.86	162.10
Amount of water (ml.)	180	175	170
Penetration depth(mm)	12.9	11.8	10.7
Normal consistency (%)	36	35	**34**
Normal consistency of cement paste (0.5% Bagasse Fiber)			
Weight of cement (gm.)	500	500	500
Weight of water (gm.)	140	130	132.5
Amount of water (ml.)	140	130	132.5
Weight of bagasse fiber (gm.)	2.5	2.5	2.5
Penetration depth(mm)	12	8.5	9.5
Normal consistency (%)	28	26	**26.4**

Table 4.3: Setting time test results

Initial and final setting time of OPC hydraulic cement paste (0%BA)					
Trial No.	Cement (gm.)	Water (gm.)	Penetration Depth (mm)	Time(Hr.)	Remarks
The start time of mixing:			-	08:30	Interpolation has been in use for penetration depth between 26mm and 22mm. Thus, the initial setting time at which 25mm needle penetration achieved was at **165** minutes.
1	500	150	40	09:00	
2	500	150	40	09:10	
3	500	150	-	-	
4	500	150	38	09:40	
5	500	150	-	-	

6	500	150	33	10:30	
7	500	150	-	-	
8	500	150	26	11:10	
9	500	150	24	11:20	
10	500	150	-	-	The final setting time is **220** minutes.
11	500	150	-	-	
12	500	150	0	12:10	
Initial and final setting Time of Cement Paste (5%BA)					
Trial No.	Cement with bagasse ash (gm.)	Water(gm.)	Penetration Depth (mm)	Time (Hr.)	Remarks
The start time of mixing:			-	08:30	Interpolation has been in use for penetration depth between 26mm and 22mm. Thus, the initial setting time at which 25mm needle penetration achieved was at **172.5** minutes.
1	492.25	152.6	40	09:00	
2	492.25	152.6			
3	492.25	152.6	38	10:00	
4	492.25	152.6	-	-	
5	492.25	152.6	35	10:30	
6	492.25	152.6	-	-	
7	492.25	152.6	34	11:00	
8	492.25	152.6	30	11:10	
9	492.25	152.6	26	11:20	
10	492.25	152.6	22	11:30	
11	492.25	152.6	-	-	Final setting time is **230** minutes
12	492.25	152.6	0	12:20	
Initial and final setting time of cement paste (10%BA)					
Trial No.	Cement with bagasse ash (gm.)	Water (gm.)	Penetration Depth (mm)	Time (Hr.)	Remarks
The start time of mixing:			-	08:30	Interpolation has been in use for penetration depth between 25.4mm and 24.3mm. Thus, the initial setting time at which 25mm needle penetration achieved was at **193.81** minutes.
1	484.5	155.04	40	09:00	
2	484.5	155.04	-	-	
3	484.5	155.04	38	09:50	
4	484.5	155.04	-	-	
5	484.5	155.04	-	-	
6	484.5	155.04	28.5	11:20	
7	484.5	155.04	-	-	
8	484.5	155.04	25.4	11:40	
9	484.5	155.04	24.3	11:50	
10	484.5	155.04	-	-	
11	484.5	155.04	-	-	The final setting time is **250** minutes
12	484.5	155.04	0	12:40	
Initial and final setting time of cement paste (15%BA)					

Trial No.	Cement with bagasse ash (gm.)	Water (gm.)	Penetration Depth (mm)	Time (Hr.)	Remarks
The start time of mixing:			-	08:30	Interpolation has been in use for penetration depth between 26mm and 17.5mm. Thus, the initial setting time at which 25mm needle penetration achieved was at **211.16** minutes.
1	476.75	171.63	40	09:00	
2	476.75	171.63	-	-	
3	476.75	171.63	39	10:00	
4	476.75	171.63	35.5	11:00	
5	476.75	171.63	-	-	
6	476.75	171.63	26	12:00	
7	476.75	171.63	-	-	
8	476.75	171.63	26	12:00	
9	476.75	171.63	17.5	12:10	
10	476.75	171.63	-	-	
11	476.75	171.63	-	-	The final setting time is **270** minutes.
12	476.75	171.63	0	01:00	

Initial and final setting time of cement paste (0.5%BF)					**M5**
Trial No.	Cement with bagasse ash (gm.)	Water (gm.)	Penetration Depth (mm)	Time (Hr.)	Remarks
The start time of mixing:			-	08:30	The initial setting time at which 25mm needle penetration achieved was at **200** minutes
1	502.5	140	40	09:00	
2	502.5	140	-	-	
3	502.5	140	38	10:00	
4	502.5	140	-	-	
5	502.5	140	33	11:00	
6	502.5	140	-	-	
7	502.5	140	28	11:30	
8	502.5	140	-	-	
9	502.5	140	25	11:50	
10	502.5	140	-	-	
11	502.5	140	-	-	The final setting time is **260** minutes.
12	502.5	140	0	12:50	

Table 4.4: Summary on normal consistency and setting time of all mixes.

Code	Normal consistency (% water)	Initial setting time (minutes)	Final setting time (minutes)	Remark
M1	26	165	220	OPC only
M2	27	172.5	230	5% BA.
M3	30	193.81	250	10% BA.
M4	34	211.16	270	15% BA.
M5	26.5	200	260	0.5% BF.

As one can see from table 5.2 above, the percentage of water required for a normal consistency of OPC hydraulic cement is 26%. The result indicates for the cement used, 26% or 130ml. of water is suitable to achieve satisfactory workability. And the percentage of water required for a normal consistency is getting higher when the percentage replacement of cement with bagasse ash gets increased. The result indicates bagasse ash needs approximately 2.24%, 11.81%, 24.69% more water than Dangote ordinary Portland cement in each 5%, 10%, 15% percentage replacement respectively to achieve satisfactory workability. Besides, the increment in each replacement level is not constant rather it is variably continuous. The increment on water requirement is due to the presence of 51.34% finer particles on the bagasse ash sample relative to the cement below the sieve size 63µm. concerning bagasse fiber, the demand for the percentage of water was not significant. According to the result, only 1.54% more water is needed for a normal consistency relative to OPC cement.

When dealt with setting time, it is understood percentage replacement of cement with bagasse ash results in an increase in setting time of mixtures. These phenomena indicate bagasse ash acts as a retarding agent for the cement paste. The setting time keeps increasing as the amount of bagasse ash increases although it is within the limit specified on the Ethiopian authority of standards. The standard specifies the initial setting time of the cement paste should not be below 45minutes and the final setting time of the paste should not exceed 10Hrs.

To find out the probable reason behind the retarding nature of bagasse ash a normal consistency test was carried out for the paste prepared from 500gm. of bagasse ash. The result was away far from the usual range of water percentage for a normal consistency. According to the test result, the percentage of water needed for a normal consistency was 160%. In other words, 800gm. of water used in the bagasse ash paste for the Vicat needle to penetrate 10mm from the surface of the paste. The scenario leads to conclude as there is a higher rate of water adsorption on the bagasse ash surface demanding lots of water for a normal consistency. An increase in setting time of the paste to the amount of water as well. As Ajaye Goyal cited in [28] “reduction in the amount of calcium hydroxide and the development of films of silica gel around cement grains may also cause the retardation of setting time”.

Bleeding is the main challenge associated with the normal consistency test of bagasse ash. Thus, to minimize the challenge and to tighten the gap between the Vicat mold and the glass plate some manual aid is needed. The rate of strength gain was also difficult to visualize and determine since the hydration process between water molecules and bagasse ash particles was too slow.

