Addis Ababa University

Addis Ababa institute of Technology

School of Civil and Environmental Engineering

Road and Transport Engineering stream

Bagasse Ash as a Partial Substitute of Cement on Concrete Rigid Pavement

By

Miheret Geremew

A thesis submitted to the School of graduate studies of Addis Ababa University
in partial fulfillment of the requirement for the Degree of
Master of Science
in
Road and Transport Engineering

Advisor
Dr. Esayas Gebreyouhannes

July, 2017

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DECLARATION

I, the undersigned declare that this thesis entitled **"Bagasse Ash as a Partial Substitute of Cement on Concrete Rigid Pavement**" is my original work, prepared under the guidance of Esayas Gebreyouhannes (Ph.D). All sources of material used for this research have been dually acknowledged. Moreover, this thesis has not been presented by any other person in this or any other university or Higher Educational Institute for an award of a degree.

Miheret Geremew

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Date ____________________

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ABSTRACT

Sugarcane bagasse ash is an industrial waste from sugar factories. This study aimed to use this material as a partial substitute of cement in a concrete rigid pavement. The availability of bagasse ash and the very reasons that the construction of concrete rigid pavements started to be in effect in Ethiopia along with the great consideration that the current global situation gave to environmental issues, are the basis for conducting this study. Past researches have indicated that sugarcane bagasse ash contains high silica which is a potential agent for pozzolanic reaction.

In this study, the range of application of using bagasse ash as a partial replacement for Ordinary Portland cement for concrete pavement has been experimentally investigated from the perspective of strength, heat of hydration and durability. Strength and thermal assessments were carried out since the early age of the concrete. Early age measurements were given emphasize so as to see the influence of this material on early age distresses such as cracking due to the heat from hydration reaction. Systematic experiments were conducted for replacement ratios of 5%, 10% and 20% by volume of cement. The percentage of replacement which yielded a relatively better response with respect to the mentioned properties, was selected as an optimum percentage of replacement.

In the experimental result, a strength enhancement was observed in concrete mixes made with bagasse ash. This enhancement was seen in concrete mixes that were prepared with bagasse ash amount of 5% and 10% replacement by volume. Moreover, the pozzolanic nature of the bagasse ash was not inhibiting the early age strength development; the enhancement had started to be seen since the concretes' early age. This was a contributory finding in reducing the risk of early age cracking that will occur in a concrete due to high initial temperature that is generated from the hydration reaction.

The bagasse ash used in this research did not pass through any treatment or modification except being sieved with a 300μm sieve. The result of the chemical analysis of bagasse ash taken from Wonji Sugar factory, Ethiopia had shown that the ash is rich in silica. The mechanical properties in compression and flexural based tensile strength were investigated from early age up to 56days. The heat of hydration characteristics at early age was also monitored using embedded thermocouples. Finally, the water penetration depth for each mix was tested as an indicator for durability. The findings from the experimental investigation were analyzed and the application for rigid concrete pavement construction was discussed. The effects of early age thermal cracking, caused by heat generated due to hydration, for longevity is emphasized. Moreover, a thermo-hygro simulation of a concrete slab panel was made using the multi-component heat of hydration model to assess the relative performance of concrete with and without bagasse ash against early age cracking. Finally, the importance of early age thermal analysis using mutual interlinkage of material aspects and structural mechanics for the durability design of rigid pavements was dealt.

Key words: - Concrete rigid pavement, Sugarcane bagasse ash, Early age strength assessment, Early age thermal assessment,

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ABBREVIATIONS AND NOTATIONS

AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
Al_2O_3	Alumina
ASTM	American Standard for Testing and Measurement
Bar	Barometer
CaO	Calcium Oxide
CBR	California Bearing Ratio
cm^2	Square Centimeter
CO_2	Carbon dioxide
CRCP	Continuously Reinforced Concrete Pavement
E	East
ERA	Ethiopian Road Authority
ESAL	Equivalent Standard Axle Load
FDRE	Federal Democratic Republic of Ethiopia
Fe_2O_3	Ferrite
FI	Flakiness Index
FM	Fineness Modulus
G	Gram
GGBFS	Ground granulated blast furnace slag
gm/cm^3	Gram per cubic centimeter
H_2O	Water
JPCP	Jointed Plain Concrete Pavement
JRCP	Jointed Reinforced Concrete Pavement
kg	Kilogram
kg/m^3	Kilogram per cubic meter
Kip	Kilo pound
kN	Kilo Newton
K_2O	Potassium Oxide
LAA	Los Angles Abrasion

ITZ	Interfacial Transitional Zone
lb/yd^3	Pound per cubic yard
LOI	Lose in Ignition
MgO	Magnesium Oxide
MnO	Manganese Oxide
MPa	Mega Pascal
N	North
Na_2O	Sodium Oxide
OPC	Ordinary Portland Cement
PCC	Portland Cement Concrete
Pci	Pound per cubic inch
Psi	Pound per square inch
P_2O_5	Phosphorus pentaoxide
PPC	Portland Pozzolana Cement
RC	Reinforced Concrete
SEM	Scanning Electron Microscope
SiO_2	Silicon dioxide
SO_3	Sulfate
SSD	Saturated Surface Dry
TiO_2	Titanium dioxide
XRD	X-ray diffraction
^0C	Degree Celsius
Ø	Diameter
µm	Micrometer
%	Percent Potassium

1. INTRODUCTION

For a country like Ethiopia which is on its way of showing economic progress, infrastructure development accounts a significant proportion in addressing most national targets. And for an infrastructure to be sustainable, its initial erection or installation should be of resource that can be reasonably affordable and easily be accessed, its final output should serve its function as adequate as possible and its entire purpose must meet the present without jeopardizing the future. Among the basic infrastructures and public service facilities, road along with its transportation system plays a paramount role in facilitating most economic, social and as a whole integrated development of a country.

Moreover, Ethiopia is in the era of construction that is stretching from small scale standardized residential houses up to various mega projects. This increased the demand for construction material in an alarming rate. This demand in turn makes government to look for private investors to build large industries and factories to meet the demand of country's need for construction materials. One of the input material in construction is cement. The production of cement involves emission of the gas; CO_2 into the atmosphere which is undesirable from environmental perspective. The Carbon dioxide come from the combustion of carbonaceous fuel and the calcination (decarbonization) of the calcareous component of the raw material mix (Bhatty et al. 2004). Out of the total amount of CO_2 emitted from a cement kiln, half of it originates from the raw material while the remaining half originates from the combustion process (Bhatty et al. 2004). There will be an emission of one ton of CO_2 per ton of clinker produced but thermally efficient systems emit slightly less than one ton while less thermally efficient systems emit slightly more than one ton (Bhatty et al. 2004). If the cement industry alone contributes CO_2 of this amount, there will be a great chance for the environment to be in threat when more industries come in effect.

The emerging of various industries and the erection of infrastructures of any scale needs to be facilitated with a doable platform. Transportation and its element which is the road and its facilities are the bases for the accomplishment of many national goals related to economic and social advancement.

Road network coverage of Ethiopia is still in a status that is under a figure that the country needs to have by now. This becomes a bottleneck for the successful achievement of the variety of the country's economic goal. Among the existing road networks, most of them especially those located in the most remote areas of the country, are of gravel and earth road which are incapable of providing their function adequately. And those asphalt roads found in the cities are serving high volume of traffic that they deteriorate and last short before meeting their desire service period which inturn leads to frequent maintenance. The main ingredient of an asphalt road: bitumen is a material that is mostly imported from outside countries; a disadvantage when its weighed in the aspect of foreign currency. Moreover, as a country which is Geographically located in tropical zone, there are areas in the country where environmental temperature is very high (very hot and arid areas but still need transportation facility to utilize the natural resource available in there) and as result make the construction of an asphalt road unsecured (structurally and functionally).

Instead of constructing an asphalt pavement or a low class gravel road which need frequent maintenance, it will be beneficial if there shall be an interest towards concrete (rigid) pavement construction. Concrete rigid pavement is a concrete pavement which of its main structural component is a concrete slab which is made of Portland cement. The constituents of concrete are cement, various grade of aggregate and water. With this, any size of aggregate which can be processed in various sizes are available in the country. Among the constraints that used to stiffen the construction of such pavement in the past years was, the unavailability of sufficient amount of cement and the degree of skill and knowledge expected from the manpower that will involve in the construction of concrete rigid pavement. The number of cement factories some half decade before were very few and they were not able to meet country's cement demand. But currently cements of various types from factories installed by private investors here in Ethiopia are joining the market. Recently Addis Ababa road authority started to construct some road sections in the town with concrete pavement and the national road authority also started looking for the construction of this type of road. The completed pilot project which is the 10km section of Chancho – Derba- Bacho road project, the recently started 81km Dichoto Galafi junction-Elidar-Beleho concrete road in Afar region and the 102.8 km Afdera – Irebti junction- Erta Ale junction- Ahmed Ela road project which is planned to be constructed in two lots in Afar region can be listed as the pioneers of concrete pavement construction in Ethiopia. This makes a forward step in concrete road construction. Along with this, certain common issues like the above mentioned environmental and sustainability factors should be under consideration while endeavoring in achieving the very function of the road. Thus there shall be an interest to look for an alternative material that can potentially replace cement (as cement is the main ingredient that contribute to the negative footprint in the environment). In speaking about sustainability, its expected that the emerging industries will impart positive as well as negative outcomes. To make industries purely advantageous their negative impact shall be inhibited in a way that is not against to the society's welfare and also to the environment. Having this, among the currently running megaprojects in Ethiopia, the sugar industry is one of it and is expected to contribute a positive impact related to foreign currency and meeting country's sugar demand. Among the waste material from sugar factories, the ash generated from the burning of bagasse is one of it. This material is simply being dispose to nearby areas around the factory in the currently operating sugar factories in Ethiopia. In the era of green technology, waste disposals like bagasse ash can be utilized for a certain industry or can be changed into a useful state so that the industry that disposes them can contribute it to another industry as a useful input.

From literature its known that bagasse ash has pozzolanic property ("siliceous or siliceous and aluminous materials which alone possess little or no cementitious value but will, in finely divided form and in the presence of moisture, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties" (Villar-Cociña et al. 2008)). From this, the objective of this paper basically focuses on using this material as a partial substitute of cement in the construction of concrete rigid pavement while aligning and keeping the above mentioned sensitive factors in parallel.

Regardless of the abundance of bagasse ash, in addition to the existing sugar factories, other factories of different production capacity are being built along with the various irrigation projects that are in service and under construction in the country. The molasses disposed from these giant factories are mostly utilized for ethanol production. And the bagasse ash from all these factories will be expected to be in thousands of tons but still there is no defined framework that let this material to be used for other purposes.

By 2020 the bagasse ash production (estimated amount of 1.9Million ton as shown in **Figure 1.1**) from the local factories will reach into a figure around 16.01% of the total cement demand of the time. This material can support the cement industry in partially replacing the raw materials that is used for producing Portland Pozzolana Cement (PPC) and it can also be used in OPC production as well. Moreover, the chain between these two industries (cement and sugar industry) is significant in the eyes of mutual cooperation of industries and formation of a healthy and sustainable industrial Ecology.

The figure below shows the progress of cement demand and bagasse ash production from the year 2010 upto 2020. The figure on future and contemporary cement demand was obtained from Chemical and Construction Inputs Industry Development Institute and the information on bagasse ash production progress was collected from Ethiopian Sugar Corporation; Communication department.

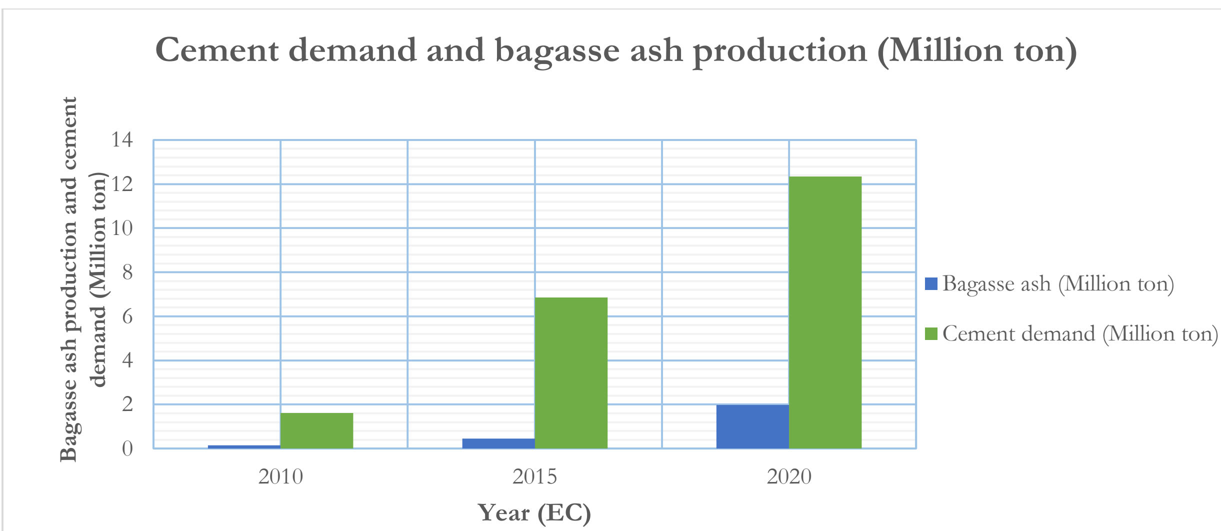


Figure 1.1 Progress of cement demand and bagasse ash production (Chemical and Construction Inputs Industry Development Institute, unpublished, 2016; Ethiopian Sugar Corporation (Communication department), unpublished, 2016 respectively).

In factories operating currently, the ash is accumulated in a large dune form and later it will be used as a fertilizer by farmers residing near the factory. But from technical perspective based on literature, this material has pozzolanic property which can make it as a candidate in cement related works. There were and still are various attempts and practical projects in Europe and in other outside countries on using bagasse ash from sugar industry as a replacing material of cement in a concrete. In a research done in 2011 in Addis Ababa Institute of Technology, it was shown that the use of bagasse ash in concrete was able to exhibit a compressive strength enhancement of about 10% with a replacement ratio of 10% (Hailu 2011). Hence, it is possible that the ash from bagasse from our sugar factories can be used as a competitive material to partially replace cement in a concrete.

This may support the endeavor of reducing cost of construction (cost for cement, even cost incurred on the factory for installation of waste management systems and facilities along with the TAX imposed for disposals). In addition, the use of such material reduces the negative environmental footprint of concrete related to CO_2 emission.

Therefore, the purpose of this study will directly focus on evaluating the bagasse ash from our sugar factories in partially replacing cement in a concrete rigid pavement. Moreover, and most significantly apart from being a replacing material, the property of bagasse ash when in use of concrete pavement will be investigated. The very sensitive parameters of concrete in concrete pavement design and construction were investigated to evaluate to what extent this material can contribute to concrete pavement construction while still being technically feasible.

1.1. Statement of the problem

Availability of basic infrastructure and the degree with which those infrastructures give service to concerned users is one of the parameter which one country is weighed. In a situation where main infrastructure like the road are not provided well, attaining of various national goals may take lots of effort as compared to same endeavor which will be done under the availability of those needs. For better productivity and ease of individual's movement, roads need to build in areas where people reside and in any active zones of the country.

As per FDRE country strategy paper 2016-2020, country's road network coverage is 120,000km (AFDB, 2016). Despite the increase in figure by a certain magnitude, there still exists a significant problem in addressing the need of road users in various regions of the country especially those located in most remote areas. Figures from regional road authorities indicate that more than two third of available routes are of gravel and earth road which regularly need periodic maintenance. The periodic maintenance includes cost for consultancy, actual retrofitting, re-graveling and other relevant items that will involve in the maintenance. And if the maintenance period doesn't meet its intended schedule and if there exist a delay due to the contractor or weather condition or any unforeseen cases, duration of contract will be extended and along with this, expense for all concerned work items will also increase. Even after spending such amount of resource, temporarily maintained roads will not be able to serve their function as adequately as expected; may need maintenance even before serving half of their intended service life.

The above conditions are magnified if the areas are remote and have extreme weather condition. Eastern and North Eastern part of the country like the Afar region are typical examples in which average daily temperature reaches 40 - 42C^0. Deploying workmanship and any development activity in this area is difficult and require more cost than any other regions do.

Moreover, as stated in the introduction section of this research, an increase in small and large scale construction make enormous amount of construction material demand whose production influence the environment significantly. Despite the positive contribution of the various mega projects that are built and are being built recently, there is residual industrial output that they will impart in to the environment which later causes threat in the environment. Claims from Environmentalists and organs in concern of climate change are now increasing drastically due to the incorporation of various industries and the impact of sophistication that they are imparting into the technological transformation. Ethiopia also joins this era and it will not be too far for the country to start encountering this crisis in a significant scale as the industry sector grows. Thus professionals will be obliged to look for an alternative road construction scheme that can solve those problems based on a resource locally available. Constructing an asphalt pavement might be a good alternative in terms of durability and comfort of road users but constructing a road with bitumen which is imported from outside countries, will costs a lot. Moreover, it will not be environmentally friendly due to the emission of anti-atmosphere gases that it releases during melting. Therefore, in order to mitigate the above problems and to use a resource which can be accessed easily, it will be better to start to utilize the available resource that the country has in way that is sustainable and environmentally acceptable.

This study, therefore, emphasizes on concrete rigid pavement construction as a solution for the above problems. Recently various cement manufacturers got introduced to the cement market of Ethiopia. But cement by itself involves production processes in its manufacturing stage which are not friendly to the environment. Therefore, there shall be an alternative mechanism to maintain the solution for the above problems balanced, i.e., meet environmental goal, utilize natural resource and construct a road that lasts long and serves well.

Thus findings of this study was expected to substantially support good practices against the above problems by deploying the concrete rigid pavement practice with a sustainable and available material. Cement was partially replaced by bagasse ash and the introduction of this material into concrete rigid pavement was evaluated as per sensitive parameters in concrete rigid pavement design and construction.

1.2. Scientific relevance

Significant number of researches conducted on sugarcane bagasse ash were indicating that the material has a pozzolanic property that can make it to be used in pastes, mortars and in concrete making (Kawade et al. 2013; Amin 2011; Shruthi et al. 2014; Kotresh et al. 2014; Patel and Raijiwala 2015; Abbasi and Zargar 2013; Malyadri and Supriya 2015; Ganesan et al. 2007). Moreover, there are several studies in using fly ash (a supplementary cementitious material) for concrete rigid pavements (Suryawanshi et al. 2012). Nevertheless, in studies related to bagasse ash, most researches focus on investigating its pozzolanic property and its degree of applicability. Apart from this, the application of this material for a specific structure was not dealt well. Thus, this study tried to fill this gap particularly by evaluating bagasse ash's applicability in concrete rigid pavement.

A research conducted in Addis Ababa Institute of Technology concluded that with a replacement value of 10% bagasse ash, a 10% increase in compressive strength was observed as compared to the control concrete (Belen et al. 2011). Later in a research conducted in the same institute, similar finding was obtained but with a more refined way (Hailu 2011). These and other related researches conducted on sugarcane bagasse ash used as a basis for the investigation of its material property. But apart from material property investigation, the technical advantage of this material in concrete rigid pavement design and construction was dealt. This research is conducted using a local bagasse ash taken from Wonji Sugar Factory and its chemical composition along with other physical properties were examined in order to observe the findings relative to former studies done using local bagasse ash. Specifically, its material property and generally its effect when introduced in a concrete particularly its response in meeting the major distresses in concrete rigid pavement was investigated. The effect of bagasse ash on thermal property of concrete was assessed with a great emphasize on early age property. Moreover, in the previous study conducted for the investigation of water permeability, it's indicated that those samples introduced with bagasse ash were able to allow more water into the concrete than the reference sample (Hailu 2011). The response of introducing this material into the concrete with various percentage of replacement was checked relative to its water permeability characteristics. Generally, the focus of this research is to investigate the use of bagasse ash specifically for concrete rigid pavement by aligning the test results obtained from laboratory experiments (strength, temperature and water permeability) and modeling.

1.3. Research questions and Objectives

1.3.1. Research questions

The aim of conducting this research was to find out to what extent the ash from the local sugar factories can be utilized in partially replacing Ordinary Portland cement for the use in concrete particularly in concrete rigid pavement. It questioned, the response of concerned parameters in the design and construction of concrete rigid pavement when the concrete is being introduced with bagasse ash. It also inquired the allowable range of replacement of bagasse ash in a concrete of rigid pavement based on the response of basic design parameters relative to considerations that was made on early age and matured property of a concrete.

1.3.2. Research Objectives

1.3.2.1. General Objective

In achieving the environmental and economic benefit of using this material, the degree with which the technical feasibility of the material has to be investigated alongside for this particular structure that is for concrete rigid pavement. Most design guidelines and specifications used in concrete rigid pavement are based on matured property of concrete. But the concrete before reaching into a matured state, it encounters distresses that is induced mostly from the environment which brings cracking risk that is ranging from simple surface crack upto deep cracks that may gradually lead to notable structural problem. Thus the margin of investigation in assessing the use of this material in concrete rigid pavement stretched from early age concrete property assessment upto matured property investigation but with a great emphasize on the early age property as the codes and guidelines used in concrete rigid pavement are too feeble to be considerate on providing solution in reducing risks that may occur during the early age of the concrete. As it has been seen in some practical projects, early age thermal cracking was the major distress that has been observed specifically in areas where environmental temperature is high during casting. The potential for early age thermal cracking is dependent on the concrete's tensile strength, coefficient of thermal expansion, temperature difference within the concrete and restraint on the member. Since the pillars of this study are bagasse ash and concrete rigid pavement, this research dealt about material property of the concrete in such a way that safeguards the structural aspect of the pavement. Thus the general objective of this study is to evaluate the effect (contributory aspect) of using this material on the early age and matured property of concrete rigid pavement but with due consideration to early age characteristics.

Specific objectives

- Investigate tensile and compressive strength development of concrete beginning from early age (for each percentage of replacements used in this research) by which there will be a good chance to assess the contributory aspect of using this material in reducing cracking risk.
- To assess the contribution of using this material from the aspect of thermal characteristics (a test which was not conducted in earlier researches which were made on local sugarcane bagasse ash).
- To assess the water permeability behavior of concrete introduced with bagasse ash.
- Identifying the optimum amount of bagasse ash that will be technically feasible when the material be in use for concrete rigid pavement construction (based on the test results obtained from the above mentioned experiments).
- Prepare a thermo-hygro simulation of a concrete slab panel with a multi-component heat of hydration model to assess the relative performance of concrete with and without bagasse ash against early age cracking.

1.4. Methodology

The methodology that is used in this research was outlined in such a way that it can address both the general and specific objectives listed above. Depending on the sort of task that was being carried out, the overall phases of study is classified under three stages: -

1.4.1. Literature survey and collection of required inputs

The plain concept prior to the commencing of this research was aligning the use of bagasse ash and concrete rigid pavement in a way that bring advantage to the technical requirements of this type of pavement. Having this, a literature survey was conducted on researches made on this area. The findings summarized from the survey were used as an investigation margin for this research. A set of defined objectives were listed based on the identified knowledge gap and a doable methodology that addressed the objectives was prepared.

After passing this stage, all the necessary inputs required for the research were collected. At this stage current and substantial data were gathered from concerned organs so as to be used as a quantitative and qualitative base in addressing the objective of the study. Ethiopian Sugar Corporation, Wonji Sugar Factory, Dangote Cement, Ethiopian Road Authority, Regional Road Authorities and Ministry of Industry (Chemical and Construction Inputs Industry Development Institute) were some of the organs which the data collection stage has involved. Moreover, this stage also included collecting materials that was used in the experiment. The source of the bagasse ash was Wonji Sugar Factory and the other ingredients of concrete (cement, fine and coarse aggregate) were purchased from local market. In addition, all the necessary guidelines, specifications and codes were collected so as to be used as a guide in material preparation and design. Previous studies related to this topic were also sorted so as to be used as a review of former studies dealt on this topic.

1.4.2. Conducting experiment

This stage is further classified into two sub categories:

i) Standard tests on concrete ingredients: - at this stage the ingredients which involve in concrete production were tested and prepared for concrete making. Cement and bagasse ash passed through fineness, density and chemical analysis tests. The property of fine and coarse aggregate was also assessed in the laboratory. This has involved conducting sieve analysis, specific gravity and absorption capacity, moisture content, silt content (on sand) and unit weight of sample aggregates. Moreover, the abrasion, crushing, impact and flaky nature of coarse aggregate were also investigated so as to conduct the experiment with a material that satisfies the required standard and specification.
ii) Mix design and main experiments: - this has involved the proportioning of ingredients for a C-35 grade of concrete. The mix design stage basically defines the amount of ingredients (m^3) that should be used to attain a certain grade of concrete and this test was carried out using full cement (without the involvement of bagasse ash). After the mix design stage, cement was replaced by various percentages of bagasse ash (replacement was by volume). With this, basically compressive and flexural strength tests were conducted at 1, 1.5, 2, 3, 7, 28 and 56 days for each percentage of replacement. Moreover, the thermal and the durability property (in terms of water penetration depth) of mix samples were assessed for concerned percentage of replacements of bagasse ash.

1.4.3. Analysis and evaluation

At this stage, the results from the above laboratory experiments were summarized and discussed. The optimum percentage of replacement with respect to percentage of replacements involved in this research was selected based on the test result. Using optimum percentage of replacement, a concrete slab depth required for a certain condition of road was designed as per AASHTO 1993 guideline. The thickness obtained was compared with a thickness that was determined using same property and road condition but with concrete property that didn't involve bagasse ash. In order to support the findings from the laboratory experiment, a simulation design was modeled using a finite element software. Finally, a conclusion was drawn and certain points were recommended based on the result obtained from the laboratory experiment, the manual design and the modeling.

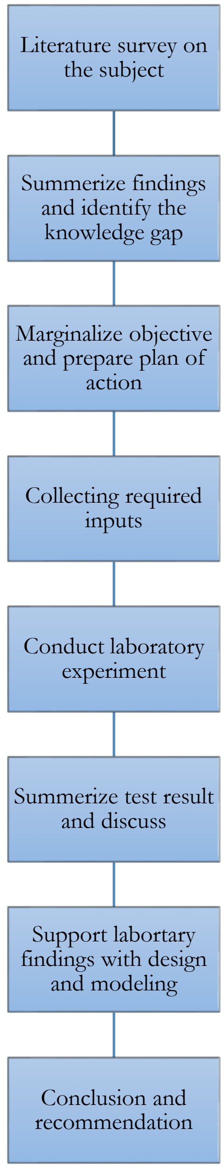


Figure 1.2. The general methodology layout used in conducting this research.

