



INVESTIGATION OF COTTON DUST ASH AS A SUPPLEMENTARY
CEMENTITIOUS MATERIAL FOR CONCRETE PRODUCTION

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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INVESTIGATION OF COTTON DUST ASH AS A SUPPLEMENTARY
CEMENTITIOUS MATERIAL FOR CONCRETE PRODUCTION

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HAWASSA UNIVERSITY
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I hereby declare that this MSc thesis is my original work and has not been presented for a thesis degree in any other university, and all resources of material used for this thesis have been duly acknowledged.

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Date February, 2020

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LIST OF ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing of Materials
CD	Cotton Dust
CDA	Cotton Dust Ash
CH	Calcium Hydroxide($\text{Ca}(\text{OH})_2$)
C-S-H	Calcium Silicate Hydrate
CTM	Compression Testing Machine
CW	Cotton Waste
ETB	Ethiopian Birr
FA	Fly Ash
FM	Fineness Modulus
GBFS	Granulated Blast Furnace Slag
GGBFS	Ground Granulated Blast Furnace Slag
GHGs	Green House Gases
HCWA	High Calcium Wood Ash
LC	Lime Cotton
LPW	Lime Powder
MCF	Mugher Cement Factory
MK	Metakaolin
mPOFA	micro Palm Oil Fuel Ash
NC	Nano Cement
NFA	Nano Fly Ash
nPOFA	nano Palm Oil Fuel Ash
NSF	Nano Silica Fume
OPC	Ordinary Portland Cement
PPC	Pozzolana Portland Cement
RHA	Rice Husk Ash
SBA	Sugarcane Bagasse Ash
SCMs	Supplementary Cementitious Materials
SF	Silica Fume
SG	Slag
WA	Wood Ash
WFS	Woven Fabric Sub Waste
WFW	Woven Fabric Waste

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ABSTRACT

A supplementary cementing material (SCM) is a material that when used in conjunction with Portland cement contributes to the properties of the hardened concrete. The objective of this research work was to investigate the Cotton Dust Ash (CDA) as SCM and thus to determine the effect of CDA on strength and durability properties of concrete. Then after determining the properties of CDA, sand, and coarse aggregate, C-25 grade concrete mix was designed and the cement was replaced by CDA at 5 % replacement interval up to 25% by weight. The concrete mix was produced and tested using slump test, concrete cube test, split test, water absorption test, sorptivity test, and carbonation test. The research results reveals that the workability of concrete decreases due to water-absorbent property and high specific surface area of CDA. The maximum strength for compressive and tensile strength was obtained at 5% replacement, and it increases until 20% of CDA by a decreasing rate. The cause of increment is when CDA is added in concrete the reactive silica present in CDA reacts with Ca(OH)_2 liberated during cement hydration and forms additional (C-S-H) gel. The CDA addition until 25% causes reduced water absorption and sorptivity of the concrete by making the pores discontinuous due to their pore blocking effect. The specimens starting from 5%, 20%, and 25% of CDA concrete shows highly alkaline, a purple-red color as 0% CDA concrete, which means un-carbonated. This is due to when CDA is available in concrete it reduces the availability of surplus lime by way of pozzolanic reaction. From the cost-benefit analysis finding the optimum point is the point that attains the target strength with higher benefits, which is an economical point, was 10.8 % CDA. Finally, this research has attempted to provide an approach to introducing cotton dust ash a cement replacement in concrete, aiming to improve the pozzolanic activity. The experimental results verified the feasibility of this approach.

Keywords: SCM, CDA, Strength properties, Durability properties, Cost-benefit analysis

CHAPTER 1. INTRODUCTION

1.1. Background of the Study

Concrete is one of the most important materials, which is used in the construction industry. It is made of two main components, which are cement and aggregates. The aggregate contains sand and blue granite metals. Cement in combination with water is the most important binding material for the preparation of concrete in the construction because it contains good mechanical strength, durability, and these properties are mainly required for concrete to be cast in any desired shape and resist load applied on it at relatively less cost.

As we know, cement is the main constituent that makes concrete; nevertheless, the production of Portland cement has a main negative impact, which production of one ton of Portland cement clinker makes about one ton of carbon dioxide and other **greenhouse gases (GHGs)**. Therefore, the emission of this significant amount of carbon dioxide should be solved by a sustainable development solution within the cement and concrete industry (Naik & Moriconi, 2005).

Researchers suggest that a real need to use new materials that can replace cement in concrete without decreasing its mechanical and durability properties and mitigation of the environmental impacts are needed.

One of the most practical used materials to replace cement is the supplementary cementitious materials (SCM), where these materials contain the basic cementitious properties to increase the mechanical properties of the concrete.

Cotton dust ash is one of the supplementary cementitious materials (SCMs) used for producing modern concrete. Cotton dust ash can provide various benefits to the concrete industry, such as improving the strength, early-age performance, and durability of concrete structures, lowering the materials' cost of proportions of concrete mix, reducing greenhouse gas emissions & degradation of the environment by waste disposal.

The main aim of this research is to examine the possibility of using cotton dust ash in concrete as a partial cement replacement and does not negatively affect the characteristics of concrete, which means targeting to improve the mechanical and the durability of concrete.

1.2. Problem Statement

A number of supplementary cementitious materials were used as alternative and partial replacement of cement such as fly ash, metakaolin, granulated blast furnace slag, silica fume, rice husk ash, natural pozzolan, etc. The main advantage of pozzolan (supplementary cementitious materials) was to improve the strength of concrete; reduces bleeding, segregation and cracking; retarding the setting time for hot weather, etc. Replacement of cement by supplementary cementitious has multiple advantages beyond strength issue; one of the issues is associated with reducing the cost of construction, decreases pollution of the nearby environment by the waste of the factory, and reduction of the emission CO₂ in the production of cement.

Cotton dust ash is one of the supplementary cementitious materials. Different researchers in different countries like in Thailand, China, Turkey, and India cotton dust ash have been used as partial replacement of cement in different applications. A concrete mixture with the additive of cotton dust ash was suitable material for mechanical properties of concrete contained with optimum replacement level of 5% and 10%, respectively, by (Israngkura et al., 2014; Israngkura Na Ayudhya, 2015). Besides, in Ethiopia, the cost of cement is the most critical and costly ingredient of concrete. To reduce the cost of cement, it better to use a cost-efficient SCM material, which is locally available material such as cotton dust ash.

Therefore, the main idea of this research is to examine the possibility of using cotton dust ash in concrete as a partial cement replacement and to improve the mechanical and durability properties of concrete; reduce the cost of construction.

1.3. Objective of the Study

1.3.1. General Objective:

To investigate the mechanical and durability properties of concrete by using cotton dust ash as supplementary cementitious material.

1.3.2. Specific Objectives

1. To investigate the physical and chemical properties of cotton dust ash as a Supplementary cementitious material (SCM)
2. To find out the workability of fresh concrete by replacing the cement by different proportions of cotton dust ash as a SCM
3. To improve concrete compressive ,tensile strength & durability(water absorption, sorptivity and carbonation) properties by replacing the cement by 5%,10%,15%,20% & 25% proportions of cotton dust ash as a SCM
4. To determine the optimum cement replacement by cotton dust ash as a SCM
5. To determine cost-benefit analysis at different proportions of cotton dust ash as a SCM

1.4. Research Scope

This study covers by starting determining of physical and chemical properties of cotton dust ash, workability of fresh concrete strength, and durability of concrete, cost-benefit analysis & optimum value when cement was replaced by 5%, 10%, 15%, 20% & 25% of cotton dust ash.

The strength test was done by testing compressive strength of concrete by testing cubes of size 150 mm × 150 mm × 150 mm in CTM and split tensile strength on cylinder of diameter 150 mm and length 300 mm; Durability tests are done such as water absorption, sorptivity, and carbonation at replacement level of 0%, 5%, 10%, 15%, 20% &25% of cotton dust ash.

1.5. Research Significance

In Ethiopia, there has been significant growth in textile industries, and the usage of concrete is significant. However, the waste of textile industries and the high cost of cement in concrete is one of the problems of the country. One of the solutions to solve the problem is using cotton dust ash as supplementary cementitious material (SCM). In the present study, an attempt has been made to improve the mechanical & durability properties of concrete with low cost in the construction industry by using cotton dust ash, and it is observed that the experiments have yielded satisfactory results.

1.6. Report organization

This research includes five chapters, as follow:

Chapter 1 presents a brief introduction of the effect of cement (OPC) to the environment; the use of supplementary cementitious material and cotton dust ash in concrete and its effect on the durability and mechanical behavior. Besides, this chapter contains the problem statement studied in this research; the objective of the study, scope, and significance of the study are included.

Chapter 2 presents an overall literature review of the use of supplementary cementitious material as a cement replacement in concrete. The study emphasizes the effect of the cotton dust ash and other supplementary cementitious material on concrete mechanical properties such as compressive and tensile, as well as durability properties as water absorption, sorptivity, and carbonation.

Chapter 3 covers many steps beginning with selecting the constituents of concrete; then the design of the concrete mix with different percentage of cotton dust ash and the used experimental testing program in terms of the properties of fresh concrete such as slump test and hardened concrete as compressive, tensile, water absorption, sorptivity, and carbonation test.

Chapter 4 expresses the analysis of results and discusses the mechanical and durability properties of concrete, as well as the followed methodology to assess the viability of the consumption of CDA material as a part of the concrete.

Chapter 5 contains a summary of the findings of this work, the conclusion, and recommendations for future works.

CHAPTER 2. LITERATURE REVIEW

2.1. Introduction

A wide-ranging list of literature has been covered for the replacement of cement using cotton dust ash and other supplementary cementitious material for concrete. According to Abdalla et al. (2019) investigation, a lot of research is ongoing into the replacement of Portland cement by waste materials and manufacturing products. These materials are known as Supplementary Cementitious Materials (SCM) and classified, as shown in Figure 2.1.

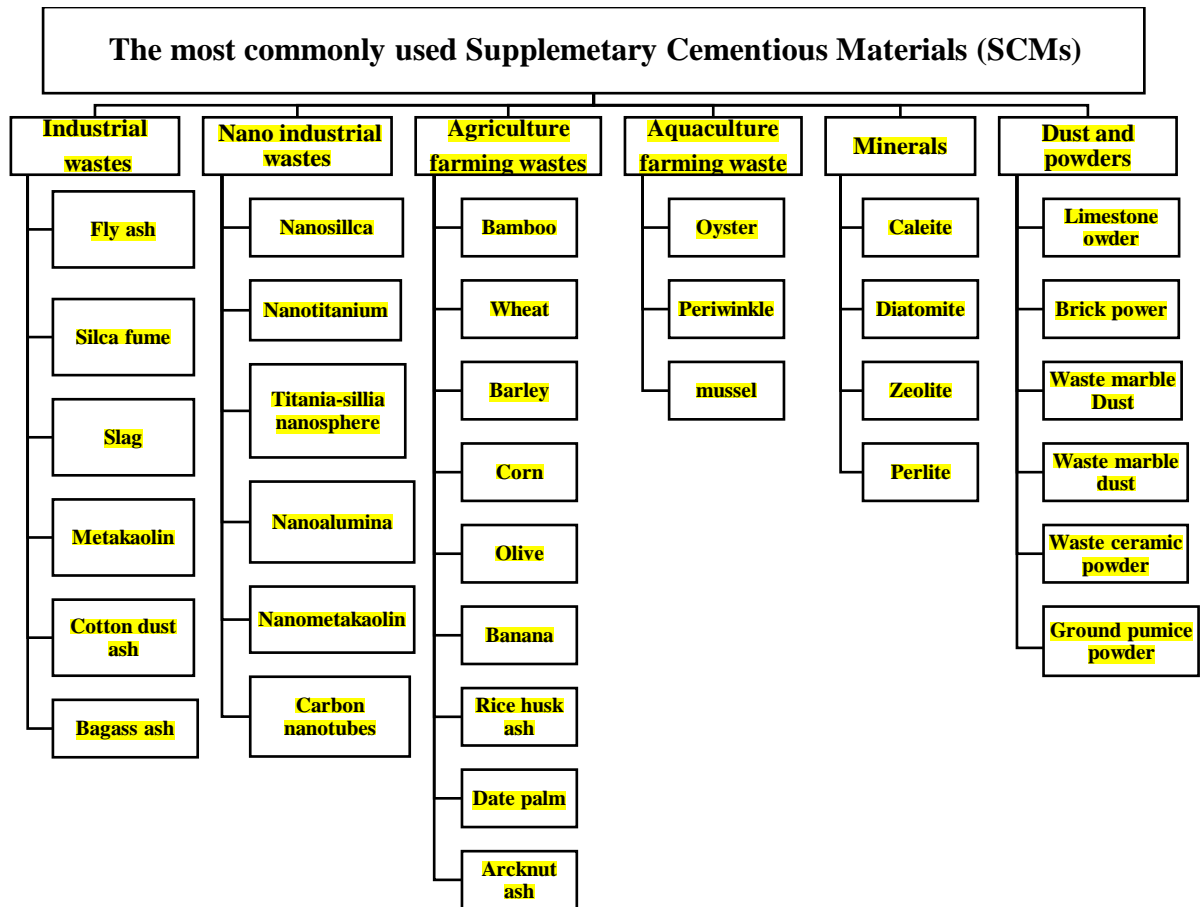
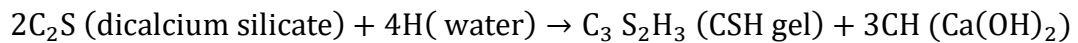
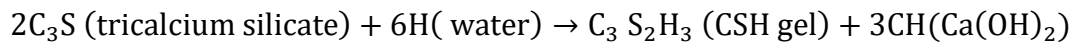


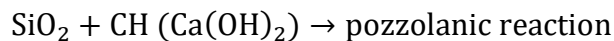
Figure 2.1: Classification of SCMs used for concrete modification (Abdalla et al., 2019)

SCM contains essential calcium, aluminates, and amorphous phases of silica; they can react within the environment of hydrating cement to provide a product, which shares **some** of the properties of Portland cement through a secondary reaction known as the pozzolanic reaction.

According to Dam (2013), The setting and hardening of the OPC takes place as a result of reaction between **these principal** compounds and water. The reaction between **these** compounds and water are shown as below:



Above reactions indicate that during the hydration process of cement, lime is released out and remains as surplus in the hydrated cement. If SCM is available in the mix, this surplus lime becomes the source for pozzolanic reaction with SCM and forms additional C-S-H gel having similar binding properties in the concrete as those produced by hydration of cement paste. The reaction of SCM with surplus lime continues as long as lime is present in the pores of liquid cement paste. The process can also be understood as follows:



When SCM is present in the concrete mass, it plays a dual role in strength development. Primarily SCM reacts with released lime and produces binder and gives additional strength to the concrete mass. The unreactive portion of SCM act as micro aggregates and fills up the matrix to give packing effect and results in increased strength. **When SCM is used as part of cementitious material, the quantum of heat liberated is low and staggers through pozzolanic reactions and thus reduces micro-cracking and improves soundness of concrete mass** (Mathur, 2007).

It is now becoming important that the replacement of cement in the construction industry is needed. The importance of replacement cement in the construction industry and its consequences are to be analyzed at the planning stage, and it has to be monitored continuously. The following literature review presents by focusing on the information relating to the replacement of cement by Supplementary Cementous Material for strength and durability properties of concrete presented by various authors.

2.2. Effect of SCM on Strength Properties of Concrete

According to Ma et al. (2018), ‘Geopolymer’ is an **amorphous** alkali aluminosilicate or alkali-activated cement. Geopolymer concrete was made by polymerizing the aluminosilicates such as fly ash (FA), Metakaolin (MK), slag (SG), rice husk ash (RHA), and high calcium wood ash (HCWA) through activation using **an alkaline solution**. The analysis found that geopolymer concrete could replace normal concrete as they are found with improved mechanical, durability & more valuable structural performance.

According to Sathawane et al.(2013) replacement of cement by **Fly ash and Rice husk** increases compressive strength, split tensile strength, flexural strength with (22.5% FA and 7.5% RHA) and also addition of FA increases in workability because it has very low binding property, addition of RHA decrease workability due to water-absorbent property and high specific surface area.

Lathamaheswari et al.(2017) reported that substitution of cement by bagasse ash increases and attains an optimum level of replacement, which is 10% for compressive strength, tensile strength, and flexural strength.