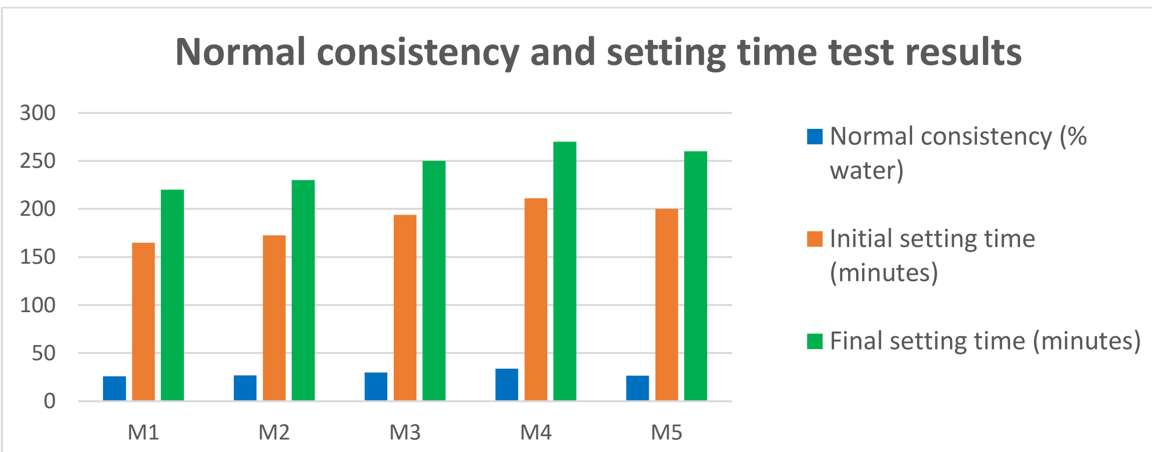

Figure 4.1- Normal consistency and setting time test results.

In a similar manner with bagasse ash, the bagasse fiber plays a retarding role on the setting time of fresh concrete. The reaction between water molecules and cement is different from the reaction that water undergoes with bagasse ash. According to [52], the endothermic reaction between water molecules and components of bagasse fiber influences the setting. Moreover, the amount of sucrose on sugarcane bagasse fiber is estimated to cover 81-87% composition retards setting and hardening indefinitely [53]. Though the retarding effect depends upon dosage, curing condition, and time of addition to the mix [54].

4.2.3 Slump test results

Table 4.5 below shows the experimental results of slump tests with water to binder ratio (W/C = 0.46) carried out to determine the workability of fresh concrete for all the mixtures.

Table 4.5: Workability of fresh concrete.

Code	Explanation	Slump value(mm.)	Slump type	ACI 211.1- 91		Remark
				Min.	Max.	
M1	OPC only	80	True slump	20mm.	80mm.	Slump is within the limit.
M2	5% BA	28	True slump	20mm.	80mm.	Slump is within the limit.
M3	10% BA	6	True slump	20mm.	80mm.	Slump is below the limit!
M4	15% BA	3	True slump	20mm.	80mm.	Slump is below the limit!
M5	Bagasse fiber only	40	True slump	20mm.	80mm.	Slump is within the limit.

Before casting strength test specimen molds, new water to binder ratio of 0.49 and 0.5 introduced respectively for the mix M3 and M4 to adjust the slump value for the upper and lower limit recommended on ACI 911.1 -91. And new true slump values of 26mm and 28mm measured respectively. The adjustment has been done based on the finding of [50] cited in [28]. According to the authors, an increase or decrease in 6kg/m^3 of water will result in approximately 25mm slump variation on fresh concrete. Each percent addition in bagasse ash would result in a dry and non-workable mixture; that is the reason why more water is necessary. As compared with M1, the slump value of M5 was reduced. The reduction in the slump with the presence of fiber will be attributed to the presence of fibers which obstructs the free flow of concrete [55].

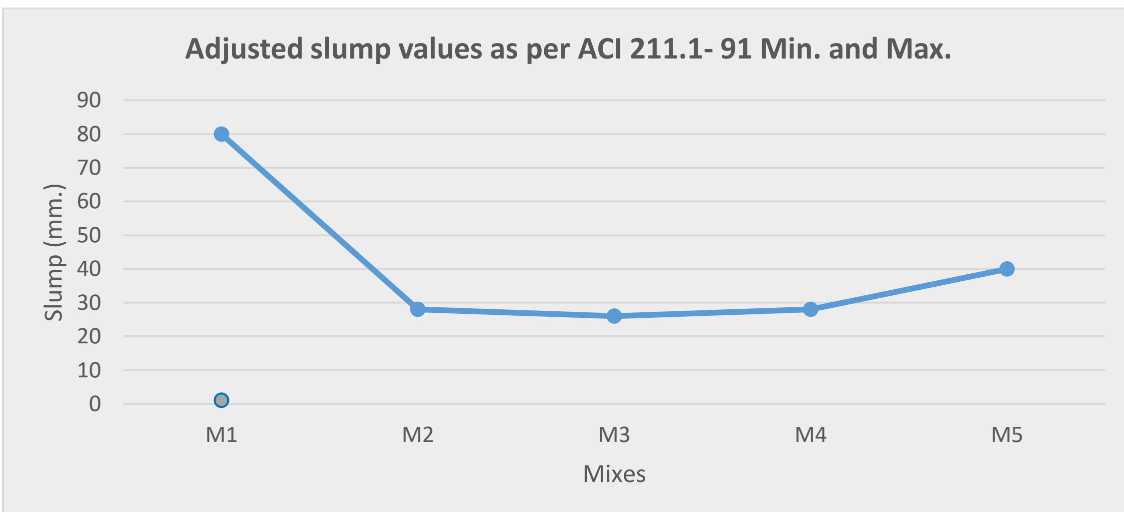

Figure 4.2- Workability test (top) and slump values of fresh concrete mixes (bottom)

4.3 Effect of bagasse ash on harden properties of Bagasse fiber reinforced concrete

Under these section compressive strength of test cubes, split tensile strength of test cylinders, and flexural strength of test beams for each curing days of 7, 14, and 28 will be presented and discussed. The maximum load causing failure of test specimens will also be summarized and comparison among results is going to be made similarly for all the listed strength test results.

Primarily, all mixes with constitute variable percentage bagasse ash and constant fiber content run for comparison with the fiber-reinforced concrete mixture with 0% bagasse ash M5, so that the better result can be chosen and goes to further comparison relative to ordinary concrete mixture M1 with neither bagasse ash nor bagasse fiber composition,

4.3.1 Compressive strength of test cubes

The fact that concrete is stronger for compressive than tensile loads makes this test crucial. Hereunder, the compressive strength of test specimens and corresponding failure loads will be summarised through table 4.6 and discussed.