2. LITERATURE REVIEW

The issue of environmental security and sustainability has led to investigation of new materials using waste disposals generated from various industries. Nowadays industrial wastes are being considered as an asset in supporting other industries. For any industry, erection of waste management system is a very crucial task that should be carried out primarily before commencement of the industry itself. This stage in any industry consumes a significant amount of resource as the built system should refuse to the outcome of any negative footprints on the environment. For this and other global issues, by-products of industries are now being synchronized to a system that can let them to be utilized by other industry in such a way that can mutually benefiting to one another.

In earlier days, the concrete industry has been considered as a major contributor of greenhouse gas emissions, mainly due to the high environmental footprint of cement. It is estimated that during the production of 1 ton of cement, approximately one ton of CO_2 will be released (Blanco-Carrasco et al. 2010). Cement is a material that was and still serving the construction industry efficiently since ancient eras. But the heat and CO_2 generated from cement during hydration reaction becomes an inevitable problem related to environmental concerns. “Recently the concrete industry is going a number of steps to reduce the carbon footprint of concrete on the environment by using less Portland cement and more fly ash or slag to enhance the mix with chemicals that allow working with less water” (Blanco-Carrasco et al. 2010).

The above environmental problems along with the intension of handling construction with a feasible range of economy, the need for improvements in the technical feasibility of structure and the integrated impact of all these are directing the concrete technology to look for an alternative material that can serve its function without jeopardizing its serviceability and durability. Also due to its large size, the concrete industry is the ideal medium for the economic and safe use of millions of tons of industrial byproducts such as fly ash and slag due to their highly pozzolanic and cementitious properties (Naik and Moriconi 2010). Studies are showing that industrial by-products such as fly ash (replacement is possible beginning from 25% up to higher percentage of replacements depending on the grade of the concrete (Padhye and Deo 2016; Suryawanshi et al. 2012)), ground granulated blast furnace slag (grade 100 GGBFS yields an equivalent or greater strength at 28 days (Levy 2012)) , silica fume (replacement percentage ranges from 10-20 on average (Ajileye 2012; Rao 2003)) and volcanic ash in various proportions are competent materials in partially replacing cement and produce a concrete which has a relatively higher strength than the conventional concrete (Cement Concrete and Aggregates Australia 2010). Partial replacement of these materials bring economic and technical advantages over the conventional concrete. In a research conducted in Patil College of Engineering, it was demonstrated that the use of fly ash in a reinforced rigid pavement can reduce cost of cement, depletion of naturally available stone metals and yields similar cost like that of flexible pavement (Suryawanshi et al. 2012).

Moreover, agricultural wastes such as rice husk ash, wheat straw ash, hazel nutshell and sugarcane bagasse ash can be used as pozzolanic materials for the development of blended cement (Ganesan et al. 2007). In a research conducted in Alagappa Chettiar College of Engineering and Technology the various test results conducted to assesses the use of sugarcane bagasse ash as a cement replacing material were showing that the bagasse ash was an effective mineral admixture, with 20% as optimal replacement ratio of cement (Ganesan et al. 2007). This and other supporting literatures were acknowledging the use of bagasse ash as a cement replacing material in a concrete and also in mortars. Section 2.1 of this study discusses in detail on researches that were conducted on sugarcane bagasse ash as a partial substitute of cement.

2.1. Sugarcane bagasse ash as a partial substitute of cement in a concrete

The siliceous content of bagasse ash examined during the investigation of its chemical composition make it a competent material to be used as a pozzolanic material for partial substitute of cement in a concrete or any structure that involves cement.

Considerable amount of studies were conducted on sugarcane bagasse ash in using it as a pozzolanic material in replacing cement within a certain percentage. The pozzolanic nature of bagasse ash was inherited from its siliceous material contented in it. "Pozzolanic materials are siliceous or siliceous and aluminous materials which alone possess little or no cementitious value but will, in finely divided form and in the presence of moisture, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties" (Villar-Cociña et al. 2008). The strength gain and its cementitious property will be achieved from the secondary hydration reaction (Pozzolanic reaction) that it undergoes with Calcium hydroxide of Portland cement. Pozzolanic reaction is a chemical reaction that occurs in Portland cement with the addition of pozzolanic materials. Pozzolanic reaction converts a silica rich precursor with no cementing properties to a Calcium Silicate (Justs et al. 2011). The Calcium Hydroxide (Portlandite) liberated from Portland cement will react with Silicic acid (H_4SiO_4) to form Calcium Silicate hydrate in the presence of water (Justs et al. 2011).

This pozzolanic reaction is responsible for additional strength gain in a concrete or any cement involving processes. Bagasse ash possessing siliceous material with it, it undergoes pozzolanic reaction and results a relatively better strength than conventional concrete. This behavior and its availability as an industrial waste, makes researchers to investigate its property and degree of applicability in a great interest.

Several researches were conducted on sugarcane bagasse ash so as to assess its range of applicability along with its response on technical parameters. The involvement of bagasse ash in a concrete was showing an increase in both compressive and flexural strength within a certain percentage of replacement. According to a research conducted on P.D.V.V.P, College of Engineering it was concluded that the cement could be advantageously replaced with sugarcane bagasse ash up to a maximum limit of 15% (Kawade et al. 2013). In another study conducted under American Society of Civil Engineers, it was indicated that the development of high early strength, reduction in water permeability, and appreciable resistance to chloride permeation and diffusion are the specific advantages that was gained in replacing this material in a concrete (Amin 2011). A research made in Alagappa Chettiar College of Engineering and Technology findings were also supporting the same idea with an optimum percentage of replacement of 20% (Ganesan et al. 2007).

In a research conducted on sugarcane bagasse ash in King Mongkut's University of Technology, the physical properties of concrete containing ground bagasse ash (ground until the particles retained on a No. 325 sieve were less than 5% by weight) including its compressive strength, water permeability, and thermal responses, were investigated (Chusilp et al. 2009). The grounded ash then used to replace a Type I Portland cement at 10, 20, and 30% by weight of binder. The finding had shown that, at the age of 28 days, the concrete samples containing 10–30% ground bagasse ash by weight of binder had greater compressive strengths than the control concrete (concrete without ground bagasse ash), while the water permeability was lower than the control concrete (Chusilp et al. 2009). The water permeability of concrete had decreased as the replacement percentage of ground bagasse ash had increased (Chusilp et al. 2009). During thermal assessment, the maximum temperature rises of concrete containing ground bagasse ash was lower than the control concrete (Chusilp et al. 2009). Generally, the results were indicating that ground bagasse ash can be used as a pozzolanic material in concrete with an acceptable strength, lower heat production, and reduced water permeability as compared to the controlled concrete.

In a study made in Abdul Wali khan University on the assessment of the impact of bagasse ash content as a partial replacement of cement had involved investigating its physical and mechanical properties on a hardened concrete, including compressive strength, splitting tensile strength, chloride diffusion, and resistance to chloride ion penetration (Amin 2010). The finding was showing that the bagasse ash was an effective mineral admixture and pozzolan with the optimal replacement ratio of 20% of cement, which reduced the chloride diffusion by more than 50% without any adverse effects on the other properties of the hardened concrete (Amin 2010).

In Rajamangala University of Technology the endeavor made to partially replace cement in a high strength concrete had involved investigating the compressive strength, the porosity, the coefficient of water absorption, the rapid chloride penetration and the chloride diffusion of the concrete (Rukzon and Chindaprasirt 2012). The test results had indicated that the incorporation of bagasse ash up to 30% replacement level had increased the resistance to chloride penetration (Rukzon and Chindaprasirt 2012). In addition, the use of 10% of bagasse ash in a concrete had shown good strength and low porosity (Rukzon and Chindaprasirt 2012). Generally, a replacement percentage of 30% was found to be acceptable for producing high-strength concrete (Rukzon and Chindaprasirt 2012).

In a study made with ultrafine sugarcane bagasse ash (sequentially produced using vibratory mill) in properties of high-performance concrete, its rheology, compressive strength (7, 28, 90, and 180 days) and rapid chloride penetrability were investigated (Cordeiro et al. 2010). The results indicated that the introduction of sugarcane bagasse ash improved the durability characteristics, and did not change the rheological and mechanical properties (Cordeiro et al. 2010).

Another study from Gorakhpur University had found that in presence of bagasse ash, setting times had increased and free lime had decreased (Singh et al. 2000). The compressive strength values increased with hydration time in the presence of bagasse ash and the values were found to be higher than that of the control concrete (Singh et al. 2000). Moreover, the blended cement was found to be more resistant in an aggressive environment (Singh et al. 2000).

Other similar researches conducted in this area also endorsed the applicability range of this material up to 10% as an optimum percentage of replacement with an appreciable range of strength enhancement (Shruthi et al. 2014, Kotresh et al. 2014, Patel and Raijiwala 2015, Abbasi and Zargar 2013, Malyadri and Supriya 2015).

In a research done in Addis Ababa Institute of Technology using a local bagasse ash from Wonji sugar factory, the result of a rigorous experimental approach had confirmed the compressive strength value of the concrete with 5% cement replacement by bagasse ash has shown a 5% compressive strength improvement at 28 days over the control concrete with 100% ordinary Portland cement (Hailu 2011). This research was conducted using a bagasse ash that was ground in such a way that its grain size distribution approached to the cement used. Moreover, this study had also revealed that 28th day flexural strength value of the control concrete and the concrete containing 5% bagasse ash has shown similar results whereas the 15% and 25% replacements have shown a lower flexural strength value (Hailu 2011). The water penetration depth result obtained in this research has shown an increase in water penetration depth as the percentage of bagasse ash increases (Hailu 2011). In this study, it is also shown that normal consistency and setting time will be longer as the percentage of bagasse ash increases. The experiments had also involved partial replacement of PPC with bagasse ash though the result was not as notable as the one seen in replacing OPC. Generally, this study summarizes the test results of the laboratory experiments to lead into an optimum bagasse ash percentage replacement of 10%.

Using the above discussed literatures as a bench mark, this study tried to address the very concerned areas that need to be dealt when sugarcane bagasse ash be in use for concrete rigid pavement. As can be seen from the literature survey, early age property of the concrete was not investigated. As the bagasse ash was used as a pozzolanic material, early strength attainment capacity of the material would have been a sensitive parameter which need to be dealt. A concrete or mortar with Pozzolanic materials delay in strength achievement thus their early age strength is relatively lower as compared to a concrete or mortar made with full Portland cement. Thus in relation to the pillar concept of this research, concrete rigid pavements shall be with good strength during their early age so as to withstand the thermal load that will be induced during hydration reaction. If early age strength is good, it will have the potential to reduce the risk of early age thermal cracking; a prevalent scenario in concrete rigid pavements mostly in tropical regions. Therefore, this study identified this knowledge gap in using this material for concrete rigid pavement and thus experiments were conducted in each parameter beginning from the concrete's early age. Moreover, in researches done using local sugarcane bagasse ash, thermal response of this material in a concrete was not dealt. In speaking about concrete rigid pavement, early age thermal effect is a very sensitive phenomenon which can bring a problem that has the ability to propagate into a notable structural failure. Thus a thorough investigation on the thermal response of this material was done during the concrete's early age. In addition, most research findings were based on laboratory experiments but this research had involved a simulation design (integrates material property with the structural property; a more realistic approach) to verify its findings as the laboratory results will have a great chance to be liable to various plus or minuses. Material property investigation was the aim of most of the researches but in this study both structural and material property were assessed simultaneously using the simulation design.

In addition, in order to support findings with other interrelated topics, the literature survey section of this study tried to see laterally supporting information for this research. This had involved an overview on the abundance of bagasse ash in Ethiopia, the trend and chronology of rigid pavement construction in Ethiopia and a comparative approach on flexible and rigid pavement.

2.2. Abundance of bagasse ash in Ethiopia

In concern of the abundance of bagasse ash, contemporarily, giant sugar factories are under construction and some already started production with their partial or full production capacity in addition to the existing factories. Among these are: Kessem project found in Fentallie and Dulecha Woredas of Afar Regional State (expected capacity of 11,000ton of sugar per day), Tendahu found in lower Awash River Basin of Afar regional state around Millie, Doubti, Assaeitta and Affambo Woredas at a distance of 670 km from Addis Ababa (with completion of phase two of the project production capacity will be of 619,000 ton of sugar per annum) and Omo Kuraz found in South Omo zone (Selamago and Gnanegatom Woredas), Bench - Maji Zone (Surma Maji and Mieinitshasha Woredas) and Keffa zone (Diecha Woreda) of Southern Nations, Nationalities & People Region (when full capacity attained a production of 278,000 tons of sugar per annum will be expected) (Ethioian Sugar Corporation 2015). The molasses disposed from the existing factories is mostly utilized for ethanol production. And when all the factories become fully operational, the bagasse ash from all these factories will be expected to be in thousands of tones as shown on the graph from **Figure 1.1**. As per the information from Ethiopian Sugar Corporation, all of the factories that are operating currently are now using bagasse as a fuel for boiler. Not only the current factories but the future intended projects will also operate in the same manner as this method reduces energy consumption. When all the factories start to operate with their full capacity, the respective bagasse ash that will be produced by that time will reach upto two million ton per annum. Bagasse ash of this amount can substantially contribute to both technical and environmental advantage to the cement industry.

Table 2.1. Annual sugar production capacity and expected bagasse ash amount of sugar factories when full operational capacity attained (Ethiopian Sugar Corporation (Communication department), unpublished, 2016).

S.No.	Sugar factories	Tone of cane per day (TCD)	Annual crushing capacity (Ton)	Bagasse (Ton)	Bagasse ash (Ton)
1	Wonji Shoa	12,500	3,000,000	870,000	108,750
2	Metehara	5,000	1,200,000	348,000	43,500
3	Fincha	12,000	2,880,000	835,200	104,400
4	Tendahu	26,000	6,240,000	1,809,600	226,200
5	Beles I	12,000	2,880,000	835,200	104,400
6	Beles II	12,000	2,880,000	835,200	104,400
7	Beles III	12,000	2,880,000	835,200	104,400
8	Kuraz I	12,000	2,880,000	835,200	104,400
9	Kuraz II	12,000	2,880,000	835,200	104,400
10	Kuraz III	12,000	2,880,000	835,200	104,400
11	Kuraz IV	24,000	5,760,000	1,670,400	208,800
12	Kuraz V	24,000	5,760,000	1,670,400	208,800
13	Kesem	11,000	2,640,000	765,600	95,700
14	Arjo dedesa	8,000	1,920,000	556,800	69,600
15	Wolkayte	24,000	5,760,000	1,670,400	208,800
		218,500	**52,440,000**	**15,207,600**	**1,900,950**

The annual production capacity data was taken from Ethiopian Sugar Corporation; communication department. As per the combined information taken from the corporation's technical office and chemical laboratory technicians in Wonji sugar factory, the bagasse that will be extracted from the cane accounts 28-30% of the total cane production. And the bagasse ash that will be obtained from the bagasse was estimated to be 11-14% of the bagasse produced. The above calculation in the table was done using the average percentage of the range and an annual operational period of 240days.

From the table it can be seen that around 2 million tons of bagasse ash per year will be disposed from the sugar industry when the intended sugar factories will start to operate with their full production capacity. This amount can significantly support and strengthen the cement industry if there will be a system and mechanism that makes the proper utilization of this material into practice.

2.3. Rigid verses flexible pavements

Rigid pavement differs from flexible pavement in terms of its load distribution mechanism. In rigid pavements most of the loads will be carried by the slab itself and certain portion of the load will be transferred to the underlying strata while in flexible pavement, the load will be carried by a layered system (subgrade up to surface coarse). The structural capacity of rigid pavement is dependent on the characteristics of concrete slab while that of flexible pavement is dependent on every layer in the system. The abundant portion of the load in rigid pavement will be carried by the slab as the layers below the slab are weak but in flexible pavement the load intensity decreases as the depth increases. Due to the very high strength of the concrete slab, the modulus of elasticity of concrete pavement is high as compared to flexible pavement. The figure below shows a typical section of rigid and flexible pavement.

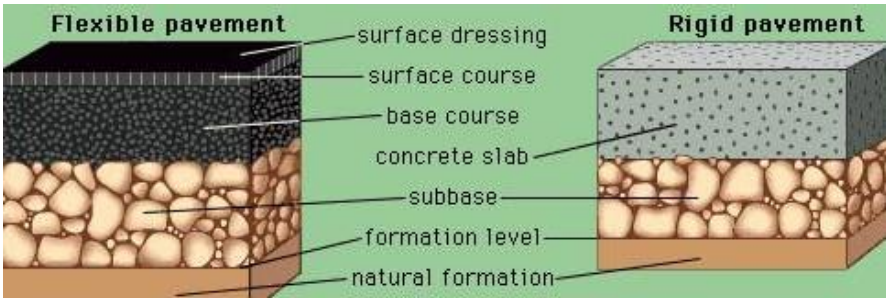


Figure 2.1. Typical section of flexible (left) and rigid pavement (right) (Rigid Pavement 2017)

The initial cost of construction of rigid pavement is high as compared to flexible pavement but since rigid pavements involve little or no maintenance during their service life, it can be comparable or less than the cost of flexible pavement for same design period. Rigid pavements can be designed in such a way that it can give service for a long period; design period may reach up to 60years. The longevity and its high rigidity make rigid pavement a preferable choice in conditions where environmental temperature is high and the traffic is very heavy (roads which mostly serve commercial vehicles of higher tonnage). Flexible pavements deform when there will be a severe exposure to higher temperature from the environment and this problem will be a lot pronounced if the construction of underlying layers was not done properly. On the contrary, rigid pavements can withstand environmental and traffic load without or less deformation as compared to flexible pavement. Flexible pavements are prone to rutting (wheel path deterioration) as the number of traffic and service life of the pavement increases. The picture below shows the response of flexible and rigid pavement to heavy load traffic.

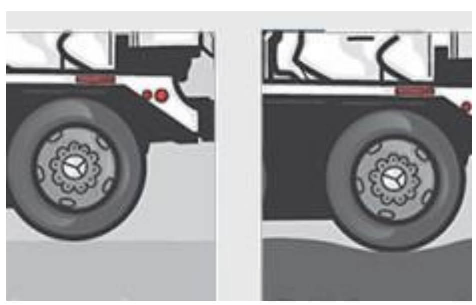


Figure 2.2. Response of flexible (right) and rigid pavement (left) to heavy load traffic (Pavements 2017).

The construction of concrete rigid pavement requires a very skillful workmanship and experience. While flexible pavements can be constructed without the involvement of sophisticated work methodology and workmanship as compared to rigid pavements. The riding quality of flexible pavement is preferable than rigid pavement as the smooth appearance of the surface dressing safeguards the non-bumpy and undisturbed movement of vehicles. While rigid pavements are with rough surface which creates a slight inconvenience while riding on them but this can be avoided by dressing the concrete slab with a thin layer of asphalt. Generally, rigid pavements are advantageous in the aspect of durability, longer service life and the input of less or no maintenance. But the initial cost of construction of concrete rigid pavements are expensive as compared to flexible pavement.

2.4. Concrete rigid pavement

Concrete pavements have been used for highways, airports, streets, local roads, parking lots, industrial facilities, and for other types of infrastructure (Delatte 2008). Concrete rigid pavements can serve many decades without or little maintenance if they are properly designed and constructed with a durable material and controlled work methodology. Design or construction errors or poorly selected materials will significantly reduce the pavement life. Therefore, a great care should be taken during materials selection, mixture proportioning, design and detailing, drainage, construction techniques, and pavement performance. Moreover, it is important to notice the degree of applicability of commonly used design guidelines and procedures to the particular project that one need to construct (Delatte 2008).

Concrete rigid pavements have certain considerable advantages over flexible pavements. Little or no maintenance, possibility to design with longer deign period (upto 60 years), ability to distribute load over a wide area with a relatively thin pavement slab, refuse to deformation under traffic load, resistant to abrasion, less affected by weathering and a relatively strong response to deterioration due to temperature fluctuation are some of the advantages that will be gained from concrete rigid pavements (ERA 2013). Whereas, if the design and construction is not properly carried out, it tends to be more troublesome and maintenance and reconstruction can be more difficult. Moreover, the initial cost of construction of concrete rigid pavement is high when compared with flexible pavement. But relative to their whole life costs, the cost of concrete rigid pavements can be considerably less than that of flexible pavements and provide a more sustainable option (ERA 2013).

"A rigid concrete pavement distributes heavy loads over a relatively wider area, with a minimal pressure on the sub-grade – the natural soil under the roadway" (Supe and Gupta 2014). However, flexible asphalt material concentrates weight and transmits it deeper into the upper flexible layer which later let it to fail. Whereas concrete rigid pavements withstand the load on their own and the stress that will be transmitted in to the subgrade will be less (Supe and Gupta 2014).

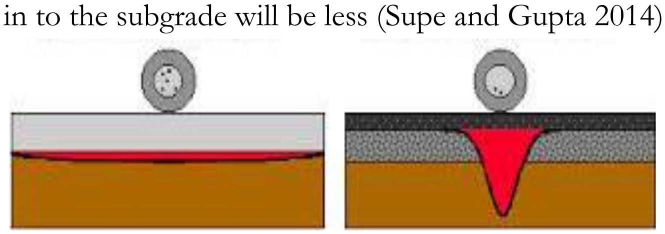


Figure 2.3. Load distribution of Rigid (left) and flexible (right) pavements (Supe and Gupta 2014)

There are three types of concrete rigid pavements that are categorized based the absence and presence of a reinforcement and joint.

A) Jointed Unreinforced Concrete Pavements (JUCP)

This pavement consists of unreinforced concrete slabs that will be casted in place and divided into panels of prescribed dimensions by joints. The dimensions of the panels will be as short as possible in order to safeguard the absence of cracking risks during concrete curing (ERA 2013). In the longitudinal direction the panels are usually jointed together by dowel bars (load transferring plain bars) to prevent vertical movement and to help maintain aggregate interlock across the transverse joints. The panels are also connected to the parallel panels by tie bars and the main function of these bar is to prevent horizontal movement (i.e. the opening of warping joints) (ERA 2013).

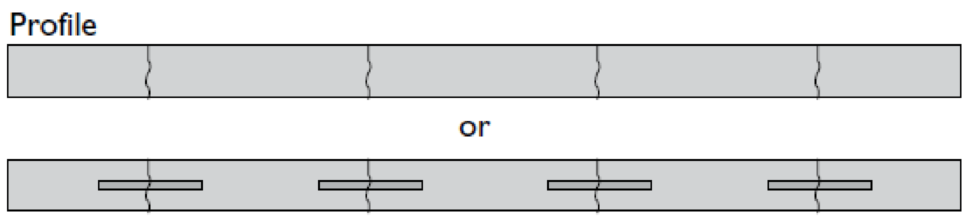


Figure 2.4. Jointed Unreinforced Concrete Pavements (JUCP) (Delatte 2008)

B) Jointed Reinforced Concrete Pavement

These pavement consists of cast in situ concrete slabs containing steel reinforcement and divided into panels that are separated by joints. The reinforcement is to prevent the developing cracks from opening and this allows much longer panels to be used than in JUCP. The panels are jointed together by dowel bars and tie bars as in JUCP. Though longitudinal reinforcement is the main reinforcement, transverse reinforcement is also used in most cases so as to facilitate the placing of longitudinal bars (ERA 2013).

Figure 2.5. Jointed Reinforced Concrete Pavements (JRCP) (Delatte 2008)

C) Continuously Reinforced Concrete Pavement

These type of concrete pavement is made of cast in situ reinforced concrete slabs but without joints. "The expansion and contraction movements are prevented by a high level of sub-base restraint" (ERA 2013). "The frequent transverse cracks are held tightly closed by a large amount of continuous high tensile steel longitudinal reinforcement" (ERA 2013).

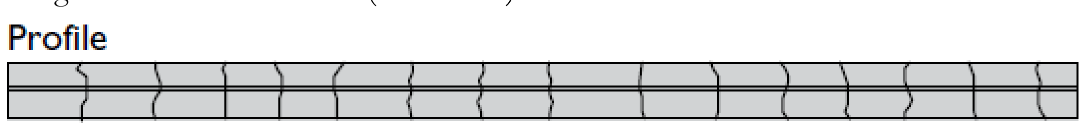


Figure 2.6. Continuously Reinforced Concrete Pavements (CRCP) (Delatte 2008)

JUCP and JRCP consume a relatively low cost as compared to CRCP. CRCP provides a high quality pavement but it will be constructed with a densely populated reinforcement which incurs a very high cost and makes the whole construction very expensive. In addition, the construction of CRCP needs an experienced and highly qualified contractor. JRCP is suitable for all levels of traffic and it is used when the risk of settlements of the sub grade cannot be neglected. Slab thickness (concrete amount) will be reduced in case of JRCP as the reinforcement involve in counteracting the load from traffic and temperature. JRCP also ensures riding quality and less joint maintenance, as the number of joints are fewer than that of JUCP's.

2.4.1. Concrete rigid pavements in Ethiopia

Concrete pavements have not been used commonly in most tropical countries such as Ethiopia. This is mainly due to lack of exposure and experience in the design and construction of concrete rigid pavements. But recently Ethiopian Road Authority is facilitating the construction of certain concrete rigid pavement projects in the arid areas of the country and on some sections of existing routes. The 10km section of Chancho – Derba- Bacho road project which was completed in the year 2016 was a pilot project which the national road authority made a trial experience in the design and construction of concrete rigid pavements. The project road is located in Oromia regional state and it starts at Chancho town (472670E, 1028063N) at a distance of 38km from Addis Ababa on the main Addis Ababa – Goha Tsion road and terminates at Becho (326646E, 1480877N) near Derba cement factory area with additional 2.3km spur road from Derba junction to Muger Cement factory passing through Derba village. The road was constructed using a JRCP type and designed to serve 40years. The pictures below show the beginning section of concrete rigid pavement and somewhere in the middle of the 10km. The pictures were taken during the commissioning phase of the project (June, 2016).

Figure 2.7. Chancho Derba Becho road project; beginning of the concrete rigid pavement (left) and somewhere in middle section of the concrete road (right)

Along with this, small sections of road in the capital city and in some towns were also constructed of concrete rigid pavements. Moreover, the 9km Beseka lake alternate route, recently started 81km Dichoto Galafi junction-Elidar-Beleho concrete road in Afar region and the 102.8 km Afdera – Irebti junction- Erta Ale junction- Ahmed Ela road project which is planned to be constructed in two lots in Afar region can ensure the flourishing of concrete pavement construction in Ethiopia. This makes a forward step in concrete road construction.