Sooraj VM (2013) said that palm oil fuel ash is an excellent pozzolanic material which replaces cement up to an optimum level of which is 10%. This replacement increases the compressive strength, split tensile strength, and flexural strength.

Replacement of cement using biomedical waste decreases the workability and density of concrete, as proved by Kumar et al. (2016). The reason for this trend is waste ash is lighter than cement; as a result, it occupies more volume than cement on an equal weight basis resulting in which more water is needed for lubrication. Nevertheless, the compressive strength increases by up to 10% of replacement.

Lavanya et al.(2012) reported that sugarcane bagasse ash replaces cement in different proportion such as 0%, 10%, 15%, 20%, 25%, 30% with water to cement ratio of 0.35, 0.41 and 0.45. According to the results obtained, it can be concluded that bagasse ash can increase the overall strength of the concrete when used up to a 15% cement replacement level with a w/c ratio of 0.35. Bagasse ash is a valuable pozzolanic material, and it can potentially use as a partial replacement for cement. Using SBA as SCM could reduce environmental problems and minimize the requirement of landfill areas to dispose of waste.

According to Joshaghani (2016), natural zeolite has proved to have pozzolanic properties in spite of its crystalline structure. Zeolite was used at 15%, 25%, and 35% weight percentages as a cement replacement material. Because of both strength and permeability, the optimum percentage of zeolite in the specimens is 35%. Although the compressive, tensile, and flexural strengths in concrete with 35% of zeolite were slightly lower than other mixtures, the permeability rate reaches the optimum and is considerably higher than other specimens are. Hence, it seems that 35% of zeolite could be more applicable for pervious concrete.

Chethan Chandru & Dr. Chandrashekar A (2015) investigated the replacement of cement by class F fly ash at the interval of 5%,10%,15%,20%,25%, and 30%. Additionally plastic fibers with a diameter of 0.18 mixed with class F fly ash at percentage of 5%, 10%, 15%, 20%, 25% and 30% also tested for cement replacement. The experimental result showed that compressive strength, split tensile strength & flexural strength increase with the addition of class F fly ash and with plastic fiber addition. The optimum value for both additions was obtained at 15% of class F fly.

A study was conducted by Singh & Kant Pareek (2015) regarding the effect of rice husk ash and plastic fibers on partial substitution of cement. RHA content was used from 5% to 15% at the interval of 5% by replacing Ordinary Portland Cement (OPC.), and plastic fibers were used from 1% to 3% at the interval of 1% by replacing the coarse aggregate. The replacement of 5% to 10% of RHA and 1% to 2% of plastic fiber showed increment on compressive and split tensile strength, but at the remaining interval, both strengths decrease.

2.3. Effect of SCM on Durability Properties of Concrete

2.3.1. Water Absorption and Sorptivity

An investigation by Barathan.S & Gobinath.B (2013) revealed that the potential of wood ash as an admixture of cement in the construction industry. The chemical properties test show that wood ash contains an appreciable amount of pozzolanic properties. Based on its pozzolanic property, wood ash (WA) content used at the interval of 10%, 20% &30%. The water requirement increases with the increase with the WA addition. The 20% WA sample shows a higher degree of hydration and compressive strength than OPC. The optimum replacement percentage of WA is, therefore, 20% for the construction industry.

Saha (2017) predicted the impact of class F fly ash on the durability properties of concrete. Class F fly ash used as partial substitution of cement on the interval of 10%, 20%, 30% &40%. The drying shrinkage was decreased with the increment of fly ash content in the mix. The presence of fly ash as a binder reduced the porosity of the concrete. Based on this, the fly ash concrete showed lower water sorptivity and chloride permeability. Additionally, a significant drop of sorptivity and chloride permeability was seen for fly ash concrete between the curing periods of 28 to 180 days.

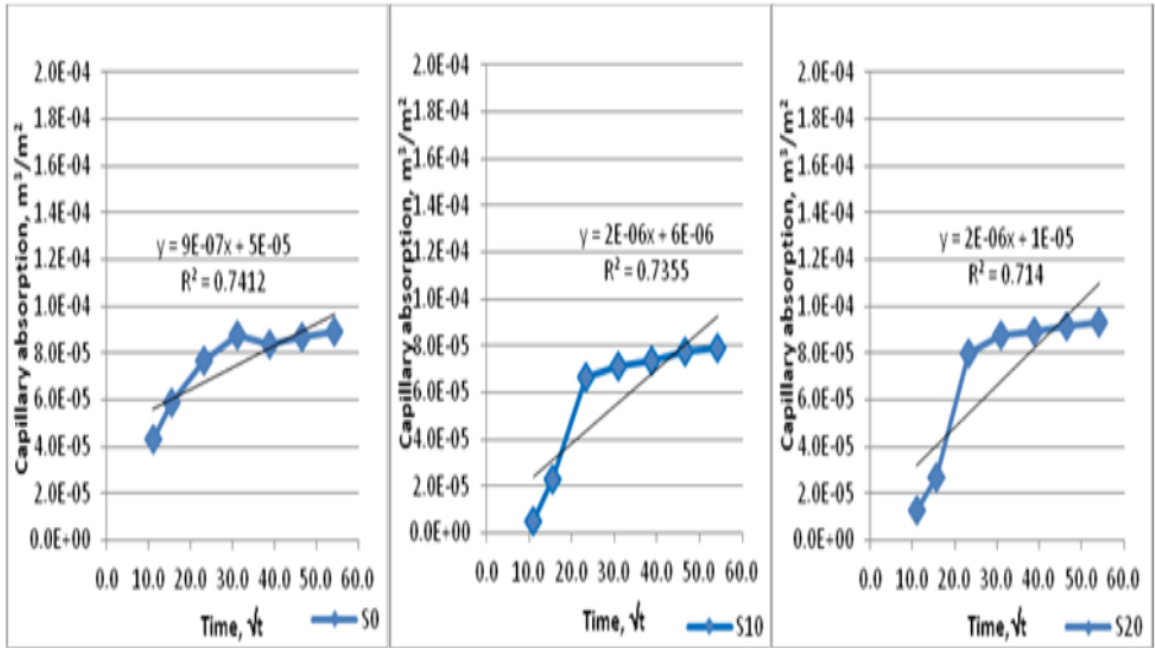
Evaluation of sorptivity and water absorption of concrete with Nanosized cementitious materials was explained by Jemimah Carmichael et al. (2019). Particle in Nano size can improve the durability properties of concrete. Permeability tests in concrete showed that the durability of concrete depends mainly on its capacity of absorption and porosity of concrete. M20grade, M30 grade, M40 grade, and M50 grade of concrete have been used. Cement was substituted with

10%, 20%, 30%, 40%, and 50% of Nanosized cement, fly ash, and silica fume. The percentage replacement of cement with NC, NFA, and NSF increases, the sorptivity & water absorption decreases for all grades of concrete.

Das & Singh (2015) have advocated the possibility of Arecanut husk ash as supplementary cementitious material for cement mortars. The replacement is prepared with an interval of 0%, 10%, 15%, 20%, and 25% Arecanut husk ash as partial substitution of Portland cement. The experimental work carried out for the determination of chemical composition, particle size, presence of crystalline matter, compressive strength, water absorption, and sorption. Water absorption and sorptivity decreased for all replacement level.

Vejmelková et al. (2010) studied the effect of fine-ground ceramics as an alternative binder in high-performance concrete. Fine-ground ceramics used as substitution with the interval of 0%, 10%, 20%, 40% & 60%. The experiment result showed that the optimum replacement for compressive strength is 20%, but as replacement increased, the strength decreased very fast. **Water absorption & thermal conductivity parameter reduced as substitution of fine-ground ceramics increases.**

Akyildiz (2018) studied the feasibility of Granulated blast furnace Slag **reinforced concrete.** Granulated blast furnace Slag (GBFS) was used as partial substitution of cement on the interval of 0%, 10%, and 20%. The experiment carried out on water absorption and sorptivity.



a. 0% GBFS

b. 10% GBFS

c. 20% GBFS

Figure 2.2: Capillary water absorption Vs. time at 0%,10%,20% of GBFS (Akyildiz, 2018)

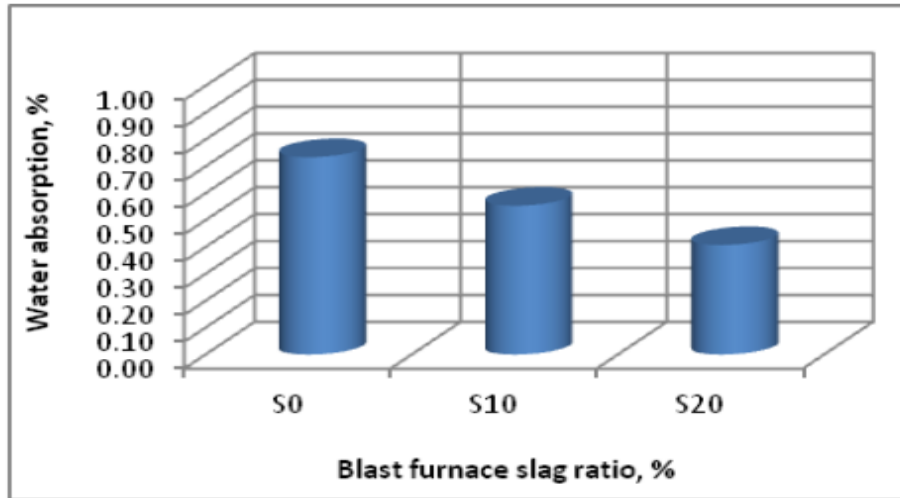


Figure 2.3: Water absorption Vs 0%,10%,20% of GBFS (Akyildiz, 2018)

As the Figure 2.2 & Figure 2.3, shows that sorptivity and water absorption decrease as replacement of as granulated blast furnace slag increases.

The effects of supplementary cementitious materials on the **physicomechanical** properties of cement paste was discussed by Shyamananda Singh et al. (2018). The experiment was carried out with a replacement of cement (OPC) by class F fly ash (FA), Silica fume (SF), and Rice husk ash (RHS) with a percentage of 20% by weight.

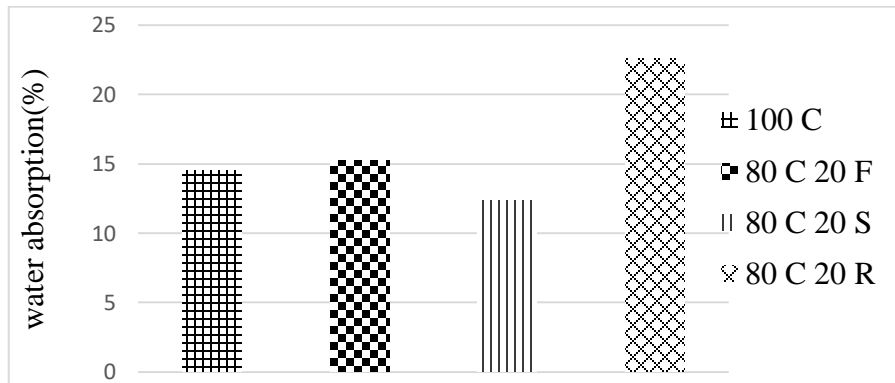


Figure 2.4: Water absorption Vs. % SCM (Shyamananda Singh et al., 2018)

The above Figure 2.4 expresses replacement of cement by silica fume was found to give better physicomechanical properties than other supplementary material. The bulk density of OPC is higher than the other pastes. Apparent porosity of specimen made by replacement of cement by rice husks ash is higher in comparison to those of other pastes. Water absorption of Rice husk ash replacement specimen is higher, which can be attributed to its higher porosity.

Evaluation of sorptivity and water absorption of concrete for grade M25 & M40 with partial substitution of cement by thermal industry waste (Fly ash) at the interval of 0%, 10%, 20%, 30% & 40% was observed by Pitroda & Umrigar (2013). The water absorption and sorptivity of fly ash concrete show higher water absorption and sorptivity than control concrete. The water absorption and sorptivity of 10% fly ash show lower value for M25, M40 grade concrete, respectively. The water absorption and sorptivity of M25 fly ash concrete is lower water absorption and sorptivity than M40 grade concrete.

A paper regarding with sorptivity of different grades of concrete such as M25, M30&M35 proportioned with 10 % of fly ash, wood husk ash and rice husk ash was delivered by Shankar & Rao (2017). For M25 grade concrete, compared to control concrete when replaced with fly ash has 52.6% lesser sorptivity whereas 59.6% smaller for concrete with cement replaced with wood ash and 6.3% more sorptivity for rice husk ash replacement. For M30 grade concrete, fly ash replaced cement concrete has 52.9% lesser sorptivity than control, whereas for Wood ash replaced cement concrete has 63.96% lesser sorptivity than control. For M35 grade concrete, fly ash replaced cement concrete has 58.4% lesser than conventional concrete, whereas Wood ash replaced cement concrete has 63.36% more sorptivity values compared to control concrete.

A study has been made by Misra et al. (2007) on the strength and sorptivity characteristics of fly ash concrete. Proportions having 0.55, 0.475, 0.40 and 0.34 w/c ratios were used. The cement replacement by fly ash was kept at 0%, 10%, 20%, 30%, 40% and 50% of total cement content (by weight) for each w/cm ratio. Concretes having a higher volume of cement replacement by fly ash showed lower values of cumulative water absorption, indicating lower porosity in a cover zone. Concretes with a lower w/cm ratio have lower water absorption for all the mixtures. The sorptivity values are least due to a lower amount of water in the mix, resulting in lower porosity, as shown in Figure 2.5.

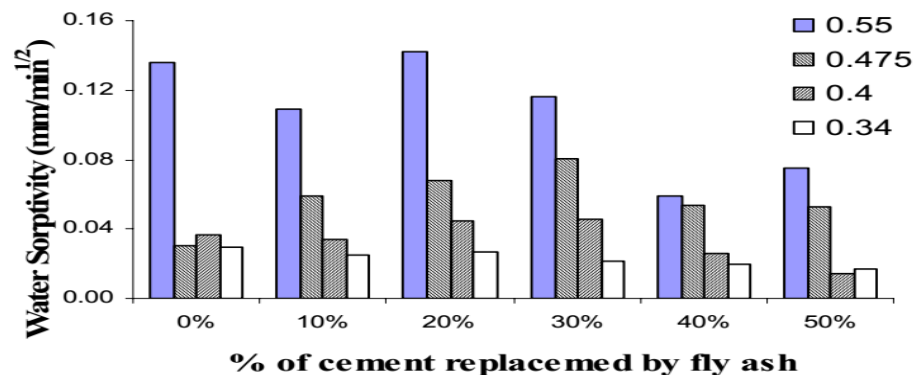


Figure 2.5: Water absorption Vs. % FA (Misra et al., 2007)

2.3.2. Carbonation

You et al. (2014) stated that Carbonation was well thought out as a cause for concrete deterioration because it reduces the pH of concrete from between 12.6 and 13.5 to about 9. For the accelerated-carbonation test, the test specimen cured for 28 days was stored in a carbonation accelerator (temperature: 25°C; relative humidity: 40%; CO₂ concentration: 15%) for 14 days. Then it was separated equally into two parts, and the part that did not turn red when 1% phenolphthalein solution was sprayed on its cross-section was used to measure the carbonation depth as shown below Figure 2.6.

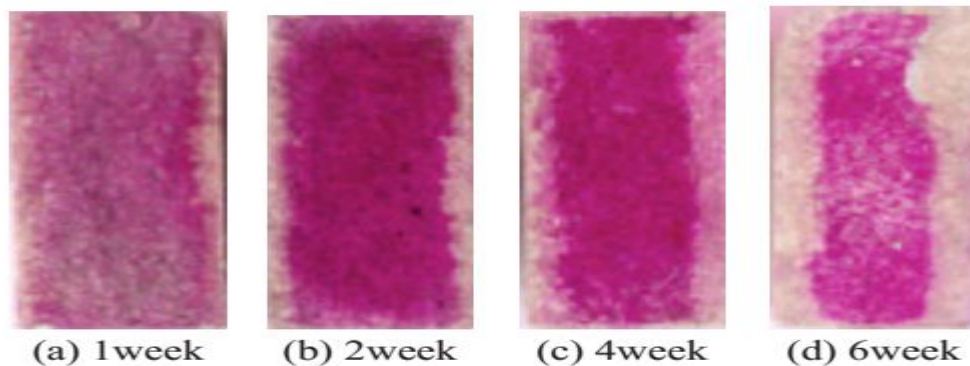


Figure 2.6: Period of CO₂ absorption Vs. carbonation depth (You et al., 2014)

A study has been made by Atiş (2003) on accelerated carbonation and testing of concrete made with fly ash. Cement (OPC) was replaced with an interval of 0%, 50%, and 70%. Water/cement ratios were ranged from 0.28 to 0.55. Fly ash concrete made with a 70% replacement ratio showed higher carbonation than that of 50% FA replacement concrete and OPC concrete for both moist and dry curing conditions. Fly ash concrete made with a 50% replacement ratio showed lower or comparable carbonation than that of control OPC concrete. High-performance fly ash concrete with low potential for carbonation could be produced with the replacement level as high as 50% on a weight basis.