Table 4.6: Average failure load and compressive strength of test cubes

S. No.	Mix Code	Average compressive strength								
		7 Days			14 Days			28 Days		
		Avg. weight (gm.)	Failure load (KN.)	Strength (Mpa.)	Avg. weight (gm.)	Failure load (KN.)	Strength (Mpa.)	Avg. weight (gm.)	Failure load (KN.)	Strength (Mpa.)
1	**M1**	8124	648.43	**28.82**	8108	726.85	**32.31**	8098	807.60	**35.89**
2	**M2**	8119	591.80	**26.30**	8089	692.27	**30.77**	8059	769.19	**34.19**
3	**M3**	8089	421.92	**18.75**	8058	540.89	**24.04**	8028	600.99	**26.71**
4	**M4**	8068	328.87	**14.62**	8037	469.79	**20.88**	8008	522.01	**23.20**
5	**M5**	8130	439.03	**19.51**	8115	547.25	**24.32**	8105	608.06	**27.03**

As one can observe in Table 4.6 above, from fiber-reinforced concrete mixtures M2 has shown better strength result in all the three curing ages. According to the test result, this cement-bagasse ash blended concrete mixture with 5% bagasse ash and 0.5% bagasse fiber content has shown a 19.95% increase in strength at 28 days relative to M5 i.e. fiber concrete mixture with 0.5% bagasse fiber reinforcement. On contrary, M3 i.e. cement-bagasse ash blended concrete mixture with 10% bagasse ash and 0.5% bagasse fiber content has shown a 1.19% reduction in strength at 28 days relative to M5. The reduction in strength becomes more pronounced in the case of M4 i.e. a mixture with 10% bagasse ash and 0.5% bagasse fiber content. This particular mix has shown a 14.17% decrease in compressive strength at 28 days as compared with M5.

The test result indicates the 5% replacement of cement with bagasse ash improves the compressive strength of the bagasse fiber reinforced concrete mix providing around 20% additional strength.

But although M2 was proven to be the best mix in strength relative to the entire mixture with bagasse fiber, it shows a 4.74% reduction in strength at 28 days of curing when compared with the conventional concrete mix M1, i.e. 0% bagasse ash and 0% bagasse fiber content. The primary and main reason for this slight reduction in strength would be the retarding effect of bagasse ash.

The second reason with the reduction in strength is associated with the availability of 51.34% finer particles on the bagasse ash sample relative to the cement below the sieve size 63µm. These fine particles cause the percentage of water required for a normal consistency to be higher which in turn reduces the strength. As presented in section 4.2.1 of this chapter, the phenomena become more pronounced when the percentage replacement of cement with bagasse ash gets increased. As more water has been needed to achieve satisfactory workability.

Different works of literature show that usage of sugar as a natural admixture to a certain level can retard the setting of cement paste and improves the compressive strength but when used in the excessive amount it changes its character and acts as an accelerator. This excessive amount of sugar i.e. above 0.08% by weight of cement may also result in internal or external crack formation in the sample through volume expansion [56]. Thus, the other reason for the reduction in strength can be the nature of bagasse fiber to hold undissolved sugar bubbles and the availability of unburned organic substances in bagasse ash approximately more than the specified limit.

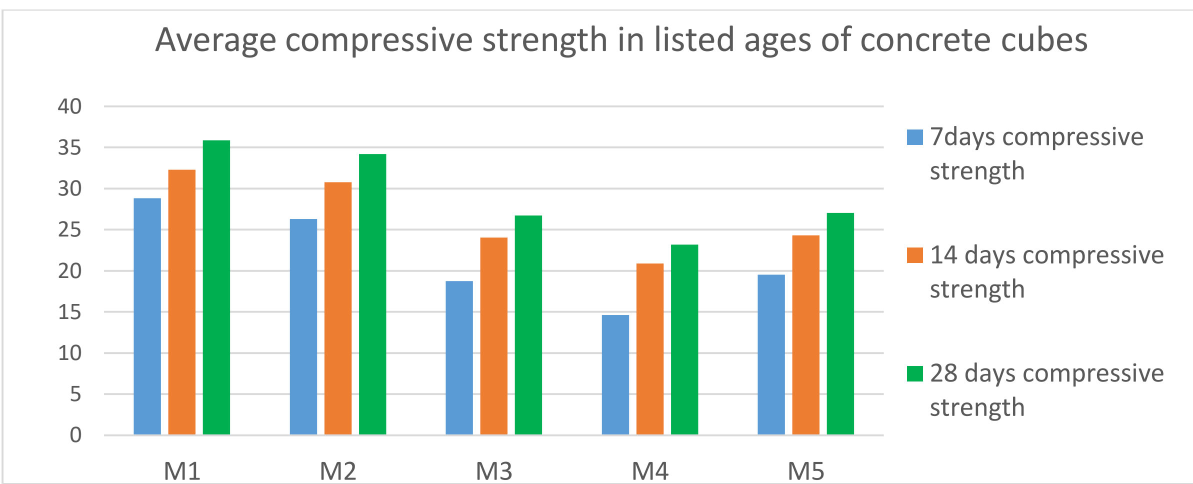

Figure 4.3- Summary on average compressive strength

4.3.2 Split tensile strength of test cylinders

The effects of fibers on the properties of concrete are more pronounced on the tensile strength test that is due to the nature of fibers to create bondage among concrete ingredients and narrow the probable tendency of crack formation. As a result, the use of constant 0.5 percent bagasse fiber in all mixtures except M1 makes these particular test more critical. Hereunder, the split tensile strength of test specimens and corresponding failure loads will be summarised through table 4.7 and discussed.

Table 4.7: Average failure load and split tensile strength of test cylinders

S. No.	Mix Code	Average split tensile strength								
		7 Days			14 Days			28 Days		
		Avg. weight (gm.)	Failure load (KN.)	Strength (Mpa.)	Avg. weight (gm.)	Failure load (KN.)	Strength (Mpa.)	Avg. weight (gm.)	Failure load (KN.)	Strength (Mpa.)
1	**M1**	12920	167.60	**2.37**	12901	184.40	**2.61**	12881	207.47	**2.94**
2	**M2**	12901	171.33	**2.31**	12870	220.43	**3.12**	12838	736.08	**3.47**
3	**M3**	12811	158.50	**1.97**	12780	158.81	**2.25**	12740	176.50	**2.45**
4	**M4**	12650	131.10	**1.71**	12610	131.68	**1.86**	12569	146.30	**2.07**
5	**M5**	13001	206.00	**2.56**	12981	207.10	**2.93**	12959	230.30	**3.26**

Table 4.7 above shows, from fiber-reinforced concrete mixtures M2, has shown better strength result in 14 and 28 days of curing ages. Here the 7 days of curing test result show the retarding effect of bagasse ash as the value indicates a 9.7% and 2.5% reduction in tensile strength relative to M5 and M1 respectively. According to the test result, the cement-bagasse ash blended fiber-reinforced concrete mixture M2 has achieved 6.05% and 15.27% more tensile strength after 28 days of curing relative to M5 and M1 respectively. On contrary, M3 and M4 have shown 24.84% and 36.50% reduction in tensile strength respectively at 28 days of curing as compared with M5. At this point, one can notice the reduction in strength becoming more significant when the percentage replacement of cement with bagasse ash increases. On the test result, the 5% replacement of cement with bagasse ash improves the split tensile strength of the bagasse fiber reinforced concrete mix providing approximately 6% additional strength after both 14 and 28 days

of curing. Thus, M2 has proven to be the best mixture in tensile strength relative to the entire mixture.