With this, this study tries to go for an alternative concrete material specifically in replacing cement in a concrete rigid pavement. In order to ensure the sustainability of the alternate material, it uses a continuously available industrial waste i.e sugarcane bagasse ash from the sugar factories. Many researches and studies were conducted on sugarcane bagasse ash in order to assess the degree of applicability of this material as a competent material in partially replacing cement. The findings of the researches and studies were supporting the material's ability to partially replace cement as a pozzolanic material. However, the response of this material on some sensitive parameters of concrete structure was not dealt thoroughly. When in use of this material for concrete rigid pavements, it's response to strength, durability and most importantly resistance to thermal effects should be well investigated. The knowledge gaps identified and sorted out in the summary of the literature review were the major areas that this research tried to address. Thus, the findings of this study tries to fill the gap noticed in previous researches by investigating the response of this material in concrete rigid pavement design and construction.

3. PHYSICO-CHEMICAL CHARACTERIZATION OF MATERIAL

Before the commencement of the main experiment, the material used in this research were prepared and their concerned property were investigated so as to assure whether prepared materials were complying with the required standard and specification.

As this study concerns about concrete rigid pavement, the property of material used in this research need to meet the material requirement that a material used for concrete rigid pavement need to fulfill. AASHTO (Standard specification for transportation materials and method of sampling and testing, 2001) was used in this research along with ACI and ASTM standards and specifications for checking of requirements in sampling method.

Most material investigation tests were conducted in laboratories found in Addis Ababa Institute of Technology. Most aggregate properties are investigated in Material Engineering laboratory as well as in Highway Engineering laboratory. Bagasse ash density and fineness tests were conducted in Reaction Engineering and Chemistry laboratory sections of Chemical Engineering laboratory respectively.

3.1. Aggregate

Aggregate constitutes more than three-fourth of the volume of concrete and the selection and proportioning of both fine and coarse aggregate significantly influence the properties of fresh and hardened concrete (Blake 1989). Thus it is essential that concerned properties of aggregate should comply with the requirement needed. In the process of preparing an aggregate which fulfill the necessary requirements, both visual and laboratory based inspection must be conducted. Aggregate with impurities should be washed thoroughly until it gets free from it. But if the presence of impurity causes a damage to the chemical and mechanical property of the aggregate, the aggregate shall totally be rejected as this can be a potential for failure on the cohesive nature of the aggregate. In addition, aggregate from single source shall be used in one project so as to arrest variability of characteristics due to variability of ingredient property. Aggregate from various sources will show various property which consequently affect the proportioning of other ingredients of the concrete and finally its strength. Thus aggregate from single source shall be used at a time since there will exist a difficulty and error prone situation in deducing a standard or setting a datum for each sources of the aggregate at a certain project.

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

3.1.1. Fine aggregate

Fine aggregates generally consist of natural sand or crushed stone with most particles smaller than 5 mm (Kosmatka et al. 2003). The sand used for this research is a natural sand sourced from Meki (a town located 131 km away from Addis Ababa). Necessary laboratory investigations were carried out to this sand in order to ensure compliance of property of the sand with the required standards and specifications. Gradation, specific gravity and absorption capacity, bulk density, moisture content and silt content were the tested parameters in order to assess the physical properties of the sand.

A) Particle size distribution

Particle size distribution of an aggregate is determined using sieve analysis. Usually the grading and grading limits are expressed in terms of percentage of material passing through each sieve. The particle size distribution and fineness modulus (FM) of the sand is checked as per the requirement of AASHTO M 6/ ASTM C 33. After taking four representative samples of the sand, sieve analysis was conducted and an average value of the four samples was taken as particle size distribution of the sand. The grading requirement and the average percentage passing obtained is summarized as follows.

Table 3.1. Grain size distribution of fine aggregate along with recommended standard.

Sieve Size (mm)	Sieve No.	Percentage passing by mass	AASHTO M 6 Specification range
9.5	#3/8	100.0	100
4.75	#4	96.1	95-100
2.36	#8	86.2	80-100
1.18	#16	68.5	50-85
0.600	#30	35.5	25-60
0.300	#50	13.1	10-30
0.150	#100	2.7	2-10
Passing 0.150	Pan	0.0	

The amounts of fine aggregate passing the 300 μm (No. 50) and 150 μm (No. 100) sieves affect workability, surface texture, air content, and bleeding of concrete; most specifications allow 5% to 30% to pass the 300 μm (No. 50) sieve (Kosmatka et al. 2003). The grain size distribution of fine aggregate along with its limits of specification is depicted in the graph below.

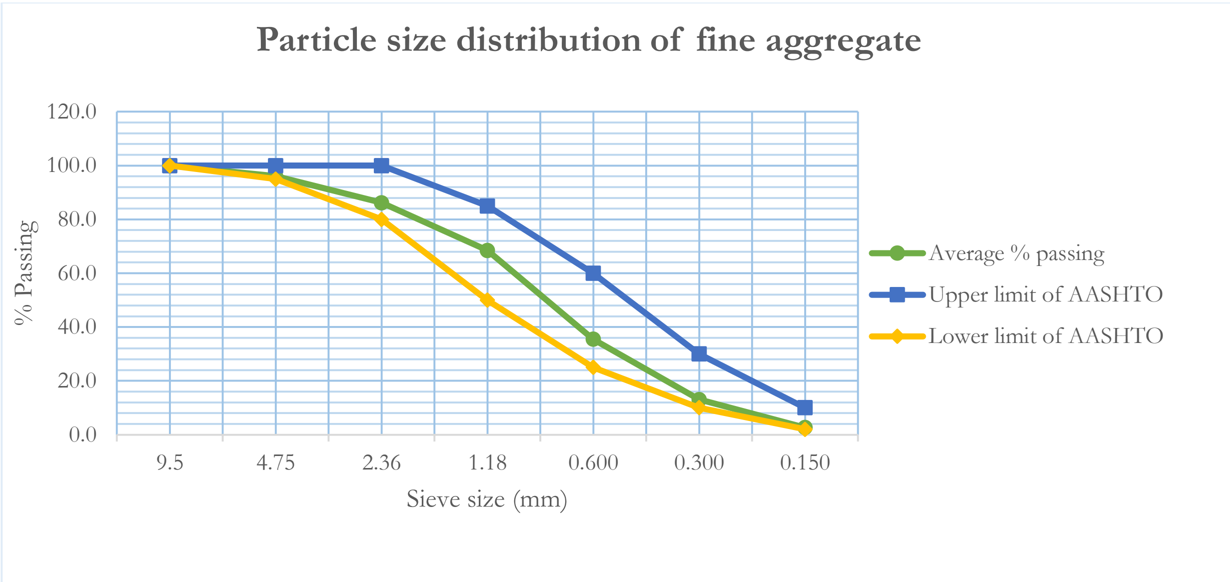


Figure 3.1. Graph for grain size distribution of fine aggregate along with limits of specification

As per ERA's 2014 standard technical specification for rigid pavement construction, the range of percentage passing for fine aggregate at each size of sieve is similar to that of AASHTO except at 150 µm sieve in which ERA's standard specify 1-10% and remaining percentage to retain on 75 µm size sieve. With which, the fine aggregate complies with both specifications.

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

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

=∑((100-96.1)+(100-86.2)+(100-68.5)+(100-35.5)+(100-13.1)+(100-2.7))/100 = **2.98**

As per AASHTO M 6, the FM for fine aggregate shall not be less than 2.3 nor more than 3.1. With this, FM of the above tested sand fall into the required range. The sieves involve in determining FM for fine aggregate are: 150 µm (No. 100), 300 µm (No. 50), 600 µm (No. 30), 1.18 mm (No. 16), 2.36 mm (No. 8) and 4.75 mm (No. 4).

B) Specific gravity and absorption capacity

The relative density or specific gravity of a sand will identify its physical property and its amount determines the volume of fine aggregate to be used in a given concrete mix. Absorption is the measurement of water that is in the concrete pores. When the pores are fully filled and there is no surface moisture, the sand will be in a saturated surface dry condition. With this, an increase in moisture (decrease in absorption) will affect the amount of water that will be used in a concrete mix. Thus both parameters need to be defined prior to mix design and subsequent steps in concrete making. Following the required standard procedure as per AASHTO T84 C128 this test was conducted and the result obtained is summarized as follows.

Bulk specific gravity = 2.31
Bulk specific gravity (SSD state) = 2.425
Apparent specific gravity = 2.61
Absorption capacity = 5.04%

C) Moisture content

The moisture content of individual ingredients of concrete affects the water cement ratio of the mix. Some aggregates be with considerable amount of moisture that they will release it while in use for concrete making and others be 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 was measured by drying both surface moisture and the moisture in the pores of the fine aggregate. This moisture content doesn't include the moisture that is chemically combined with the minerals in the aggregate.
Following the testing procedure and sampling method stated on AASHTO T 255-00, the moisture content of the sand is obtained as 1.78%.

D) Bulk density (Unit Weight)

Bulk density is the mass of a unit volume of bulk aggregate material, in which the volume includes the volume of individual particles and the volume of the voids among the particles. And it is expressed in a unit Kg/m^3. This parameter defines the volume that the fine aggregate will occupy in the concrete. As per the sampling procedure and testing method stated on AASHTO T19/ T 19M-00, the fine aggregate is tested and its unit weight is obtained as $1.315gm/cm^3$.

E) Silt content

Silty or clayey particles in the sand form a coating on the fine aggregate by which they prevent the bond between the cement and the aggregate. If these materials present in a significant quantity, they will lead to high water cement ratio which later affect the strength of the concrete.
Silt content test determines the particles in the sand that are less than 200mm sieve size. The permissible value of silt content in a sand as per Ethiopian standard is 6% (Dinku 2002). The sand used for this experiment showed a silt content of 9.19% before it was washed. Since this the value exceeds the permissible range, the sand was washed and tested that its silt content decreased to 1.25%.

Table 3.2. Summary of physical property of fine aggregate used in the experiment

Item No.	Description	Result
1	Bulk specific gravity	2.31
	Bulk specific gravity (SSD state)	2.43
	Apparent specific gravity	2.61
	Absorption (%)	5.04
2	Unit Weight (gm/cm^3)	1.32
3	Moisture content (%)	1.78
4	Silt content (%)	1.25

3.1.2. Coarse aggregate

The coarse aggregate used for this research is crushed rock that was available in the material laboratory of Addis Ababa Institute of Technology. In order to free the aggregate from undesirable dust material, it was thoroughly washed and dried in open air. The aggregate has a nominal size of 19mm.

All tests conducted for the assessment of physical property of the fine aggregate also conducted on the coarse aggregate. In addition to those tests, aggregate's resistance to abrasion, impact and crushing were assessed by means of Los Angeles abrasion test, aggregate impact value assessment and aggregate crushing value respectively. Since this research specifically deals about rigid pavement, it's essential that these properties of the aggregate be determined. Resistance of the aggregate against traffic load of any motion and frequency depends on those properties of the coarse aggregate. Moreover, the flaky nature of the aggregate was also determined using a flakiness index measuring slot.

The physical property of the coarse aggregate used in this research is summarized and tabulated as follows: -

Table 3.3. Summary of physical property of coarse aggregate used in the experiment

Item No.	Description	Result
1	Nominal size (mm)	19
2	Bulk specific gravity	2.71
	Bulk specific gravity (SSD state)	2.76
	Apparent specific gravity	2.86
	Absorption (%)	1.93
3	Unit Weight (gm/cm^3)	1.52
4	Moisture content (%)	1.78
5	Flakiness index (%)	26.57
6	Aggregate crushing value (%)	22.12
7	Aggregate impact value (%)	9.03
8	Los Angeles abrasion	18.25

The first four tests from the above table are conducted with similar procedure used for fine aggregate testing but with a specification used particularly for coarse aggregate.

The flakiness index (FI) of an aggregate sample is found by separating the flaky particles and expressing their mass as a percentage of the mass of the sample. The test is applicable to material passing a 63mm sieve and retained on 6.3mm sieve. Aggregates are classified as flaky when they have a thickness of less than 60% of their mean sieve size (Dinku, 2002). With this, sample material was prepared as per the recommended method and test was conducted and a result of 26.57% was obtained. For concrete pavements, most guidelines limit a flakiness index of less than 35% as a desirable range and the British standard limit the upper range as 40%.

Aggregate used in road construction should be strong enough to withstand crushing due to wheel load. Aggregate crushing value (ACV) gives a relative measure of the resistance of an aggregate to crushing under gradually applied load. Its determined by measuring the material passing 2.36mm sieve after crushing under a load of 400KN (Highway engineering laboratory manual, unpublished, Addis Ababa Institute of Technology). The ACV value of an aggregate used for this research is tested in a laboratory using ACV measuring apparatus (shown in **Figure 3.2**) and a result of 22.12% was obtained. The maximum permissible value of ACV as per the British standard is 30%.

Figure 3.2. Sample aggregate under ACV test

Due to movement of vehicles on the road, the aggregate will be subjected into impact resulting in their breaking into small pieces. Thus the aggregate need to have sufficient toughness to resist their disintegration due to impact (Dronacharya Group Institutions 2013). The toughness of an aggregate is measured by assessing its response to impact load. Aggregate Impact Value (AIV) gives a relative measure of resistance of an aggregate to a sudden shock or impact (Dinku 2002). Sample aggregate is sieved and compacted with three layers inside the cylindrical steel cup shown in **Figure 3.3**. And a hammer of 14kg is allowed to freely fall into the prepared aggregate fifteen times. After the introduction of the impact, the resulting aggregate was sieved with 2.36mm sieve. Making all the necessary calculations, a result of 9.03% AIV value was obtained. An aggregate with AIV value less than 10% is considered as exceptionally strong aggregate.

Figure 3.3. Sample aggregate prepared for conducting AIV test and an apparatus used for measuring AIV

When vehicles move on the road, the soil particle present between pneumatic tyres and road surface causes abrasion of road aggregate. Therefore, the road aggregate should be strong enough to resist abrasion. Resistance to abrasion of aggregate is determined in laboratory using Los Angles test machine (Dronacharya Group Institutions 2016). In order to investigate the abrasion resistance of aggregate used in this research, the Los Angles abrasion (LAA) test machine in Highway Engineering laboratory was used. Using a sample of aggregate prepared as per the prescribed requirement test sample preparation, LAA test was conducted and a result of 18.25% was obtained. The maximum permissible value of LAA as per AASHTO T 96 is 40%.

Figure 3.4. Sample aggregate on a tray after passing an abrasion test

The coarse aggregate gradation requirement of AASHTO M 80 allows a broad range of grading and variety of grading sizes. For a nominal size of 19mm aggregate, the specification range shown in **Table 3.4** was selected and used. As shown in **Table 3.4**, each size of aggregate fall into the required range but due to the wide range of grading, each aggregate size was proportioned as per the required range in such a way that the cumulative percentage retaining from all sizes be 100%.

Table 3.4. Grain size distribution of coarse aggregate along with recommended standard

Sieve Size (mm)	Sieve No.	Percentage passing by mass	AASHTO M 80 Specification range
25	#1	100	100
19	#3/4	98.1	90-100
12.5	#1/2	45.2	20-55
9.5	#3/8	10.4	0-15
4.75	#4	1.16	0-5
Pan			

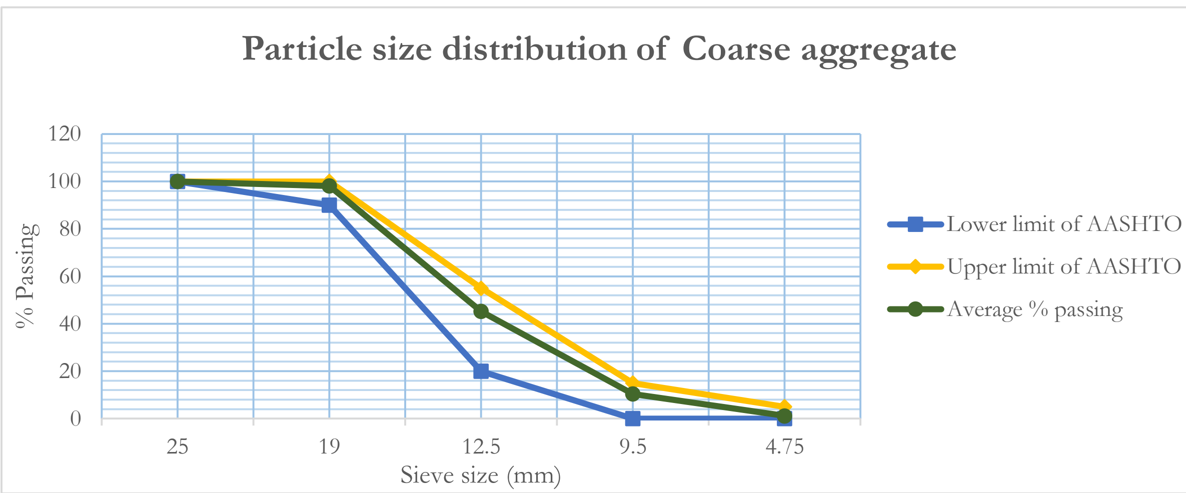


Figure 3.5. Graph for grain size distribution of coarse aggregate along with limits of specification

3.2. Cement

The cement used for this research is an Ordinary Portland Cement (OPC) of grade 42.5 with Dangote brand. The option of using Portland Pozzolana cement (PPC) was not considered in this research as previous research made on local sugarcane bagasse ash had shown a relatively lower result when this type of cement was used along with the bagasse ash (Hailu 2011). As the rate of hydration of cement and the amount of heat that will be generated from it, will significantly be depend on its fineness property, the fineness of this cement was investigated in Chemistry analysis section of Chemical Engineering Laboratory in Addis Ababa Institute of technology using Blaine air permeability testing apparatus and also by conducting a particle size distribution test in Material Engineering laboratory.

The fineness of cement is measured as specific surface area by observing the time taken for a fixed quantity of air to flow through a compacted cement bed of specified dimensions and porosity. Under standardized conditions the specific surface of cement is proportional to $\sqrt{T}$ where T is the time for a given quantity of air to flow through the compacted cement bed. The number and size range of individual pores in the specified bed are determined by the cement particle size distribution which also determines the time for the specified air flow (ES 1176-6:2005 2005).

The test for fineness of cement used for this research was conducted with permeability apparatus shown in **Figure 3.6** and it is calculated from its specific surface as follows: -

$$\mathbf{S = (S_S\sqrt{T})/\sqrt{T_S}} \qquad \text{Eq. 3.2(a)}$$

Where: - S = Specific surface of the test sample (m^2/kg)

S_S = Specific surface of the standard sample used in calibration of apparatus (m^2/kg)

T = Measured time interval of manometer drop for test sample (Seconds)

Ts = Measured time interval of manometer drop for standard sample used in calibration of apparatus (Seconds).

The apparatus used in this research is calibrated using a standard sample which of its specific surface (S_S) is 3774 ± 58 cm^2/g. And the corresponding measured time interval during calibration with the standard sample (T_S) is 29.77 Seconds.

The fineness test for the cement used for this research was conducted using three samples of cement and the average time interval required to flow air through the three samples is taken as the measured time interval of manometer drop for test sample (T). The time interval from the three samples were obtained as 20.65, 21.76 and 20.04 Seconds. The average time interval of the three samples is therefore 20.82 Seconds. The above obtained figure is then substituted in Eq. 3.2(a) and the specific surface of cement used is calculated as follows: -

$$S = (3774\ cm^2/g * \sqrt{20.82\ Sec})/\sqrt{29.77 Sec}$$
$$=3156.115\ cm^2/g = 315.6115 m^2/kg$$

As per ASTM 204 00 the value obtained in cm^2/g will be rounded to the nearest 10units (ASTM standard is used because the apparatus was calibrated using ASTM standard and calibration procedure), giving an approximate value of 3160cm^2/g (316m^2/kg).

AASHTO M 85 recommends the specific surface of type I cement (general purpose Portland cement used when there is no special property is required by the concrete) measured with air permeability method to have a minimum average value of 280m^2/kg, a minimum value for any of the sample as 260m^2/kg, a maximum average value of 400m^2/kg and a maximum value for any of the sample be 420m^2/kg. The cement used in this research complies with all the above limits.

Figure 3.6. Blaine air permeability apparatus used to test fineness of cement and bagasse ash

In addition to the Blaine air permeability test, particle size distribution of the cement was also checked and it showed a distribution pattern as shown below.

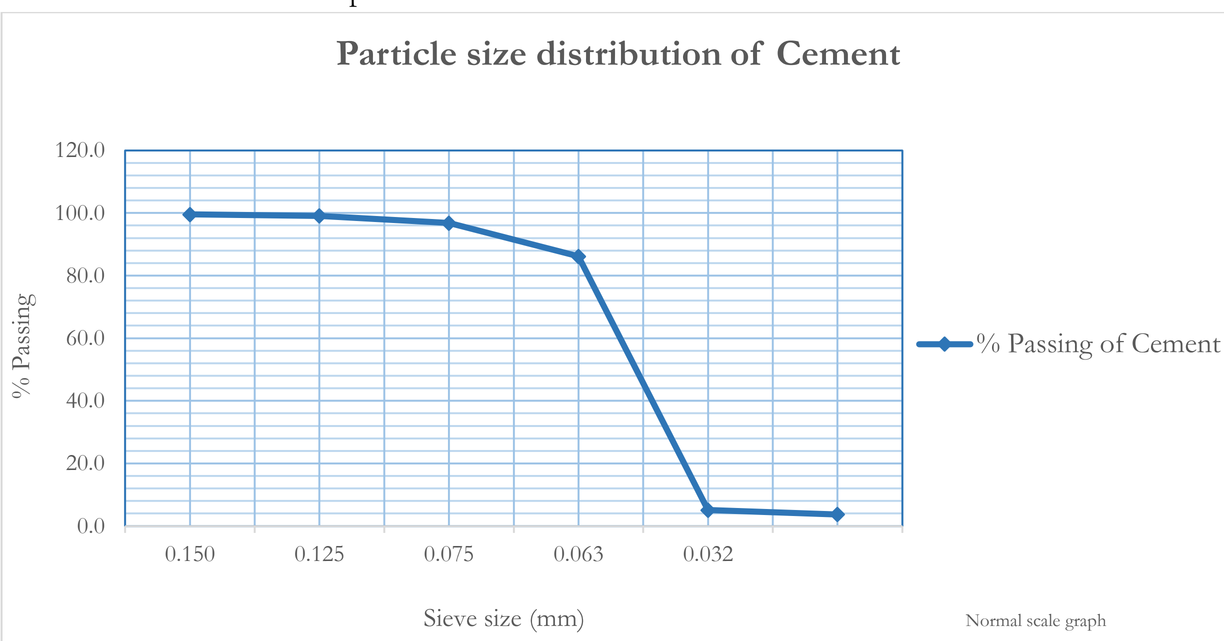


Figure 3.7. Particle size distribution of cement used in this research

The chemical composition of the cement was inferred relative to the standard restrained by ES 1176-6:2005 (2005) for OPC cements. The standard specifies the content of the compositional range of oxides that need to be in a Portland cement. All Portland cements that will be produced within the country, needs to adhere with the chemical composition shown in the table below. Any OPC product which of its constituent deviates from the specified range cannot join the market as a certified product.

Table 3.5. Oxide composition of OPC cement as per ES 1176-6:2005 (2005)

Oxide	Percentage
SiO_2	18-24
Al_2O_3	2.6-8
Fe_2O_3	1.5-7
CaO	61-69
MgO	0.5-4
SO_3	0.2-4
K_2O	0.2-1

3.3. Bagasse ash

The bagasse ash used to partially replace cement in this research is collected from Wonji Sugar Factory. It is directly collected from the ash storing funnel and also from the ash disposing conveyor (shown on **Figure 3.8**) three days after being disposed and stay exposed to the external environment. The ash was collected at the beginning of the off season (a season by which factories stay without sugar production) that by the time of collection the ash was exposed to rain, sun light and heat and other environmental conditions. According to personnel from kiln operation section of the factory, the raw bagasse got burned with a continuous temperature reaching up to 700^0C.

Sufficient amount of bagasse ash was then collected and transported to Addis Ababa Institute of Technology being packed with large plastic bags. Before commencement of chemical investigation and subsequent tests, the bagasse ash was dried in an oven with a maximum temperature of 105^0C by which the moisture contained in it was removed.

Figure 3.8. Disposed bagasse ash at Wonji sugar factory

As one of the aim of this paper is to evaluate the degree of applicability of bagasse ash without letting it passing through significant physical and chemical pretreatment, the experiment which involved bagasse ash was conducted using an oven dried and sieved (with 300μm sieve) bagasse ash. Preparation of material did not involve fineness modification though fibrous and rarely available large and lumpy particles along with part of bagasse ash larger than 300μm was sieved out. The picture below shows bagasse ash before and after sieved with 300μm sieve.

Figure 3.9. Bagasse ash before (left) and after (right) sieving (with 300 μm sieve)

The particle size distribution of bagasse ash sample sieved with 300μm sieve and that of cement showed a gradation pattern as plotted in the graph below. From the graph it can be inferred that the percentage passing of bagasse ash at larger size sieves is lesser than that of cement and showed a little increment in the finer sieve (32 μm).

Table 3.6. Particle size distribution of sieved bagasse ash (300 μm sieve) and OPC cement.

Sieve Size (mm)	Sieve No.	% passing of cement	% passing of sieved bagasse ash
0.150	#3/8	99.5	76.1
0.125	#4	99.1	68.7
0.075	#8	94.9	50.7
0.063	#16	83.9	39.6
0.032	#30	1.4	4.5
Pan	#50	0.0	3.0

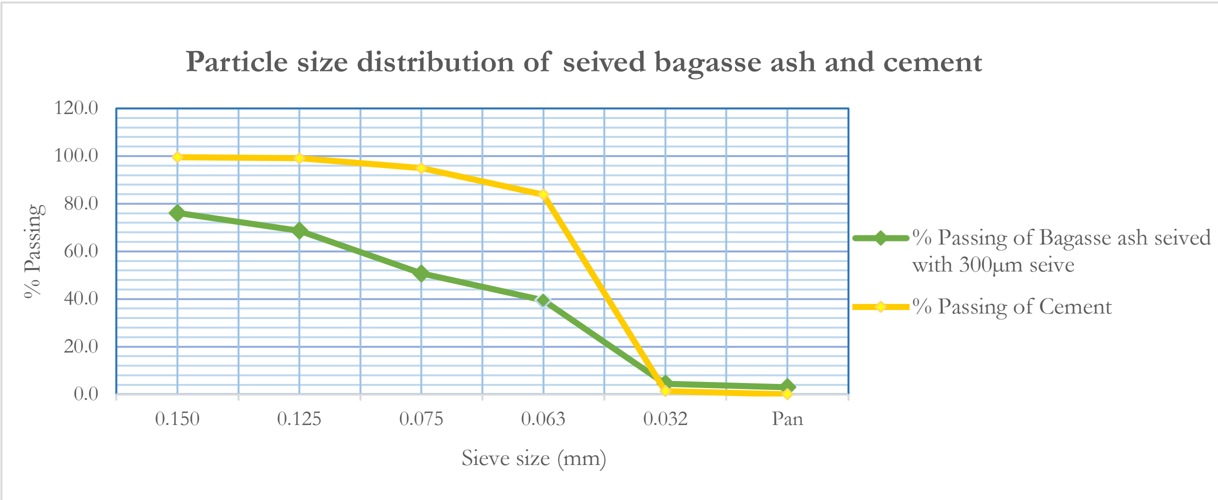


Figure 3.10. Particle size distribution of sieved bagasse ash (300 μm sieve) and OPC cement.