According to Bucher et al. (2017), the combination of MK and limestone filler (in CEM II/A-LL with 15% MK) had good behavior against carbonation, with a carbonation depth almost the same to that of the CEM I samples. The formation of hemicarboaluminates, which might be considered as a CO₂ sink (like C-S-H and portlandite) and thus protect CO₂ suction. Additionally, Ghahari et al. (2016) investigated that silica fume physically and chemically fills the pores of specimens and reduces carbonation depth. MK could provide an advantage to decrease the clinker content in concretes.

Tang et al. (2019) predicted the capacity of micro and Nano palm oil fuel ash to evaluate the carbonation resistance of the concrete in accelerated condition. The percentage of the addition was 10–30% of mPOFA, and 0.5–1.5% of nPOFA were mixed into concrete mixtures to conclude the optimum amount for attaining the maximum carbonation resistance after 28 days of water curing and accelerated CO₂ conditions up to 70 days of exposure. The carbonation depth was known by phenolphthalein solution. The maximum carbonation resistance of concrete was found after the addition of 10% mPOFA and 0.5% nPOFA.

Accelerated carbonation test of concrete made with micro-silica was discussed by Kumara & Kujur (2014). Concrete samples were made with PPC cement of w/c cement ratio 0.5 at the interval of 0%, 5%, and 10%. All concrete cube samples were exposed to accelerated carbonation test (CO₂ concentration = 10±0.5%, RH = 60%, and temperature 30⁰ C) after 28 days of curing followed by laboratory conditioning. Carbonation depth was measured by spraying phenolphthalein solution on the exposed surface. The carbonation test results showed that carbonation depth decreases with an increase in micro silica content.

2.4. Cotton Dust and Cotton Dust Ash

Raw cotton is a natural product, and not all are usable in the spinning process. On the stage of blowing of spinning process machinery, some portion is not used in machine-like unusable or unspinnable fiber, which we called cotton dust or waste that is broken, immature, un-uniformed, bolls damage fibers are going to waste or dust (HossainMohammad, 2018).

According to Israngkura et al. (2014), in the use of cotton dust as a fuel of a boiler in a fabric manufacture process, cotton dust is burned to heat water in a boiler to produce steam that will be used to drive power plants. From the incineration process, cotton dust ash was produced that has a grey-black color. Following this, Israngkura Na Ayudhya (2015) conducted that the CD was incinerated in a furnace at 800⁰C. After that, CD burned for four hours before the furnace was turned off, and CDA was then permitted to cool down naturally to room temperature. During the heating system, moisture in the specimens was allowed to outflow freely. Then the surface dust was blown away. This dust was nothing but CDA powder. The chemical compositions of cotton dust & cotton dust ash and their corresponding applications of are illustrated in Table 2.1.

Table 2.1: Compositions of cotton dust and cotton dust ash with their corresponding applications

Chemical composition (%)							Type	Application	Author
CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	SO ₃	Na ₂ O	Cotton dust ash	As SCM in concrete	Israngkura et al.(2014)
23.8	60.1	10.5	1.02	3.8	-	-			
30.80	11.69	1.75	2.09	13.88	1.54	10.03	Cotton dust ash	As SCM in concrete	Israngkura Na Ayudhya(2015)
29.42	24.35	0.58	13.89	0.45	-	-	Cotton dust	As SCM in brick	Algin & Turgut (2008)

2.4.2. Previous Studies

The subsequent sections summarize the previous studies in the field of the application of cotton dust ash as a cement replacement in concrete.

This literature review mainly focuses on presenting the effect of the cotton dust ash on the strength properties of concrete because most literature about cotton dust ash was written in its effect on the strength of concrete.

Aghaee & Foroughi (2013) investigated the mechanical properties of lightweight concrete partition with a core of cotton textile waste. The bending of lightweight concrete was tested in this study with and without cotton fiber. The test result showed that those samples without a fiber core face practiced a brittle break, but those with a fiber core break softly. This showed that the samples without a cotton fiber collapse instantly after the first crack. This means the first-crack point is the same as the ultimate failure point. Nevertheless, after the first crack has begun in the samples having a cotton fiber, it can withstand the load until 30 mm deflection without collapsing. This specimen has a high ductility characteristic. Based on this test result, Cotton fiber increases the ductility of concrete.

The advantage of textile waste as an alternative thermal insulation building material was studied by Briga-sá et al. (2013), and experimental work was conducted using an external double wall, with the air-box filled with woven fabric waste (WFW) and woven fabric sub waste (WFS). Two heat flowmeters and four surface temperatures sensors were placed on the wall surface to determine the thermal conductivity of the wastes. The results showed that the presence of WFW and WFS in the external double wall increased its thermal behavior by 56% and 30%, respectively.

According to Algin & Turgut (2008), cotton and limestone powder wastes were used as brick material by replacing cement. The physical and mechanical properties of concrete mixes having a high level of CW and LPW were examined. The average compressive strength values were decreased as the percentage CW replacement increased. The LC-30 mix (30% CW) may be applicable for the structural applications such as masonry units, whereas the LC-40 and LC-40/20 mixes may be used for the non-structural applications. Generally, the addition of 10–40% CW replacements in CW–LPW matrix does not show a sudden brittle fracture even above the failure loads and specifies high-energy absorption capacity by permitting lower laboring cost.

The cotton stalk fibers can form a deformable flexible interfacial layer between fibers and matrix, the strength of which is stronger than that of the matrix. Besides, this interfacial layer has a certain flexibility. This flexibility will relax the additional stress in the course of shaping

and improve the whole strength and water-resistant property of the composites remarkably (Burgueño et al., 2005a, 2005b; Li et al., 2003).

A study was conducted by (Israngkura et al., 2014) on the mechanical strength of concrete where cotton dust ash was used as a replacement of ordinary Portland cement. The concrete was made with cementitious materials containing cotton dust ash at 0%, 5%, 10%, 15%, and 20% by weight. According to the experiment, the result from the compressive strength decreased as CDA replacement. Additionally, 5% of CDA replacement gave the highest compressive strength when it was compared with the compressive strength of specimens mixed with 10%, 15%, and 20% of CDA substitution. Flexural strength and split tensile strength shows the same result as compressive strength. Besides, the failure pattern of control and CDA concrete in the flexural strength test observed that CDA concrete was more ductile as compared to control concrete. The reason was when the matrix cracked; the load was transmitted from the composite to the CDA at the crack surfaces, which prevents the brittle failure of the composite.

It has been reported by (Israngkura Na Ayudhya, 2015) cotton dust ash as supplementary cementitious material in concrete. The percentage of substitution was at 0%, 5%, 10%, 15%, and 20% by weight. The workability of fresh CDA concrete decreased as a percentage of CD ash increased. The compressive strength of CDA concrete decreased as a percentage of CDA increased. The maximum compressive strength was found at 10% CDA as compared to 5%, 15%, and 20%. At 60 days, the strength of concrete mixed cotton dust ash (10% cotton dust ash) was 2.75% higher than the control mix. A similar result was found in tensile split tensile strength and flexural strength as compressive strength, where 10% of CDA is the optimum value. Replacement of the mixture should not be more than 10% of the replacement level for the best results in the concrete production for concrete structures.

2.5. Concluding Remarks

A brief literature review on the replacement of cement by cotton dust ash and other supplementary cementitious material (SCM) was carried out which gives more workability and

gets more strength due to its pozzolanic properties was presented. What this research aims to fill the gap that most previous literature shows the application of textile waste (cotton dust ash) on non-structural members such as concrete hollow & solid blocks, pavement blocks, bricks, etc. for strength only. While this thesis presented the advantage of **textile**, waste (cotton dust ash) in concrete that can be used for a structural member not only with respect of strength but also durability properties such as water permeability, carbonation, and reduction in the cost of cement.

CHAPTER 3. MATERIALS AND METHODS

3.1. Introduction

The overall workflow diagram of the study has been presented below in Figure 3.1

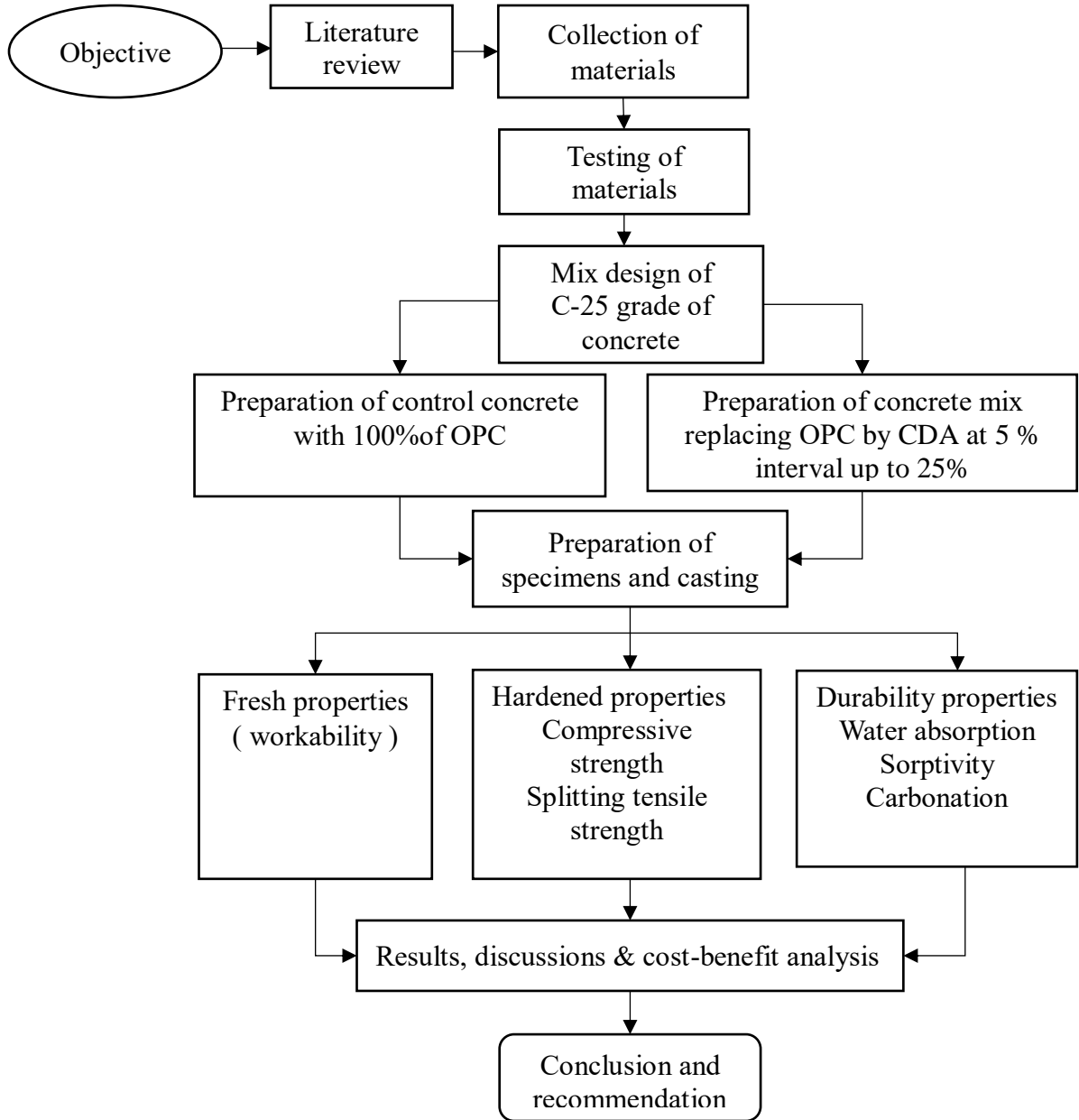


Figure 3.1: The overall workflow diagram

Before starting the main experiment, the material & experimental program, which is used in this research, was prepared. As this study concerned about mechanical and durability of concrete, the property of material & experimental procedure used in this research need to meet the material requirement of ASTM (American Society for Testing and Materials) along with ACI (American Concrete Institute) standards and specifications for checking of requirements in sampling method. Most material & experiment investigation tests were carried out in laboratories found in the Mekelle Institute of Technology. The physical and chemical properties Cotton dust ash tested on Messebo cement factory.

3.2. Characterizations of Constituent Materials

3.2.1. Aggregate

Aggregates are inert granular materials such as sand, gravel, or crushed stone that, along with water and Portland cement, are an essential ingredient in concrete. Since at least three-quarters of the volume of concrete is occupied by aggregate, it is not astonishing that its quality is of considerable importance. For a good concrete mix, aggregates need to be clean, hard, strong particles free of absorbed chemicals or coatings of clay and other fine materials that could cause the deterioration of concrete. In the process of preparing an aggregate that fulfills the requirements, both visual and laboratory-based inspection must be conducted. Besides, aggregate from a single source shall be used in one research to have consistent work. Aggregate from various sources will show various properties, which consequently affect the proportioning of other ingredients of the concrete and, finally, its strength. Thus, aggregate from the single source shall be used at a time since there will exist a difficulty and the error-prone situation in deducing a standard or setting a datum for each source of the aggregate at a certain project. Aggregates are divided into two distinct categories--fine and coarse. Fine aggregates generally consist of natural sand or crushed stone, with most particles passing through a #3/8 (9.5 mm) sieve. Coarse aggregates are generally ranged between #3/8 (9.5mm) and #1.5 (37.5mm) in diameter.

Thus considering the above factors, an aggregate, which fulfills the necessary specification, was selected, and an entire experiment conducted following the required procedure and standard.

3.2.1.1 Fine aggregate

Sand is a type of grains of mineral matter derived from the disintegration of rocks. The prime use of sand, as fine aggregate, is in the production of concrete. As fine aggregate made up to 30% of the total volume of concrete, consequently gradation and fineness modulus of sand are among the basic factors affecting the performance of fresh and hardened concrete (Sabih et al., 2016). The sand used for this study, sourced from Mekelle, specifically Quha. Basic laboratory investigations were carried out to this sand to ensure compliance of property of the sand with the required standards and specifications. Silt content, gradation, specific gravity and absorption capacity, bulk density, moisture content, and were then tested parameters to assess the physical properties of the sand.

A. Silt content

Silt and fine dust may be present in aggregate in the form of surface coatings, which interfere with the bond between the aggregate and the cement paste. The presence of such materials in the sand used to make concrete or mortar decreases the bond between materials to be bound together, hence the strength of the mixture. Even when they are in the latter form, silt and fine dust should not be present in excessive quantities because, owing to their fineness and, therefore, large surface area, silt, and fine dust increase the amount of water necessary to wet all the particles in the mix.

The determination of silt content is as follows: take a cylinder with a capacity of 100ml and fill with the sand about 30ml. The cylinder is now covered with the palm of the hand, shaken vigorously, repeatedly turned upside down, and then allowed to stand for 3 hours. The silt, which became dispersed on shaking, will now settle in a layer above the sand, and the height of this layer can be expressed as a percentage of the height of the sand below.

$$\text{Silt content (\%)} = \frac{A}{B}$$

Where,

A = amount of silt deposited above the sand

B = amount of clean sand

The silt content of this experiment is about 2.22%.

“According to the Ethiopian Standard, it is recommended to wash the sand or reject if the silt content exceeds a value of 6%.”(Dinku, 2002). So the silt content is of this research is accepted.

B. Particle size distribution

The particle size distribution of an aggregate, which determined by sieve analysis, is known as grading of the aggregates. If all the particles of an aggregate are of uniform size, the compacted mass will contain more voids, whereas aggregate comprising particles of various sizes will give a mass with lesser voids. The particle size distribution of a mass of aggregate should be such that the smaller particles fill the voids between the larger particles. The proper grading of an aggregate produces dense concrete and needs less quantity of fine aggregate and cement waste; therefore, coarse and fine aggregates must be well-graded to produce quality concrete(Pawar et al., 2016).