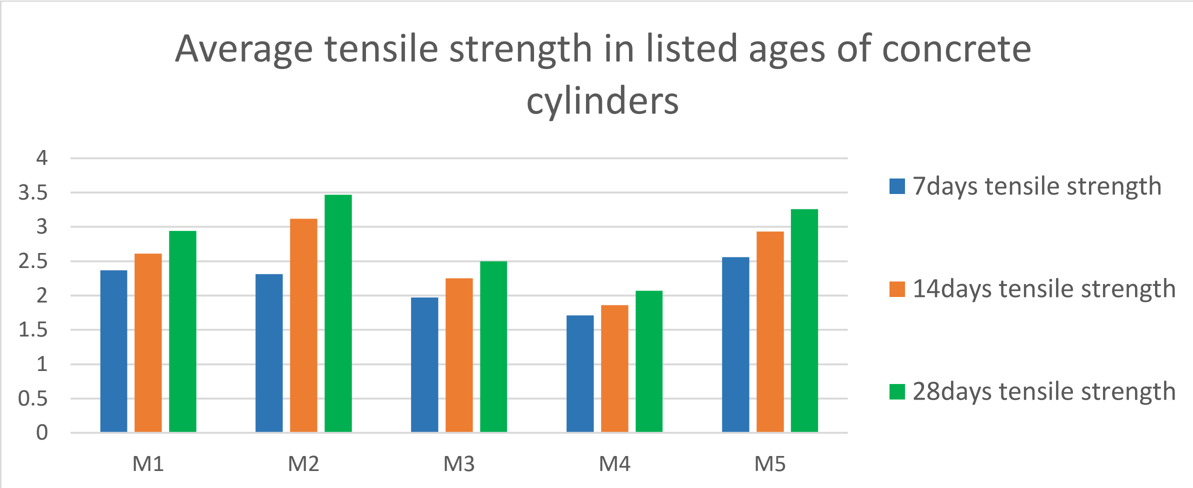

Figure 4.4- Summary on average split tensile strength.

4.3.3 Flexural strength of test beams

Hereunder, the flexural strength of test specimens and corresponding failure loads will be summarised through table 4.8 and discussed.

Table 4.8: Average failure load and flexural strength of test beams

S. No.	Mix Code	Average flexural strength					
		7 Days		14 Days		28 Days	
		Failure load (KN.)	Strength (Mpa.)	Failure load (KN.)	Strength (Mpa.)	Failure load (KN.)	Strength (Mpa.)
1	**M1**	8.07	**3.63**	9.20	**4.14**	10.11	**4.55**
2	**M2**	8.49	**3.82**	10.50	**4.72**	11.67	**5.25**
3	**M3**	7.80	**3.51**	8.11	**3.65**	8.91	**4.01**
4	**M4**	7.73	**3.48**	8.09	**3.64**	8.89	**4.00**
5	**M5**	8.32	**3.74**	9.91	**4.46**	10.89	**4.90**

As one can observe in Table 4.8 above, from fiber-reinforced concrete mixtures M2 has shown better flexural strength result in all the three curing ages. According to the test result, this FRC concrete mixture has shown 6.67% and 13.3% more strength at 28 days relative to the control mix M5 and conventional concrete M1 respectively.

On the other hand cement-bagasse ash blended FRC concrete mixtures, M3 and M4 have shown relatively similar results with 18.16% and 18.37% reduction in strength respectively at 28 days relative to M5. Similarly, as compared with the conventional concrete M1, these mixes have also shown 11.87% and 12.09% flexural strength reduction respectively at 28 days of curing. The bagasse fiber together with the utilized percentage of bagasse ash as a mineral additive would be taken as the main reason for improved flexural strength.

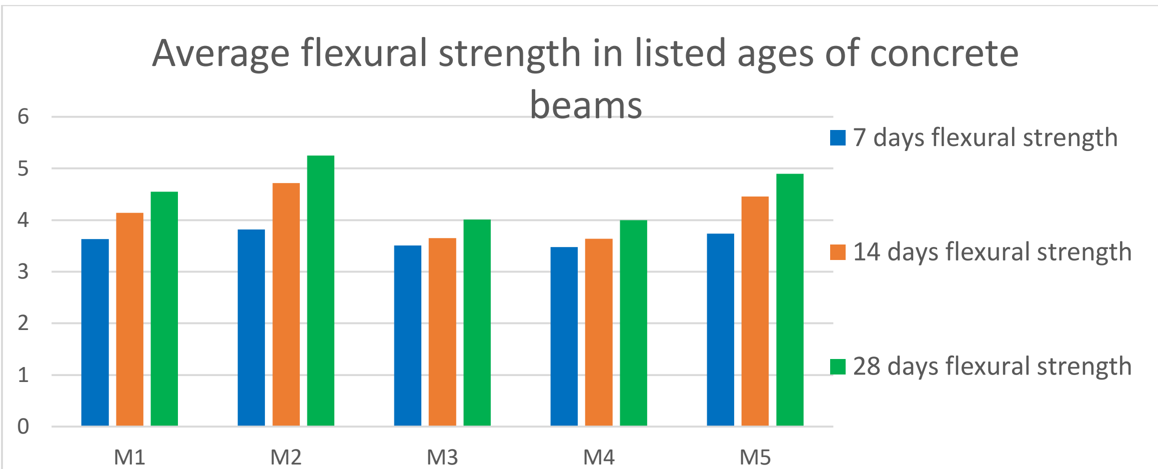

Figure 4.5- Summary on average flexural strength

4.4 Economic advantage of replacing cement with bagasse ash in bagasse fiber reinforced concrete

4.4.1 Introduction

The cost associated with running a business or production of certain material might be grouped into two major categories. The first is accounting cost which includes the cost of labor, equipment, or materials. These costs are sometimes referred to as direct costs or explicit costs that occur in exchange for a defined good or service. Generally, accounting costs include those costs that have a specific monetary value one needs to pay or to receive the associated benefit [57].

The second category is an economic cost which is also known by the name overhead cost and indirect cost interchangeably. This cost typically includes opportunity costs or implicit cost means the benefit that one could have received if he/she had chosen one course of action, but didn't because he/she went with another option [57]. Paper work-related office costs and utility line bills are also included in overhead cost estimation.

4.4.2 Considerations made for economic analysis of bagasse ash

As bagasse ash is the by-product of the sugar industry we shall not count both accounting and overhead types of costs directly to make a comparison with cement production. That is since both cost types are associated directly with the production of sugar. The economic analysis for this study has been carried out qualitatively and quantitatively taking only major post-production costs for both bagasse ash and bagasse fiber blended fiber reinforced concrete and ordinary concrete mixture. Costs identified as post-production include packaging cost, transportation cost, any extra costs incurred from utilizing sugarcane bagasse in concrete as fiber, and partial replacement of cement with bagasse ash.

4.4.3 Qualitative analysis

The advantage of utilizing waste sugarcane bagasse and bagasse ash as fiber and supplementary cementitious material in mass concrete production respectively would help to minimize the amount of dumped surplus waste in the premises of sugar factories. And this in turn brings economic return as the land use can be utilized for further cane plantation site, green area, or any other purposes. The remaining liquid in bagasse is extremely volatile as a result, the deposition sites in these factories have caused bad odor and this odor becomes significant when it gets daylight. Moreover, the organic dust which continuously risen around the collection area of both bagasse and the ash consists of the most pith particles with some rind fibers and the powder is hazardous for laborers' eye and respiratory system making to work nearby difficult.

The cost related to the medication of laborers together with environmental cost connected with any potential cleanup, remediation, removal, restoration, or other response costs for the actual or potential deterioration of natural assets due to economic activities should also be noticed. Therefore potential utilization of sugarcane bagasse and bagasse ash together as fiber and partial replacement of cement would have significant environmental benefit reducing the cement content in concrete which in turn decreases the growing CO_2 emission which is contributing to the current global warming. This is of course more than to quantify in monitory terms as dealing with the survival of human lives.

When dealing with the cost in terms of energy consumption, clinker burning process in cement factories takes greater amount of fuel consumption (more than 90% of the total need) and about 30% of the factory's total electric power intake [28]. Therefore, utilization of bagasse ash to the recommended percentage (a 5% replacement, based on this research) as cement replacing material can totally eliminate the cost of clinker production for the minimized cement amount.