Bagasse ash prepared in the above manner is taken into Geological Survey of Ethiopia for chemical analysis. LIBO2 FUSION, HFattack, gravimetric, colorimeteric and AAS analytical method was used in order to assess its chemical composition. The result exhibited a high silica content as shown in the table below. Based on the chemical composition obtained, it is possible to modify the constituents of the ash in a way that can comply with a specific requirement. But since the aim of this research doesn't involve any sort of modification, the bagasse ash with a chemical composition shown below was used in conducting concerned experiments. The full Chemical analysis of the ash (as reported by Geological Survey of Ethiopia) is attached in the appendix section of this study.

Table 3.7. Chemical composition of bagasse ash and Dangote OPC cement

Investigated constituents	Chemical composition of bagasse ash (%)	Chemical composition of Dangote OPC cement (%)
SiO_2	66.92	22.82
Al_2O_3	7.06	5.41
Fe_2O_3	6.12	3.37
CaO	3.6	66.32
MgO	1.96	1.46
Na_2O	4.28	-
K_2O	4.92	-
MnO	0.2	-
P_2O_5	0.02	-
TiO_2	0.05	-
H_2O	0.01	-
LOI (Loose in Ignition)	3.65	-
SO_3	0.25	2.16
$SiO_2 + Al_2O_3 + Fe_2O_3$	80.1	31.6

All chemical constituents of the cement fall in the range specified by Ethiopian standard set for chemical composition of Type I OPC cement (**Table 3.5**)

As can be inferred from **Figure 3.11**, the silica content of bagasse ash is relatively higher than the other supplementary cementitious materials shown in the figure. And its composition is closer to fly ash as compared to the other supplementary cementitious materials. Currently, in standards and specifications such as AASHTO, fly ash is used as an admixture in concrete making. A material exhibiting a relatively similar chemical composition such as sugarcane bagasse ash can also be used in a standard manner if thorough investigation made and the material be standardized. When dealing with the modeling section of this study, the finite element software used considers the supplementary cementitious material to be fly ash. As the bagasse ash showed a relatively similar behavior like that of fly ash, the property of the bagasse ash was fed into the software instead of fly ash's property.

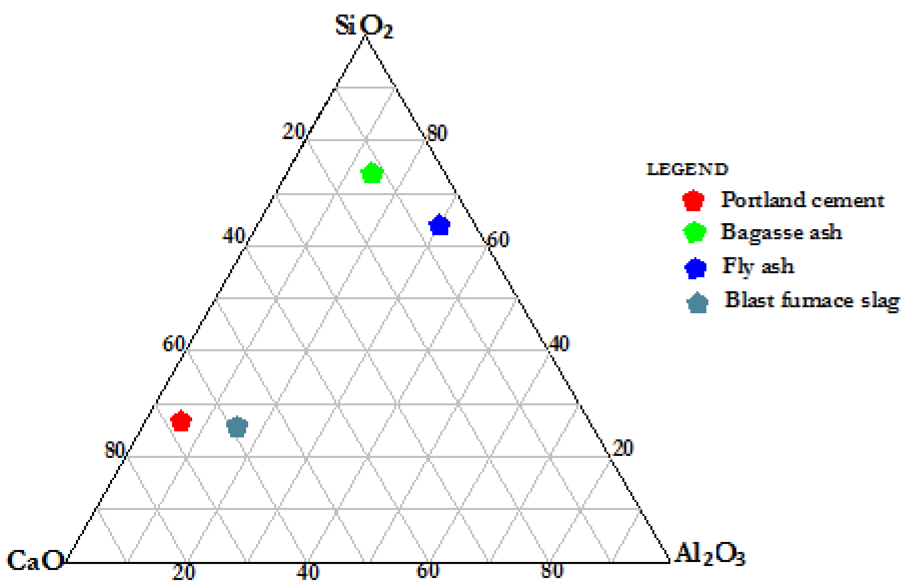


Figure 3.11. Ternary diagram of bagasse ash relative to other supplementary cementitious materials.

The percentage of constituents used in the diagram are average values based on the range of abundance (Feng and Clark 2011; Composition of Portland Cement 2016; Akbarnejad and Houben 2010; Srinivasan and Sathiya 2010) of that particular constituent in that particular material.

Sample prepared in the same manner was used for testing its fineness from its specific surface area. The specific surface area of three sample of bagasse ash were taken and the average time interval required to flow air through the three samples is taken as the representative time interval at which the manometer drop for test sample which was obtained as 24.49 Seconds. The specific surface area of sample bagasse ash is then calculated using Eq. 3.2 (a) as follows.

$$S = (3774\ cm^2/g * \sqrt{24.49}\ Sec)/\sqrt{29.77} Sec$$
$$= 3422.99 cm^2/g = 342.229 m^2/kg$$

The value obtained in cm^2/g will be rounded to the nearest 10units and the above result will be going to have a figure of $3430cm^2/g$ ($343m^2/kg$).

The density of bagasse ash used in this research was investigated in Chemical Engineering laboratory; Reaction Engineering section. A 100ml pycnometer, a weighing balance and Tuluene (a low density liquid which of its density is 0.867gm/ml) was used to test the density of the bagasse ash. And a result of 2.0441gm/ml or $2.0441gm/cm^3$ was obtained.

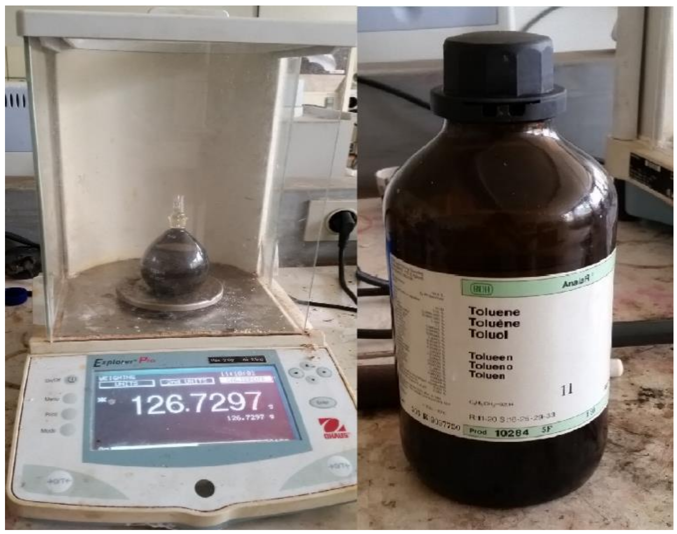


Figure 3.12. Pycnometer + bagasse ash sample + Tuluene in a weighing balance (left) and a bottle of Tuluene (right)

3.4. Water

Material preparation involved washing, sieving and drying of aggregates and the water used for washing purpose is a clean tap water from Addis Ababa Institute of Technology. The experiment was also conducted using the water from the same source.

4. EXPERIMENTAL PROGRAM

The aim of this study is to assess the use of bagasse ash as a cement replacing material in a concrete rigid pavement. The preliminary task in dealing with its degree of applicability is, investigating the impact of introducing this material into the strength of the concrete. Like that of any type of structure, concrete rigid pavements suffer damages and structural problems at early age and later in a gradual state during their service period. Early age structural problems are either due to poor quality of material and work methodology or because of the impact of the environment into the erected structure. The strength of a concrete in a concrete rigid pavement design is based on a 28th day compressive and flexural strength value of the concrete. The pavement will be open for traffic after the concrete slab passes its full strength achievement period. This can safeguard the capacity of the concrete in withstanding the designed traffic load. But before reaching into that state, the concrete may suffer from loads that come from the environment or may encounter failure due to poor construction scheme. Since the aim of this study focuses on material property and structure of the concrete slab, it tries to investigate early age strength attainment of the concrete so as to inhibit damages that may occur before the concrete attain its full strength.

Most concrete rigid pavements are being constructed in a very arid area which are with a very high temperature and rate of evaporation. Since the concrete slab be casted in an open environment, it has the chance to absorb the heat from the environment. Normally when Portland cement is mixed with water, heat will be liberated and this heat is called the heat of hydration and is the result of the exothermic chemical reaction between cement and water. The heat generated by the cement's hydration raises the temperature of the concrete (PCA 1997). Hot weather construction and the concrete's native heat generated due to hydration altogether increases internal temperature of the concrete core. Due to this problem, the concrete will be subjected to a thermal stress that is generated from hydration of cement and absorbed heat from the environment. The concrete encounter this stress at its early age and if the developed strength of the concrete by the time of occurrence of this stress exceeds the thermal stress, it can reduce early age cracking. But if the reverse happens, the heat generated in the very middle section of the concrete core will try to find a way to get a relief from the confined heat and one of the way to dissipate the heat generated within the concrete might be by forming an opening in the surface of the concrete which is to crack.

Early age strength development pattern of concrete without bagasse ash and those with bagasse ash were assessed so as to investigate the contribution of introducing this material into the concrete's early age strength characteristics.

As mentioned in the above paragraphs the heat generated in a concrete during hydration reaction along with the heat that may be absorbed from the environment (if construction is in hot weather) form high internal temperature in the concrete core which later will be a potential for early age cracking. Therefore, this study also involved investigation of temperature of concrete made with full cement and those made with bagasse ash replacement percentage of 10 and 20. By which there was a chance to observe the contributory aspect of introducing this material in reducing the temperature. Resistance of concrete against percolation of moisture and other impurities should also be checked so as to avoid penetration of water along with other undesirable materials with it. If concrete is porous and allows moisture to move through it, there will be a great chance for the concrete to lose its durability and the reinforcement (if any) within the concrete to be corroded. With this, the permeability (respective of water penetration depth) nature of the concrete with bagasse ash and without bagasse ash was assessed.

With this, the laboratory experiment program basically involved strength (compressive and flexural beginning from early age), thermal characteristics and water penetration depth assessment of concrete without bagasse ash and with bagasse ash of various percentage of replacement.

The overall layout of the experimental program comprises laboratory experiments that were mainly conducted to assess strength, thermal characteristics and durability of concrete without bagasse ash and with bagasse ash of various percentage of replacement. Before commencing the above listed experiments, mix design was conducted for a grade of concrete of 35MPa using full cement.

With this, the experimental program layout illustrates how the mix design was made and strength (compressive and flexural), temperature and water penetration depth experiments were arranged and conducted.

4.1. Mix design and trail mix

Mix design is the process of defining the quantity and proportioning of concrete ingredients so as the concrete be able to satisfy the required grade. For the purpose of this study, the mix design was conducted for a characteristics compressive strength of 35Mpa and was made using ACI 211.1 – 91 (2002). It was prepared using Ordinary Portland cement and without the involvement of any kind of admixtures.

ACI 211.1 – 91 (2002) recommends a slump range of 3in-1in (76.2mm-25.4mm in metric unit) for pavement structures and if vibration is used to consolidate the concrete. An average slump of 2in or 50.8mm was taken for the trail mix design. For this study an aggregate with 19mm nominal size was used and for a slump of 2in and for an aggregate with a nominal size of 19mm (3/4in) with a non-air entrained concrete, the corresponding water and air content selected from ACI 211.1 – 91 (2002) table was 315lb/yd^3 (186.8kg/m^3 in metric unit) and 2% respectively.

The 28-day compressive strength value selected for this study is 35Mpa (5076.3 Psi). ACI 211.1 – 91 (2002) recommends a water cement ratio or water cementitious material ratio for concrete with a nominal size of aggregate of 0.75in to 1in is 0.4746 (obtained by interpolation). From this, it was possible to determine the cement content as follows: -

W/C = 0.4746 Water content = 186.8kg/m^3 Cement content = 186.8/0.4746 ⟹ 393.5kg/m^3
The above water cement ratio value stays valid for concrete with full cement. But when other cementitious materials are added on the concrete, the water to cementitious material ratio will be determined using **Eq 4.1 (b).**
Replacement of the bagasse ash was made by volume. Replacement by weight was another possibility to investigate the effect of partial replacement of bagasse ash on the mechanical and hydration properties. Replacement by weight ensures a constant water to cement weight ratio. However, in the current study, the authors chose the volume based replacement ratio to ensure a constant volume of cementitious material per unit volume of binary mix. In order to compute the volume equivalency of the bagasse ash, **Eq 4.1 (a)** was used.

$$F_w = 1/(1+(3.15/G_p)((1/F_v)-1)) \quad \text{Eq 4.1.(a)}$$

Where: - F_w = Pozzolanic materials percentage by weight, expressed as a decimal factor
G_p = Specific gravity of pozzolanic materials (Sp. Gravity of the bagasse ash is 2.0441)
F_v = Pozzolanic materials percentage by absolute volume of the total absolute volume of cement plus pozzolanic materials expressed as a decimal factor.
3.15 = Specific gravity of Portland cement.
In order to compute the equivalent weight for the replaced volume amount, Eq 4.1.(a) was used and 1% replacement was assumed.

$$F_w = 1/(1+(3.15/2.0441)((1/0.01)-1)) = 0.006512 = 0.6512\%$$

Therefore, replacing of 1% volume of cement by equal volume of bagasse ash is equivalent to replacing 0.65% weight of cement with bagasse ash.

A replacement percentage of 5, 10 and 20 were used in these study. These percentage of replacements were chosen based on the observed maximum percentage of replacement shown in earlier researches. Most studies conducted on sugarcane bagasse ash were showing a maximum percentage of replacement ranging from 10-15% (either by weight or volume replacement). Moreover, in a factory (controlled system), the maximum amount of pozzolan that will be introduced into a Portland pozzolana cement is 35% (ES 1177-1:2005 2005). The bagasse ash used in this research did not pass through any treatment except being sieved with a 300μm sieve. Thus based on the above reasons, it was anticipated that the increase in amount of bagasse ash may decrease the strength of the concrete after a percentage of replacement ranging from 5-10%. Thus the margin of replacement in this study went upto only 20% and included 5% and 10% in between. An iterative experiment can be carried out by narrowing the gap between consecutive percentage of replacements but in this study these percentage of replacements were enough to show the pattern in finding the optimum percentage of replacement.

The respective water to cementitious material ratio value for each percentage of replacement was determined using the formula in **Eq. 4.1 (b)**

$$W/(C+P) = 3.15(W/C)/(3.15(1-F_v)+G_pF_y) \quad \text{Eq. 4.1 (b)}$$

Where: - C = weight of cement

P = Weight of pozzolanic material

W/(C+P) for a 5% replacement = 3.15(0.4746)/(3.15(1- 0.05)+(2.0441*0.05)) = 0.4831

W/(C+P) for a 10% replacement = 3.15(0.4746)/3.15(1- 0.1)+(2.0441*0.1)) = 0.4918

W/(C+P) for a 20% replacement = 3.15(0.4746)/(3.15(1- 0.2)+(2.0441*0.2)) = 0.5104

From the above calculation sum of weight of cement and weight of pozzolanic material for the respective percentage of replacements was obtained as follows: -

C+P for 5% replacement = 186.8/0.4831 = 386. 66kg/m^3

C+P for 10% replacement = 186.8/0.4918 = 379. 83kg/m^3

C+P for 20% replacement = 186.8/0.5104= 365.98kg/m^3

Using the above values, the cement and bagasse ash amount used for each percentage of replacement including the controlled sample is summarized as follows: -

Table 4.1. Summary of quantity of cement and bagasse ash used in each percentage of replacement.

Percentage of replacement	Cement content (kg/m^3)	Bagasse ash content (kg/m^3)
0	393.50	0.00
5	374.09	12.57
10	355.14	24.69
20	318.40	47.58

ACI 211.1-91 (2002) recommends coarse aggregate content based on the fineness modulus of fine aggregate and nominal maximum size of coarse aggregate. The fineness modulus value of fine aggregate used in this study is 2.98 and the nominal size of coarse aggregate is 19mm (3/4in). With this, the corresponding volume of oven-dry-rodded coarse aggregate per unit volume of concrete was obtained as 0.602 (interpolation).

The first estimate of weight of fresh concrete for a 19mm nominal size of coarse aggregate and a non-air entrained concrete 3960lb/yd^3 or 2349.37kg/m^3.

The proportioning of fine and coarse aggregate per cubic meter of concrete made with full cement was calculated as follows: -

Coarse aggregate = Dry rodded density of coarse aggregate * volume of oven-dry-rodded coarse aggregate per unit volume of concrete = 1520kg/m^3 * 0.602 = 915.04kg/m^3

Fine aggregate = Fresh concrete weight - cement content - water content - coarse aggregate content

= 2349.37- 393.5-186.8-915.04 = 853.7kg/m^3

ACI 211.1-91 (2002) recommends the fresh concrete weight to be adjusted to 15 lb per yd^3 for each 100 lb difference in cement content from 550 lb. Accordingly, adjustments was made for concerned mixes. In addition to that, depending on the absorption capacity and natural moisture content of aggregates, adjustment was made on the proportioning of ingredients.

Unlike field work, errors due to human involvement and variation in material properties are controlled in a laboratory test thus the mix design was done using a target mean strength of 35Mpa.

A 28-day average compressive strength value of 41.87Mpa was obtained during a trail mix from three cubes with a dimension of 15cm*15cm*15cm. Apart from the main strength tests, the temperature and permeability tests were also conducted using the above proportioning of ingredients.

4.2. Flexural and compressive strength

The stresses in rigid pavement are either due to traffic load or environmental effects (curling and wrapping stresses). Environmental effects at early age is related to temperature during casting of the concrete slab. Same effect during service period of the pavement is due to the continuous fluctuation of temperature during the day and night time.

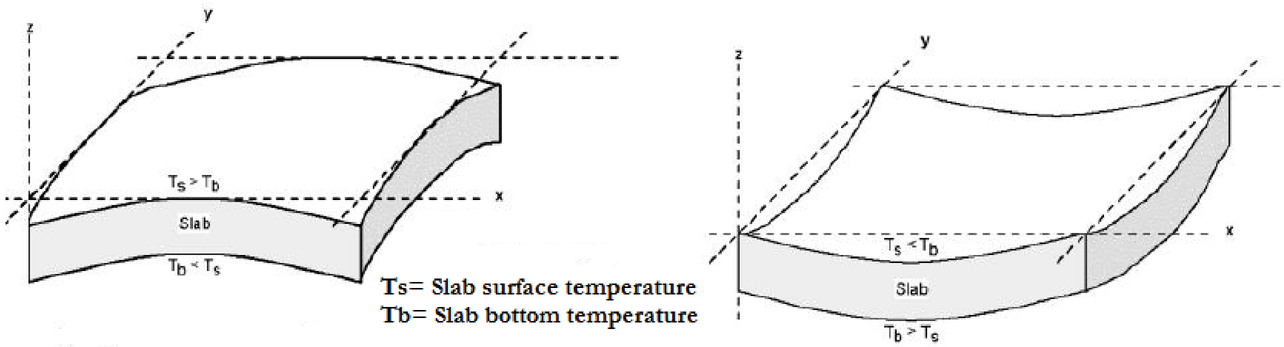


Figure 4.1. Slab response to temperature during the day (left) and night (right) time. (Rigid Pavement Response 2016)

The thermal stress that will be induced during early age of concrete (due to heat from the environment and heat liberated during hydration reaction of cement) should be resisted by the concrete so as to reduce early age cracking. In a similar manner, the concrete structure will be expected to withstand the continuous temperature fluctuation that will be expected during service life of the pavement.

Thus, for the concrete structure to withstand the stresses that will be developed during the above situations, it should be with a desirable strength development beginning from it's early age. The stresses will be resisted by the flexural strength of the concrete. Flexural strength is a measure of the tensile strength of an unreinforced concrete beam or slab to resist failure in bending (Supe and Gupta 2014).

Therefore, in this study, the strength development of concrete prepared with 100% Ordinary Portland cement and sample prepared with the incorporation of bagasse ash of various percentages were assessed starting from early age. Concrete samples were tested at 1, 1.5, 2, 3, 7, 28 and 56 days for investigating both the compressive (15cm*15cm*15cm cubes) and the flexural (10cm*10cm*50cm beams) strength development. For each percentage of replacement and for each day of investigation, two samples were used and the average of the two samples was taken as the strength of that concrete mix at that specific day. A total of 56 cubes and 56 beams were prepared for conducting the experiment with the exception of samples casted to be used as a spare. And this samples are used only for compressive and flexural strength test purpose. For the ease of identification, samples were coded as described below: -

CBAC 0 = A concrete cube sample with 0% bagasse ash.
CBAC 5 = A concrete cube sample with 95% OPC and 5% bagasse ash (by volume replacement)
CBAC 10 = A concrete cube sample with 90% OPC and 10% bagasse ash (by volume replacement)
CBAC 20 = A concrete cube sample with 80% OPC and 20% bagasse ash (by volume replacement)
CBAF 0 = A concrete beam sample with 0% bagasse ash.
CBAF 5 = A concrete beam sample with 95% OPC and 5% bagasse ash (by volume replacement)
CBAF 10 = A concrete beam sample with 90% OPC and 10% bagasse ash (by volume replacement)
CBAF 20 = A concrete beam sample with 80% OPC and 20% bagasse ash (by volume replacement)

The flexural strength of the concrete beams was tested using a third point loading in which half of the load will be applied at each third of the span length. The concrete beams were supported at their end and loaded at their interior location. The pictures below show a sample of beam prepared for flexural strength test and a diagrammatic representation of a third point loading setup.

Figure 4.2. Concrete beam prepared for flexural strength test (Third point loading).

4.3. Temperature rise

The thermal property of concrete especially at its early age is important that it has the ability to affect the structure and functionality of the concrete. The heat generated during hydration reaction of cement increases the concrete's temperature. During normal concreting, this heat will be dissipated into air or soil that the temperature difference within the concrete structure will not be significant

(PCA 1997). But during casting of massive structures and in constructions that involve bulk concreting at a time, the heat cannot be easily released. If the temperature rise is significantly high and the concrete undergoes non-uniform or rapid cooling, stresses due to thermal contraction in conjunction with structural restraint can result in cracking before or after the concrete eventually cools to the surrounding temperature (PCA 1997). This problem, will be a lot pronounced when the casting temperature is high.

In hot weather concreting, the thermal stress induced within the concrete will have the potential to exhibit early age structural failure. The corrective measures in hot weather concreting involves, cooling of aggregate and mixing water, using cooler part of the day or season for casting, using of chemical admixtures such as retardants and water reducers and using of pozzolanic materials such as fly ash and slag. From **Table 3.7**. it can be seen that the bagasse ash that is used in this experiment is with 66.92% SiO_2. By this, the silicate content of the bagasse ash will be expected to undertake secondary hydration reaction with the Calcium Hydroxide that is released from hydration reaction of Portland cement. This delays the duration by which the whole chemical reaction within the concrete will occur. By which, the heat that will be expected to dissipate during early reaction will be reduced as substantial reaction will be attained after the completion of the secondary hydration reaction (part of strength expected to be gained from the pozzolans will be in effect later).

On the basis of this, the effect of introducing bagasse ash on the thermal behavior of the concrete was investigated in the laboratory. For this, three samples were prepared with a replacement percentage of 0, 10 and 20. A rectangular formwork were prepared with a dimension of 25cm*25cm*40cm for casting of the concrete samples. Since it was not possible to conduct a study in an actual slab, it was assumed as if this concrete sections represent part of a rigid pavement slab somewhere in the middle of the slab where temperature will be high. 40cm represents the depth of the concrete slab and the other dimensions represent portion of the slab. It was assumed that the sides of the concrete sample should be confined from adjacent concrete thus blocked with a formwork. The sample was allowed to reside in a soil covered with polyethylene sheet; this was made simply to simulate the layers below the slab. The entire side of the formwork was covered by a plastic cover and a thick towel after the concrete was poured. This was done to represent the confinement of the concrete that is from the adjacent concrete and also to minimize the escape of heat from the concrete section through formwork openings. The photo below shows the entire setup of sample prepared for temperature test.

Figure 4.3. A rectangular formwork (greased) prepared for casting sample concrete for temperature test.

Figure 4.4. Sample concrete (right after casting) prepared for temperature test.

The concrete was burrowed using a 6 diameter plain bar at three different depths. This was held five and eight hours after casting of the concrete for samples prepared without and with bagasse ash respectively. Reading was held some hours after casting of the concrete as recording was inconvenient during initial time. The concrete with bagasse ash consumed a relatively longer time to set, thus temperature measurement started eight hours after casting. For the purpose of this study, the temperature rise was monitored at mid-depth, near bottom of concrete and near upper surface of concrete. The middle depth was 20cm below the surface of the sample concrete as the entire depth of the concrete was 40cm. The temperature near bottom and surface of the concrete was measured 7.5cm from the bottom and surface of the concrete respectively. These depth of investigation was chosen as per ASTM C 1064/C 1064M – 99 which specifies a 3in. [75 mm] of concrete cover from the utmost surface of the concrete. Therefore, concerned depth of investigations for the top, middle, bottom of concrete's temperature was 7.5cm, 20cm and 32.5cm from the surface of the concrete respectively. For 10% and 20% replacement, the setting time was more than five hours and the concrete reached at a plastic state around eight and half hour after its placement.

After forming a hole at concerned depths, the temperature sensors (thermocouples) were buried into the concrete at the three different depths and immediately sealed with a paste of cement so as to prevent the evacuation of concrete's internal temperature.