The particle size distribution and fineness modulus (FM) of the sand were conducted as per the ASTM C33 (2004). After taking three representative samples of the sand, sieve analysis was conducted, and an average value of the three samples was taken as the particle size distribution of the sand. The grading requirement and the average percentage of passing obtained are summarized as follows.

Table 3.1: Gradation of fine aggregate

Sieve size (mm)	Percentage pass by mass	Specification as per ASTM
9.5	100	100
4.75	97.7	95-100
2.36	90	80-100
1.18	75	50-85
0.60	45	25-60
0.30	20	5-30
0.15	5.4	0-10
Passing 0.15	1.2	-
Finesse modules (FM)=3		

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

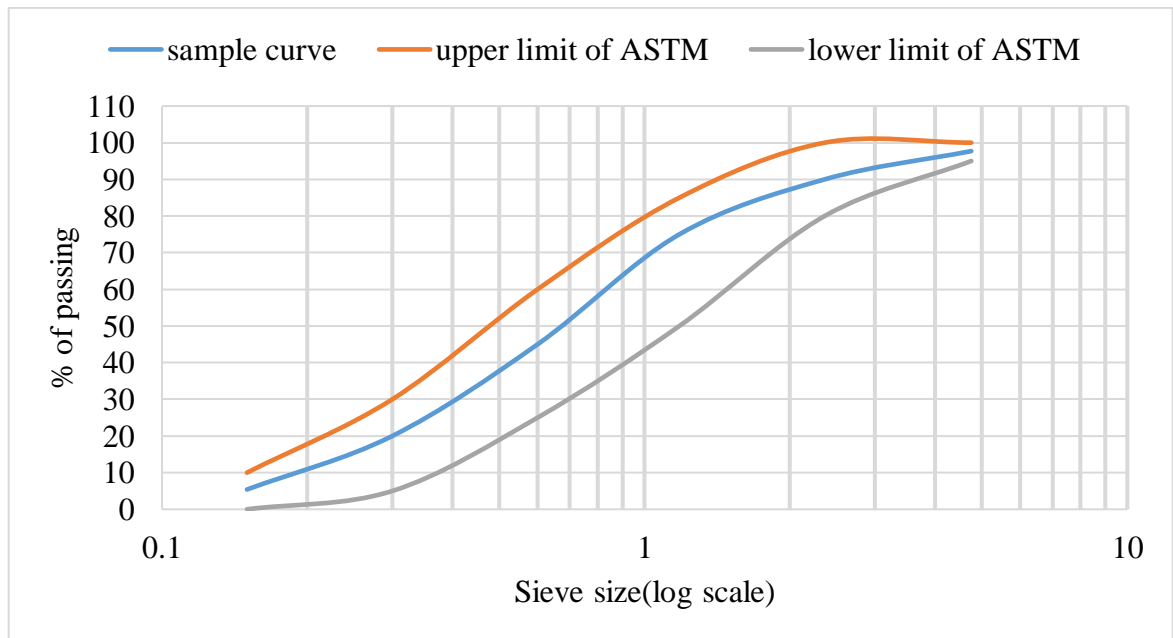


Figure 3.2: Gradation curve of fine aggregate

C. Relative density (specific gravity) and absorption capacity

The relative density (specific gravity) is another physical property of aggregate. The specific gravity of an aggregate is the ratio between the weight of aggregate and the equal volume of water. Besides, its value determines the volume of fine aggregate to be used in a given concrete mix. Following ASTM C128 (2004) the test procedure was conducted as follows.

A sample of aggregate is immersed in water for 24 ± 4 hr. to fill the pores. It was taken out from the water; the water is dried from the surface of the particles by a towel, and then mass measured. Subsequently, the sample was placed in a water-filled container and the mass of the sample is determined as it is in the container. Lastly, the sample is oven-dried, and the mass determined again. Using the mass values thus obtained and formulas in this test method, it is possible to calculate density, relative density (specific gravity), and absorption.

D. Moisture content

The moisture content of the individual ingredients of concrete affects the water-cement ratio of the mix. Some aggregates are with a considerable amount of moisture that they will release it while in use for concrete making, and others are too dry that they will absorb water from the mix and consequently affect the water-cement ratio of the mix. Thus, the percentage of evaporable moisture content does not include the moisture that is chemically combined with the minerals in the aggregate. Following the testing procedure and sampling method stated on ASTM C70 (2004) the moisture content of the sand calculated.

Table 3.2: Test result of physical properties of fine aggregate

Description	Result
Silt content	2.22%
Specific gravity(SSD)	2.62
Specific gravity (OD)	2.60
Specific gravity (Apparent)	2.66
Absorption capacity	0.87%
Moisture content	1.69%

3.2.1.2 Coarse aggregate

Coarse aggregate shall consist of naturally occurring materials such as gravel or resulting from the crushing of parent rock, including natural rock, slags, expanded clays and shales (lightweight aggregates) and other approved inert materials with similar characteristics, having hard, strong, durable particles, conforming to the specific requirements. The physical properties of coarse aggregate used in this research are summarized as follow:

Table 3.3: Gradation of coarse aggregate

Sieve size (mm)	Percentage pass by Mass	Specification as per ASTM
37.5	98	95-100
25	71.06	-
19	50	70-35
12.5	21.06	-
9.5	20	10-30
4.75	0.04	0-5
Passing 4.75	0	-

The grain size distribution of coarse aggregate along its limits of the specification is represented in the graph below.

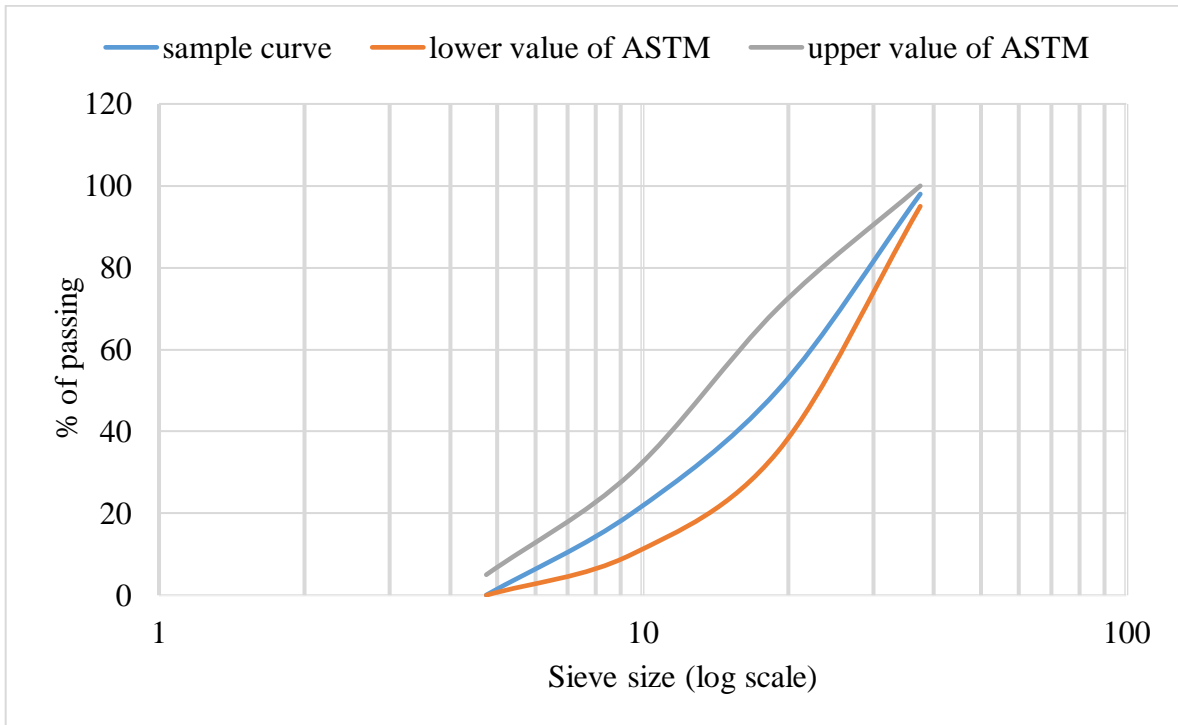


Figure 3.3: Gradation curve of coarse aggregate

The physical properties of coarse aggregate is summarized as follow:

Table 3.4: Summary of physical properties of coarse aggregate

Description	Result
Nominal maximum size	25mm
Specific gravity (SSD)	2.73
Specific gravity(OD)	2.71
Specific gravity(Apparent)	2.76
Absorption capacity	0.63%
Moisture content	0.30%

3.2.2. Cement

Cement, in the general sense of the word, can be described as a material with adhesive and cohesive properties, which make it capable of bonding mineral fragments into a compact whole.

A) Raw materials of Portland cement

1. Calcareous materials, CaO [e.g., Limestone]
 - Principal Constituent and its proportion can be regulated
 - Excess of lime reduces the strength and makes the cement expand & disintegrate
 - A lesser amount of lime also reduces the strength by quick setting
2. Argillaceous materials, Al₂O₃ and SiO₂ [e.g., Clay]
 - Imparts strength
 - Makes quick setting
 - Excess of alumina weakens the cement
- 3 Powdered Coal or fuel oil
 - For burning
- 4 Gypsum (CaSO₄·2H₂O)
 - Retards and enhances the quick setting

The oxides account for over 90% of the cement. In this thesis, the product of the Messebo Cement factory of grade 42.5 OPC was used. The oxide composition of OPC expressed as follows:

Table 3.5: Chemical & physical properties of OPC of Messebo cement factory

Oxides of OPC cement	Percentage of oxides
CaO	62.387%
SiO ₂	22.459%
Fe ₂ O ₃	3.67%
Al ₂ O ₃	4.929%
MgO	1.46%
SO ₃	2.62%
Blaine value	3130 cm ² /g
Loss on ignition	1.778

3.2.3. Cotton Dust Ash (CDA)

Cotton dust is one of industrial waste, which is a dust waste extracted into the atmosphere as a result of the process of the weaving of cotton fibers in the spinning stage of textile mills. Cotton dust was burned at 700-800⁰C heat. From the combustion process, cotton dust ash was generated that has a grey-black color (Israngkura Na Ayudhya, 2015). In this research, cotton dust was obtained from the Almeda Textile Industry of spinning shade. Then cotton dust ash was prepared by incinerated cotton dust in a furnace at 800⁰C for 4hr.



(a)



(b)

Figure 3.4: (a) Cotton dust ; (b) Cotton dust ash

The physical and chemical properties of cotton dust ash, according to Messebo Cement Factory shown below.

Table 3.6: Test result of chemical & physical properties of CDA

Chemical properties (%)	
CaO	10.08
SiO ₂	37.96
Fe ₂ O ₃	11.24
Al ₂ O ₃	4.72
MgO	4.89
Physical properties	
Blaine value(cm ² /g)	3841
Density (g/ml)	2.49
Fineness (%)	6

According to ASTM C595 (2004) Pozzolan (Supplementary Cementitious Material) should be a siliceous or siliceous and aluminous material, which in itself has little or no cementitious value but which can, in finely divided form and the occurrence of water, chemically react with Ca(OH)_2 at ordinary temperatures to form compounds owning cementitious properties.

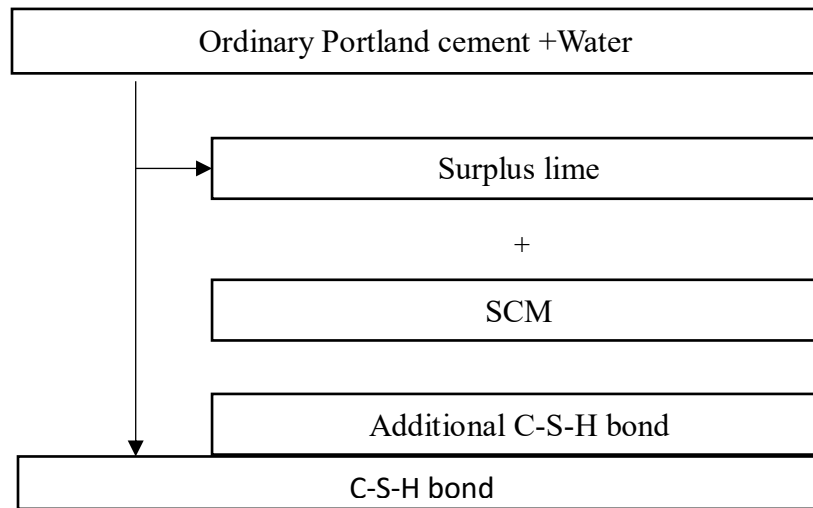


Figure 3.5: The chemical reaction of supplementary cementitious material

Supplementary cementitious materials such as Silica fume, GGBFS, Metakaolin are classified as a pozzolan in (ASTM C1240, 2004; ASTM C150, 2004; ASTM C618, 2004; ASTM C989, 2004) due to their higher content of silicon.

Table 3.7: Chemical composition of SCM according to ASTM

Type of SCM	Chemical composition (%)			Specification
	CaO	SiO ₂	Al ₂ O ₃	
OPC	62.387	22.459	4.929	ASTM C150 (2004)
Silica fume	0.42	97.7	0.18	ASTMC1240 (2004)
GGBFS	36.86	37.4	8.98	ASTM C989 (2004)
Metakaolin	0.41	51.95	44.27	ASTM C618 (2004)
Cotton dust ash	10.08	37.96	4.72	Experimental result

Cotton dust ash is a new material that is not classified in ASTM. CDA contains more silicon than other oxides, and the ternary diagram Figure 3.6 shows CDA is near the specified in Table 3.7 pozzolan (SCM) in ASTM rather than OPC. Therefore, CDA is better to be classified as pozzolan material.

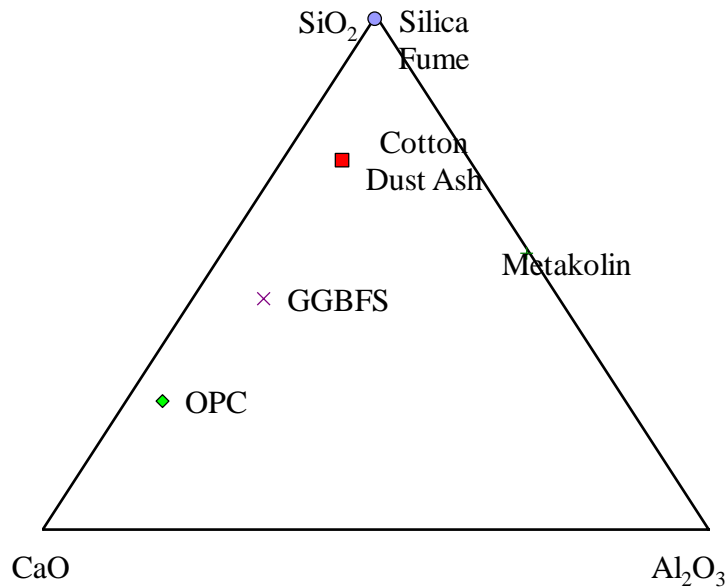


Figure 3.6: Ternary diagram

3.2.4. Chemical Indicator

A chemical indicator is any substance that gives a visible sign, usually by a color change, presence or absence of a threshold concentration a chemical species, such as an acid or an alkali in a solution. A dilute solution of phenolphthalein was used to detect the presence of alkalinity in concrete. The solution is colorless to pH 8.5, pink from approximately pH 8.6 to 8.9, and deep red above pH 9.0.

3.2.5. Water

Water is a key ingredient in concrete, that when mixed with Portland cement, forms a paste that binds the aggregates together. Water causes the hardening of concrete through hydration. Hydration is a chemical reaction between cement and water to form cementitious hydration

products. Water needs to be of suitable quality for use in concrete as not to adversely influence the potential properties of concrete. Almost any water that is drinkable and has no pronounced taste or odour, also known as potable water, can be used as mixing water in concrete.

Water that is not fit for drinking is suitable for use in concrete. Acceptance criteria for water to be used in concrete are given in. Potable water can be used in concrete without any testing or qualification.