4.4.4 Quantitative analysis

To optimize the lack of consistent data on the topic, the analysis has been made with an ideal case study. Assuming active construction site which needs 1m^3 concrete at the premises of Addis Ababa Science and Technology University, the production costs of ordinary concrete mixture and/or if the concrete would be bagasse fiber reinforced concrete in which 5% of the total cement content partially replaced with bagasse ash has been analyzed. The comparison between bagasse ash and partially replaced cement especially on transportation case would have been reasonable if it had made after the action of the concerned body on the availability of bagasse ash everywhere countrywide in a similar manner with cement. At the same time, the reality would be shown more if the market mechanism had been built on bagasse ash already. This is to eliminate the variation that might happen in the future when the material is available in every building material shop for sale with some market price.

This analysis is made based on recent and actual conditions taking the current market price of materials and transportation costs being implemented on the ground. The manual method of mixing considered and the accounted costs are material purchase cost, labor cost including cost related to material preparation to the specification, and material transportation cost. At these points, the mix designed using ACI-211.1-91 and final compositions of the constituent materials for a cubic meter of concrete presented under chapter three of the document shall be referred.

Table 4.9: Cost comparison between ordinary concrete and bagasse ash blended FRC mixture.

Materials	(M1)			(M2)			Remark
	Weight (kg/m^3)	Purchase price (ETB)		Weight (kg/m^3)	Purchase price (ETB)		
		Per 100 kg	Total		Per 100 kg	Total	
Cement	385.4	515	1,984.84	366.13	515	1,885.57	Dangote OPC grade 42.5 (July 2020 G.C)
Fine aggregate	766	130		766	130		Metehara level 1
Coarse aggregate	1024	110		1024	110		Gravel retained on 4.75mm
Bagasse ash	-	-	-	13.3	-	-	
Bagasse fiber	-	-	-	11.73	-	-	
Water	177	2.85	0.5	177	2.85	0.5	Potable water
Transportation cost							
Cement	385.4	25	96.38	366.13	25	91.53	
Fine aggregate	766	20	153.2	766	20	153.2	Collected from Bole sub city “Goro square”
Coarse aggregate	1024	20	204.8	1024	20	204.8	Collected from Bole sub city “Goro square”
Bagasse ash	-	-	-	13.3	50	6.65	
Bagasse fiber	-	-	-	11.73	50	5.87	
Total			2,439.72	Total		2,348.12	
Labor cost including the material preparation							
For M1, the preparation of 1 m^3 concrete and casting molds takes a single day with a total of 300 birrs. (2 daily laborers with a daily fee of 150 birrs.)				For M2, the preparation of 1 m^3 FRC and casting molds takes a single day with a total of 375 birrs. (2 daily laborers with a daily fee of 150 birrs.) And 1 additional daily labor working half a day for sieving the ash and preparing the fiber to the specification.			Unprocessed bagasse fiber needs separation of dust, decomposed parts, and nodes before utilization. Similarly, bagasse ash should be sieved to the required size before replacing cement.
Grand total			2,739.72	Grand total		2,723.12	Variation = 16.6Br.

Nb. According to a material transportation survey made within 80 km. radius from Addis Ababa, trucks of different loading capacity charges 20 - 25 birr per quintal of an item. The fare differs depending on the hauling distance and difficulty of the route. Since unprocessed bagasse ash and bagasse fiber have high volume, the transportation fee for these analysis becomes double the normal price. The price taken considers the actual cost paid during transporting all materials for the study.

The computed economic analysis does not consider equipment cost as equipment shall not be planned to be installed permanently for the study matter and it should be important to account depreciation cost and salvage value if it would be. Based on the comparison, the preparation of ordinary concrete mixture takes an additional 0.61% increase in price than the cost incurred to prepare FRC with 5% bagasse ash to replace cement. The price change may get fluctuated when appropriate market mechanisms for bagasse ash and bagasse fiber are installed at any time in the future. The mechanism will help create market chains among suppliers, sellers, and final consumers. The market chain further helps to reduce the cost of material preparation as the sellers can already prepare the bagasse ash and bagasse fiber to the required fineness and aspect ratio respectively.

CHAPTER 5- CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSION

The study tried to meet all drawn objectives so far and after investigating the combined effect of bagasse ash and sugarcane bagasse fiber on properties of fiber-reinforced concrete the following conclusions have been drawn:

The reduction in the slump of fresh concrete is associated with almost all fiber types incorporated in concrete. Higher water Absorption capacity and moderate ductile property as needed make bagasse fiber contribute less to the tensile strength of concrete. The phenomena can be corrected by manual preparation of the fiber to the recommended aspect ratio and removal of the water-absorbent spongy part of it and nodes before mixing with concrete.

The investigation discovered that both bagasse ash and bagasse fiber plays a retarding role on the setting time of fresh concrete. The higher percentage content of sucrose in the fiber and higher water absorption tendency of bagasse ash surface influences the setting. Furthermore, the normal consistency of fresh concrete paste gets increased with an increasing percentage of bagasse ash. Although it is not as much as the ash, bagasse fiber reinforced concrete also implies higher water demand for certain workability.

The result of the research has shown that among the fiber reinforced concrete mixtures, the maximum strength of hardening concrete achieved from M2 i.e. a mix with 5% replacement of cement using bagasse ash and incorporation of 0.5% bagasse fiber. According to the investigation, 19.6%, 6.05%, and 6.67% more strength have succeeded for the computed compressive, split tensile, and flexural strength tests at 28 days of curing by this mix relative to the final FRC mix with only 0.5% bagasse fiber content. And as compared with 10% and 15% replacement levels resulting 25.58% and 33.94% compressive strength reduction at 28 days of curing respectively, one can say only slight to no compressive strength reduction with 5% replacement level relative to the conventional concrete mixture M1.

Furthermore, from the overall results of the experiment, it can also be concluded that all three strength test results (compressive strength, split tensile strength, and flexural strength) get decreased with an increase percentage replacement of bagasse ash more than 5% by weight of cement. And this is true in all the three tested curing ages of the samples.

From the computed economic analysis, it can be generalized that combined utilization of bagasse fiber and bagasse ash as a reinforcing material and cement replacing material respectively helps to reduce the cost of construction. And this cost reduction would have been significant if an appropriate market mechanism had been installed for the materials which assure the availability of those materials with the required standards.

5.2 RECOMMENDATIONS

The following recommendations are forwarded based on this study and other similar studies conducted in this area.

5.2.1 Recommendations from the study

From the study, it has been observed that utilization of bagasse fiber and bagasse ash together while concrete production not only enhances harden properties of concrete but also it can be taken as an additional business area creating job opportunity for unemployed youths in the country. Therefore the government and construction stakeholders shall emphasize implementing the finding of this study and related works so that a market chain shall be created and many unemployed youths from all corners of the country can get organized together in small and micro enterprises to prepare and supply the materials with some profit.

5.2.2 Recommendation for further study

This research studied some of the basic physical and chemical properties of bagasse ash and bagasse fiber from Wonjji sugar factory However, further studies are required on the following items:

- Effects of different burning temperature used by different sugar factories.
- As the fineness of bagasse ash is believed to change the outcome of the study, the effects of cement replacing bagasse ash sample with different fineness shall also be studied.
- The pozzolanic reaction of the bagasse ash using more advanced methods like X-ray Diffraction (XRD) Analysis and Scanning Electron Microscopy (SEM).
- Effects of further treatments applied for bagasse ash before replacing cement.
- Further curing ages shall be studied so that the retarding effect of bagasse ash on strength results can well be noticed
- Effects of different aspect ratios of bagasse fiber.

