JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

ENVIRONMENTAL ENGINEERING POST GRADUATE PROGRAM

PARTIAL REPLACEMENT OF SAND WITH BOTTLE PLASTIC WASTE AS A MEANS OF RESOURCE RECOVERY IN THE PRODUCTION OF BRICKS

BY: KELELAW ASEGDEW

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIRE MENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN ENVIRONMENTAL ENGINEERING

JULY, 2021

JIMMA, ETHIOPIA

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ADVISOR: DR. DEJENE BEYENE

CO-ADVISOR: MR. WAGARI MOSISA

JULY, 2021

JIMMA, ETHIOPIA

DECLARATION

I declared that this thesis entitled ‘’ Partial Replacement of sand with PET plastic waste as a means of resource recovery in the production of Bricks” is my original work, and has not been presented by any other person for any an award of a degree in this or any other university, and all sources of material used for thesis have been dually acknowledged.

Student name Signature

Kelelaw Asegdew

As master research advisors, we hereby certify that we have read and evaluate this MSc research prepared under our guidance, by Mr. Kelelaw Asegdew: Partial Replacement of sand with PET plastic waste as a means of resource recovery in the production of Bricks. We recommend that it can be submitted as fulfilling the MSc thesis requirements.

Advisor Signature Date

Dr. Dejene Beyene

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Mr. Wagari Mosisa

ABSTRACT

The increase in use of plastics without recycling has been creating environmental pollution and other undesirable effects like agricultural effect and huge amount of its wastes. The objective of this study was to examine the partial replacement for fine aggregates (sand) with PET plastic waste as a means of resource recovery for better environmental management. The materials used for this study were:-plastic waste, cement, sand, water, fly Ash. Brick mix design were prepared and a total of 5 mixes with 45 samples were prepared consisting of 20% of cement ,30% sand and 50% fly ash, this ratios were used during preparing normal fly ash brick. The specimens were produced with percentage replacements of the sand by 0%, 10%, 20%, 40% and 50% of PET plastic waste aggregate. Moreover, a control mix with no replacement of the sand was used to make a comparative analysis. According to ASTM standard and ES specification the compressive strength result at 10% and 20% replacement satisfy the standard but at 40% and 50% replacement could not satisfy the standard. Also like compressive strength there was an increase of tensile strength and flexural strength were recorded with increasing PET bottle aggregate content up to 10% and 20% replacement respectively as compared to the control sample, but more than this percentage replacement of fine aggregate with PET bottle fiber results in reduction of tensile strength and flexural strength as compared to the control sample. Also, the percentage of water absorption and moisture content were increase as the plastic waste content in the brick increase as shown in the test result, lastly as plastic content in brick matrix increased the temperature required to melt the brick decreased, so the temperature resistance of the brick decreased as the plastic content in the brick matrix increase. The overall results shown that it was possible to use recycled PET bottle plastic waste in brick production as a partial replacement for sand; nevertheless, the % replacement should limited.

Keywords; Compressive strength; Environmental Management; Fine Aggregate; PET Plastic Waste; Water absorption

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Table of Contents

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

ANRS	Amhara National Regional State
ASTM	American Society for Testing and Materials
CTM	Compressive Testing Machines
EOL	End of Life
ES	Ethiopian Standard
ETP	Effluent Treatment Plant
HDPE	High Density Polyethylene
MSW	Municipal Solid Waste
PET	Polyethylene Terephthalate
PLC	Private Limited Company
PPC	Portland Posolana Cement
UNEP	United Nation Environment Program

CHAPTER ONE

INTRODUCTION

1.1. Background of the study

Worldwide, efforts continue to be made to maintain a clean environment, free of pollutants that are generated mainly from either industrial or agricultural activities. As part of these ongoing actions recycling has been in common usage in developed countries since the late 1960s (Amadi., 2020). The introduction of convenience products to consumers in the 1950s, however, also led to what some have termed a "throwaway society". The recycling of wastes constitutes operations that permit extracting materials or reusing them, such as fuel or extracting metals and organic materials to treat the soil or refining the oils. Recycling and composting are encouraged by environmental action plans (Irena *et al*., 2020).

As 2018 estimation 6.3 billion tons of plastic has been produced worldwide, of which an estimated 9% has been recycled and another 12% has been incinerated. They contribute to approximately10% of discarded waste and Landfills are the source of effect of plastic to environment. Earlier trend of recycling plastic bottles came into existence but it did not work efficiently. In fact 70% percent of the plastic is left as waste every year (Achitra *et al*., 2018).

In Ethiopia, the amount of waste PET was expected to increase with the increase of social needs. The consumption rate in Ethiopia was 23 million tons per annum estimated in 2009. From this 1 million tons per annum was recycled, 1.8 million tons per annum was incinerated and 20.2 million tones was disposed to the environment without landfill (EWPRE, 2009). The amount of plastic waste generated from Debre Birehan town was 0.253 Kg/capita/day reported in previous studies done in Addis Ababa (Nicolas, 2013).