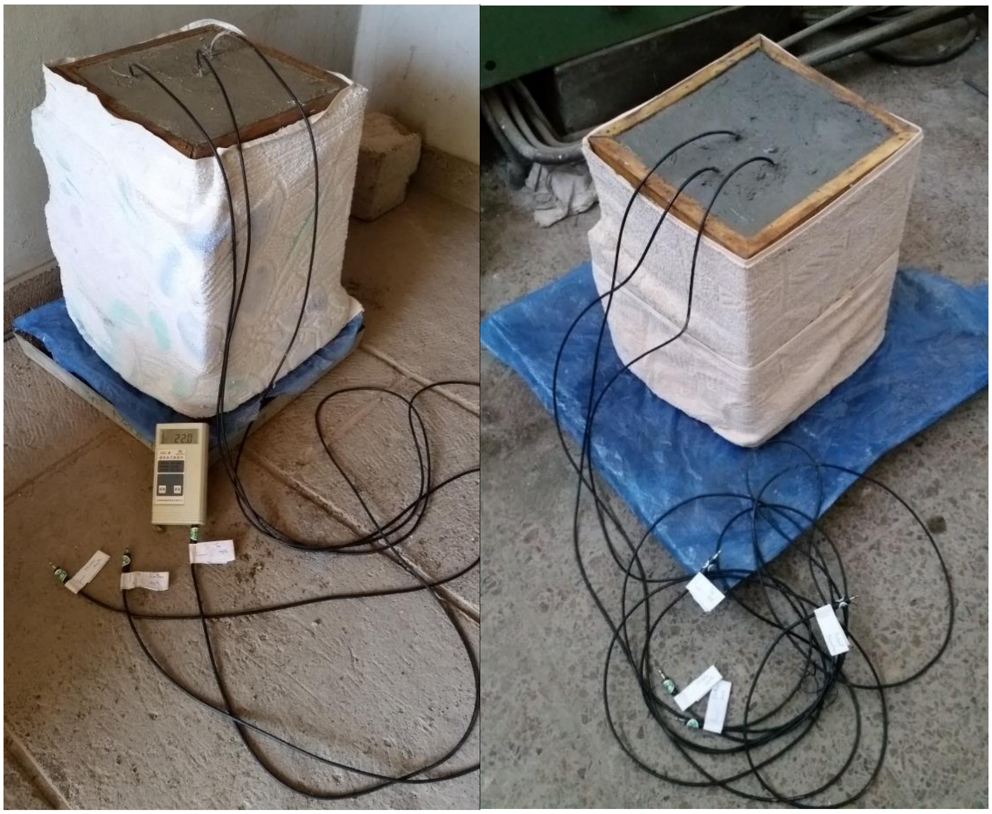


Figure 4.5. Temperature measurement of concrete samples with different percentages of bagasse ash

4.4. Water penetration depth

Permeability is a property that governs the rate of flow of fluid into a porous solid (Abobaker 2015). It can also be defined as the ability to resist weathering action, chemical attack, abrasion, or any process of deterioration. It occurs in a hardened concrete in two scenarios; first from the trapped air pockets that appear due to incomplete compaction and second from the empty space that occur due to loss of mixing water by evaporation (Abobaker 2015). A permeable concrete may allow the ingress of any fluid or deleterious substances which later affect the durability of the concrete structure and trigger corrosion of reinforcement if the concrete is RC structure.

Permeability of the concrete is affected by water to cement ratio, property of cement, curing duration and hydration process. The lower the water cement ratio, the lower will be the permeability of the concrete. The voids and unfilled space after completion of hydration has an effect in the number of pores that will be formed after the concrete cures. The higher the water cement ratio, the higher chance for the pores in the concrete will be formed after completion of hydration which later result allowable space for water to enter into the concrete structure.

The coarser the cement, the higher will be the permeability of the concrete as the lumpy and unhydrated cement will not make a flow to grasp the space which is originally occupied by the water.

Proper curing increases the impermeability of the concrete. Moreover, as hydration process progresses as desired, rate of permeability will decrease since the rate of formation of unhydrated cement will decrease. The graph below shows the relationship among initial moist curing, water to cement ratio and permeability.

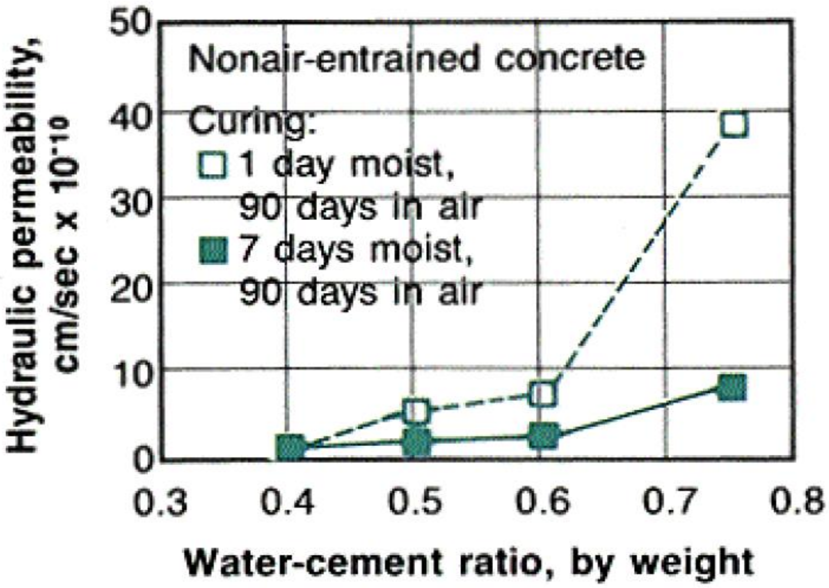


Figure 4.6. Relationship among hydraulic permeability, water to cement ratio and initial moist curing (Abobaker 2015)

The use of admixtures such as silica fume, latex emulsions, and high-range water reducers allows placement of highly impermeable concrete (Abobaker 2015). The water penetration depth of concrete with bagasse ash increases as the bagasse ash content of the concrete increases and all the concretes with bagasse ash have a penetration depth greater than those that are without bagasse ash with the exception of the average penetration depth for the concrete with 5% bagasse ash (Hailu 2011).
In this study, the water permeability of the concrete is assessed in a non-steady ("the depth of water penetration is measured without the water flow necessarily reaching a constant value" (Hailu 2011)) state water permeability test. Specimens served a water pressure of 3Bar, 5Bar and 7Bar for the first, second and third 24hrs respectively [ISO/DIS/7031]. The entire experiment requires 72hours to be completed and specimens will be ready for the experiment after 28days of being casted.

A concrete cube prepared without bagasse ash and samples prepared with bagasse ash of 10% and 20% were prepared to conduct the experiment. Three sample cubes were prepared for each percentage of replacement and an average value was taken. Measurement was conducted on 28-day sample specimens.

Figure 4.7. Sample concrete cubes under water penetration depth experiment

After the samples spent 72 consecutive hours while being in an experiment, they were split (along the direction which the pattern of depth of penetration of water can clearly be revealed) by the end of the 72 hour. The maximum and average depth of penetration of water was then recorded so as to observe the effect of bagasse ash on water penetration depth of the concrete.

5. RESULTS AND DISCUSSION

In concrete rigid pavement, two basic things need to be under consideration: the stresses and loads that the pavement will serve during its early age and same phenomena that it encounters during its operational period. Most rigid pavement specifications and design guidelines are based on concrete property which completes its maturity period. The concrete property that will be introduced during the design stage is based on 28 day compressive and flexural strength test. With this, unless there is a situation where traffic prediction was conducted in a feeble manner and the intended material quality gets jeopardized, the concrete section will have the required strength to withstand the load which comes from the traffic and also from the environment. But before reaching into 28 days, the pavement slab will experience self-equilibrated stresses mainly triggered by thermal and/or hydral action. The heat that will be generated from hydration reaction along with environmental temperature, (especially if concreting is in hot weather) will form a thermal stress that lets the concrete slab to be subjected into stress and eventually gets cracked. This phenomenon is called early age cracking and is basically due to the induced thermal stress within the concrete. Without considering this aspect, the concrete may structurally and functionally fail before reaching into the required state. Thus, this study focuses on both early age and matured property of the concrete but with a great emphasize to early age characteristics as matured property of the concrete is already being in consideration in a comprehensive manner in most specifications and design guidelines.

With this, the strength (compressive and flexural) of the concrete and its thermal characteristics were assessed beginning from the concrete's early age. And concrete's durability characteristics was also investigated in its matured state (28 days) with respect to water penetration depth assessment. By this, it was possible to see the contributory aspect of using bagasse ash in concrete rigid pavements.

It was expected for the laboratory experiments could be with certain limitations that measurements and results obtained during the experiment might have the chance to be corrupted with certain plus or minus figures from the real situation in the samples. For this, a finite element software: DuCOM-COM3D: was used to evaluate results. Same sample prepared for temperature test was modeled in the software and the response of temperature was observed relative to the temperature read during the laboratory experiment. This was used to evaluate the extent with which the simulation and the result from the laboratory experiment can vary from each other. Thus, based on this, a thermo-hygro simulation of a concrete slab panel was made using the multi-component heat of hydration model (Maekawa 1999) to assess the relative performance of concrete with and without bagasse ash against early age cracking.

Regarding the native property of bagasse 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 a research done on this material in the year 2011 (Hailu 2011). Bagasse ash which did not pass through any modification (except being sieved with 300μm sieve) exhibited a specific surface area value of 3430cm^2/g (343m^2/kg). This figure is a relatively higher value when it is compared with the specific surface area of the cement (3160cm^2/g (316m^2/kg)) used in this research. Bagasse ash taken from the same source but passed through a thorough pulverization, showed a specific surface area 62% higher than the cement that was used by the time (Hailu 2011). The specific surface area of cement and bagasse ash used in this research had shown a small gap between them. Since the bagasse ash used in this research did not pass through any modification interms of fineness, it was not able to show higher specific surface area as compared to the cement but still a relatively higher value.

The gradation of bagasse ash at 75µm sieve was showing a percentage passing amount that is 53.42% lower than that of the cement in the same sieve. It showed a lower percentage passing value as compared to the cement in all sieves except at 32µm sieve.

The results of the major experiments are presented and discussed as shown below.

5.1. Results and discussion on flexural and compressive strength test

5.1.1. Results and discussion on flexural strength test

The experimental program of concrete samples for flexural strength test was arranged in a fashion described in the experiment schedule section of this study. A third point loading machine was used to measure the flexural strength of the concrete beams.

ASTM C78/C78M (2010) standard testing method for flexural strength test was used for determining the flexural strength of beams. According to the standard, the load should be applied at a rate that can constantly increases the extreme fiber stress between 125 and 175 psi/min (0.86 and 1.21 MPa/min), until rupture occurs (ASTM C78/C78M – 10 2010). For this study, a loading rate of 0.02MPa/sec was used to test all the beams. The test results were read from the display board of the measuring device as time (in second) verses load (in KN) graph. The display board from the measuring device plots the progress of the test in a graph and also shows the numerical value (both load in KN and stress in MPa) until the specimen fail and the test being completed. The picture below shows a concrete beam which is under flexural strength test.

Figure 5.1. A concrete beam under flexural strength test (left) and data recorded in the display board (right)

During the test, most of the beams were failing by forming a crack which was occurring in the mid 1/3rd span of the beam and few were falling abruptly without showing a noticeable warning. The picture below shows the two sides of a beam which failed by forming a crack in the interior section of the beam.

Figure 5.2. A concrete beam after completion of flexural strength test.

At the end of every experiment, failure load and stress values were recorded for each sample. For each percentage of replacement at each test day, two samples were prepared and the average of the two samples was taken as the flexural strength of that specific concrete type at that specific day. The table below shows the average flexural strength value obtained for each percentage of replacement at each day. The detail test result is attached on the appendix section of this study.

Table 5.1. Summary of average failure load result in flexural strength test.

TEST RESULTS FOR FLEXURAL STRENGTH								
Percentage of replacement	Code	Test day						
		1 day	1.5 day	2 days	3 days	7 days	28 days	56 days
		Test Result (Failure load (KN))						
0%	CBAF 0	2.79	3.91	4.97	5.72	8.21	11.09	11.21
5%	CBAF 5	3.36	4.54	5.67	6.70	8.94	11.70	12.10
10%	CBAF 10	3.66	4.91	6.11	6.98	8.47	12.14	12.58
20%	CBAF 20	1.51	1.83	2.06	4.08	7.40	9.60	10.38

Table 5.2. Summary of average flexural strength test values.

TEST RESULTS FOR FLEXURAL STRENGTH								
Percentage of replacement	**Code**	**Test day**						
		1 day	**1.5 day**	**2 days**	**3 days**	**7 days**	**28 days**	**56 days**
		Test Result (Strength (N/mm²))						
0%	CBAF 0	1.26	1.76	2.24	2.58	3.70	5.00	5.05
5%	CBAF 5	1.52	2.05	2.56	3.02	4.03	5.27	5.45
10%	CBAF 10	1.65	2.21	2.75	3.14	3.81	5.47	5.67
20%	CBAF 20	0.68	0.82	0.93	1.84	3.33	4.33	4.68

From the result it can clearly be seen that a concrete with 5% and 10% bagasse ash had shown a higher flexural strength value as compared to the other samples in each test day. While a replacement ratio of 20% indicated a reduced flexural strength as compared to the reference mix.

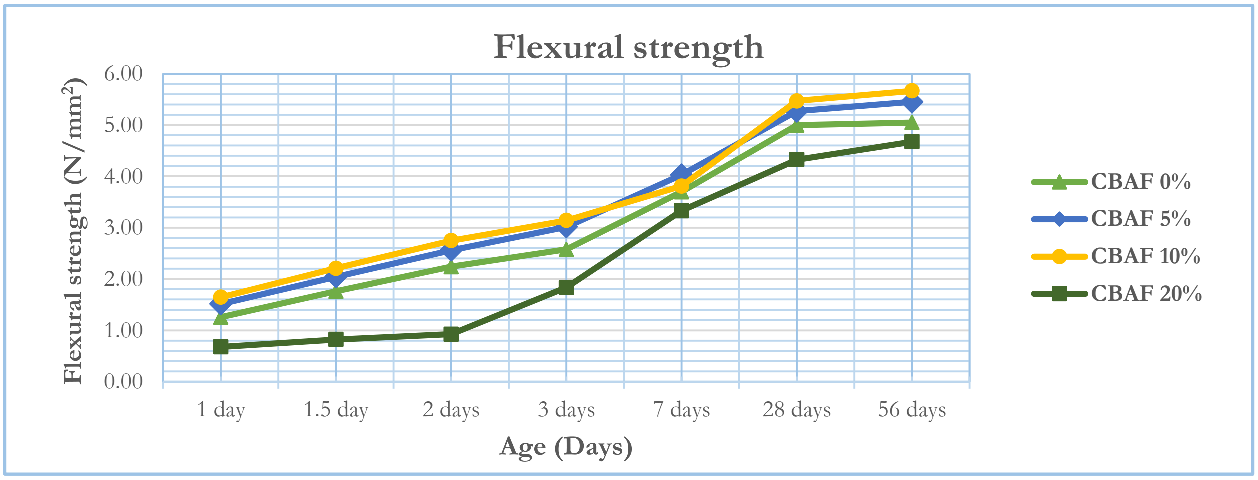


Figure 5.3. Average flexural strength value of concrete beams

Interestingly, the enhancement in flexural strength for the 5% and 10% replacement ratio was observed to be higher starting from the early age. The flexural strength for the 10% replacement ratio mix showed an enhancement of 31% from the reference mix. This notable increase in strength is crucial for minimizing the risk of early age thermal cracking in hot-weather concreting of rigid pavements and other mass concrete structures.

5.1.2. Results and discussion on compressive strength test

Compressive strength test is a common performance measure of concrete durability and quality. One of the input parameter in concrete rigid pavement design is the modulus of elasticity of the concrete that will be determined from the 28th day compressive strength test value.

Figure 5.4. A concrete cube under compressive strength test.

The test schedule for compressive strength was arranged in a similar manner like that of the flexural strength. Two samples of concrete cubes were prepared for testing the compressive strength of a concrete in each percentage of replacement and at each day of investigation. The average compressive strength value of the concrete is summarized as shown in the table below. The detail of the compressive strength test result of concrete samples are attached in the appendix section of this report.

Table 5.3. Summary of average failure load result in compressive strength test.

TEST RESULTS FOR COMPRESSIVE STRENGTH								
Percentage of replacement	**Code**	**Test day**						
		1 day	**1.5 day**	**2 days**	**3 days**	**7 days**	**28 days**	**56 days**
		Test Result (Failure load (KN))						
0%	CBAC 0	147.4	232.1	314.0	356.9	550.8	919.8	973.7
5%	CBAC 5	184.3	250.3	315.7	403.9	593.6	973.5	1012.7
10%	CBAC 10	147.7	235.0	320.8	392.1	570.0	931.9	980.3
20%	CBAC 20	149.3	208.3	264.8	360.3	421.8	874.4	921.8

Table 5.4. Summary of average compressive strength test values.

TEST RESULTS FOR COMPRESSIVE STRENGTH								
Percentage of replacement	**Code**	**Test day**						
		1 day	**1.5 day**	**2 days**	**3 days**	**7 days**	**28 days**	**56 days**
		Test Result (Strength (N/mm^2))						
0%	CBAC 0	6.55	10.32	13.96	15.86	24.48	40.88	43.27
5%	CBAC 5	8.19	11.13	14.03	17.95	26.39	43.26	45.00
10%	CBAC 10	6.57	10.45	14.26	17.43	25.33	41.41	43.56
20%	CBAC 20	6.64	9.26	11.77	14.05	18.75	38.86	40.96

Form the result it can be seen that the average compressive strength value of concrete with 5% bagasse ash was showing a relatively high strength value than the other concrete samples. The 28-day compressive strength value of concrete with 5% and 10% bagasse ash replacements were showing a strength enhancement of about 5.8% and 1.29% respectively.

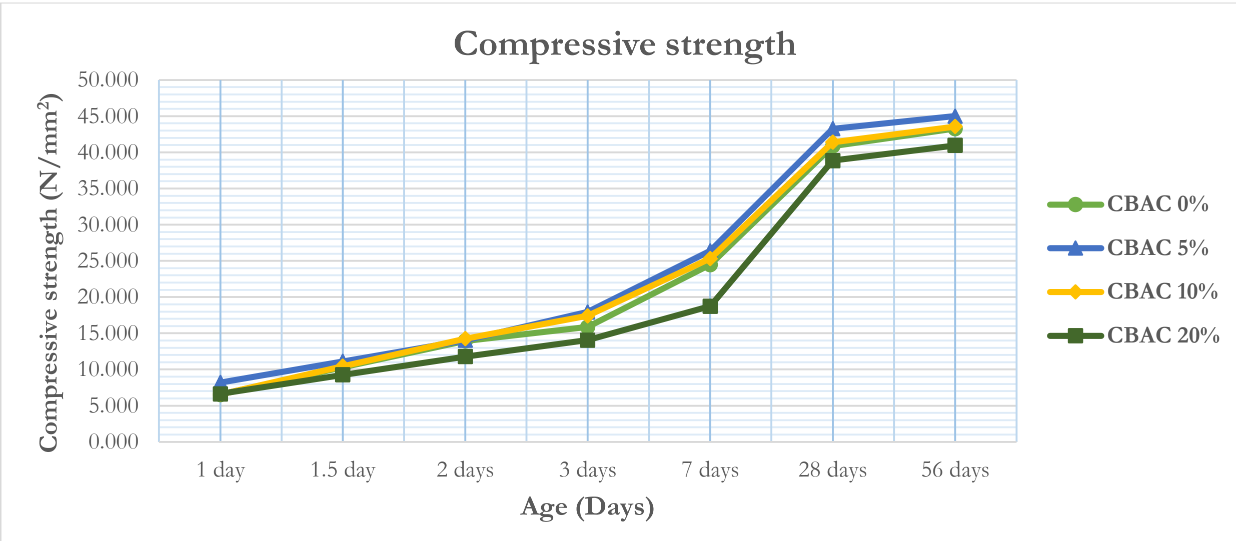


Figure 5.5. Average compressive strength value of concrete samples.

The compressive strength for the 5% and 10% bagasse ash replacement had shown an improvement in compressive strength in contrast with the reference mix. However, as replacement ratio increases to 20%, the compressive strength tends to reduce from the reference. It is interesting to note that the strength gain obtained in flexure is greater than the strength enhancement achieved in compressive strength. The pronounced flexural strength gain due to the replacement of 10% bagasse ash may be attributed to the enhanced microstructure at the interface between aggregates and the paste. This Interfacial Transition Zone (ITZ) is characterized by relatively porous nature with high concentration of Calcium Hydroxide released from the hydration of cement (Liao et al. 2004). However, the addition of bagasse ash as a partial replacement had believed to enhance the microstructure of the ITZ possibly due to the secondary hydration reaction created among water, bagasse ash and Calcium Hydroxide.

When the compressive and flexural strength values of concrete made with various percentages of replacement of bagasse were analyzed jointly, an optimum percentage of replacement of 10% was found to be promising from the aspect of strength.

5.2. Results and discussion on temperature rise

The temperature rise test with 100% OPC concrete was done in a relatively colder season (maximum ambient temperature was 16.7^{0}C). But the other two samples i.e. concrete sample with bagasse ash percentage replacement of 10% and 20% were casted simultaneously and at same temperature (18^{0}C). Since two of the samples were casted at different temperature from the other one, the analysis of the result tried to synchronize the obtained values relative to the ambient temperature recorded for the respective time period of concerned concrete sample.

The temperature was measured using a thermocouple which has a temperature sensor/detector at one end and a jack that will be connected into a reader on the other end.

Figure 5.6. Thermocouples and temperature reader that was used to measure temperature

Readings were recorded with a one hour interval beginning from the initial setting time of the concrete (five and eight hours after casting for concrete without and with bagasse ash respectively). The depth of interests (reading points) were 7.5cm, 20cm and 32.5cm down from the surface of the concrete. Thus, three thermocouples were buried in each concrete sample to read the temperature near surface of the concrete, at middle depth and near bottom of the concrete. In addition to the three thermocouples, additional one thermocouple was used to read the ambient temperature of the time.

The temperature read from each concrete sample at each depth of interest was recorded along with the respective ambient temperature in an interval of one hour. Readings were taken continuously until the concrete sample reached its maximum temperature rise and a few hours after it attains this point. The detail reading of each sample of concrete is attached in the appendix section of this report.

In order to build a clear margin in comparing the thermal response of the three samples, the readings form the three depths of investigation were deducted from their respective ambient temperature so as to see the gradient they formed relative to their surrounding temperature. These temperature values are depicted in a graph so as to observe the temperature rise pattern of sample concretes. The temperature pattern of the three concrete samples at each depth is plotted independently so as to compare them with their respective depth of investigation (**Figure 5.7- 5.9**). Moreover, the tables presented below show the detail figure of temperature recorded.

Table 5.5. Early age thermal response of concrete without bagasse ash.

Time	Difference between ambient and top depth temperature (^{0}C)	Difference between ambient and middle depth temperature (^{0}C)	Difference between ambient and bottom depth temperature (^{0}C)
3:16PM	0.10	1.70	1.10
4:16PM	-0.10	1.80	1.00
5:16PM	0.50	2.80	2.00
6:16PM	0.80	3.50	2.70
7:16PM	1.40	4.10	3.30
8:16PM	2.10	4.80	3.60
9:16PM	4.30	7.30	5.80
10:16PM	4.50	7.80	6.10
11:16PM	5.40	9.10	7.10
12:16PM	6.50	10.50	8.30
1:16AM	7.40	11.90	9.90
2:16AM	9.70	14.50	11.60
3:16AM	9.40	14.60	12.40
4:16AM	9.40	14.80	12.60
5:16AM	9.50	15.10	13.00
6:16AM	**10.80**	**16.60**	14.60
7:16AM	9.10	14.90	13.10
8:16AM	10.40	16.40	**14.80**
9:16AM	7.00	12.80	11.30
10:16AM	8.00	13.50	12.00
11:16AM	7.20	12.80	11.20
12:16AM	6.60	12.00	10.40
Average	**5.91**	**10.15**	**8.54**

Table 5.6. Early age thermal response of concrete with 10% bagasse ash.

Time	Difference between ambient and top depth temperature (^{0}C)	Difference between ambient and middle depth temperature (^{0}C)	Difference between ambient and bottom depth temperature (^{0}C)
7:30PM	0.70	2.70	2.40
8:30PM	1.80	4.10	3.80
9:30PM	2.20	4.70	4.60
10:30PM	1.59	5.90	5.70
11:30PM	3.90	7.00	6.80
12:30PM	4.70	8.20	7.90
1:30AM	5.00	8.80	8.50
2:30AM	5.50	9.70	9.40
3:30AM	6.20	10.50	10.30
4:30AM	6.50	11.00	10.80
5:30AM	6.60	11.20	11.00
6:30AM	7.00	11.70	11.60
7:30AM	**8.80**	**13.80**	**13.90**
8:30AM	6.50	11.60	11.90
9:30AM	4.50	9.40	9.80
10:30AM	4.10	8.80	9.20
11:30AM	3.80	8.10	8.50
12:30PM	3.50	7.60	8.00
1:30PM	3.30	7.20	7.60
2:30PM	2.90	6.70	7.10
3:30PM	2.20	5.70	6.20
4:30PM	0.70	2.70	4.60
5:30PM	0.40	2.50	4.50
6:30PM	0.80	2.90	4.90
7:30PM	1.10	3.30	5.40
8:30PM	1.20	3.70	5.70
Average	**3.67**	**7.29**	**7.70**

Table 5.7. Early age thermal response of concrete with 20% bagasse ash.

Time	Difference between ambient and top depth temperature (^{0}C)	Difference between ambient and middle depth temperature (^{0}C)	Difference between ambient and bottom depth temperature (^{0}C)
7:30PM	-1.00	0.30	0.40
8:30PM	-0.20	0.10	1.00
9:30PM	-0.40	0.60	1.00
10:30PM	-0.10	0.90	1.40
11:30PM	0.40	2.00	1.70
12:30PM	1.10	2.80	2.70
1:30AM	1.30	3.20	3.10
2:30AM	1.80	4.10	3.90
3:30AM	2.60	5.10	4.70
4:30AM	3.10	5.90	5.30
5:30AM	3.30	6.20	5.70
6:30AM	4.00	7.20	6.50
7:30AM	**6.00**	**9.70**	**9.00**
8:30AM	4.00	8.00	6.70
9:30AM	2.00	6.30	4.80
10:30AM	0.90	6.20	5.00
11:30AM	1.30	5.90	5.10
12:30PM	1.70	5.80	5.20
1:30PM	2.20	5.80	5.20
2:30PM	2.10	6.00	5.40
3:30PM	1.60	5.30	4.70
4:30PM	0.60	4.00	3.30
5:30PM	0.40	3.90	3.20
6:30PM	0.80	4.30	3.70
7:30PM	1.20	4.70	4.30
8:30PM	1.30	5.00	4.70
Average	**1.62**	**4.59**	**4.14**

Table 5.8. Summary of average temperature rise.

Percentage of replacement of bagasse ash	Average difference between ambient and top depth temperature (^{0}C)	Average difference between ambient and middle depth temperature (^{0}C)	Average difference between ambient and bottom depth temperature (^{0}C)
0%	5.91	10.15	8.54
10%	3.67	7.29	7.70
20%	1.62	4.59	4.14

From the table it can be inferred that, the average temperature of the concrete for each depth of investigations were dropping as the percentage of bagasse ash increases. Moreover, the maximum middle depth temperature reached by the concrete sample with 20%, 10% and 0% bagasse ash was 9.7 ^{0}C, 13.8 ^{0}C and 16.6 ^{0}C respectively. The maximum middle depth temperature reached by a concrete sample with 0% bagasse ash was 16.6 ^{0}C which was a higher value (even though it was casted in a cold season) as compared to other samples of concrete.