- As usage of bagasse fiber in high percentage discouraged by different previous studies, effects of different percentage of bagasse fiber especially below 0.5% shall be studied.
- The cost analysis shall further be studied accounting the overhead and implicit cost types.
- As bagasse fiber is proved to enhance the split tensile strength of concrete, future researcher shall demonstrate the application on some structure like street furniture not just from the view of durability but also from aesthetic point of view.

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APPENDIX A

Compressive strength of concrete test cubes

A-1 Seventh-day compressive strength

Mold		Dimension (mm)			Curing Age	7 days
		L	W	H		
Cube		150	150	150		
Code	Individual Sample Name	Weight (gm.)	Failure Load (KN)		Strength (MPa.)	Remark
M1	M1-1	8127	668.87		29.73	
	M1-2	8124	636.08		28.27	
	M1-3	8121	640.35		28.46	
	Average	**8124**	**648.43**		**28.82**	
M2	M2-1	8121	581.4		25.84	
	M2-2	8122	598.8		26.61	
	M2-3	8114	595.2		26.45	
	Average	**8119**	**591.8**		**26.30**	
M3	M3-1	8094	419.56		18.65	
	M3-2	8090	425		18.89	
	M3-3	8083	421.2		18.72	
	Average	**8089**	**421.92**		**18.75**	
M4	M4-1	8060	321.1		14.27	
	M4-2	8073	330.5		14.69	
	M4-3	8071	335.02		14.89	
	Average	**8068**	**328.87**		**14.62**	
M5	M5-1	8139	418.4		18.60	
	M5-2	8130	450.5		20.02	
	M5-3	8121	448.2		19.92	
	Average	**8130**	**439.03**		**19.51**	

A-2 Fourteenth-Day Compressive Strength

Mold		Dimension (mm)			Curing Age	14 days
		L	W	H		
Cube		150	150	150		
Code	Individual Sample Name	Weight (gm.)	Failure Load (KN)		Strength (MPa.)	Remark
M1	M1-1	8112	776.18		34.50	
	M1-2	8109	674.75		29.99	
	M1-3	8103	729.61		32.43	
	Average	**8108**	**726.85**		**32.31**	
M2	M2-1	8089	703.53		31.27	
	M2-2	8093	692.42		30.77	
	M2-3	8085	680.85		30.26	
	Average	**8089**	**692.27**		**30.77**	
M3	M3-1	8058	576.05		25.60	
	M3-2	8063	506.94		22.53	
	M3-3	8053	539.68		23.99	
	Average	**8058**	**540.89**		**24.04**	
M4	M4-1	8034	455.18		20.23	
	M4-2	8031	485.51		21.58	
	M4-3	8046	468.69		20.83	
	Average	**8037**	**469.79**		**20.88**	
M5	M5-1	8112	589.48		26.20	
	M5-2	8116	511.19		22.72	
	M5-3	8117	541.08		24.05	
	Average	**8115**	**547.25**		**24.32**	

A-3 Twenty-Eighth Day Compressive Strength

Mold		Dimension (mm)			Curing Age	28 days
		L	W	H		
Cube		150	150	150		
Code	Individual Sample Name	Weight (gm.)	Failure Load (KN)		Strength (MPa.)	Remark
M1	M1-1	8099	862.43		38.33	
	M1-2	8096	749.72		33.32	
	M1-3	8099	810.67		36.03	
	Average	**8098**	**807.60**		**35.89**	
M2	M2-1	8062	781.7		34.74	
	M2-2	8063	769.36		34.19	
	M2-3	8052	756.5		33.62	
	Average	**8059**	**769.19**		**34.19**	
M3	M3-1	8029	640.06		28.45	
	M3-2	8030	563.27		25.03	
	M3-3	8025	599.65		26.65	
	Average	**8028**	**600.99**		**26.71**	
M4	M4-1	8012	505.77		22.48	
	M4-2	8009	539.48		23.98	
	M4-3	8003	520.78		23.15	
	Average	**8008**	**522.01**		**23.20**	
M5	M5-1	8108	654.99		29.11	
	M5-2	8107	568.00		25.24	
	M5-3	8100	601.2		26.72	
	Average	**8105**	**608.06**		**27.03**	

APPENDIX B

Split tensile strength of concrete test cylinders

B-1 Seventh- Day Split Tensile Strength

Mold		Dimension (mm)		Curing Age	7 days
		Diameter (ϕ)	H		
Cylinder		150	300		
Code	Individual Sample Name	Weight (gm.)	Failure Load (KN)	Strength (MPa.)	Remark
M1	M1-1	12926	160.2	2.268	(ϕ)16mm and H=32mm
	M1-2	12925	172.5	2.442	
	M1-3	12909	170.1	2.408	
	Average	**12920**	**167.60**	**2.373**	
M2	M2-1	12900	204.90	2.549	(ϕ)16mm and H=32mm
	M2-2	12905	149.50	2.116	
	M2-3	12898	159.60	2.259	
	Average	**12901**	**171.33**	**2.308**	
M3	M3-1	12815	162.5	2.022	(ϕ)16mm and H=32mm
	M3-2	12818	152.9	1.902	
	M3-3	12800	160.1	1.992	
	Average	**12811**	**158.50**	**1.972**	
M4	M4-1	12640	127.7	1.589	(ϕ)16mm and H=32mm
	M4-2	12654	135.2	1.914	
	M4-3	12656	130.4	1.622	(ϕ)16mm and H=32mm
	Average	**12650**	**131.10**	**1.708**	
M5	M5-1	12995	200.4	2.493	
	M5-2	12997	218.4	2.716	
	M5-3	13011	199.2	2.478	
	Average	**13001**	**206.00**	**2.562**	

B-2 Fourteenth Day Split Tensile Strength

Mold		Dimension (mm)		Curing Age	14 days
		Diameter (ϕ)	H		
Cylinder		150	300		
Code	Individual Sample Name	Weight (gm.)	Failure Load (KN)	Strength (MPa.)	Remark
M1	M1-1	12903	183.76	2.601	
	M1-2	12903	184.95	2.618	
	M1-3	12897	184.50	2.611	
	Average	**12901**	**184.40**	**2.609**	
M2	M2-1	12870	209.70	2.968	
	M2-2	12869	231.13	3.271	
	M2-3	12871	220.45	3.120	
	Average	**12870**	**220.43**	**3.120**	
M3	M3-1	12782	174.16	2.465	
	M3-2	12784	144.72	2.048	
	M3-3	12774	157.56	2.230	
	Average	**12780**	**158.81**	**2.248**	
M4	M4-1	12610	134.04	1.897	
	M4-2	12609	130.35	1.845	
	M4-3	12611	130.67	1.850	
	Average	**12610**	**131.68**	**1.864**	
M5	M5-1	12983	204.68	2.897	
	M5-2	12984	207.29	2.934	
	M5-3	12976	209.32	2.963	
	Average	**12981**	**207.1**	**2.931**	

B-3 Twenty-Eighth Day Split Tensile Strength

Mold		Dimension (mm)		Curing Age	28 days
		Diameter (ϕ)	H		
Cylinder		150	300		
Code	Individual Sample Name	Weight (gm.)	Failure Load (KN)	Strength (MPa.)	Remark
M1	M1-1	12883	207.56	2.938	
	M1-2	12885	209.94	2.972	
	M1-3	12875	204.92	2.900	
	Average	**12881**	**207.47**	**2.936**	
M2	M2-1	12838	233	3.298	
	M2-2	12840	258.08	3.653	
	M2-3	12836	245	3.468	
	Average	**12838**	**245.36**	**3.473**	
M3	M3-1	12740	193.5	2.739	
	M3-2	12741	160.8	2.276	
	M3-3	12739	175.1	2.478	
	Average	**12740**	**176.5**	**2.498**	
M4	M4-1	12570	148.9	2.108	
	M4-2	12574	144.8	2.05	
	M4-3	12563	145.2	2.055	
	Average	**12569**	**146.3**	**2.071**	
M5	M5-1	12960	227.4	3.219	
	M5-2	12960	231	3.270	
	M5-3	12957	232.6	3.292	
	Average	**12959**	**230.3**	**3.260**	

NB: The average split tensile strength values are calculated only from the individual samples strength value. This is to consider the effect of the size of each mold on final result if average failure load had been used.