This waste plastic leads to various problems such as landfill problem and if disposed in water bodies it causes water pollution leading to the death of various aquatic lives. Hence there was a need to find any solution for this problem of disposal of plastic. Later on plastic bottle fly ash bricks came in existence. This trend acted as a boon in the construction industry. It solved various major issues such as disposal of plastic, preservation of environment and providing shelter at low cost (Shankar *et al*., 2017).

In Ethiopia used plastics were not properly disposed and it creates the lot of environmental issues and open burning of plastics leads to air pollution. To avoid these problems reusing of plastics should be improvised for several works with economic and environmental feasibility. Recycling the plastics has advantages since it was widely used and has a long service life, which means that the waste was being removed from the waste stream for a long period (Dinesh *et al*., 2016).

Plastic aggregate (PA) was produced by mechanically separating and processing plastic waste. A life cycle analysis of mixed household plastics shows that mechanical recycling provides a higher net positive environmental impact than the recovery of energy or land-filling. Different types of plastic waste have been used as aggregate, filler or fibre in cement mortar and concrete after mechanical treatment. They include: polyethylene Terephthalate (PET) bottles, polyvinyl chloride, high density polyethylene, HDPE, thermosetting plastics, mixed plastic waste, expanded polystyrene foam, polyurethane foam, polycarbonate, and glass reinforced plastic (Mohan Das *et al*., 2018).

The incorporation of plastic aggregate could significantly improve some properties of brick because plastic has high toughness, good abrasion behavior, low thermal conductivity and high heat capacity compared to other materials. Plastic aggregate was significantly lighter than natural aggregate (NA) and therefore its incorporation lowers the densities of the resulting brick. This property can be used to develop lightweight brick. The use of shredded waste plastic aggregate in brick can reduce the dead weight of brick (Akcaozoglu *et al*., 2010).

There were different plastic waste management techniques these are incineration, biological process and recycling.

Incineration was burning of plastics which have a complex chemical process. During plastic combustion, different phases take place, such as warming, degradation, flash over, combustion all present at the same time. Low-molecular compounds could be vaporized directly in the air, and depending on their variety were able to form a combustible mixture, or oxidize in to solid form. Macro-molecular plastics have to decompose into small molecule compounds to initiate the combustion process, so, Incineration has adverse health effects which generated carbon monoxide gas *(CO)* and carbon dioxide *(CO2)* during the combustion process which lead to air pollution (Agnes *et al*., 2016).

Biological treatment process was a technique which converted Biodegradable polymers to carbon dioxide, mineral salts, and water due to the action of microorganisms and enzymes under aerobic and specific environmental conditions. "Biodegradable" polymer means that it could be biologically degraded, but without time limits (process is very slow and can take up to years)., the time of biodegradation affects the right treatment when it becomes waste but most plastic waste could not degrade easily (Irena *et al*., 2020).

Recycling and Reusing: - Reusing encourages users to reuse a product or pass it to those who can reuse products like, used plastic bottles, clothes, papers, bottles, tins. Recycling program consist of recovery of recyclable wastes, processing into new materials or products and the marketing of these products (Irena *et al*., 2020).

Many researchers have tried to utilize plastic waste and few have suggested its utilization in brick production in many forms. The utilization of plastic waste in the construction industry has two glaring dividends, one, environmental impact is addressed by disposal of the waste and second, the economic impact and this waste has the edge of being available large quantity, everywhere and at low value This study concerned on Recycling technique which was the best option to manage plastic wastes as compare to Biological treatment process and Incineration, because this management technique has no adverse effect on the environment (Eldho *et al*., 2012).

In this study, raw materials used were sand, waste plastics, fly ash and lime with different proportions. The different types of bricks were tested to find the compressive strength and water absorption value. This study mainly focused to find the proper disposal options for plastics and also to motivate the use of plastic in the production of building materials. The study was made to incorporate different waste material in brick production such as plastic waste, fly ash, bottom ash. The focus was towards reuse of industrial waste like PET and fly ash rather than its disposal .PET has characteristics like versatility, hardness, chemical resistance (Kewal *et al*., 2015).

The plastic sand brick made of plastic bottle waste, fine aggregate and quarry dust gives strength equal to conventional paver bricks. They concluded that recycling of plastic was better than disposing it and reduce plastic pollution. The plastic sand paver bricks production leads to cost efficiency and results in removal of plastic waste which is abolishing lands which can be used for other requirements. This could also reduce the emission of greenhouse gases (Jayashankar, 2018).