3.3. Concrete Mix Design

Concrete mix design is the process of selecting the ingredients for a concrete mixture and deciding on their proportions. When designing a concrete mix, it should always consider the desired strength, durability, and workability of the concrete for the project in question. For this study, the mix design was conducted for a characteristic compressive strength of 25MPa and was made using ACI 211.1-91(2002) . It was prepared using Ordinary Portland cement and without the involvement of any admixtures. The summary of the ingredient is shown in table 3.9 & followed steps are found in the appendix B.

Table 3.8: Mix Proportioning of Concrete Mixes with CDA

% CDA	Cement (kg/m ³)	Cotton dust ash (kg/m ³)	Coarse aggregate (kg/m ³)	Fine aggregate (kg/m ³)	Water (kg/m ³)
0	340	0	1003	862	190
5	323	17	1003	862	190
10	306	34	1003	862	190
15	289	51	1003	862	190
20	272	68	1003	862	190
25	255	85	1003	862	190

3.4. Mixing of Ingredients and Casting of Samples

3.4.1. Mixing of Ingredients

Laboratory drum mixer was used for the preparation and mixing of all concrete mixtures. A drum mixer is a mechanical device, which uses a revolving drum to combine cement, coarse aggregate, fine aggregate, water and cotton dust ash to form a homogenous mass. Coarse aggregate was dry however fine aggregate was in wet conditions. Therefore, necessary water corrections were applied before the mixing operation. All the ingredients, i.e., cement, cotton dust ash, coarse aggregate, fine aggregate and water were weighted with an accuracy of 1.0 gram. Drum mixer was started and firstly, coarse aggregate and fine aggregate were dry mixed thoroughly. After that, cement was added in the drum mixer and it was rotated till a uniform mass was obtained. In the end, water was added very carefully, to prevent any loss of water during the mixing operations. For the distribution effects of the mixing materials, one-third of CDA was firstly added into the running mixer after the concrete was well mixed. The mixing time was three minutes. Then, two-third of CDA was secondly added gradually to the running mixer. The mixing time continues for 6-min. The drum mixer was rotated until we got a concrete mass with uniform colour and consistency.

3.4.2. Sample Preparation

All the concrete specimens were cast in steel moulds. All the moulds were cleaned and oiled properly before the mixing of concrete ingredients. They were properly tightened to correct dimensions before casting operations. Care was taken to ensure that there must not be any gap left to avoid the leakage of slurry. Concrete specimens were compacted in two layers using a vibrating table. After the casting operations, concrete specimens were left in the casting room for approximately 24 hours, after which they were de-moulded and placed in the curing tank.

3.5. Test Procedures

3.5.1. Workability (Slump Test)

The concrete slump test measures the consistency of fresh concrete before it sets. It is performed to check the workability of freshly made concrete, and therefore the ease with which concrete flows.



Figure 3.7: Slump test result

This study has followed the procedure of the ASTM C143(2004) standard test method for slump of hydraulic cement concrete with the replacement of cement by cotton dust ash 0%, 5%, 10%, 15%, 20%, 25% as follow: A sample of freshly mixed concrete is placed and compacted by rodding in a mold shaped as the frustum of a cone. The mold is raised, and the concrete allowed diminishing. The vertical distance between the original and displaced position of the center of the top surface of the concrete is measured and reported as a slump of the concrete.

3.5.2. Compressive Strength

The compressive strength of any material is defined as the resistance to failure under the action of compressive forces. Especially for concrete, compressive strength is an important parameter to determine the performance of the material during service conditions.



Figure 3.8: Compressive Strength Test on Compression Testing Machine

The compressive strength test was carried as per ASTM C39 (2004) standard. It was carried out as follows: Concrete specimens were cast with a dimension of 15cm*15cm*15cm for curing 3,7,28 days with the replacement of cement by cotton dust ash of 0%,5%,10%,15%,20% , and 25%. Every partial replacement contained three specimens for testing. Then after bearing surfaces of the testing machine was wiped clean and any loose sand or other material removed from the surfaces of the specimen, which are to be in contact with the compression platens. The axis of the specimen was carefully aligned with the center of the seated platen. Then the load was applied without shock and increased continuously at a rate of approximately 0.68 kN/sec until the resistance of the specimen to the increasing load breaks down, and no greater load can

be sustained. The maximum load applied to the specimen was recorded. Compressive strength is calculated by dividing the failure load with the area of application of load.

$$\text{Compressive strength } f_{cu} = \frac{\text{failure load}}{\text{area}}$$

3.5.3. Split Tensile Strength

The split tensile strength test is a method of determining the tensile strength of concrete using a cylinder, which splits across the vertical diameter. It is an indirect method of testing the tensile strength of concrete.



Figure 3.9: Splitting tensile strength test of concrete

The test was carried out according to the ASTM C496 (2004) procedure. Initially, three cylindrical concrete ($\phi 150\text{mm}$ & 300mm in height) specimens were prepared for every replacement of cement by cotton dust ash (0%, 5%, 20%, and 25%) for curing 28 days. Then the cylindrical specimen was placed in a manner that the longitudinal axis is perpendicular to

the load. The bearing strips are placed between the specimen and both upper and lower bearing blocks of the testing machine. The load was applied without shock and increased continuously at a nominal rate of 2 kN. /sec. The maximum applied load indicated by the testing machine at failure was recorded, and tensile strength calculated.

Computations: the splitting tensile strength of the specimen is calculated as follows:

$$T = \frac{2p}{\pi Ld}$$

Where:

T: splitting tensile strength

P: maximum applied load indicated by testing machine

L: Length specimen

d: diameter of specimen

3.5.4. Durability of Concrete

Concrete is a composite material comprising of cement, sand & coarse aggregate. Every material has pores, which contains voids in it. Aggregates have a more substantial void ranging from 1mm to 10mm, which cement paste fills these. Even cement has voids ranging from 1micron to 10micron (Neville, 2011). Due to this interconnected and continuous link to fill one void by other material, concrete is prone to permeate fluid or gases into it. The presence of voids in concrete makes permeable, which in turn allows water or gas to flow into it. The permeability of concrete is the ability of concrete to resist the water flow or any other substance into it when the external force is applied. If concrete is permeable, deleterious materials like water, CO₂, SO₂ & Cl, which permeates through the pores of the concrete and reacts with the reinforcement forms rust, which increases the volume of the reinforcement and damages the structure. Prior understanding of the extent and rate of permeation helps to design structure better.

Apart from many types of water permeability testes, this research tested on water absorption and sorptivity tests.

3.5.4.1. Water Absorption

Water absorption of concrete is an indicator of how dense the microstructure of concrete is. The water absorption test was carried out by following the ASTM C642 (2004) procedure. Initially, two cylindrical concrete (ϕ 100mm & 200mm in height) specimens were prepared for every replacement of cement by cotton dust ash (0%, 5%, 10%, 15%, 20%, and 25%) for curing 28 days. After 28 curing period, the specimens were taken out and insert into an oven at a temperature of 100 to 110°C for 24 hr. until the two consecutive samples weight values difference is less than 0.5 %. After getting oven-dry mass, the specimens were immersed in water for not less than 48 hr. until two successive values of mass were constant and surface-dry the specimen by disposing of surface moisture with a towel and determine the mass. Then the water absorption was calculated by the following formula:

$$\text{Water absorption (\%)} = \frac{w_2 - w_1}{w_1} \times (100)$$

Where:

w_1 = weight after oven dry (kg)

w_2 = weight after immersion in water (kg)

3.5.4.2. Sorptivity

The sorptivity test is a simple and rapid test to determine the tendency of concrete to absorb water by capillary suction. The test was developed by Hall (1981) and is based on Darcy's law of unsaturated flow. This test method is used to determine the rate of absorption (sorptivity) of water by hydraulic cement concrete by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen

is exposed to water. The exposed surface of the specimen is immersed in water and water ingress of unsaturated concrete dominated by capillary suction during initial contact with water.

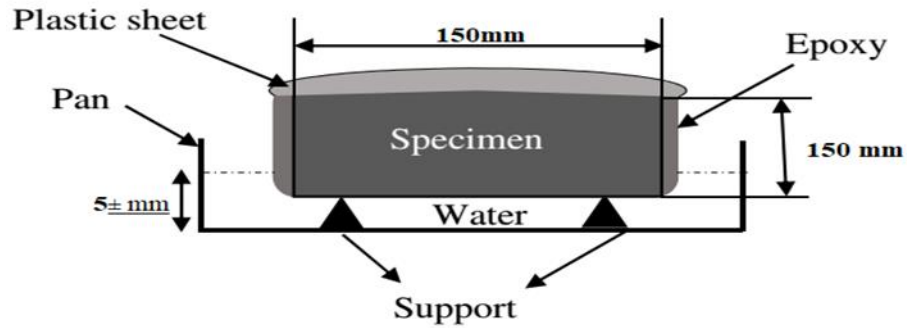


Figure 3.10: Sorptivity test (ASTM C1585, 2004)

ASTM C1585 (2004) were followed to conduct the test. Two cube concrete of size (150mm * 150mm * 150mm) specimens were prepared for every replacement of cement by cotton dust ash (0%, 5%, 20% and 25%) for curing 28 days. Then after curing, the samples were pre-conditioned for 3 days in a hot air oven at 110°C. The sides of the specimen were sealed to achieve unidirectional flow. Locally available wax and the resin was used as a sealant. Weights of the specimen after sealing were taken as initial weight. The initial mass of the sample was taken, and at time 0, it was immersed to a depth of 5-10 mm in the water. At selected times (typically 1, 2, 3, 4, 5, 9, 12, 16, 20 and 25 minutes), the sample was removed from the water, the stopwatch stopped, excess water blotted off with a damp paper towel or cloth, and the sample weighed. It was then replaced in water, and the stopwatch was started again. After collecting the data, capillary water absorption (I) can be calculated as:

$$I = \frac{\Delta m}{a \times d}$$

Where:

I = water absorption in (mm)

Δm = change in mass of a sample at a time t (kg)

a = area of a sample that have a contact with water (mm^2)

d = density of water ($\frac{\text{kg}}{\text{m}^3}$)

The gain in mass per unit area over the density of water (I) is plotted versus the square root of the elapsed time (\sqrt{t}). The slope of the line of best fit of these points was reported as the sorptivity(S).

$$I = S\sqrt{t} + b$$

3.5.4.3. Carbonation

Carbonation is a serious problem for many reinforced concrete buildings that have been in service for some decades. Carbon dioxide in the atmosphere, when it comes into contact with concrete, starts off chemical reactions, which tend to reduce the concrete's protective effect on its reinforcements. Carbonation has been considered as a deterioration factor in concrete because it reduces the pH of concrete from 12.6 and 13.5 to about 9.

For the accelerated-carbonation test, the test specimen ($\phi 150\text{mm}$ & 300mm in height) cured for 28 days was exposed to the atmosphere in a (temperature: 25°C ; relative humidity: in door; CO_2 concentration: 3%) for 120 days. Then it was divided equally into two parts, and the part that did not turn red when a dilute solution of phenolphthalein was sprayed on its cross-section was used to measure the carbonation depth. The majority of research works on concrete carbonation use a phenolphthalein indicator to assess carbonation depth. This involves spraying broken concrete faces of a dilute solution of phenolphthalein.

CHAPTER 4. RESULTS AND DISCUSSION

4.1. Introduction

This chapter explains the results and discusses the essentials of mechanical & durability properties of concrete analysis and the methodology followed to highlight the usefulness of considering cotton dust ash materials as a main component within the concrete mix. The experimental results and analysis were obtained for a slump test to check the change of fresh concrete properties with cement replaced by cotton dust ash. Besides, compression strength test, split tensile strength test, water absorption test, sorptivity test, and carbonation test to investigate the change of hardened concrete properties with substitution of cement by cotton dust ash.

Regarding the native property of cotton dust ash, the chemical analysis of it had shown that it is rich in silica content with certain alkali chemical constituents. This result is similar to the finding of research done on this material by (Israngkura Na Ayudhya, 2015); Israngkura et al. (2014). Cotton dust ash, which exhibited a specific surface area value of $3841\text{cm}^2/\text{g}$. This value is a relatively higher value when it is compared with the specific surface area of the OPC cement $3130\text{cm}^2/\text{g}$ used in this research.

4.2. Workability of Concrete:

The final output results for different replacement of cement by cotton dust ash regarding slump values for fresh concrete are listed in Table 4.1. Moreover, the effect of cotton dust ash content on the workability of the fresh concrete is shown in Figure 4.1.

Table 4.1: Test result of slump

% CDA	Slump(mm)
0	75
5	50
10	34
15	25
20	0
25	0

The results showed that the workability decreases rapidly by the increase of CDA content. The decrease of workability agrees with the finding reported by (Israngkura Na Ayudhya, 2015). The addition of cotton dust ash decreases workability due to water-absorbent property and high specific surface area.

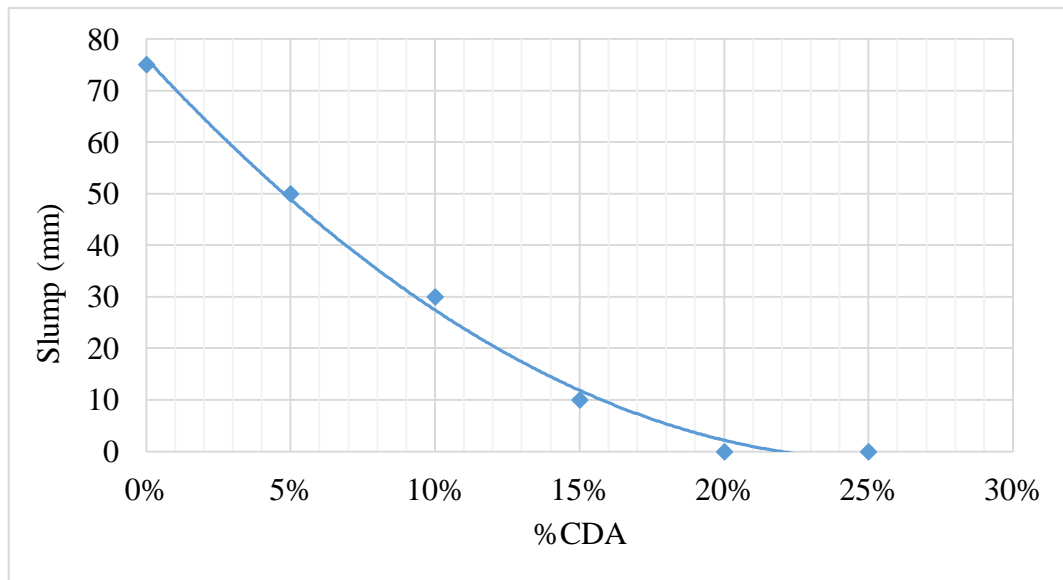


Figure 4.1: Slump (mm) Vs. CDA (%)

4.3. Compressive Strength

The average compressive strength values as a function of the percentage of cotton dust ash and age are shown in Tables 4.2.

Table 4.2: Average test result of compressive strength (MPa)

Curing period(days)	% CDA					
	0%	5%	10%	15%	20%	25%
3	19.641	27.330	22.975	21.231	20.97	18.09
7	23.470	32.527	24.655	25.039	24.94	22.83
28	27.825	41.824	33.913	31.996	27.90	25.72

An increase in the compressive strength is observed as the amount of the cotton dust ash increased until 28 days curing up to 20% replacement.

Table 4.3: Increment in compressive strength from control (%)

% CDA	% of Increments		
	3 Day curing	7 Day curing	28 Day curing
5	39.148	38.590	50.311
10	16.975	5.049	21.880
15	8.095	6.685	14.990
20	6.766	6.263	0.270

SCM had low early age strength when compared with control concrete (Dam, 2013). In contrary CDA increased early strength of concrete unlike other SCM. This might due to thermal resistivity of CDA which retained the heat of hydration and increased the cement reactions at early age (Israngkura et al., 2014). Figure 4.2 shows the increment is increasing at a decreasing rate. Though the increment is increasing at a decreasing rate, the compressive strength was improved until 20% replacement. The cause of increment is when cotton dust ash is added in concrete; the reactive silica present in cotton dust ash reacts with calcium hydroxide liberated

during cement hydration and forms calcium silicate hydrate (C-S-H) gel. Compact C-S-H gel gives higher strength. Beyond 20% CDA the compressive strength starts to decrease, this might be due to the amount of cement, hydration process and CDA activity. As the amount of cement decreased the formation of $\text{Ca}(\text{OH})_2$ decreased consequently pozzolanic reaction with CDA reduced.