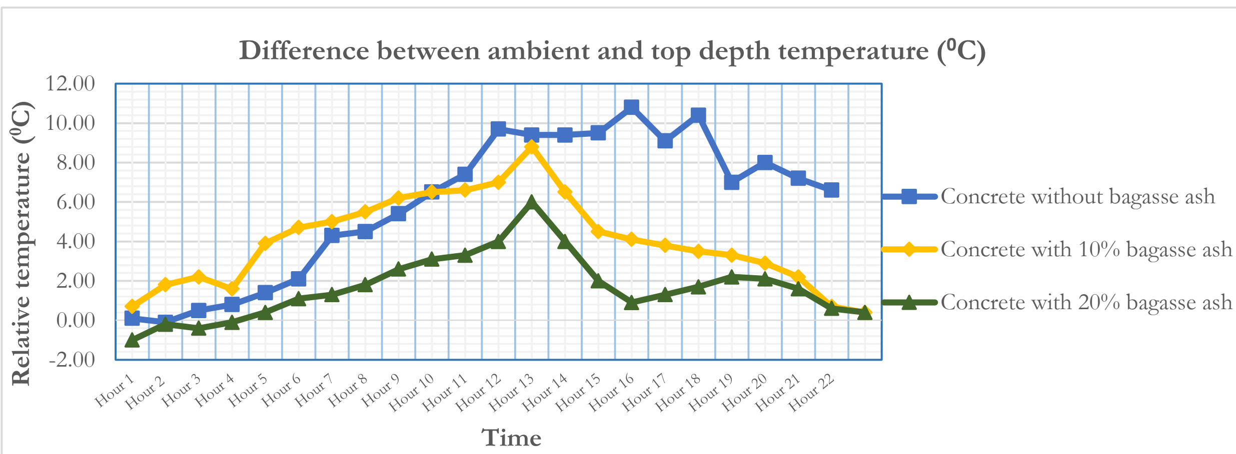


Figure 5.7. Difference between ambient and top depth temperature (^{0}C).

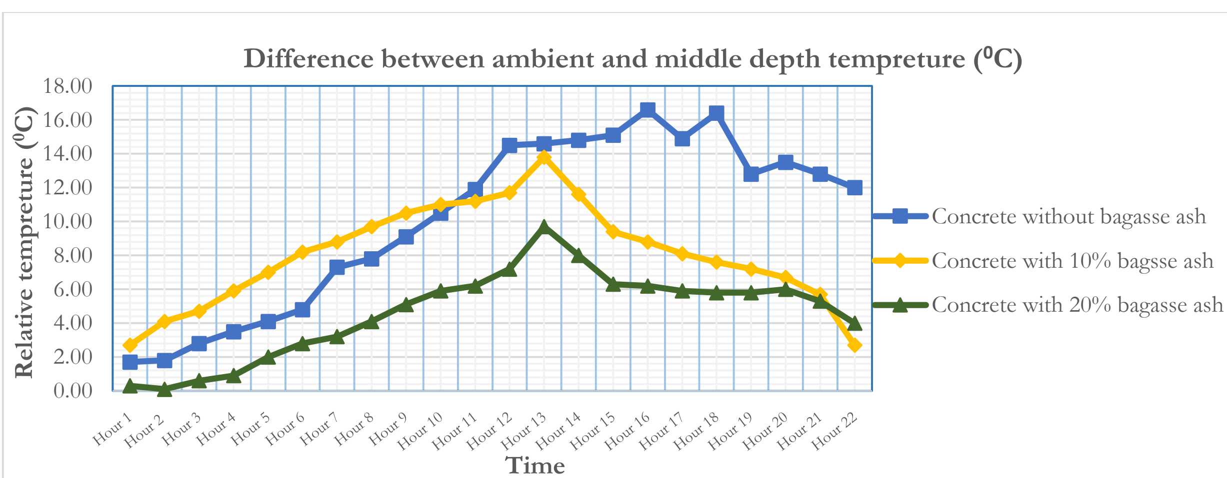


Figure 5.8. Difference between ambient and middle depth temperature (^{0}C).

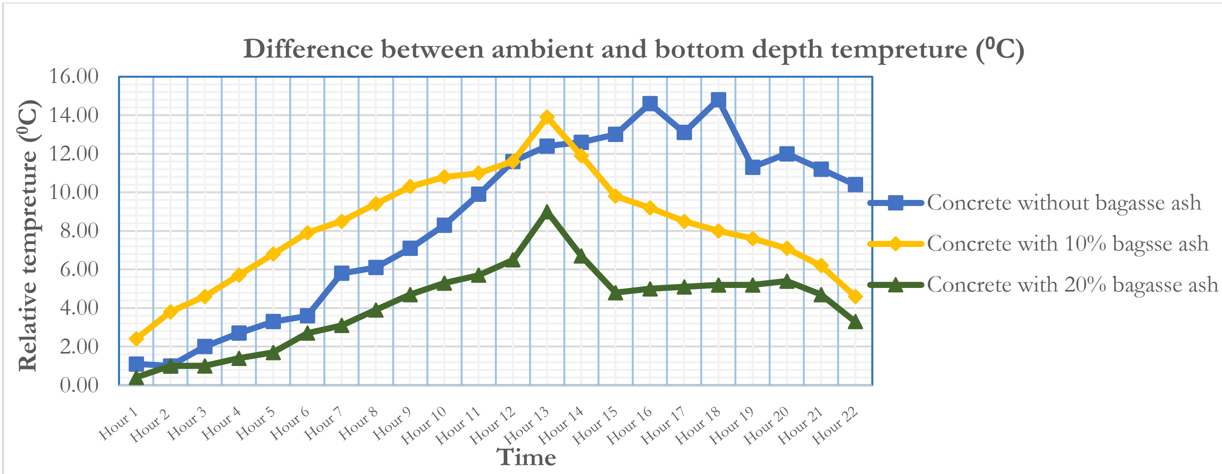


Figure 5.9. Difference between ambient and bottom depth temperature (^{0}C).

In all the three depth of investigations, the highest and lowest peak relative temperature values were observed in a concrete sample with 0% and 20% bagasse ash respectively. During the initial phase of measurement, the concrete sample with 10% bagasse ash was showing a higher relative temperature value than the concrete sample made without bagasse ash. But in all the three depths, the concrete without bagasse ash was exhibiting a dominant relative temperature value.

A concrete sample with 20% bagasse ash was showing a relatively low temperature rise in contrast to those made with 10% and 0% replacement. The maximum temperature rise recorded in a concrete sample with 20% bagasse ash was 41.56% lesser than the one recorded by the concrete sample made without bagasse ash. Generally, the experimental results indicated that the maximum temperature rise had decreased with the increase in bagasse ash replacement ratio. The decrease in temperature rise combined with the enhancement of flexural strength at early age makes the bagasse ash an ideal cementitious material for reducing the risk of early age thermal cracking particularly in rigid pavement construction and mass concreting.

5.3. Result and discussion on water penetration depth test

The water pentation response of this material was investigated from the concrete's ability to withstand the ingress of water. As discussed in the experimental schedule of this study, the water penetration depth test was conducted using three group of concrete samples; a concrete samples made without bagasse ash and samples made with 10% and 20% bagasse ash. For each group, three cube samples (15cm*15cm*15cm) were prepared and pass through a water penetration depth test.

After a 72 hours test duration, sample concretes were taken off from the testing machine and split into two halves so as to see the depth of water penetration.

Figure 5.10. A concrete cube passing water penetration test when ready to be split (left) and after it was split (right).

After the split, the portion of concrete in which water entered appeared to be darker than the rest of the portion of the concrete. The boundary between the darker portion and the rest of the concrete portion was marked and measurements were taken.

Figure 5.11. Concrete cube sample split after passing water penetration test.

The average and maximum water penetration depth of each concrete samples were measured from the split concrete pieces for each sample group and tabulated as follows.

Table 5.9. Average and maximum water penetration depth.

Percentage of replacement	Average water penetration depth (mm)	Maximum water penetration depth (mm)
0%	23	31
10%	20	40
20%	31	50

The average water penetration depth of concrete samples made without bagasse ash and samples made with 10% bagasse ash had shown a comparable value though the depth of penetration was 3mm lower for the later. The average water penetration depth for the 20% replacement ratio was the highest value (31mm) relative to the other two sample groups. With this, the 10% replacement showed superior performance towards resistance for water penetration which indirectly relates to durability performance.

This test was conducted using a cube of concrete with size 150mm*150mm*150mm. A sample concrete with shape (cylindrical) and size which fits on the base of water penetration depth measuring apparatus would have been preferable and can give a more representative result than a concrete sample with cube shape. Thus, this test result shall be seen in a relative aspect; a result obtained with a concrete sample which was not in a convenient state for the apparatus.

Based on the overall experimental observations, it can be easily noted that the replacement of 10% bagasse ash contributed to the increase in strength (compressive and flexure), reduced generation of heat due to hydration and increased resistance against water penetration. This makes the material ideal for use in hot weather concreting of pavements as well as other mass concrete structures.

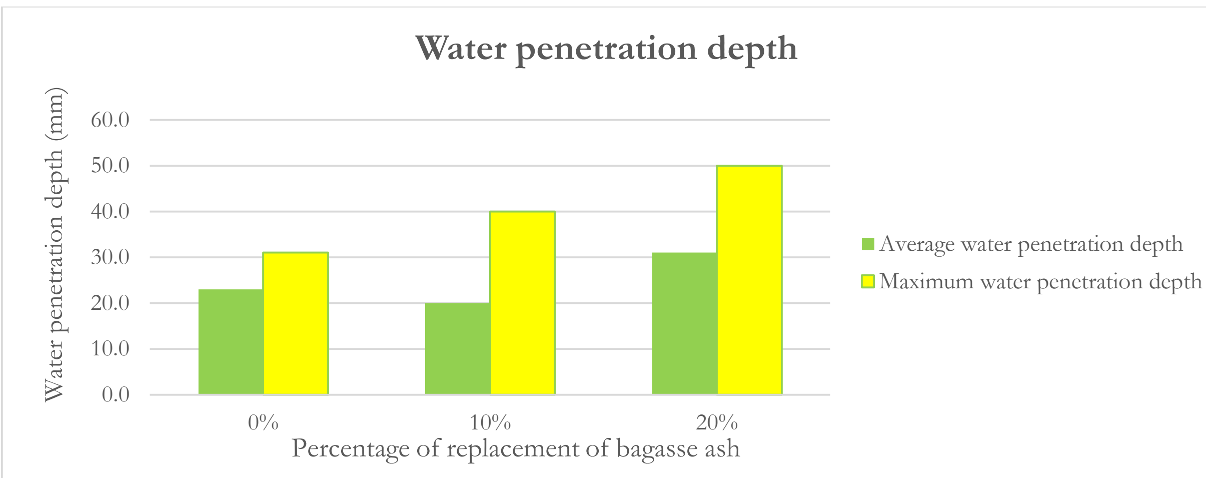


Figure 5.12. Average and maximum water penetration depth

In speaking about permeability characteristics, "Testing concrete for permeability has not been generally standardized so that the values of the coefficient of permeability quoted in different publications may not be comparable" (Neville 2011). In such tests, as are used, the steady-state flow of water through concrete due to a pressure gradient is measured, and Darcy's equation is used to calculate the coefficient of permeability, K (Neville 2011). There is an expression that has been developed by Valenta to convert the depth of penetration of water into the coefficient of permeability, K (in meters per second) equivalent to that used in Darcy's law (Neville 2011).

$$K = ev^2/2ht \quad \text{Eq. 5.1}$$

Where: - e = depth of penetration of water in a concrete in meters,

h = hydraulic head in meters,

t = time under pressure in seconds,

v= the fraction of the volume of concrete occupied by pores.

The value of v represents discrete pores, such as air bubbles, which do not become filled with water except under pressure, and can be calculated from the increase in the mass of concrete during the test and typically, v lies between 0.02 and 0.06 (Neville 2011). The hydraulic head is applied by pressure which usually ranges between 0.1 and 0.7 MPa (Neville 2011). The coefficient of permeability is directly proportional to the depth of penetration of water in the concrete thus an increase in depth of penetration of water increases the coefficient of permeability.

A concrete with depth of penetration of water less than 50 mm is classified as 'impermeable' and a concrete with depth of penetration of water less than 30mm is considered as 'impermeable under aggressive conditions' (Neville 2011). Therefore, the above concrete samples with all percentage of replacements can be considered as impermeable as per the above mentioned d criteria.

6. DESIGN AND MODELING

6.1. Design

The objective of structural pavement design is to provide a road which can resist the anticipated traffic load and stresses without deteriorating in its service life. This is mainly achieved by designing a pavement structure that can withstand the stresses on the subgrade in an acceptable range as the load from the traffic will be expected to be dominantly resisted by the concrete slab in the case of concrete rigid pavement.

Therefore, this study aimed to see the impact of the laboratory test results on the design aspect. In the laboratory, the incorporation of bagasse ash in the concrete as a cement replacing material was showing a relatively better concrete characteristic as compared to the concrete made without bagasse ash. Therefore, in this section of the study, the effect of bagasse ash in the design of concrete pavement slab was dealt using the results obtained from the laboratory experiments.

Two different design standards were proposed to be used in the design so as to broaden the comparison margin and to illustrate material's effect in the determination of slab thickness. The candidate standards were ERA (2013) and AASHTO (1993) concrete rigid pavement design standards and guidelines. But ERA 2013 manual doesn't allow designers to entertain such a relatively narrow material property gap. Therefore, AASHTO (1993) standard was used to compute depth of the slab.

AASHTO (1993) design guideline uses an empirical approach to compute the slab thickness. It is used to relate observed or measurable phenomena with outcomes and its input design parameters require calibration of past and present practice, experience and pavement performance. The design standard uses average values for most of the variables used in the estimation of pavement performance. The principal empirical equation used to determine slab thickness in AASHTO standard is presented as follows:-

$$\log_{10}(W_{18}) = Z_R \times S_o + 7.35 \times \log_{10}(D+1) - 0.06 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.5-1.5}\right)}{1+\frac{1.624 \times 10^7}{(D+1)^{8.46}}} + (4.22 - 0.32 p_t) \times \log_{10}\left[\frac{(S_c')(C_d)(D^{0.75}-1.132)}{215.63(J)\left(D^{0.75} - \frac{18.42}{\left(E_c/k\right)^{0.25}}\right)}\right]$$

(AASHTO 1993) ……………………………………………………………… ………… Eq. 6.1

Where:- W_{18} = Predicted ESALs for the design period.

Z_R = Standard normal deviate for the desired reliability

S_o = Combined standard error of the traffic prediction and performance prediction

D = Slab depth (inches)

P_t = Terminal (final) serviceability index

ΔPSI = Difference between the initial design serviceability index, Po, and the design terminal serviceability index, Pt

S_c = Modulus of rupture of PCC (flexural strength)

C_d = Drainage coefficient

J = Load transfer coefficient used to adjust for load transfer characteristics of a specific design

E_c = Elastic modulus of PCC

K = Modulus of subgrade reaction (Psi/in)

The design inputs required for slab depth determination along with the corresponding adopted values used in this study are listed below. Most of the input parameters were not the concern of this study except material properties related to modulus of elasticity and modulus of rupture of concrete. Therefore, the only variables were these two parameters which of their value was obtained from the laboratory test. The other parameters were estimated based on the design inputs considered in some practical projects and kept constant for both type of concrete.

Modulus of subgrade reaction (K)

The sub layers below the concrete slab in rigid pavements are generally represented with K-value (an effective modulus of sub grade reaction). The AASHTO 1993 design guide procedure for determining the effective modulus of sub grade reaction value is rather complex based on the sub grade soil resilient modulus, considering the seasonal variation and then adjusting upwards and downwards for the sub base type and thickness, potential loss of support and presence of bed rock within 3.05 meters of depth below the surface. Effective modulus of reaction can be determined either by plate load test (using 750mm ø plate) or indirectly from subgrade and sub-base CBR. As the purpose of this study focuses on the concrete property only, an effective modulus of subgrade reaction value of **180Psi/in** was used.

Design traffic W_{18}

The expected axle load spectrum over the deign period will be expressed in terms of an equivalent number of 18kip ESAL calculated using load equivalency factor that relates the damage encountered by a given axle type and the damage encountered by standard axle of that type. For the computation, in this study, W_{18} value of **160million ESAL** was used.

Modulus of elasticity of concrete (E_c)

ACI recommends a correlation for the modulus of elasticity of concrete with normal weight Portland cement as:-

$$E_c = 57,000\ (f_c')^{0.5}$$

Where:- E_c = PCC elastic modulus (Psi)

f_c' = PCC 28 day compressive strength (cylindrical) (Psi)

The equivalent cylindrical strength calculated from cubical compressive strength result was computed as cubical strength/1.25.

The average cubical strength of concrete made without bagasse ash and that of concrete made with 10% bagasse ash (optimum value selected based on laboratory test result) at their 28 day age was obtained as 40.875MPa and 41.41MPa respectively. From this, the corresponding cylindrical strength value for 0% and 10% bagasse ash replacement was calculated as 32.7MPa and 33.128MPa. Therefore, the corresponding modulus of elasticity of concrete for the two concrete samples was obtained as

$= 57,000(32.7*145.0377)^{0.5} =$ **3,925,449Psi** (For 0% replacement)

$= 57,000(33.128*145.0377)^{0.5} =$ **3,951,054Psi** (For 10% replacement)

Modulus of rupture (Sc')

Modulus of rupture of concrete is a 28 day flexural strength value based on a third point loading. The 28 day flexural strength values obtained for a 0% and 10% replacement of bagasse ash was 5MPa and 5.47MPa (**725.18Psi** and **793.35Psi** in imperial unit) respectively.

Change in serviceability (ΔPSI)

It is difference the between initial and terminal serviceability of the road. A rating of 5 being an excellent serviceability status and 0 be the worst. For this study, initial and terminal serviceability value of 4.5 and 2.5 was taken respectively and ΔPSI became **2**.

Reliability (Z_R and S_o)

The reliability of the pavement design performance process is the probability that a pavement section designed using the process will perform satisfactorily over the traffic and environmental condition (AASHTO 1993). Z_R and S_o values account for degree of certainty of the road's performance for the intended traffic, environmental condition and other unforeseen situation that may occur during service life.

AASHTO 1993 recommends a reliability range for various types of road in a rural area and urban area. For the sake of this study a reliability value of 95% (Z_R = -**1.645**) and S_o value of **0.35** was considered.

Drainage factor (C_d)

Drainage factor determines the ability of subsurface drainage being removed within 1 to 72 hours. Different drainage coefficients, which represent the relative loss of pavement strength due to the duration of exposure of pavement structure to moisture levels approaching saturation and quality of drainage, are suggested in the AASTHO (1993) guide. For the purpose of this study, a C_d value of **1** was taken.

Load transfer factor (J)

Load transfer factor is a factor used to account the ability of a concrete pavement structure to transfer load across discontinuities such as joints or cracks (AASHTO 1993). The value of J recommended for plain jointed pavement or a reinforced jointed pavement with a load transferring device such as dowel bars and tie bars ("Protected corner" condition at AASHO road test) is 3.2. Thus a J value of **3.2** was taken for this study.

Therefore, using the above inputs, a slab thickness was estimated in an iterative manner using the above ASSHTO equation. An excel template was prepared to easily go for the calculation in the iteration and the slab depth that can withstand the specified traffic was calculated as shown in the tables below. Two tables; one for the concrete prepared without bagasse ash and the other for a concrete prepared with 10% bagasse ash.

Table 6.1. Determination of slab depth using ASSHTO (1993) standard for a concrete made without bagasse ash.

D	Z_R	S_O	ΔPSI	S_C	C_d	J	E_C	K	P_t	Log 10(W_{18})	W_{18} Calculated	W_{18} Design	W_{18} Calculated/ W_{18} Design
8.52	-1.645	0.35	2	725.18	1	3.2	3,925,449.00	180	2.5	6.624575604	4,212,846.19	160,000,000.00	0.03
9.33	-1.645	0.35	2	725.18	1	3.2	3,925,449.00	180	2.5	6.864945519	7,327,326.09	160,000,000.00	0.05
10.50	-1.645	0.35	2	725.18	1	3.2	3,925,449.00	180	2.5	7.187593737	15,402,589.37	160,000,000.00	0.10
11.30	-1.645	0.35	2	725.18	1	3.2	3,925,449.00	180	2.5	7.39234211	24,679,826.96	160,000,000.00	0.15
11.70	-1.645	0.35	2	725.18	1	3.2	3,925,449.00	180	2.5	7.490253733	30,921,014.38	160,000,000.00	0.19
12.20	-1.645	0.35	2	725.18	1	3.2	3,925,449.00	180	2.5	7.608730744	40,619,141.83	160,000,000.00	0.25
12.50	-1.645	0.35	2	725.18	1	3.2	3,925,449.00	180	2.5	7.677830542	47,624,512.38	160,000,000.00	0.30
12.80	-1.645	0.35	2	725.18	1	3.2	3,925,449.00	180	2.5	7.745507192	55,655,385.04	160,000,000.00	0.35
13.30	-1.645	0.35	2	725.18	1	3.2	3,925,449.00	180	2.5	7.85528042	71,660,596.61	160,000,000.00	0.45
13.60	-1.645	0.35	2	725.18	1	3.2	3,925,449.00	180	2.5	7.919412577	83,063,949.55	160,000,000.00	0.52
13.90	-1.645	0.35	2	725.18	1	3.2	3,925,449.00	180	2.5	7.98230361	96,007,157.13	160,000,000.00	0.60
14.10	-1.645	0.35	2	725.18	1	3.2	3,925,449.00	180	2.5	8.023563648	105,575,621.79	160,000,000.00	0.66
14.50	-1.645	0.35	2	725.18	1	3.2	3,925,449.00	180	2.5	8.10453936	127,215,303.92	160,000,000.00	0.80
14.70	-1.645	0.35	2	725.18	1	3.2	3,925,449.00	180	2.5	8.144279372	139,405,327.93	160,000,000.00	0.87
14.75	-1.645	0.35	2	725.18	1	3.2	3,925,449.00	180	2.5	8.154138466	142,606,219.29	160,000,000.00	0.89
14.80	-1.645	0.35	2	725.18	1	3.2	3,925,449.00	180	2.5	8.163967554	145,870,527.59	160,000,000.00	0.91
14.85	-1.645	0.35	2	725.18	1	3.2	3,925,449.00	180	2.5	8.173766811	149,199,308.76	160,000,000.00	0.93
14.95	-1.645	0.35	2	725.18	1	3.2	3,925,449.00	180	2.5	8.193276533	156,054,584.94	160,000,000.00	0.98
15.00	-1.645	0.35	2	725.18	1	3.2	3,925,449.00	180	2.5	8.202987343	159,583,263.73	160,000,000.00	1.00

Table 6.2. Determination of slab depth using ASSHTO (1993) standard for a concrete made with 10% bagasse ash.

D	Z_R	S_O	ΔPSI	S_C	C_d	J	E_C	K	P_t	Log 10(W_{18})	W_{18} Calculated	W_{18} Design	W_{18} Calculated/ W_{18} Design
8.52	-1.645	0.35	2	793.35	1	3.2	3,951,054.00	180	2.5	6.756967599	5,714,360.03	160,000,000.00	0.04
9.33	-1.645	0.35	2	793.35	1	3.2	3,951,054.00	180	2.5	6.997434314	9,941,097.07	160,000,000.00	0.06
10.50	-1.645	0.35	2	793.35	1	3.2	3,951,054.00	180	2.5	7.320192049	20,902,202.39	160,000,000.00	0.13
11.30	-1.645	0.35	2	793.35	1	3.2	3,951,054.00	180	2.5	7.52500057	33,496,587.87	160,000,000.00	0.21
11.70	-1.645	0.35	2	793.35	1	3.2	3,951,054.00	180	2.5	7.622938823	41,969,985.90	160,000,000.00	0.26
12.20	-1.645	0.35	2	793.35	1	3.2	3,951,054.00	180	2.5	7.741446408	55,137,415.80	160,000,000.00	0.34
12.50	-1.645	0.35	2	793.35	1	3.2	3,951,054.00	180	2.5	7.810563259	64,649,215.46	160,000,000.00	0.40
12.80	-1.645	0.35	2	793.35	1	3.2	3,951,054.00	180	2.5	7.878256087	75,553,760.89	160,000,000.00	0.47
13.30	-1.645	0.35	2	793.35	1	3.2	3,951,054.00	180	2.5	7.988054517	97,286,933.96	160,000,000.00	0.61
13.60	-1.645	0.35	2	793.35	1	3.2	3,951,054.00	180	2.5	8.052200833	112,771,883.17	160,000,000.00	0.70
13.90	-1.645	0.35	2	793.35	1	3.2	3,951,054.00	180	2.5	8.115105366	130,348,298.23	160,000,000.00	0.81
14.10	-1.645	0.35	2	793.35	1	3.2	3,951,054.00	180	2.5	8.156374061	143,342,198.38	160,000,000.00	0.90
14.30	-1.645	0.35	2	793.35	1	3.2	3,951,054.00	180	2.5	8.197123588	157,443,083.82	160,000,000.00	0.98
14.34	-1.645	0.35	2	793.35	1	3.2	3,951,054.00	180	2.5	8.205212289	160,402,926.92	160,000,000.00	1.00

As shown in the iterative calculation above, a slab designed with a concrete of 10% bagasse ash had yielded a relatively small depth (14.34in or 364mm) as compared to the slab thickness (15in or 381mm) designed with a concrete of 0% bagasse ash. From this, it can be inferred that a more conservative result was obtained when a concrete with 10% bagasse ash was used for a concrete slab pavement which of its thickness determined using an ordinary concrete property (concrete without bagasse ash).

This extra benefit was gained in addition to the technical advantage (reduction in temperature and a relatively better strength development since early age) that this material has exhibited during the laboratory tests.

Therefore, from the findings of this study, it can be said that, the incorporation of bagasse ash as a cement replacing material into the concrete with a 10% replacement was showing the above mentioned technical advantages and also a more conservative strength on the design and construction of concrete rigid pavement.

6.2 Modeling

As mentioned in the result and discussion section of this study, it was expected for the results obtained during the laboratory experiment can be liable to certain pluses or minuses from their real situation. Moreover, it was not possible to prepare a prototype slab and see the response of the stresses. Thus a finite element software: DuCOM-COM3D: was used to simulate some of the laboratory experiments and portion of concrete rigid pavement slab. With this, it was possible to evaluate the extent with which the simulation and the result from the laboratory experiment can vary from each other. In addition, it was possible to simulate a slab and see the induced stresses relative to the developed strength.