APPENDIX C

Flexural strength of concrete test beams

C-1 Seventh- Day Flexural Strength

Mold		Dimension (mm)			Curing Age	7 days
		L	B	D		
Beam		500	100	100		
Code	Individual Sample Name	Failure Load (KN)			Strength (N/mm^2)	Remark
M1	M1-1	8.12			3.65	
	M1-2	8.05			3.62	
	M1-3	8.04			3.62	
	Average	**8.07**			**3.63**	
M2	M2-1	8.44			3.80	
	M2-2	8.40			3.78	
	M2-3	8.62			3.88	
	Average	**8.49**			**3.82**	
M3	M3-1	7.85			3.53	
	M3-2	7.65			3.44	
	M3-3	7.90			3.56	
	Average	**7.8**			**3.51**	
M4	M4-1	7.63			3.43	
	M4-2	7.80			3.51	
	M4-3	7.76			3.49	
	Average	**7.73**			**3.48**	
M5	M5-1	8.30			3.74	
	M5-2	8.32			3.74	
	M5-3	8.34			3.75	
	Average	**8.32**			**3.74**	

C-2 Fourteenth- Day Flexural Strength

Mold		Dimension (mm)			Curing Age	14 days
		L	B	D		
Beam		500	100	100		
Code	Individual Sample Name	Failure Load (KN)			Strength (N/mm^2)	Remark
M1	M1-1	9.31			4.19	
	M1-2	9.15			4.12	
	M1-3	9.14			4.11	
	Average	**9.20**			**4.14**	
M2	M2-1	10.30			4.63	
	M2-2	10.30			4.63	
	M2-3	10.90			4.90	
	Average	**10.50**			**4.72**	
M3	M3-1	8.15			3.67	
	M3-2	8.17			3.68	
	M3-3	8.01			3.60	
	Average	**8.11**			**3.65**	
M4	M4-1	8.03			3.61	
	M4-2	8.11			3.65	
	M4-3	8.13			3.66	
	Average	**8.09**			**3.64**	
M5	M5-1	9.98			4.49	
	M5-2	9.94			4.47	
	M5-3	9.81			4.41	
	Average	**9.91**			**4.46**	

C-3 Twenty-eighth Day Flexural Strength

Mold		Dimension (mm)			Curing Age	28 days
		L	B	D		
Beam		500	100	100		
Code	Individual Sample Name	Failure Load (KN)			Strength (N/mm^2)	Remark
M1	M1-1	10.11			4.55	
	M1-2	10.15			4.57	
	M1-3	10.07			4.53	
	Average	**10.11**			**4.55**	
M2	M2-1	11.50			5.17	
	M2-2	11.50			5.17	
	M2-3	12.01			5.40	
	Average	**11.67**			**5.25**	
M3	M3-1	8.92			4.01	
	M3-2	8.87			3.99	
	M3-3	8.94			4.02	
	Average	**8.91**			**4.01**	
M4	M4-1	8.83			3.97	
	M4-2	8.91			4.01	
	M4-3	8.93			4.02	
	Average	**8.89**			**4.00**	
M5	M5-1	10.79			4.86	
	M5-2	10.93			4.92	
	M5-3	10.95			4.93	
	Average	**10.89**			**4.90**	

APPENDIX D

Experiments on physical and chemical material properties

All physical properties of the material have been tasted in Addis Ababa Science and Technology Civil Engineering Material Laboratory following procedures detailed in the construction material laboratory manual prepared by Abebe Dinku in 2002. Whereas chemical properties of bagasse ash have been carried out in a geological survey of Ethiopia. Hereunder, the details of material experiments undertaken and their result are going to be presented.

A Rodded bulk density of aggregates

A jar with 5-liter storage capacity, steel rod for compaction, and weighting balance have been prepared and sample fine and coarse aggregates in (SSD) condition poured into the jar separately and respectively in three layers so that each layer get sufficient compaction. The weight of each aggregate type recorded and bulk density computed by dividing the weight by volume of the jar.

Materials	Weight (Kg)	The volume of a jar (m^3)	Bulk density (Kg/m^3)
Coarse aggregate	8.3	0.005	1660
Fine aggregate	8.05	0.005	1610

B, Silt content of fine aggregate

The silt content of the sand to be used in the mix was determined by using a glass jar that has a capacity of greater than 100ml. After 30ml of sand was poured in to ajar, approximately a 3/4 of a jar was filled with water. The jar was shacked vigorously for about a minute and left for about an hour to allow the silt to settle on the layer of the sand. The amount of fines forming separate on the top of the washed sand was measured. Finally, the percentage of silt content of sand was determined by dividing the amount of silt deposited above the sand by the amount of clean sand.

According to the Ethiopian Standards, it is recommended to wash the sand or reject if the silt content of sand exceeds a value of 6%.

Table2 Silt content of sand

Samples No.	Amount of silt (A)	Amount of clean sand (B)	Silt=A/B*100 (%)
I	4.1mm	100mm	4.1
II	3.9mm	100mm	3.9
Avg.	4mm	100mm	4

It can be seen from the above table, the percentage of silt in the sand found out to be 4% < 6% so, the sand is suitable for mixing.

C, Moisture content of aggregate

The moisture content of aggregates to be used in the mix was determined by taking a 500gm sample from an individual type of aggregates (A) measured weight of the oven-dried sample (B).

Description	Fine aggregate			Coarse aggregate		
	Sample1	Sample2	Avg.	Sample1	Sample2	Avg.
Original weight in gm. (A)	500	500	500	500	500	500
Oven dried weight in gm. (B)	490.1	490.2	490.15	495.7	495.6	495.65
Moisture content C (%) = $\frac{A-B}{B}$*100	2.02	2	2	0.87	0.89	0.88

D, Specific gravity and absorption capacity of fine aggregate

D1, Specific gravity of sand

As presented on the guide of construction material laboratory manual,

Weight of the sand sample = 500gm.

A (weight of oven-dry sample in the air) = 494.6gm

W (weight of pycnometer) = 250gm.

V (volume of pycnometer) = 1000cm^3.

Va = Volume of water added to pycnometer = 805cm^3

C (weight of pycnometer filled with sample plus water);

C = 0.9976Va + 500 + W

C = 0.9976 *805 + 500 + 250

C = 1553.07gm.

B (weight of flask filled with water);

B = 0.9976V + W

B = 0.9976* 1000 + 250

B = 1247.6gm.

Calculation:

Bulk Specific Gravity:

Bulk sp. gravity = $\frac{A}{B+500-C}$ [46]……Where,

A = weight of oven-dry sample in the air (gm.)

B = weight of pycnometer filled with water (gm.)

C = weight of pycnometer with sample and water to calibration mark (gm.)