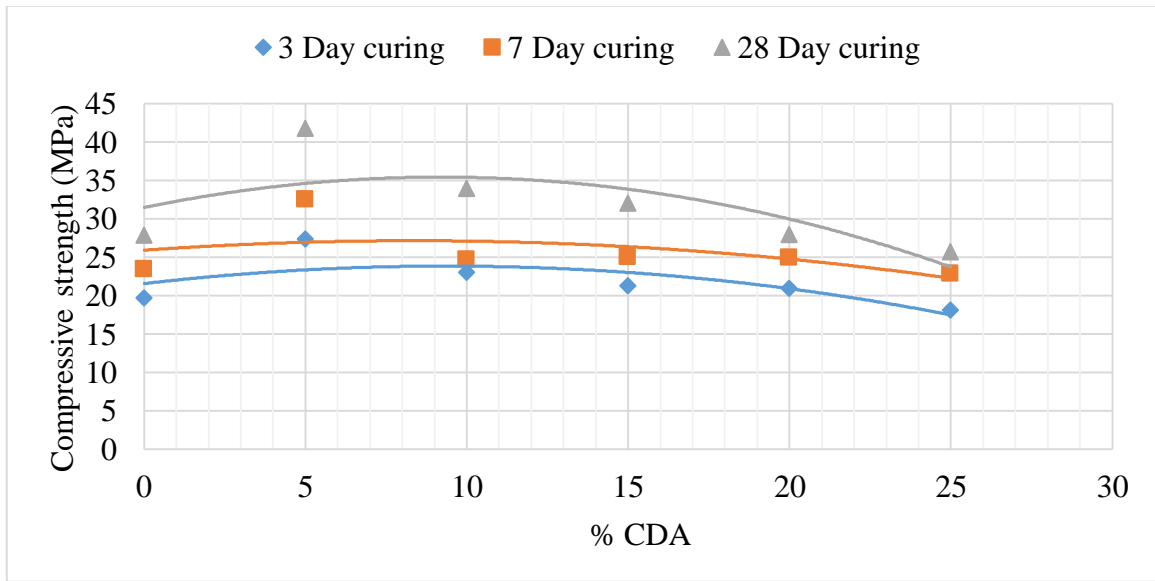


Figure 4.2: Compressive strength Vs. CDA (%)

4.4. Split Tensile Strength

Table 4.4 contains a test result of split tensile strength.

Table 4.4: Test result of the split tensile strength (MPa)

% CDA	28 – Days split tensile strength (MPa)
0%	3.01
5%	4.01
20%	3.04
25%	2.74

Figure 4.3 shows the split tensile strength as a function of CDA replacement at the age of 28 days. The results showed that as the amount of CDA increases, the split tensile strength increase with a decreasing rate. 5% of the CDA mix shows the maximum split tensile strength and greater by 33.22% than control. The 20% CDA mix indicates a split tensile strength that was similar to that of the control mix. The significant increase in split tensile strength may result from the chemical reaction between the active silicon dioxide of CDA and the $\text{Ca}(\text{OH})_2$ in the hydrated cement to form C-S-H. It can be inferred that the microstructure of the interface zone can be improved further with time in consequence of a secondary reaction between the $\text{Ca}(\text{OH})_2$ present there and pozzolana, thus leading to an even denser interface zone. The formation of highly dense reaction products with the consequent increase in the denseness and compactness of the concrete also led to the increase in the split tensile strength of the concrete. This result agrees with the finding of (Xiong, Liu, Li, & Xie, 2002) and Natarajan & Gnanadurai (2019), which cement replaced by Fly ash (Metakoline) which have similar physical and chemical properties.

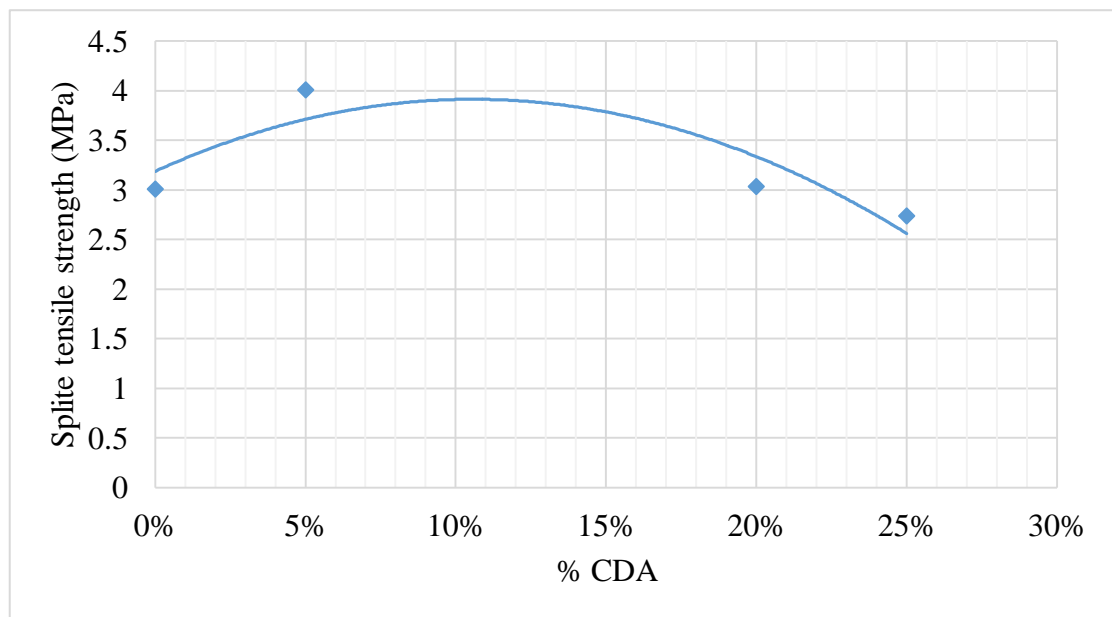


Figure 4.3: Split tensile strength Vs. CDA (%)

4.5. Water Absorption

The average water absorption of the concrete mixes expressed as a percentage is shown in Table 4.5.

Table 4.5: Test result of water absorption

Percentage of CDA	Water absorption(%)
0%	6.31
5%	4.59
10%	4.91
15%	4.98
20%	5.27
25%	6.15

It can be shown that in Figure 4.4, the amount of water absorbed by the concrete mixes decreased with an increasing rate as the percentage of CDA replaced cement increases until 25%.

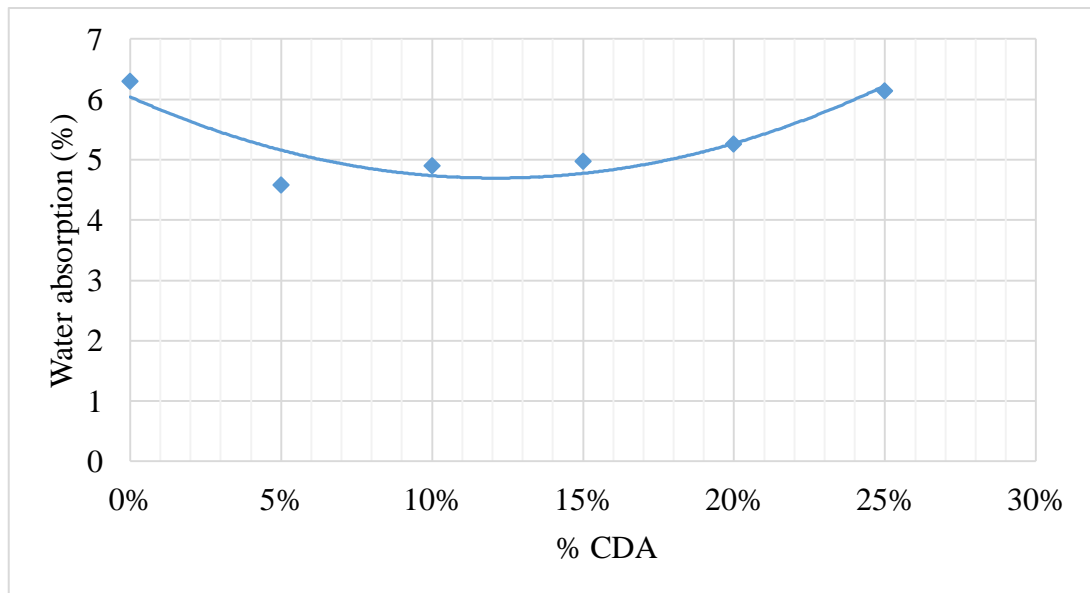


Figure 4.4: Water absorption Vs. CDA (%)

Water absorption decreased by 27.6%,22.19%,21.08%,16.48% & 2.54% from control concrete for 5%,10%,15%,20% & 25% respectively. This showed that the filling capacity of CDA reduces pores of the concrete, and also, the inclusion of CDA forms the stable non-water-soluble reaction products that fill the pores of the concrete. The CDA addition causes reduced water absorption of the concrete by making the pores discontinuous due to their pore blocking effect. Moreover, the increased specific surface area of the CDA creates an increased number of reaction sites that actively react with the cement forming pozzolanic reaction and hence aids in the formation of stable phases of concrete. The higher fineness and denseness of the CDA also contribute to the filling of the voids available in the concrete (Israngkura Na Ayudhya, 2015).

4.6. Sorptivity

The average capillary absorption of the water by the concrete specimens at 0 % CDA, 5 % CDA,20% CDA,25% was done. The detailed capillary absorption & sorptivity values of the concrete specimens for 0 % CDA, 5 % CDA are shown in Table 4.6, Table 4.7, Figure 4.5 & Figure 4.6 shown below, respectively, and for the rest replacement found in the appendix F.

Table 4.6 : Capillary water absorption test result for 0% CDA

Time (min)	0	1	2	3	4	5	9	12	16	20	25
\sqrt{t} (min)	0	1	1.414	1.732	2	2.236	3	3.464	4	4.472	5
I_{Avg} (mm)	0	0.13	0.27	0.38	0.51	0.58	0.69	0.84	0.98	1.09	1.24

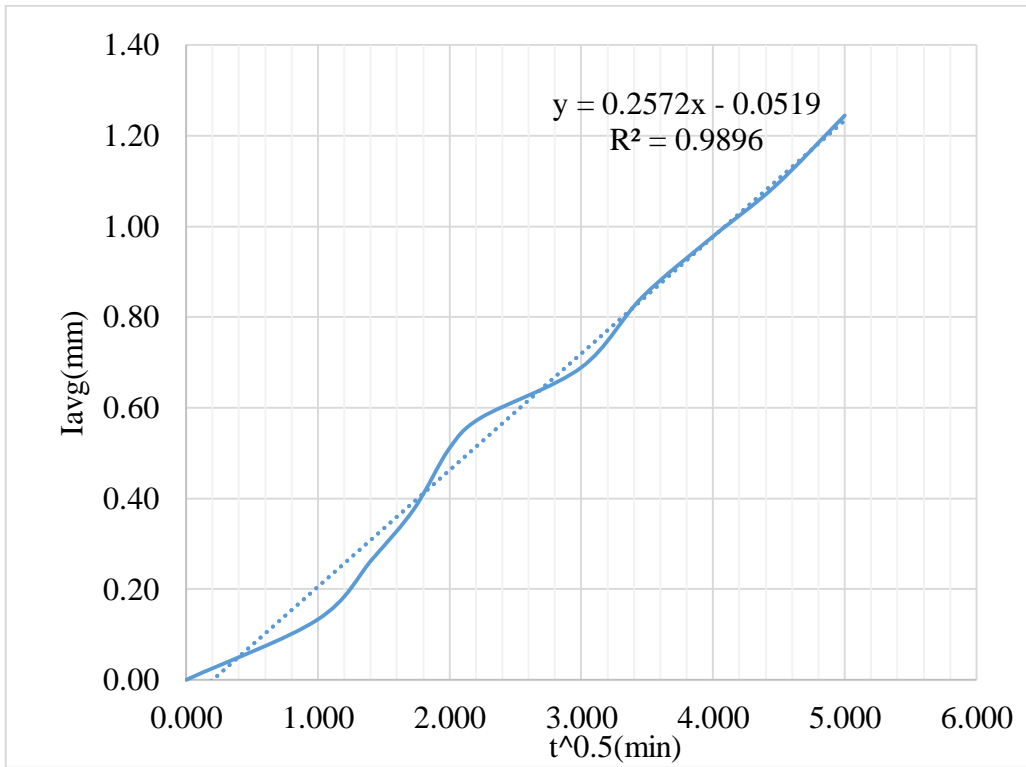


Figure 4.5: Iavg (mm) for 0% CDA Vs. \sqrt{t} (min)

Table 4.7 : Capillary water absorption test result for 5% CDA

Time (min)	0	1	2	3	4	5	9	12	16	20	25
\sqrt{t} (min)	0	1	1.414	1.732	2	2.236	3	3.464	4	4.472	5
I_{Avg} (mm)	0	0.13	0.15	0.17	0.22	0.24	0.3	0.34	0.38	0.43	0.51

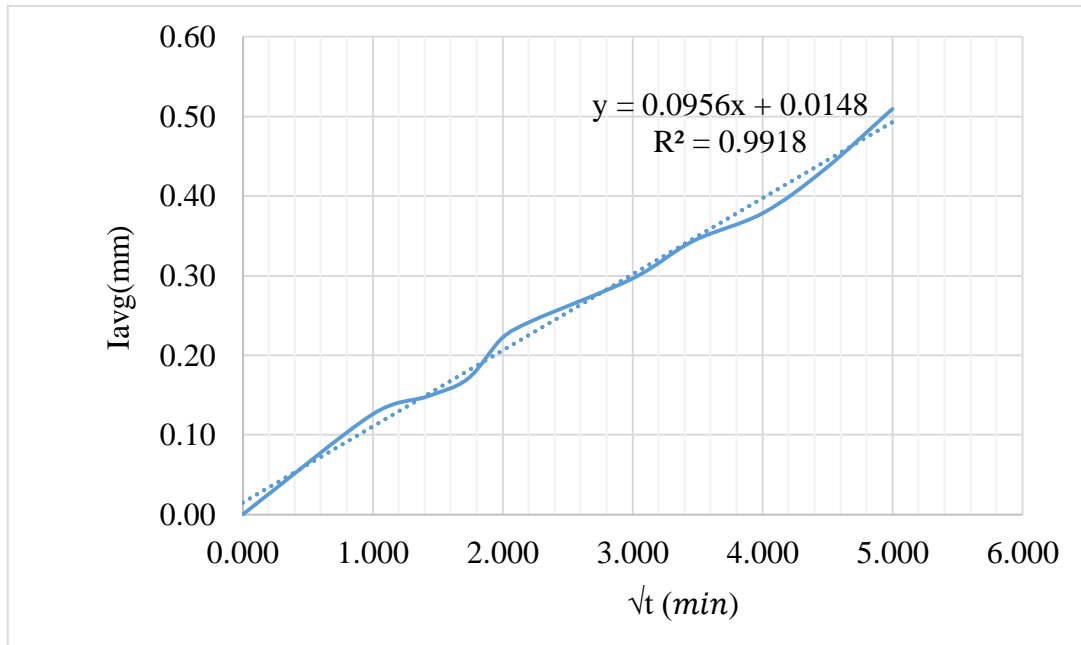


Figure 4.6: Iavg (mm) for 5% CDA Vs \sqrt{t} (min)

Sorptivity results are found from the graph of capillary water absorption versus the square root of time. The sorptivity results are summarized in the following Table 4.8.

Table 4.8: Sorptivity values

CDA (%)	Sorptivity(mm/min)
0	0.257
5	0.095
20	0.205
25	0.208

Figure 4.7 shows that sorptivity decreased with an increasing rate as the percentage of CDA increased to 25%. Sorptivity is decreased by 62.83 %, 20.06 % & 19.13% than control for 5%, 20% & 25% respectively. This clearly shows the positive influence of CDA in reducing the volume permeable pore and thereby reducing the water uptake by the concrete. Micro-fines present in CDA tend to fill up the voids present in concrete and making the concrete

microstructure denser, leaving lesser voids as compared to control concrete. Micro-fines are not only reducing the size of the voids but also modifying the internal pore structure by blocking interconnecting capillary pores. That is the reason for the decrease in the sorptivity of concrete with the inclusion of CDA as a partial substitute for cement.