DuCOM-COM3D is a finite element software with sections dealing about responses with respect to material property, structural property and the integrated result of the two. With the material property used in the laboratory, same sample prepared in the laboratory for temperature test was modeled in DuCOM-COM3D and the temperature read were depicted in the graph below. During modeling, the 25cm*25cm*40cm concrete sample was quartered (as shown in **Figure 6.1**) so as to see the temperature in the most inner section of the concrete at concerned depths. The concrete section was quartered laterally (both direction) and the 40cm depth which was intended to represent the slab thickness kept as it was. With this, the concrete sample quartered symmetrically with a dimension 12.5cm*12.5cm*40cm. The mesh arrangement near the bottom and surface of the concrete was in an arrangement denser than in the middle section (as shown in **Figure 6.1**). As these sections of the concrete are areas where temperature exchange from surrounding or external environment take place, they were expected to show a relatively notable differences within small intervals thus meshed within small gaps.

The temperature test conducted in the laboratory for concrete samples with 0%, 10% and 20% bagasse ash were simulated in the software in a quarter model. The temperature read from each sample at their respective depth of interest (marked yellow nodes in the model shown in **Figure 6.1**) was drawn in the graph along with their respective result obtained from the laboratory experiment.

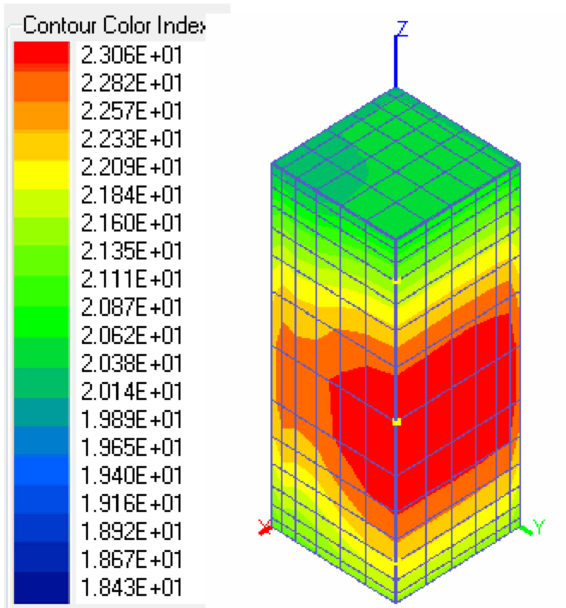


Figure 6.1. Quartered concrete section modeled for temperature test.

During modeling the quarter of the concrete sample prepared for temperature test, the system was assumed to be closed (no interaction with the external environment; neither heat nor moisture will migrate in or/and out) in the interfaces except in the upper face of the concrete. Thus the interface condition was adjusted in a way that simulates this scenario. The two longer sides which were in contact with the formwork during the laboratory experiment, the other two longer sides that get confinement from adjacent concrete and the bottom face which resides on the soil covered with polyethylene sheet during laboratory experiments were the faces that were assumed as closed system during the modeling. The upper face is exposed to the external environment thus the interface condition allows movement of heat and moisture with in and out of the concrete. The picture below (**Figure 6.2**) shows these interface conditions.

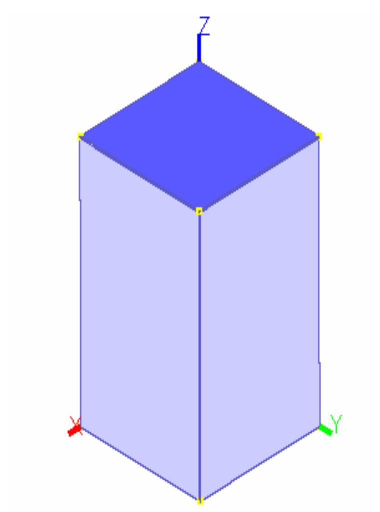
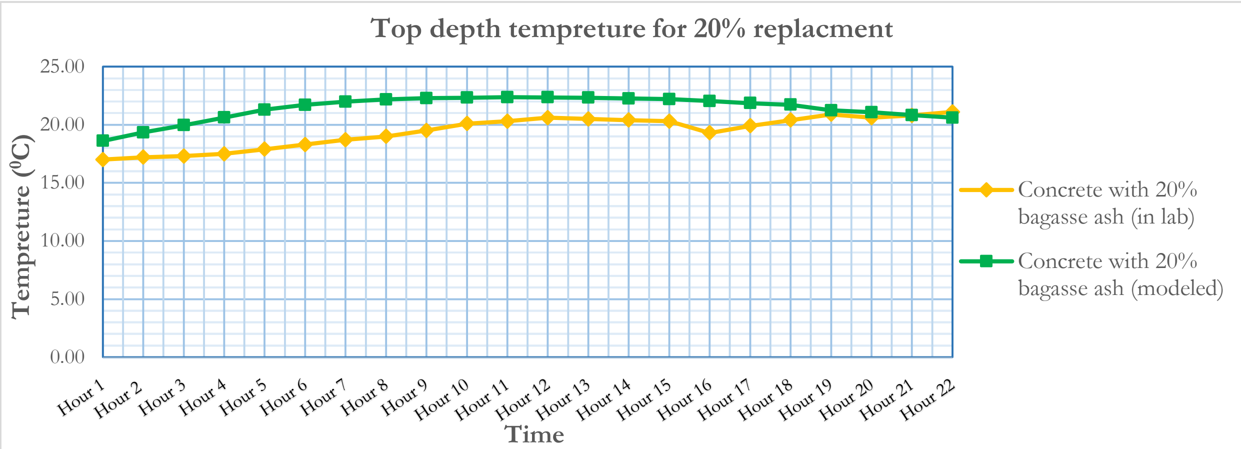


Figure 6.2. The quartered concrete model showing interface conditions before it was meshed.

As mentioned in the experimental program section of this study, temperature reading during laboratory experiment had started some hours after casting the concrete. In the simulation, temperature readings were recorded in such a way that readings were held right after casting of the concrete. Thus, the graphs (from **Figure 6.3** upto **Figure 6.11**) which compare the result from the laboratory and the model are illustrated based on the corresponding time interval of one another



. **Figure 6.3.** Top depth temperature for 0% replacement.

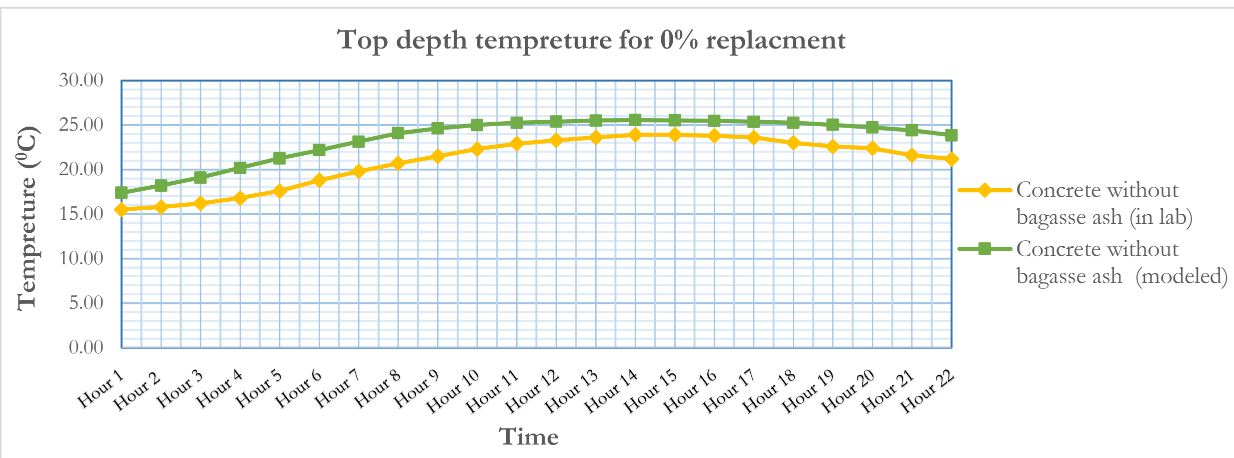


Figure 6.4. Top depth temperature for 10% replacement

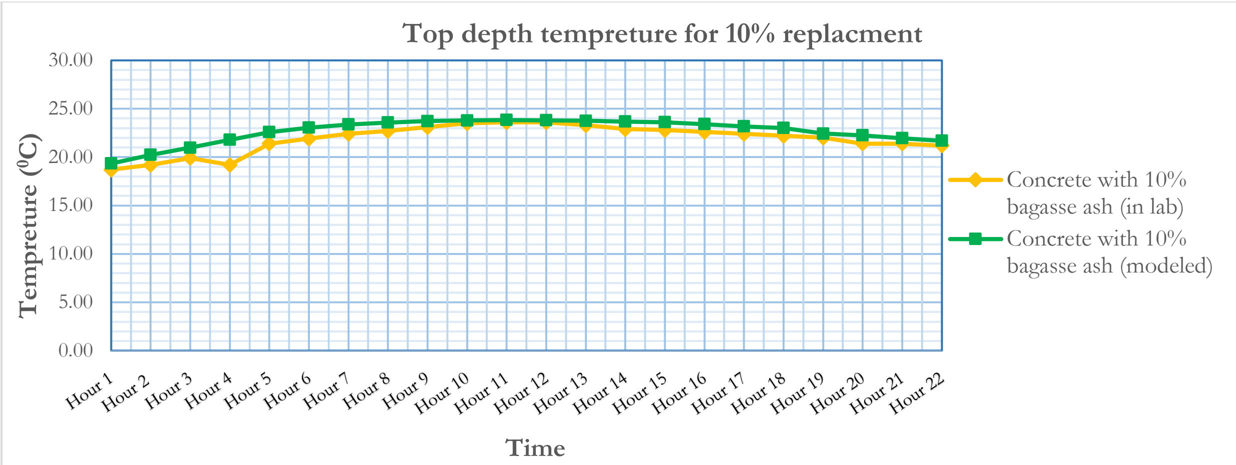


Figure 6.5. Top depth temperature for 20% replacement

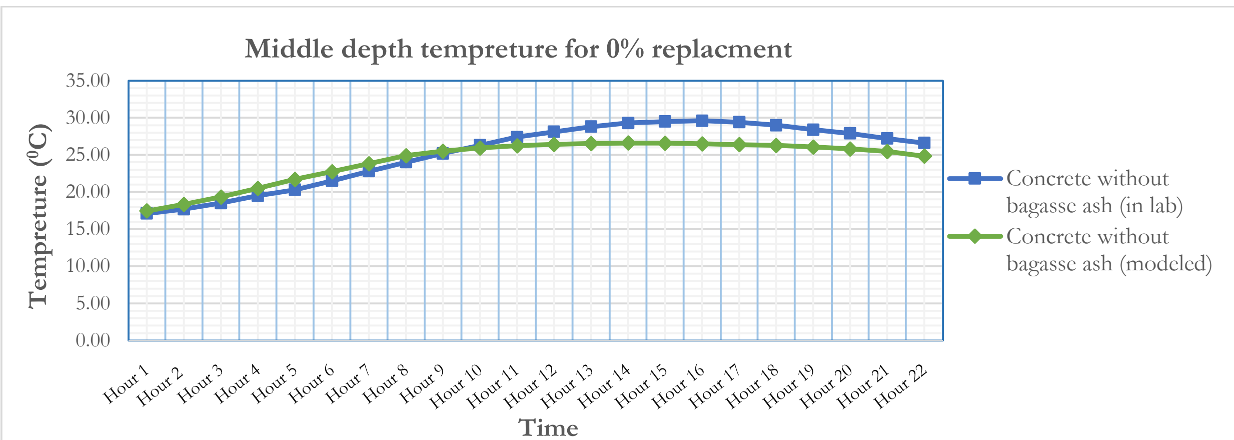


Figure 6.6. Middle depth temperature for 0% replacement

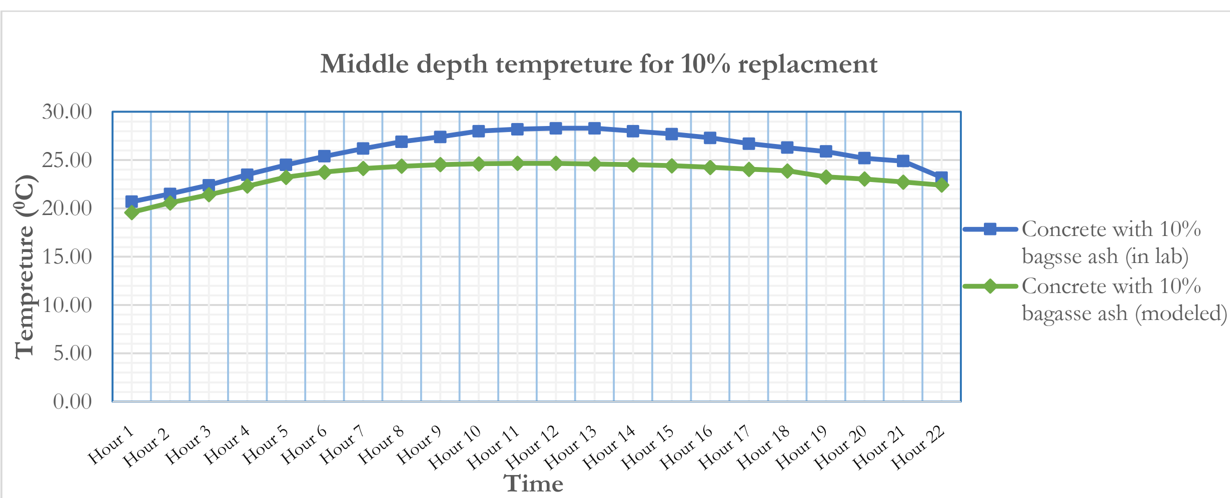


Figure 6.7. Middle depth temperature for 10% replacement

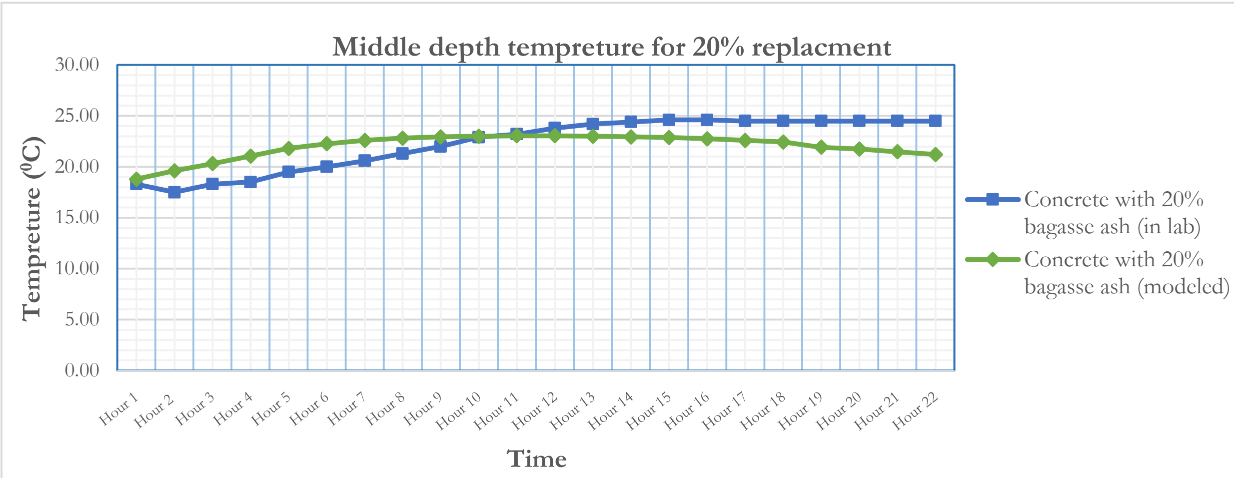


Figure 6.8. Middle depth temperature for 20% replacement

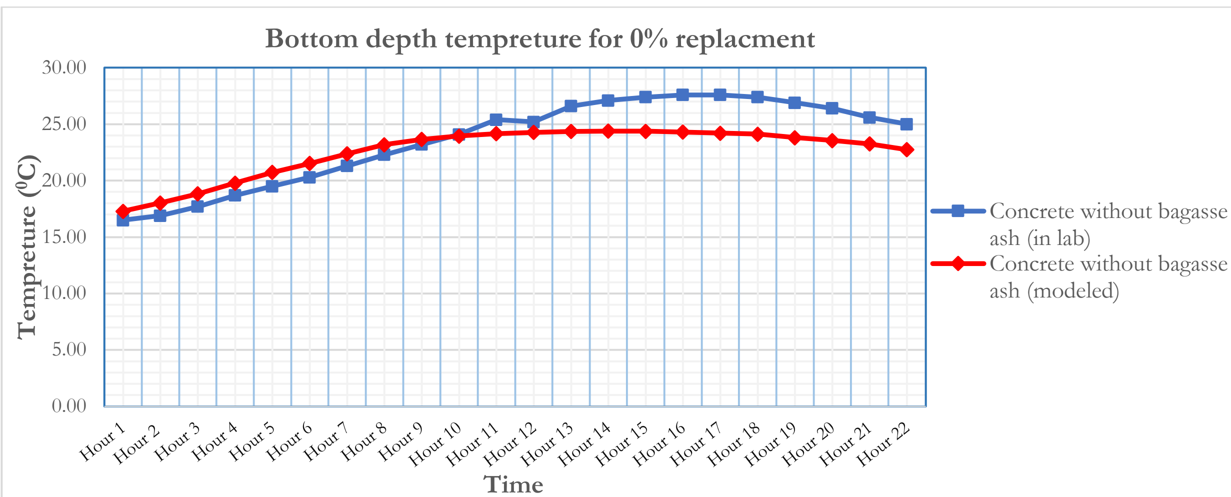


Figure 6.9. Bottom depth temperature for 0% replacement

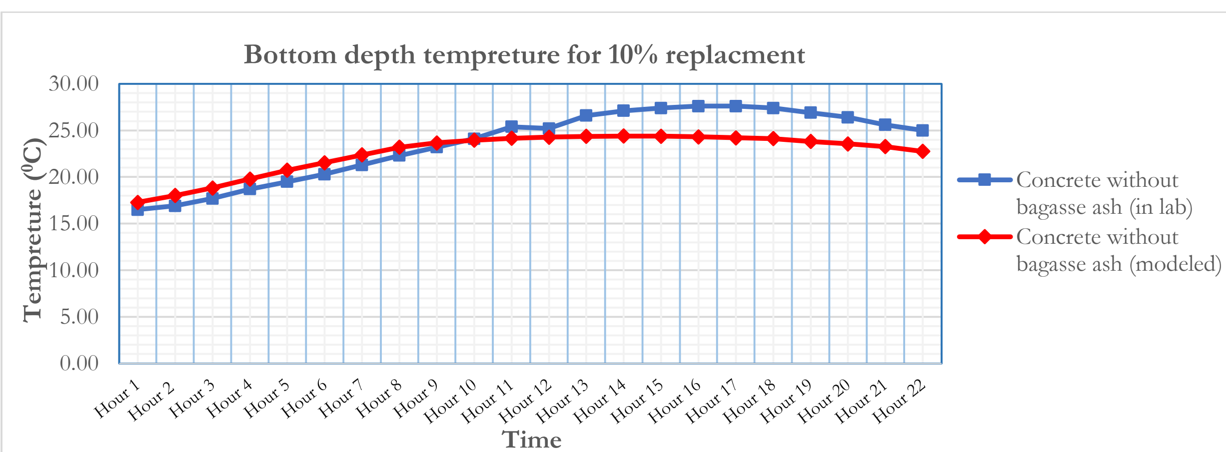


Figure 6.10. Bottom depth temperature for 10% replacement

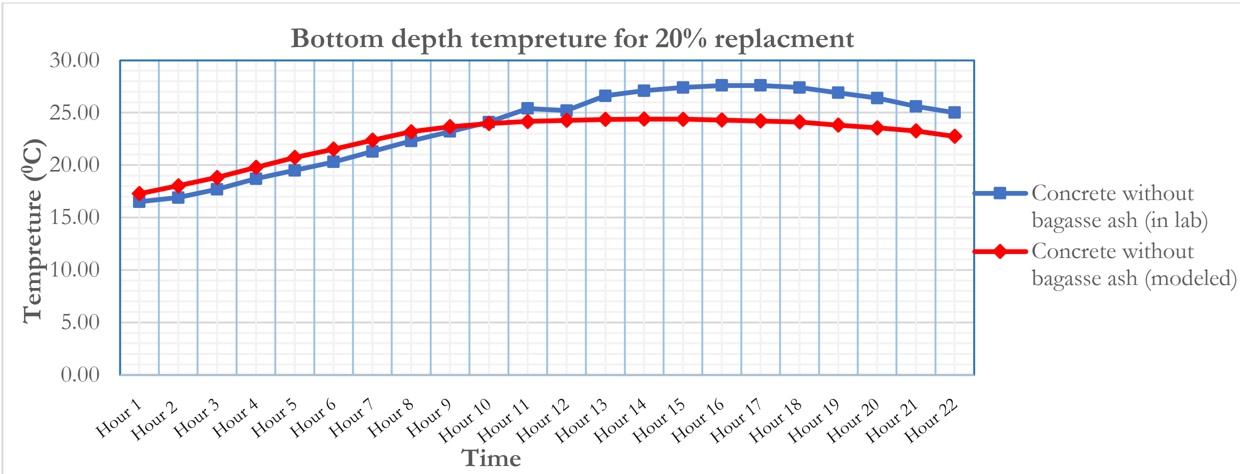


Figure 6.11. Bottom depth temperature for 20% replacement

From the above graphs, it can be seen that the pattern or trend of progress of the temperature is relatively similar in both the modeling and laboratory test. As shown in the graphs, there were certain discrepancies between the laboratory test result and the modeling. Since the defined interface conditions used for closed system during the modeling were absolutely insulated as compared to the laboratory conditions (the timber formwork and the soil), slight discrepancies were excepted to happen. But in a relative speaking, the result obtained from both testing methods is showing a similar trend which verifies that the material has a property that exhibits a temperature pattern as shown in the graphs.

With this, the study proceeds to the modeling of a panel of concrete rigid pavement slab to see the structural responses. Material characteristics, environment and boundary conditions (number of iteration steps and duration of investigation) were the input parameters that this software sought for the combined analysis of material and structure simultaneously. Like that of the model in the temperature measurement, a quarter model (2500*1750*400mm) is used for a slab panel which of its dimension is 5000*3200*400mm and also meshed in the same pattern like that of the concrete sample in which temperature measured. A restraint was provided in the X and Y direction assuming rotation are not allowed due to adjacent slab panels and from a shoulder. In order to monitor the relative difference of early age stress development, a case with 10% replacement of bagasse ash and 100% OPC were analyzed. The figure below shows a slab model prepared for this purpose (**Figure 6.12**).

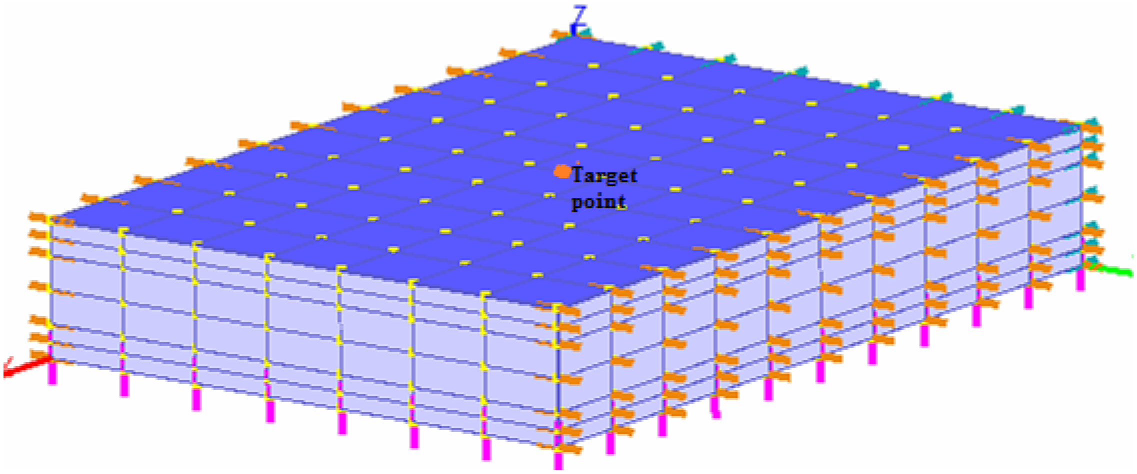


Figure 6.12. A quarter model slab panel with restraints

Two different slab panels were modeled which are of concrete with 0% and 10% (optimum amount) bagasse ash. The stress induced within the slabs were compared with the flexural strength obtained from the laboratory for the respective percentage of replacements. An ambient temperature of 30^{0}C was given throughout the analysis period. Analysis was allowed to run for early age period only as the stresses that will be induced during matured age can be dealt and addressed during the design and construction.

The temperature development seen within the two slabs are depicted and demonstrated in the two graphs shown below.