Thus, Bulk sp. gravity = $\frac{494.6}{1247.6+500-1553.07}$

= 2.54

Bulk Specific Gravity (saturated-surface dry condition):

Bulk Specific Gravity (saturated-surface dry basis) = $\frac{500}{B+500-C}$ [46].

Thus, Bulk Sp. Gravity (saturated-surface dry basis) = $\frac{500}{1247.6+500-1553.07}$

= **2.57**

Apparent Specific Gravity:

Apparent Specific Gravity = $\frac{A}{B+A-C}$ [46]

Thus, Apparent Specific Gravity = $\frac{494.6}{1247.6+494.6-1553.07}$

= 2.62

D2, the Absorption capacity of sand

Absorption (%):

Absorption (%) = $\frac{500-A}{A}$*100 [46]

Thus, Absorption (%) = $\frac{500-494.6}{494.6}$*100

= 1.09%

E, Specific gravity and absorption capacity of coarse aggregate

E1, Specific gravity of coarse aggregate

Similarly, as presented on the guide of construction material laboratory manual,

W (weight of sample taken) = 5000gm.

A (weight of oven-dry sample in the air) = 4970

B (weight of saturated-surface-dry sample in air) = 5010gm.

C (weight of saturated sample in water) = 3162gm.

Calculation:

Bulk specific gravity:

Bulk specific gravity = $\frac{A}{B-C}$ [46]

Thus, bulk sp. gravity = $\frac{4970}{5010-3162}$

= 2.69

Bulk specific gravity (saturated surface dry condition):

Bulk specific gravity (SSD) = $\frac{B}{B-C}$ [46]

Thus, Bulk sp. gravity (SSD) = $\frac{5010}{5010-3162}$

= 2.71

Apparent specific gravity:

Apparent specific gravity = $\frac{A}{A-C}$ [46]

Thus, Apparent sp. Gravity = $\frac{4970}{4970-3162}$

= 2.75

E2, the Absorption capacity of coarse aggregate

Absorption (%):

Absorption (%) = $\frac{B-A}{A}$*100 [46]

Thus, Absorption capacity (%) = $\frac{5010-4970}{5010}$*100

= 0.8

APPENDIX E

Sample pictures from the research

Picture 1: bagasse fiber preparation to the required aspect ratio (left) and sieve shaker for sieving bagasse ash and initial separation of unwanted parts of the fiber (right)

Picture 2: cement paste preparation for consistency test (left) and percentage bagasse ash replaced cement paste under the consistency test (right)

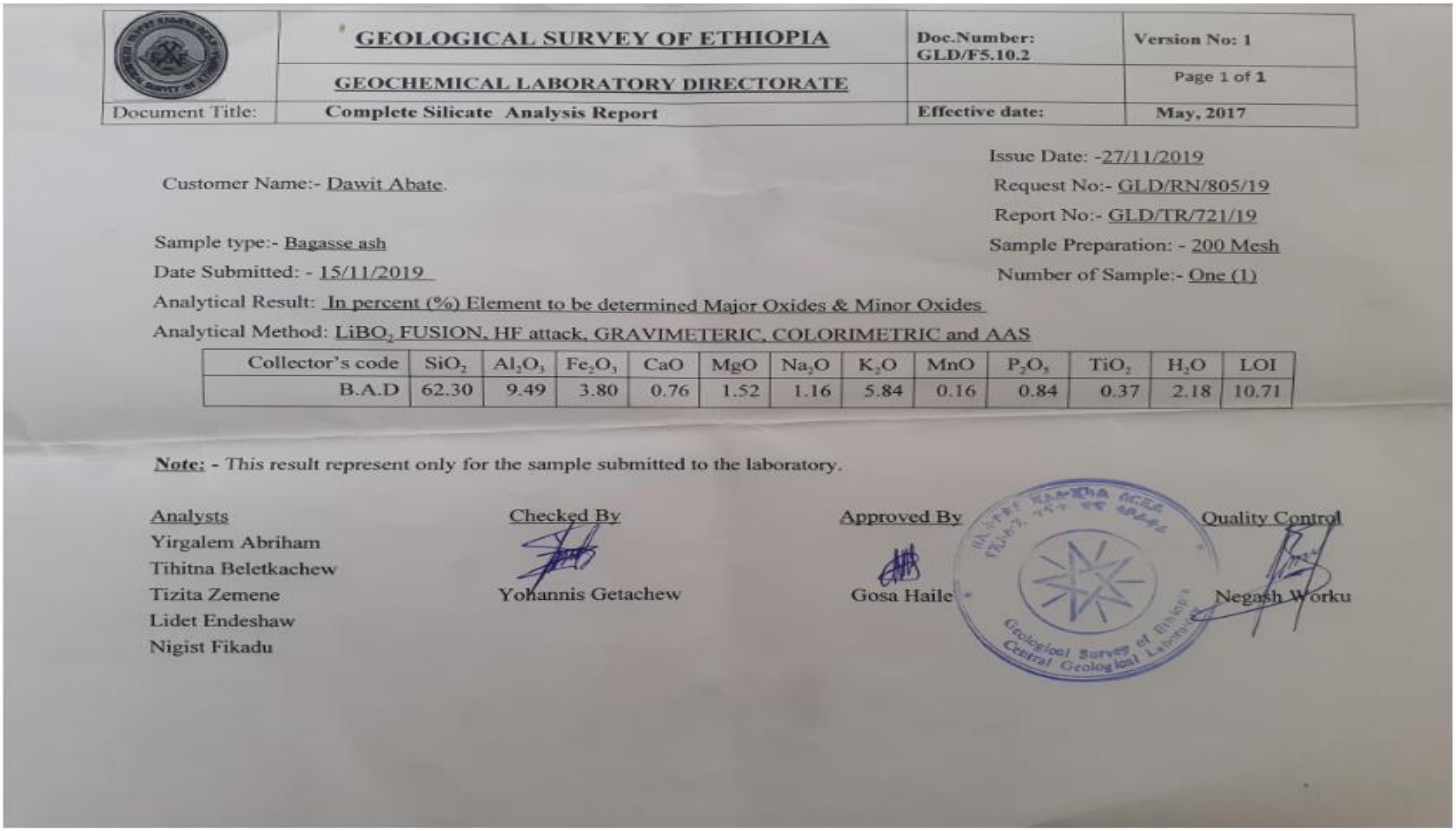
Picture 3: Oiled test specimen molds ready to take prepared concrete (left) and workability test (right)

Picture 4: casted concrete molds (left) and test specimens in curing pond (right)

Picture 5: compressive strength test (left) and split tensile strength test (right)

APPENDIX F

Chemical composition of bagasse ash



	GEOLOGICAL SURVEY OF ETHIOPIA	Doc.Number: GLD/F5.10.2	Version No: 1
	GEOCHEMICAL LABORATORY DIRECTORATE		Page 1 of 1
Document Title:	Complete Silicate Analysis Report	Effective date:	May, 2017

Issue Date: -27/11/2019

Customer Name:- Dawit Abate.

Request No:- GLD/RN/805/19

Report No:- GLD/TR/721/19

Sample type:- Bagasse ash

Sample Preparation: - 200 Mesh

Date Submitted: - 15/11/2019

Number of Sample:- One (1)

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides

Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
B.A.D	62.30	9.49	3.80	0.76	1.52	1.16	5.84	0.16	0.84	0.37	2.18	10.71

Note: - This result represent only for the sample submitted to the laboratory.

Analysts	Checked By	Approved By	Quality Control
Yirgalem Abriham Tihitna Beletkachew Tizita Zemene Lidet Endeshaw Nigist Fikadu	Yohannis Getachew	Gosa Haile	Negash Worku