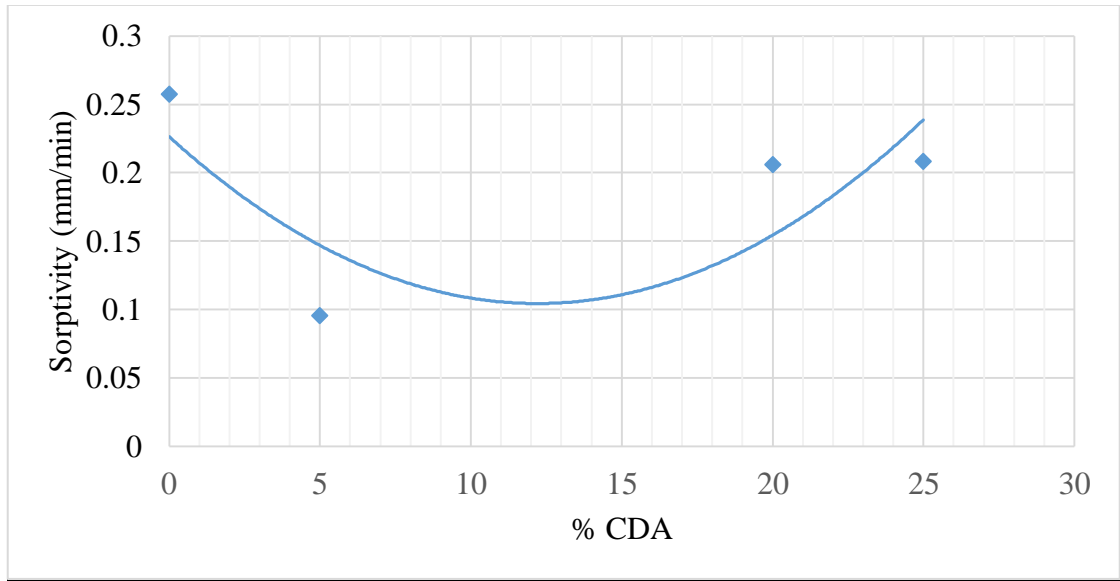
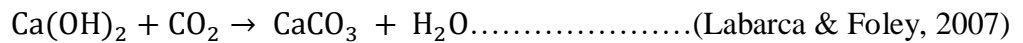


Figure 4.7: Sorptivity Vs. CDA(%)

4.7. Carbonation

Carbonation in concrete occurs when calcium hydroxides (lime) of the hydrated Portland cement react with carbon dioxide from atmospheres in the presence of moisture and form calcium carbonate.



The carbonation process in concrete consequences in two damaging effects (i) shrinkage may occur (ii) concrete immediately adjacent to steel reinforcement may reduce its resistance to corrosion (Zulu, 2017). The rate of carbonation rest on the permeability of concrete, the amount of surplus lime and environmental conditions such as moisture and temperature (Mathur, 2007).

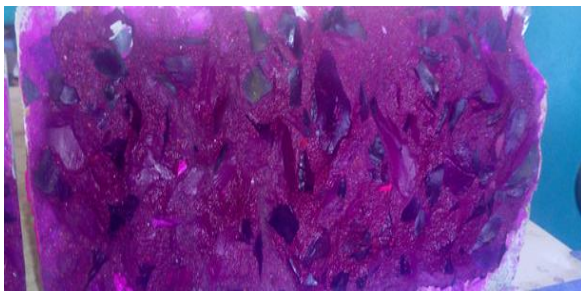
Concrete specimen for carbonation was tested for 0%,5%,20% and 25% of cement replaced by CDA after 28 days curing and exposing to 3% CO₂ for 120 days. The formation of CaCO₃ was tested by spraying phenolphthalein solution on a newly fractured specimen of 0%, 5%, 20% up to 25% of CDA concrete. The specimens starting from 5%,20% & 25% of CDA concrete in Figure 4.8 shows highly alkaline, a purple-red color as 0% CDA concrete, which means uncarbonated. This is due to when CDA is available in concrete; it reduces the availability of surplus lime by way of pozzolanic reaction, reduces permeability, and as a result improves the resistance of concrete against the carbonation phenomenon.



(a) 0 % of CDA



(b) 5% of CDA



(c) 20 % of CDA



(d) 25 % of CDA

Figure 4.8: Carbonation Vs. % CDA

4.8. Cost-Benefit Analysis

Besides, of improvement in concrete strength, cotton dust ash is also highly economical because it is a residue obtained from textile industries, which is disposed of in the open land. Therefore, it can be utilized free of cost, unlike other admixtures. The cost-benefit, which is gained from CDA, is a direct benefit and indirect benefit. Besides cost-benefit, analysis is done with respect to compressive strength and the workability of the mix, which is acceptable in the construction site. The optimum point of CDA, which can be used in the construction site, is up to 15% of CDA according to the requirement of slump (ACI 211.1-91, 2002). Based up on this, the cost-benefit analysis is done as follow:

4.8.1. Direct Cost-Benefit

It is well known that direct benefit is the benefit, which directly gained from the cost of the replaced cotton dust ash. This determines that the amount of replacement of OPC cement causes for reduction of the price of the cement. The cost of the following materials was considered to determine the direct benefit.

A. Cost of Cotton dust ash

The cost of cotton dust ash was estimated by observation and interviewing of spinning shade workers of the Almeda textile industry. According to this, the main cost for cotton dust ash was for transportation from the production site (spinning shade) to the disposal area and burning. The cost approximately is estimated as follows:

Table 4.9: Cost of 1000 kg cotton dust ash ETB/kg

Type	Estimated cost based on salary
Labor	13.05 ETB/ hr.
Fuel	56.78 ETB/hr.
Total =69.83 ETB/hr.	
Cost per kg cotton dust ash = 69.83/1000= 0.0698 ETB/kg	

B. Ingredient quantity used

The ingredients such as cement, cotton dust ash, water, fine aggregate, coarse aggregate, which was used to make one cubic meter of concrete need to be determined hence cost-benefit analysis, is calculated based on the cost of the constituents.

Table 4.10: Cost of ingredients per m³ of concrete

Concrete ingredient	Cost per truck	Cost per m ³ or quintal	Cost per kg
Coarse aggregate	7600 ETB	475 ETB/m ³	0.4 ETB/kg
Fine aggregate	9500 ETB	593.75 ETB/ m ³	0.4 ETB/kg
Cement	-	400 ETB/quintal	4 ETB/kg
Water	-	5 ETB/m ³	0.005 ETB/kg
Cotton dust ash	-	-	0.069 ETB/kg

Table 4.11: Cost of compressive control concrete at 28 day curing period

Coarse Aggregate (kg/m ³)	Fine Aggregate (kg/m ³)	Cement (kg/m ³)	Water (kg/m ³)	Cost/m ³	Cost/m ³ /Mpa At 28 days
Weight of ingredients per m ³ of concrete				1/0.01 = 100	2107/27.83
1003	862	340	190	100*21.07=	=
Weight of ingredients per trial batch (0.01m ³)				2107ETB/m ³	75.71ETB/ m ³ /MPa
10.03	8.62	3.40	1.90		
Cost per trial batch of concrete (ETB/kg)					
4.012	3.448	13.6	0.0095		
Total = 21.07					

Table 4.12: Cost of concrete with CDA (ETB/m³)

% CDA	Weight Of CDA (kg)	Weight Of Cement (kg)	Cost of cement +CDA (ETB)	Cost of concrete With CDA (ETB/m ³)
0	-	3.40	13.6	21.07
5	0.17	3.23	12.93	20.40
10	0.34	3.06	12.26	19.73
15	0.51	2.89	11.60	19.07

Table 4.13: Cost/m³/Mpa (ETB/m³/MPa)

% CDA	28 days compressive Strength (MPa)	Cost of concrete With CDA (ETB/m ³)	Cost/m ³ /MPa (ETB/m ³ /MPa)
0	27.83	2107	75.71
5	41.82	2040	48.78
10	33.92	1973	58.17
15	32.00	1907	59.59

Table 4.14: Benefit/m³/MPa

% CDA	28 days compressive Strength (MPa)	Benefit (ETB/m ³)	Benefit/m ³ /MPa
0	27.83	0	0
5	41.82	67	1.60
10	33.92	134	3.95
15	32.00	200	6.25

4.8.2. Indirect Cost-Benefit

Indirect cost benefits are related to environmental impact, which includes the decrease in released carbon dioxide and the amount of cement consumed because of less cement manufactured due to replacement of cement by CDA & decreases the amount of waste on landfills. According to Gale et al. (2010), the cement industry is accountable for approximately 5% of global anthropogenic carbon dioxide emissions. The industry releases nearly 900 kg of CO₂ for every 1000 kg of cement produced. In Ethiopia, such as Mughher Cement Factory (MCF) alone emits 463,844 tons of CO₂/year on average based on emission test and mass balance performed (Gebreeyessus et al., 2014). According to Mengistu et al. (2019) report, Ethiopia collects carbon tax starts at \$5 per ton of carbon dioxide in 2018 and rises to \$30 per ton in 2030.

Following this Naqi & Jang (2019) stated that cement manufactured from locally available minerals and industrial wastes that can be blended with OPC as a substitute or full replacement with novel clinkers to decrease the energy requirements & to mitigate carbon dioxide emissions is strongly desired. In this research cost of CO₂ is a carbon tax, which means as carbon tax decreases emission of CO₂ decreases. Based on the above information, the indirect benefit of CDA analysis is shown in Table 4.15.

Table 4.15: Indirect cost-benefit analysis

% CDA	Weight of OPC replaced by CDA in (kg)	Weight of reduced CO ₂ per (kg)	Indirect cost benefit per (ETB)	Indirect cost benefit per m ³ of concrete
0	0.00	0.00	0.00	0.00
5	0.17	0.153	0.005	0.49
10	0.34	0.306	0.009	0.97
15	0.51	0.459	0.015	1.50

Table 4.16: Sum of direct and indirect cost benefit analysis

% CDA	0	5	10	15
Compressive strength(MPa)	27.83	41.82	33.92	32.00
Cost (ETB/m ³)	2107	2040	1973	1907
Direct benefit(ETB/m ³)	0.00	67	134	200
Indirect benefit (ETB/m ³)	0.00	0.49	0.97	1.50
Total benefit(ETB/m ³)	0.00	67.49	134.97	201.50
Benefit (ETB/m ³ /MPa)	0.00	1.61	3.98	6.30
Cost (ETB/m ³ /MPa)	75.71	48.78	58.17	59.59

Table 4.16 results showed that the point that has the least cost with respect to strength is 5% of CDA, while the point that has a higher benefit is 15% of CDA. Based on this, what is needed is

a point that is economical (with respect to benefit) and attains optimum strength. The optimum point is the point that attains the target strength with higher benefits, which is an economical point. The optimum point is shown in Figure 4.9 as the intersection of the graph of Benefit (ETB/m³/MPa) & Cost (ETB/m³/MPa) Vs. % CDA which is 10.8% CDA.

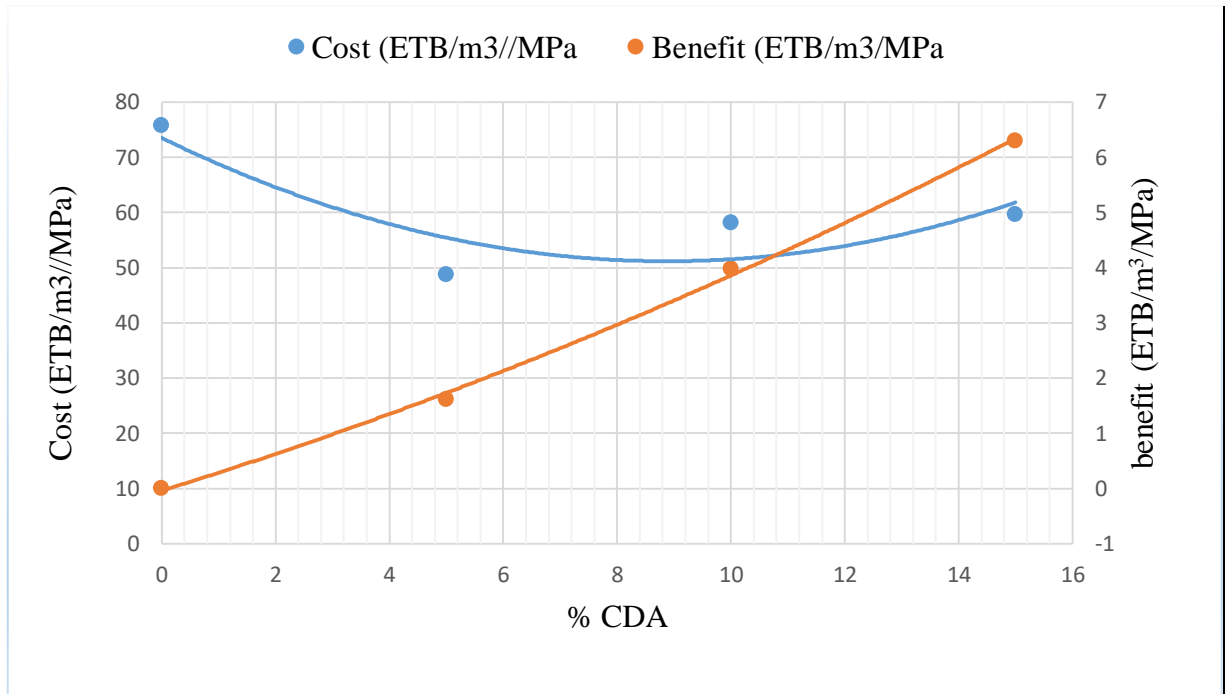


Figure 4.9: Optimum point of CDA with respect to cost (ETB/m³/MPa) & benefit (ETB/m³/MPa)

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The present experimental investigation was conducted to study the feasibility of cotton dust ash as a partial replacement of cement in concrete. Workability, compressive strength, splitting tensile strength, water absorption, sorptivity and carbonation of concrete were tested by replacing cement with CDA at 5%, 10%, 15%, 20% & 25% in concrete. Test results indicate that CDA, an industrial by-product, is a suitable substitute for cement in concrete.

1. Regarding the native property of cotton dust ash, the chemical analysis of it had shown that it is rich in silica content with certain alkali chemical constituents. CDA exhibited a specific surface area value of $3841\text{cm}^2/\text{g}$. This value is a relatively higher value when it is compared with the specific surface area of the OPC cement $3130\text{cm}^2/\text{g}$ used in this research.
2. The workability of concrete was decreased as the percentage replacement of cement with CDA was increased. The reason was due to water-absorbent property and high specific surface area.
3. The compressive strength of concrete was increased with the addition of CDA as partial replacement of cement. Concrete mix with 5% CDA replacement level had a maximum compressive strength at all ages and it increases with a decreasing rate until 20% of CDA addition. The cause of increment is when cotton dust ash is added in concrete; the reactive silica present in cotton dust ash reacts with calcium hydroxide liberated during cement hydration and forms additional calcium silicate hydrate (C-S-H) gel. This additional C-S-H gel gives higher strength.
4. Splitting tensile strength of concrete was increased with the presence of CDA as partial replacement of cement. Concrete mix with 5% CDA addition had maximum splitting tensile strength and increases with a decreasing rate until 25% of CDA addition. This is due to a secondary reaction between the $\text{Ca}(\text{OH})_2$ present there and pozzolana, thus leading to an even denser interface zone; same as in case of compressive strength.

5. Water absorption of concrete was decreased with an increasing rate in replacement of cement with CDA. Concrete mix with 5% CDA replacement level had the lowest water absorption among all mixes, and it decreases until 25% CDA addition. The higher fineness and denseness of the CDA also contribute to the filling of the voids available in the concrete.
6. The sorptivity of concrete was decreased with an increasing rate as cement is substituted by CDA. Concrete mix with 5% CDA replacement level had the lowest sorptivity among all mixes and it decreases until 25% CDA addition. This clearly shows the positive influence of CDA in reducing the volume permeable pore and thereby reducing the water uptake by the concrete.
7. The specimens starting from 5%, 20% & 25% of CDA concrete shows highly alkaline, a purple-red color as 0% CDA concrete, which means un-carbonated. This is due when CDA is available in concrete; it reduces the availability of surplus lime by way of pozzolanic reaction, reduces permeability, and as a result, improves the resistance of concrete against the carbonation phenomenon.
8. Besides, of improvement in concrete strength, cotton dust ash is also highly economical because it is a residue obtained from textile industries, which is disposed of in the open land. From the cost-benefit analysis finding the optimum point is the point that attains the target strength with higher benefits, which is an economical point, was 10.8 % CDA.