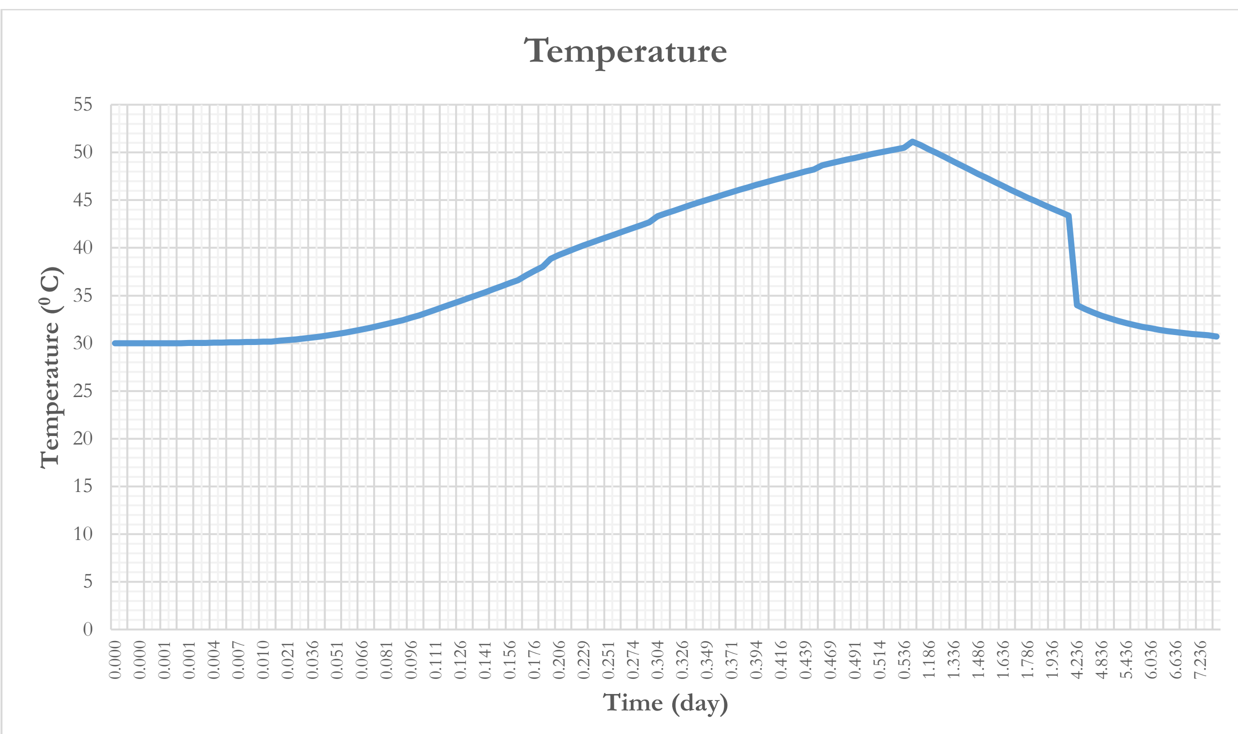


Figure 6.13. Temperature profile of concrete slab with 0% bagasse ash

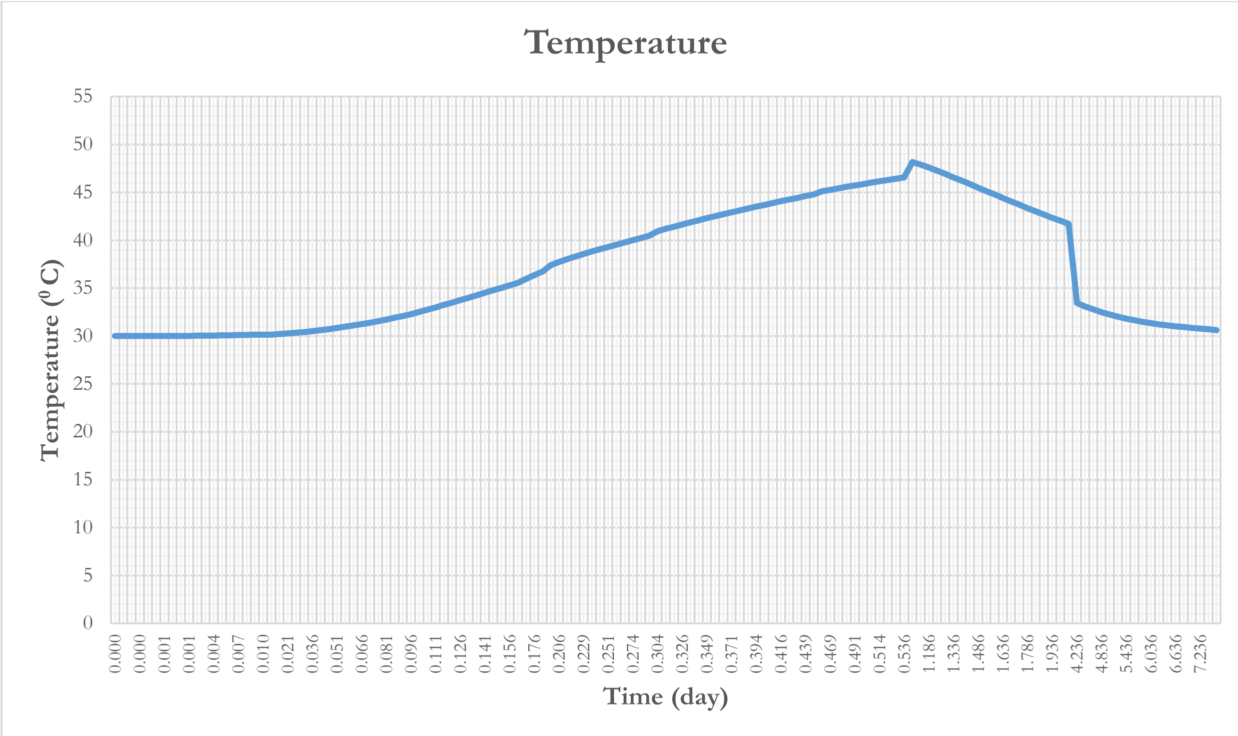


Figure 6.14. Temperature profile of concrete slab with 10% bagasse ash

As can be seen from the graphs, the two slabs reached into their maximum temperature at age of 24.086hour. These readings were obtained in the middle depth of the slabs. A maximum temperature of 51.14 ^{0}C and 48.16 ^{0}C was read for the slab with 0% and 10% bagasse ash respectively. And the average temperature read from the slab with and without bagasse ash was 38.58 and 37.18 ^{0}C respectively. The maximum temperature exhibited by a slab without bagasse ash was higher than the other slab by 2.98 ^{0}C. From this, it can be inferred that the presence of the bagasse ash was able to inhibit the production of heat by a certain magnitude which can be considered as a contributory finding in reducing the thermal load that will be induced within the slab during its early age.

Unlike the customary practice of rigid pavement design, in this study stress analysis at the early age was conducted using a thermo-hygro mechanistic model (Maekawa 1999). The stress analysis for the slab made without bagasse ash was iterated up to 6.7days while the slab modeled with 10% bagasse ash was analyzed up to 11.44days. The maximum stress developed by the slab with 10% bagasse ash was 3.42N/mm^2 while the one obtained for a slab without bagasse ash was 3.55N/mm^2. From this, it can be inferred that the stress developed within the slab with 10% bagasse ash was smaller than the stress developed within the slab made without bagasse ash. The lesser the heat produced, the lesser thermal stress that will be induced.

The flexural strength obtained (using 50cm*10cm*10cm beam) during the laboratory test for 1, 1.5, 2 and 3 days were taken and compared with the induced stress in the slab for the respective percentage of replacements. The table below shows the flexural strength obtained in the laboratory and the stress developed in the modeled slab.

Table 6.3 Tensile stress Vs flexural strength for 0% replacement

Tensile stress Vs flexural strength for 0% replacement				
	1 day	1.5 day	2 days	3 days
Flexural strength (N/mm^2)	1.26	1.76	2.24	2.58
Tensile stress (N/mm^2)	-0.83*	0.53	1.3	2.79

*designates compressional stress

Table 6.4 Tensile stress Vs flexural strength for 10% replacement

Tensile stress Vs flexural strength for 10% replacement				
	1 day	1.5 day	2 days	3 days
Flexural strength (N/mm^2)	1.65	2.21	2.75	3.14
Tensile stress (N/mm^2)	-0.68*	0.43	1.05	2.28

*designates compressional stress

The early age stresses induced within the slab with 10% bagasse ash were less than the strength of the concrete recorded during the same time. The developed strength within the concrete was able to withstand the induced stress in all concerned days of investigation. But the slab without bagasse ash was showing a tensile stress greater than its respective strength at its third day. The induced stress was greater than its respective strength by 7.53%. Moreover, the induced stress at each day of investigation in the slab with 10% bagasse ash is less than the stress developed in the slab without bagasse ash. The same concept was also revealed in the strength; at each day of investigation, the strength developed in a concrete with 10% bagasse ash was greater than the strength developed in the concrete made without bagasse ash.

The graph below shows the stress pattern and magnitude seen in the modeled slabs with 0% and 10% bagasse ash. In the graph, in both cases, the stress that was developed due to the generation of heat was less than the stress developed in the endeavor of dissipating that stress and regain original condition. This is due to the dynamic stiffness that concrete has during its early age. The compression stress developed during hydration reaction (to dissipate the thermal stress) was served with a less stiffen concrete property as compared to the stress induced to contract and regain its original condition. When the concrete tries to contract, the concrete property will not be as less stiffen as it was before thus the stress due to contraction will be served with a concrete property stiffer than it was before which in turn increases the stress that will be developed to contract. Therefore, the tensile stress is greater than the compressional stress as shown in the graph. If concrete stiffness would have been uniform like steel and other material with constant stiffness, the magnitude of compressional and tensile stress would have been the same.

The stress profile shown on the two slabs during their early age is depicted in the graph below.

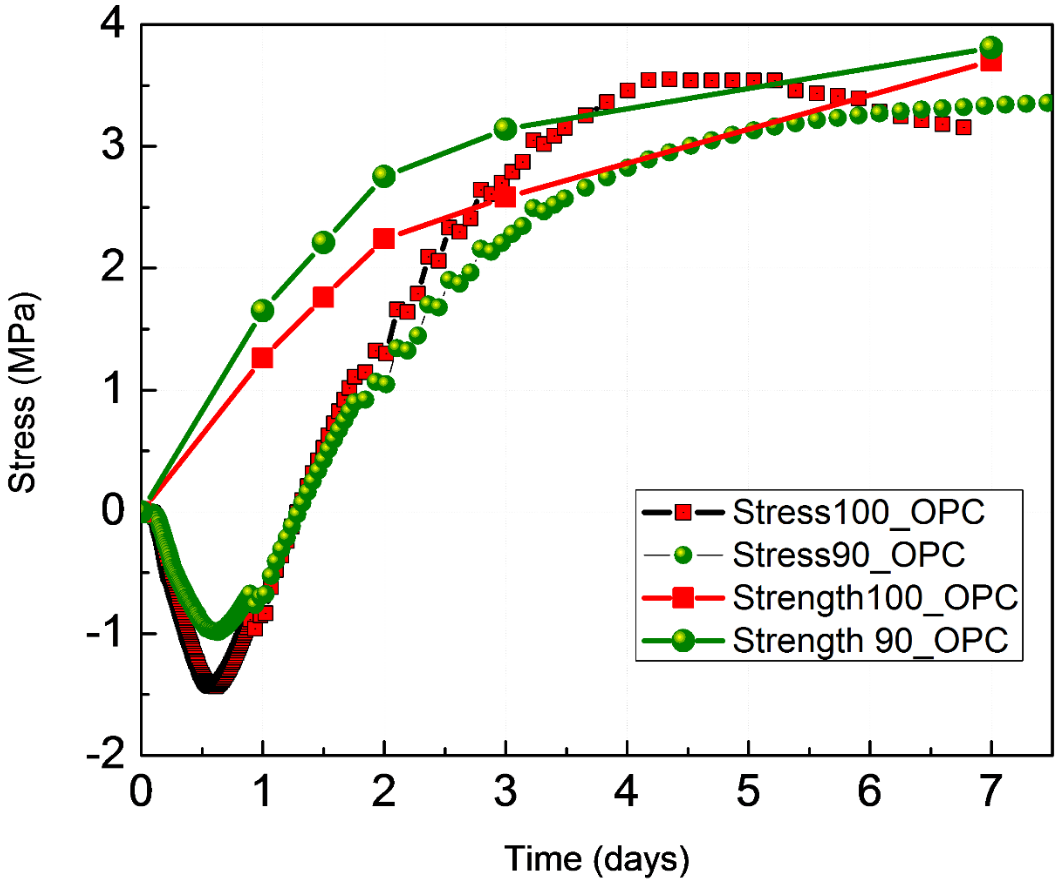


Figure 6.15. Stress and strength of concrete slab without and with 10% bagasse ash.

As can be seen from the above graph, the evolution of early age stress for concrete without and with 10% replacement ratio was analyzed using a multi-component heat of hydration model and was compared with experimentally measured tensile strength values. The strength to maximum stress ratio was compared and the ratio was found to be higher for the mix with 10% replacement ratio, indicating higher margin of safety against early age thermal cracking risk. This is a desirable characteristic that can contribute to the reduction in early age cracking that occurs due to thermal stress in concrete rigid pavements. When the lesser maximum stress and temperature shown in the slab made with concrete of 10% bagasse ash coupled with the other technical advantages that the incorporation of this material had shown in the laboratory experiment, it favors the advantage of using this material in concrete rigid pavement.

7. CONCLUSION AND RECOMMENDATION

Based on the objective, scope and findings of this study, the following points were concluded and recommended.

7.1 Conclusion

This study tried to address the very features of area of investigations, which had to be carried out in studying the use of bagasse ash as a cement replacing material in concrete rigid pavement. The use of bagasse ash in concrete rigid pavement has showed certain technical advantages and as per the findings of this research, this material can substitute cement upto 10% (by volume). This finding was obtained using the bagasse ash which did not pass through any treatment or modification except being sieved with a 300μm sieve. Moreover, the bagasse ash was introduced into the mix in powder form which may affect the uniform distribution of this material within the mix. The bagasse ash used in this research was found to be rich in silica with the presence of certain alkali, henceforth it's a potential as a pozzolanic material. Although the bagasse ash as a pozzolanic material reacts with Calcium hydroxide slowly and is expected to reduce the early age strength, the result we obtained from the laboratory experiments were showing a strength enhancement achieved beginning from the early age of the concrete. And this found to be very contributory in reducing early age stresses that will be induced in the concrete due to the thermal effect that will be generated from the hydration reaction and the external environment (if concreting is in hot weather).

Replacement of cement by up to 10% in concrete production was found to enhance the compressive strength by 1.23%, flexural tensile strength by 8.65% at 28 days. The strength enhancement shown after 24 hours was 31% higher than the reference mix in flexural strength.

The heat of hydration measured in terms of temperature rise was monitored and a reduction in temperature by 20.28% was observed for 10% replacement ratio as compared to the reference mix.

The average water penetration depth of concrete samples made without bagasse ash and samples made with 10% bagasse ash were showing a close value though sample concretes made with 10% bagasse ash had shown a penetration depth which is lesser than 3mm of the concrete sample made without bagasse ash.

A slab depth designed using AASHTO (1993) guideline had revealed that a more conservative result was obtained when a concrete with 10% bagasse ash was used for a concrete slab pavement which of its thickness determined using an ordinary concrete property (concrete without bagasse ash).

The evolution of early age stress for concrete without and with 10% replacement ratio was analyzed using a multi-component heat of hydration model and was compared with experimentally measured tensile strength values. Interestingly, the strength to maximum stress ratio was compared and the ratio was found to be higher for the mix with 10% replacement ratio, indicating higher margin of safety against early age thermal cracking risk.

7.2 Recommendation

The findings of this study and other similar studies conducted on local sugarcane bagasse ash can be used as a preliminary base for further investigations that will be made on the use of this material as a potential pozzolanic material in concrete making. The abundance of this material as an industrial waste and the very economic, technical and environmental advantage that it showed during the studies are a promising findings that can support an endeavor that may be made in the future to utilize this material in a standardized form.

On the basis of this study and other similar studies that was particularly conducted on this area, further investigations shall be made on

- Concrete rigid pavement specifications and design guidelines to be considerate on early age property of the concrete.
- The degree of response in strength, permeability, temperature, shrinkage, and other relevant parameters of concrete when the chemical composition of the bagasse ash modified with external chemical constituents, when the physical nature of the bagasse ash (fineness) modified and when the constituents and proportioning of concrete such as water-cement ratio varies.
- The resistance capacity or degree of deterioration of sample concrete with various percentages of bagasse ash against sulfate attack, ingression of chloride ions and other deleterious substances (expected threats that may come from surface and subsurface drainage to the concrete slab).
- As the decrease in temperature shown in 20% replacement was considerable, further studies can focus on improving the bagasse ash property in a way that it can give desirable strength and impermeability at 20% or higher percentage of replacement but with the production of less heat.
- Detail and thorough investigation on the microstructure of the concrete with bagasse ash using SEM or XRD by which there will be a chance to see the ITZ matrix along with the remaining portion of the mix.
- Detail and iterative study on the chemistry of the mixture (water, cement and bagasse ash) and its impact in the concrete property.
- Extensive and iterative study to formulate a standard use of sugarcane bagasse ash in concrete rigid pavements and other structures which seek the presence of concrete.

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9. APPENDIX

APPENDIX A

A.1. Recorded failure load values during compressive strength test.

TEST RESULTS FOR COMPRESSIVE STRENGTH								
Percentage of replacement	Code	Test day						
		1 day	1.5 day	2 days	3 days	7 days	28 days	56 days
0%	CBAC 0	Test Result (Failure load (KN))						
		148.30	232.18	310.70	338.37	498.10	942.23	972.39
		146.40	231.95	317.30	375.40	603.40	897.45	975.09
		Average value						
		147.350	**232.065**	**314.000**	**356.885**	**550.750**	**919.841**	**973.739**
5%	CBAC 5	Test Result (Failure load (KN))						
		178.85	251.97	324.20	401.40	583.14	984.76	1017.85
		189.65	248.60	307.10	406.31	604.06	962.26	1007.49
		Average value						
		184.25	**250.29**	**315.65**	**403.86**	**593.60**	**973.51**	**1012.67**
10%	CBAC 10	Test Result (Failure load (KN))						
		149.40	237.35	322.80	389.90	620.60	930.08	984.32
		146.01	232.62	318.80	394.20	519.40	933.68	976.21
		Average value						
		147.71	**234.99**	**320.80**	**392.05**	**570.00**	**931.88**	**980.27**
20%	CBAC 20	Test Result (Failure load (KN))						
		164.10	211.70	255.60	271.70	418.80	875.84	942.68
		134.50	204.90	274.00	360.30	424.80	872.92	900.83
		Average value						
		149.30	**208.30**	**264.80**	**360.30**	**421.80**	**874.38**	**921.76**

A.2. Recorded strength values during compressive strength test.

TEST RESULTS FOR COMPRESSIVE STRENGTH								
Percentage of replacement	Code	Test day						
		1 day	1.5 day	2 days	3 days	7 days	28 days	56 days
0%	CBAC 0	Test Result (Strength (N/mm²))						
		6.590	10.320	13.810	15.040	22.140	41.870	43.210
		6.510	10.310	14.100	16.686	26.820	39.880	43.330
		Average value						
		6.550	**10.315**	**13.955**	**15.863**	**24.480**	**40.875**	**43.27**
5%	CBAC 5	Test Result (Strength (N/mm²))						
		7.95	11.20	14.41	17.84	25.92	43.76	45.23
		8.43	11.05	13.65	18.06	26.85	42.76	44.77
		Average value						
		8.19	**11.125**	**14.03**	**17.95**	**26.385**	**43.26**	**45.00**
10%	CBAC 10	Test Result (Strength (N/mm²))						
		6.64	10.55	14.35	17.33	27.58	41.33	43.74
		6.49	10.34	14.17	17.52	23.08	41.49	43.38
		Average value						
		6.565	**10.445**	**14.26**	**17.425**	**25.33**	**41.41**	**43.56**
20%	CBAC 20	Test Result (Strength (N/mm²))						
		7.29	9.41	11.36	12.08	18.62	38.92	41.89
		5.98	9.11	12.18	16.01	18.88	38.79	40.03
		Average value						
		6.635	**9.26**	**11.77**	**14.045**	**18.75**	**38.855**	**40.96**

APPENDIX B

B.1. Recorded failure load values during flexural strength test.

TEST RESULTS FOR FLEXURAL STRENGTH								
Percentage of replacement	**Code**	**Test day**						
		1 day	**1.5 day**	**2 days**	**3 days**	**7 days**	**28 days**	**56 days**
0%	CBAF 0	Test Result (Failure load (KN))						
		2.78	3.71	4.57	5.39	8.32	11.38	11.83
		2.80	4.11	5.37	6.04	8.10	10.81	10.59
		Average value						
		2.79	**3.91**	**4.97**	**5.72**	**8.21**	**11.09**	**11.21**
5%	CBAF 5	Test Result (Failure load (KN))						
		3.37	4.42	5.44	7.50	9.12	11.83	12.59
		3.35	4.66	5.90	5.90	8.77	11.57	11.61
		Average value						
		3.36	**4.54**	**5.67**	**6.70**	**8.94**	**11.70**	**12.10**
10%	CBAF 10	Test Result (Failure load (KN))						
		3.72	5.13	6.52	7.00	8.14	12.34	12.08
		3.60	4.68	5.71	6.96	8.79	11.94	13.08
		Average value						
		3.66	**4.91**	**6.11**	**6.98**	**8.47**	**12.14**	**12.58**
20%	CBAF 20	Test Result (Failure load (KN))						
		1.37	1.98	2.54	2.91	7.95	8.70	10.12
		1.65	1.69	1.58	5.25	6.85	10.50	10.63
		Average value						
		1.51	**1.83**	**2.06**	**4.08**	**7.40**	**9.60**	**10.38**

B.2. Recorded strength values during flexural strength test.

TEST RESULT FOR FLEXURAL STRENGTH								
Percentage of replacement	Code	Test day						
		1 day	1.5 day	2 days	3 days	7 days	28 days	56 days
0%	CBAF 0	Test Result (Strength (N/mm²))						
		1.25	1.67	2.06	2.43	3.75	5.12	5.33
		1.26	1.85	2.42	2.72	3.65	4.87	4.77
		Average value						
		1.26	**1.76**	**2.24**	**2.58**	**3.70**	**5.00**	**5.05**
5%	CBAF 5	Test Result (Strength (N/mm²))						
		1.52	1.99	2.45	3.38	4.11	5.33	5.67
		1.51	2.10	2.67	2.65	3.95	5.21	5.23
		Average value						
		1.52	**2.05**	**2.56**	**3.02**	**4.03**	**5.27**	**5.45**
10%	CBAF 10	Test Result (Strength (N/mm²))						
		1.67	2.31	2.93	3.15	3.66	5.56	5.44
		1.62	2.11	2.57	3.13	3.96	5.38	5.89
		Average value						
		1.65	**2.21**	**2.75**	**3.14**	**3.81**	**5.47**	**5.67**
20%	CBAF 20	Test Result (Strength (N/mm²))						
		0.62	0.89	1.14	1.31	3.58	4.73	4.56
		0.74	0.76	0.71	2.36	3.08	3.92	4.79
		Average value						
		0.68	**0.82**	**0.93**	**1.84**	**3.33**	**4.33**	**4.68**

APPENDIX C

C.1. Early age thermal assessment of concrete without bagasse ash.

Time	Recorded temperature (^0C)			
	Ambient T^0	At top depth	At middle depth	At bottom depth
3:16PM	15.4	15.50	17.10	16.50
4:16PM	15.9	15.80	17.70	16.90
5:16PM	15.7	16.20	18.50	17.70
6:16PM	16.0	16.80	19.50	18.70
7:16PM	16.2	17.60	20.30	19.50
8:16PM	16.7	18.80	21.50	20.30
9:16PM	15.5	19.80	22.80	21.30
10:16PM	16.2	20.70	24.00	22.30
11:16PM	16.1	21.50	25.20	23.20
12:16PM	15.8	22.30	26.30	24.10
1:16AM	15.5	22.90	27.40	25.40
2:16AM	13.6	23.30	28.10	25.20
3:16AM	14.2	23.60	28.80	26.60
4:16AM	14.5	23.90	29.30	27.10
5:16AM	14.4	23.90	29.50	27.40
6:16AM	13.0	23.80	29.60	27.60
7:16AM	14.5	23.60	29.40	27.60
8:16AM	12.6	23.00	29.00	27.40
9:16AM	15.6	22.60	28.40	26.90
10:16AM	14.4	22.40	27.90	26.40
11:16AM	14.4	21.60	27.20	25.60
12:16AM	14.6	21.20	26.60	25.00

C.2. Early age thermal assessment of concrete with 10% bagasse ash.

Time	Recorded temperature (^0C)			
	Ambient T^0	At top depth	At middle depth	At bottom depth
7:30PM	18.00	18.70	20.70	20.40
8:30PM	17.40	19.20	21.50	21.20
9:30PM	17.70	19.90	22.40	22.30
10:30PM	17.60	19.19	23.50	23.30
11:30PM	17.50	21.40	24.50	24.30
12:30PM	17.20	21.90	25.40	25.10
1:30AM	17.40	22.40	26.20	25.90
2:30AM	17.20	22.70	26.90	26.60
3:30AM	16.90	23.10	27.40	27.20
4:30AM	17.00	23.50	28.00	27.80
5:30AM	17.00	23.60	28.20	28.00
6:30AM	16.60	23.60	28.30	28.20
7:30AM	14.50	23.30	28.30	28.40
8:30AM	16.40	22.90	28.00	28.30
9:30AM	18.30	22.80	27.70	28.10
10:30AM	18.50	22.60	27.30	27.70
11:30AM	18.60	22.40	26.70	27.10
12:30PM	18.70	22.20	26.30	26.70
1:30PM	18.70	22.00	25.90	26.30
2:30PM	18.50	21.40	25.20	25.60
3:30PM	19.20	21.40	24.90	25.40
4:30PM	20.50	21.20	23.20	25.10
5:30PM	20.4	20.8	22.9	24.9
6:30PM	19.8	20.6	22.7	24.7
7:30PM	19.1	20.2	22.4	24.5
8:30PM	18.5	19.7	22.2	24.2

C.3. Early age thermal assessment of concrete with 20% bagasse ash

Time	Recorded temperature (^{0}C)			
	Ambient T^0	At top depth	At middle depth	At bottom depth
7:30PM	18.00	17.00	18.30	18.40
8:30PM	17.40	17.20	17.50	18.40
9:30PM	17.70	17.30	18.30	18.70
10:30PM	17.60	17.50	18.50	19.00
11:30PM	17.50	17.90	19.50	19.20
12:30PM	17.20	18.30	20.00	19.90
1:30AM	17.40	18.70	20.60	20.50
2:30AM	17.20	19.00	21.30	21.10
3:30AM	16.90	19.50	22.00	21.60
4:30AM	17.00	20.10	22.90	22.30
5:30AM	17.00	20.30	23.20	22.70
6:30AM	16.60	20.60	23.80	23.10
7:30AM	14.50	20.50	24.20	23.50
8:30AM	16.40	20.40	24.40	23.10
9:30AM	18.30	20.30	24.60	23.10
10:30AM	18.40	19.30	24.60	23.40
11:30AM	18.60	19.90	24.50	23.70
12:30PM	18.70	20.40	24.50	23.90
1:30PM	18.70	20.90	24.50	23.90
2:30PM	18.50	20.60	24.50	23.90
3:30PM	19.20	20.80	24.50	23.90
4:30PM	20.50	21.10	24.50	23.80
5:30PM	20.40	20.80	24.30	23.60
6:30PM	19.80	20.60	24.10	23.50
7:30PM	19.10	20.30	23.80	23.40
8:30PM	18.50	19.80	23.50	23.20

APPENDIX D

Chemical analysis of bagasse ash

Geological Survey of Ethiopia:Geochemical Laboratory Directorate
Geochemical Laboratory Complete Silicate Analysis Report Format Form G0004
FILE ID ;7173/16 pvt Originator;Mihret Geremew(AAiT)
Sample type; Powder Date Submmitted;08/10/2016
Preparation :-200 MESH
Number of Sample: 1 **Element to be determined Major Oxides & Minor Oxides**
Analytical Method: LIBO2 FUSION , HFattack,GRAVIMETERIC,COLORIMETRIC and AAS
Analytical Results in PERCENT

FIELD NO	Lab No	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI	SO3
M.G.1	7173/16	66.92	7.06	6.12	3.60	1.96	4.28	4.92	0.2	0.02	0.05	0.01	3.65	0.25

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QUALITY CONTROL
for
Hanna Bizuwork

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08-30-2016