5.2. Recommendations

Based on the study, it is recommended that:

1. The result encourages the use of CDA, as pozzolanic material for partial replacement of cement by CDA to produce better concrete strength, particularly for convectional and ready mix concrete.
2. The utilization of supplementary cementitious material like CDA concrete can compensate for the environmental and economic issues caused by cement production. As a result, cement producers should pay attention to the production of SCM like CDA to minimize CO₂ emission and sustainable use of cement raw material resources.
3. Additionally, it is suggested for future works for extending this research to a wider perspective in order to be able to recognize more parameters and different combinations of parameters governing the effect on the behavior and engineering properties of fresh and hardened concrete containing CDA such as:
 - Compaction factor
 - Rapid chloride-ion permeability
 - Fire resistant
 - Acidic attack
 - Fatigue resistant

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APPENDICES

Appendix A: Chemical and Physical Properties Analysis of Cotton Dust Ash



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MR/4/017
Issue No-1
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Date: 16/08/2019
ቁጥር
Ref. No. Ms 14/12/3.6/2019

TO: Institute of Technology Hawassa Univesity Departement of Civil Engineering

Subject: Cotton stack Analysis Confirmation.


According to the request (Ref.No 4/104/3010/11, dated 15/09/2011E.C) to cooperate Mieraf Tekle to conduct "Cotton stack analysis" in our laboratory.

Hence, the analysis result of the "Cotton stack" according to our laboratory Cotton stack analysis Procedure is tabulated below.

The Analysis Results.

Sample Type	Chemical Composition %						Physical Test		
	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	LOI	Blaine Value cm ² /g	Density g/ml	Fineness %
Cotton Stack	37.96	11.24	4.72	10.08	4.89	10.69	3841	2.49	6.00

With best regards,



Araya G/yohannes
Production Control, Quality and Optimization Manager

ጥራትን በተግባር
Quality in Action መስጠት ሲሚንቶ ፋብሪካ ም.የተ.የግ.ማህ. **Messebo Cement Factory PLC**

P.O.Box: 810, Mekele, Ethiopia. P.O. Box: 0320, Addis Ababa.

Figure A.1: Chemical and physical properties analysis of cotton dust ash

Appendix B: Concrete Mix Design Procedure

Step 1: Slump flow

The concrete slump represents the followability/workability of a concrete mix. The selected slump from table A1.5.3.1 for Beams and reinforced walls (75-100) mm

Step 2: Aggregate size

From gradation, analysis above maximum size of the coarse aggregate is 25 mm.

Step 3: Mixing water and air content

Based on the above two steps the amount of water from table A1.5.3.3 is $193 \frac{kg}{m^3}$ and approximate amount of entrapped air in non-air-entrained concrete is 1.5%.

Step 4: Selection of water-cement ratio from table A1.5.3.4 (a) =0.59

Step 4.1: Pozzolanic materials

This step also gives the option of including pozzolanic materials. Replacement of the cotton dust ash was made by weight. Replacement by weight was one possibility to investigate the effect of partial replacement of cotton on the mechanical and durability properties. Replacement by weight ensures a constant water to cement weight ratio.

Step 5: From the information developed in Steps 3 and 4, the required cement content is found to be $\frac{193}{0.59} \approx 340 \text{ kg/m}^3$

Step 6: Coarse aggregate

The quantity of coarse aggregate was estimated from Table A 1.5.3.6. For a fine aggregate having a fineness modulus of 3.0 and a 25 mm nominal maximum size of coarse aggregate, the table indicates that 0.65m^3 of coarse aggregate total aggregate = $0.65 * 1533.665 \cong 1000 \frac{\text{kg}}{\text{m}^3}$

Step 7: First estimation of fresh concrete

From table A1.5.3.7.1, the mass of a cubic meter of non-air-entrained concrete made with aggregate having a nominal maximum size of 25 mm is estimated to be 2380 kg.

Step 8: Calculating of fine aggregate on mass basis

Water = 193

Coarse aggregate = 1000

Cement = 340

Fine aggregate = $2380 - 193 - 1000 - 340 = 847 \frac{\text{kg}}{\text{m}^3}$

Table B. 1: Moisture & water absorption of aggregate

Type	Moisture content	Water absorption
Coarse aggregate	0.30%	0.6254%
Fine aggregate	1.698%	0.874%

Step 8: Adjustment of coarse aggregate and fine aggregate

Coarse aggregate (wet) = $1000 \frac{\text{kg}}{\text{m}^3} * 1.003 = 1003 \frac{\text{kg}}{\text{m}^3}$

Fine aggregates (wet) = $847 \frac{\text{kg}}{\text{m}^3} * 1.01698 = 862 \frac{\text{kg}}{\text{m}^3}$

Absorbed water is not part of mixing and must be excluded from the adjustment in added water.

$$\text{Water from Coarse aggregate} = 0.3 - 0.6254 = -0.3254$$

$$\text{Water from fine aggregate} = 1.698 - 0.874 = 0.824$$

Therefore, the new adjusted water

$$193 - 847 * (0.00824) + 1000 * (0.003254) = 190$$

Table B.2: The final adjusted quantity

Type	Quantity ($\frac{kg}{m^3}$)
Water (to be add)	190
Cement	340
Coarse aggregate	1003
Fine aggregate	862

The above quantity showed for preparing control concrete. When cement was replaced by of cotton dust ash (on weight basis), the quantity changed as follow.

Table B.3: Mix Proportioning of Concrete Mixes with CDA

% CDA	Cement (kg/m^3)	Cotton dust ash (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Water (kg/m^3)
0	340	0	1003	862	190
5	323	17	1003	862	190
10	306	34	1003	862	190
15	289	51	1003	862	190
20	272	68	1003	862	190
25	255	85	1003	862	190

The above is for $1m^3$ of concrete. For use for laboratory trial, the quantity was arranged depending on the type of test and size of specimen with the addition of 35% wastage.

Appendix C: Compressive Strength Measurements

Table C.1: 3-day curing period compressive strength

% CDA	P (kN.)	Area(mm ²)	$f_{cu} = \frac{P}{A \times 1000}$ (MPa)
0% -1	450.3	0.0225	20.013
0% -2	429	0.0225	19.067
0% -3	446.5	0.0225	19.844
Avg=19.641			
5%-1	695.7	0.0225	30.920
5%-2	567.8	0.0225	25.236
5%-3	581.3	0.0225	25.836
Avg = 27.330			
10%-1	544.9	0.0225	24.218
10%-2	454.5	0.0225	20.200
10%-3	551.4	0.0225	24.507
Avg=22.975			
15%-1	494.7	0.0225	21.987
15%-2	427.3	0.0225	18.991
15%-3	511.1	0.0225	22.716
Avg=21.231			
20%-1	484.3	0.0225	21.524
20%-2	424.1	0.0225	18.849
20%-3	507	0.0225	22.533
Avg=20.969			
25%-1	420.43	0.0225	18.686
25%-2	390.05	0.0225	17.336
25%-3	440.05	0.0225	19.558
Avg =18.526			

Table C.2: 7-day curing period compressive strength

% CDA	P (kN.)	Area(mm ²)	$f_{cu} = \frac{P}{A \times 1000}$ (MPa)
0% -1	404.4	0.0225	17.973
0% -2	614.8	0.0225	27.324
0% -3	565	0.0225	25.111
Avg=23.470			
5%-1	659.2	0.0225	29.298
5%-2	841.5	0.0225	37.400
5%-3	694.9	0.0225	30.884
Avg=32.527			
10%-1	566.9	0.0225	25.196
10%-2	491.5	0.0225	22.844
10%-3	538.3	0.0225	23.924
Avg=24.655			
15%-1	538.4	0.0225	23.929
15%-2	638.6	0.0225	28.382
15%-3	513.1	0.0225	22.804
Avg=25.039			
20%-1	491.4	0.0225	21.840
20%-2	613.6	0.0225	27.271
20%-3	578.4	0.0225	25.707
Avg=24.939			
25%-1	493.34	0.0225	21.926
25%-2	535	0.0225	23.778
25%-3	505.5	0.0225	22.467
Avg=22.724			

Table C.3: 28-day curing period compressive strength

% CDA	P (kN.)	Area(mm ²)	$f_{cu} = \frac{P}{A \times 1000}$ (MPa)	
0% -1	731.2	0.0225	32.498	
0% -2	483.4	0.0225	21.484	
0% -3	663.6	0.0225	29.493	
				Avg=27.825
5%-1	986.3	0.0225	43.836	
5%-2	900.4	0.0225	40.018	
5%-3	936.4	0.0225	41.618	
				Avg=41.824
10%-1	848.4	0.0225	37.707	
10%-2	694.7	0.0225	30.876	
10%-3	746	0.0225	33.156	
				Avg=33.913
15%-1	696.6	0.0225	30.960	
15%-2	657.4	0.0225	29.218	
15%-3	805.7	0.0225	35.809	
				Avg=31.996
20%-1	625.7	0.0225	27.809	
20%-2	704	0.0225	31.289	
20%-3	553.6	0.0225	24.604	
				Avg=27.901
25%-1	623.56	0.0225	27.714	
25%-2	585.76	0.0225	26.034	
25%-3	526.87	0.0225	23.416	
				Avg =25.721

Appendix D: Split Tensile Strength Measurements

Table D.1:28 – Days split tensile strength

% CDA	P (kN.)	$A=\pi ld(m^2)$	$T = \frac{P}{A} \times 1000(MPa)$
0% -1	190.00	0.141	4.244
0%- 2	240.65	0.141	3.471
0% -3	208.45	0.141	4.314
			Avg = 3.014
5%-1	300	0.141	2.687
5%-2	245.34	0.141	3.404
5%-3	305	0.141	2.949
			Avg = 4.009
20%-1	210	0.141	2.970
20%-2	234.03	0.141	3.310
20%-3	200.456	0.141	2.835
			Avg = 3.039
25%-1	180.987	0.141	2.560
25%-2	195.456	0.141	2.765
25%-3	205.205	0.141	2.903
			Avg=2.742

Appendix E: Water Absorption

Table E.1: Test result of water absorption

% CDA	w ₁	w ₂	Δw	water absorption = $\frac{W_1 - W_2}{W_1} \times 100$
0	3.534	3.757	0.223	6.31
5	3.468	3.695	0.227	4.59
10	3.643	3.822	0.179	4.91
15	3.604	3.783	0.179	4.98
20	3.558	3.745	0.188	5.27
25	3.532	3.750	0.218	6.15

Appendix F: Sorptivity

Table F.1: Capillary water absorption test result for 20% CDA

time (min)	0	1	2	3	4	5	9	12	16	20	25
\sqrt{t}	0	1	1.414	1.732	2	2.236	3	3.464	4	4.472	5
I _{Avg} (mm)	0	1.11	1.22	1.29	1.31	1.31	1.36	1.4	1.44	1.53	1.49

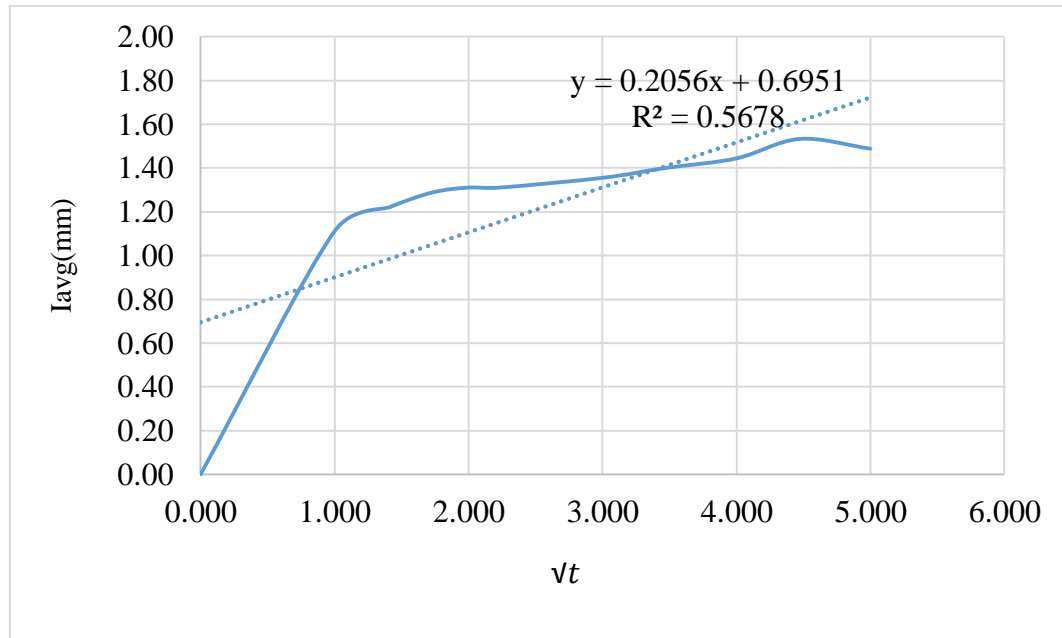


Figure F.1: I_{avg} (mm) for 20% CDA Vs. \sqrt{t} (min)

Table F.2: Capillary water absorption test result for 25% CDA

time (min)	0	1	2	3	4	5	9	12	16	20	25
\sqrt{t}	0	1	1.414	1.732	2	2.236	3	3.464	4	4.472	5
I_{Avg} (mm)	0	0.13	0.17	0.21	0.27	0.3	0.34	0.37	0.41	0.49	0.52

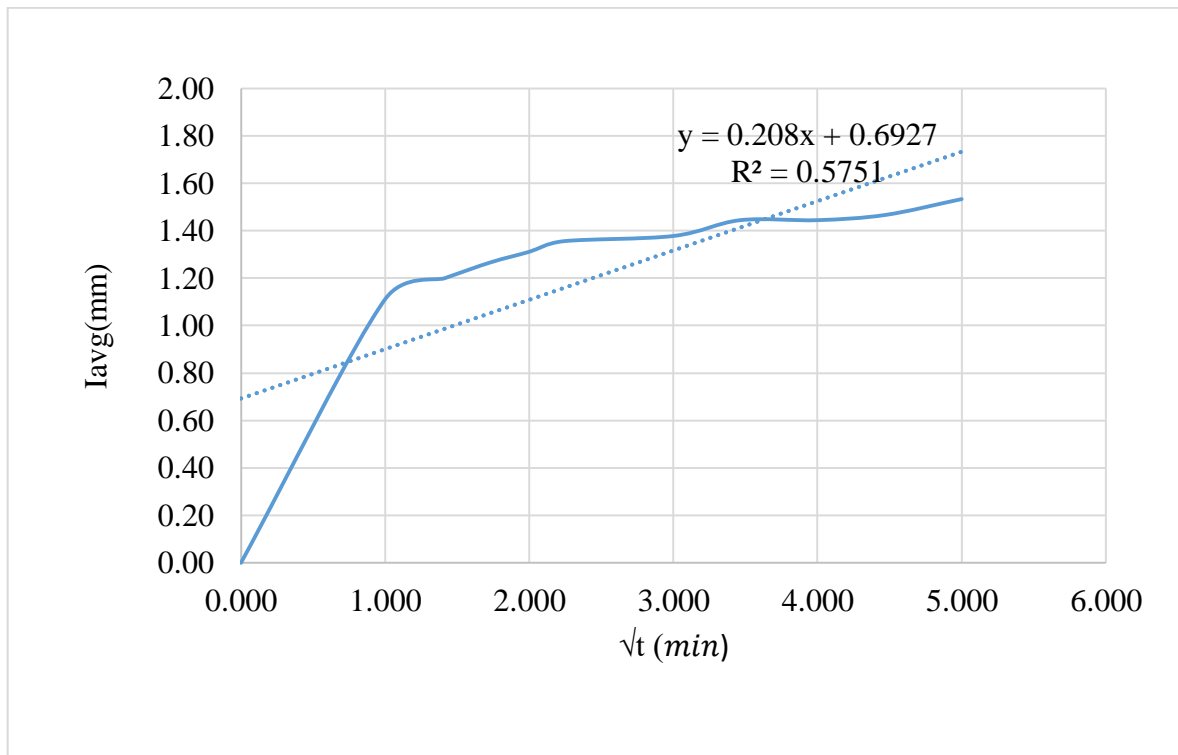


Figure F. 2: I_{avg} (mm) for 25% CDA Vs. \sqrt{t} (min)