1.2. Statement of problem

. The consumption rate in Ethiopia was 23 million tons per annum estimated in 2009. From this 1 million tons per annum was recycled, 1.8 million tons per annum was incinerated and 20.2 million tones was disposed to the environment without landfill (EWPRE, 2009). A Lot of plastic waste was produced every day by humans because of needs in Debre birehan town. The amount of plastic waste generated from Debre Birehan town was 0.253 Kg/capita/day reported in previous studies done in Addis Ababa (Nicolas, 2013). Plastics might be easy and convenient for everyday use. In the long run, overuse of plastics and lack of proper recycling were going to yield many undesirable effects in the agricultural and going to yield environmental pollution. Waste plastic bottles were major cause of solid waste disposal. This was an environmental issue as waste plastic bottles are difficult to biodegrade and involves processes either to recycle or reuse. So, we cannot stop using plastic but disposal of plastics could be done by recycling it. To reduce the pollution by plastic, plastic was recycled and used in manufacturing of plastic fly ash bricks. Building materials like river sand were popularly used in construction, however, these materials were expensive and in the present scenario the construction cost as scarcity of sand is increasing day by day. In order to counteract this problem, sand is partially replaced by bottle plastic waste material (IJCIET, 2017).

In Ethiopia, the amount of waste PET was expected to increase with the increase of social needs. This was considered as one of the major environmental challenges facing municipalities around the Ethiopia country because waste PET is not easily biodegradable even after a long period of landfill treatment. The best management strategy for scrap PET that was worn out beyond hope for reuse was recycling. Utilization of scrap PET should minimize environmental impact and maximize conservation of natural resources. One possible solution for this disposal problem was to incorporate PET particles into sand-based materials. Scrap PET could be shredded into raw materials for use in hundreds PET plastics products (Okunola *et al*., 2019).

1.3. Objectives

1.3.1. General objective

The general objective of the study was to partial replacement of sand with PET bottle plastic waste as means of resource recovery in the production of fly ash Bricks.

1.3.2. Specific objectives

- ✓ To evaluate the compressive strength between plastic brick compared with ES 86 specificatio n, ASTM standard specification and control sample.
- ✓ To determine the splitting tensile strength and flexural strength of the prepared plastic fly ash brick specimen.
- ✓ To evaluate the water absorption, moisture content, unit weight and oven test between plastic Flyash brick with different percentage of plastic waste.

1.4. Research questions

- ✓ What is the compressive strength of plastic bricks?
- ✓ What is the splitting tensile strength and flexural strength of the prepared plastic fly ash brick specimen?
- ✓ What are the water absorption, moisture content, unit weight and oven test between plastic Fl yash brick with different percentage of plastic waste?

1.5. Significance of the study

The results obtained from this study are expected to contribute to the construction industry as an alternative aggregate source and the brick produced from plastic waste used for wall, road side, parking and water tanker. It also encourage PET plastic factories to think of side business for PET plastic waste recycling as the economic benefit is obvious. It provides sustainable markets for recycled PET plastic waste and it encourages material recovery of large amounts of PET bottles. Large amount of plastic waste produced every year, therefore, t his study explores measures that help build capacity of stakeholder's to regulate and coordinate th e available resources as well as activities in relation to bottle plastic waste management. As a res ult of this, many stakeholders could benefit from the outcome of this study. In particular, it create job opportunities to plastic bottle collector and manufacturer of bricks and it might enable policy makers of the Debre Birehan town administration might enable them to revisit the existing policy of solid waste management, especially that of PET bottle campaign. Reuse of PET plastic waste has a dual advantage cost of material was low also it solves the problem of disposal of plastic waste to the environment. Finally this could alleviate environmental pollution to some extent and which could save nature diminishing resources.

1.6. Scope of the study

This study concentrated on the performance of a single gradation of PET bottle plastic wastes. The waste plastic bottle collected were chosen from those used as packaging plastic bottle for water and beverage which were resin code one to avoid any inconsistent properties that might arise by mixing materials from different plastic resin code. The study was done on class A fly ash bricks. Debre Birehan town administrations have nine kebeles, in order to Scope with shortage of time and resources the geographical scope of the study focuses on six kebeles, in addition the study could not consider the following, one was chemical components, properties or density of plastic bottle in the market, the other was plastic waste generation rate could not studied.

CHAPTER TWO

LITERATURE REVIEW

2.1. General

The increase in the popularity of using environmental friendly, low cost and lightweight construction materials in building industry has brought about environment benefit the as well as maintaining the material requirements affirmed in the standards (Callister *et al*., 2008). Brick was one of the most accommodating masonry units. Attempts have been made to incorporate waste in the production of bricks such as the use of paper processing residues, cigarette butts, fly ash, textile effluent treatment plant (ETP) sludge, polystyrene foam, plastic fiber, straw, polystyrene fabric, cotton waste, dried sludge collected from an industrial wastewater treatment plant, rice husk ash, granulated blast furnace slag, rubber, craft pulp production residue, limestone dust and wood sawdust, processed waste tea, petroleum effluent treatment plant sludge, welding flux slag and waste paper pulp (Raut *et al*., 2011).

The use of various types of waste materials in different proportions and adopted different methods to produce bricks. Different tests have conducted on produced bricks to evaluate their properties following the various available standards. Compressive strength and water absorption were two common parameters considered by most researchers as required by various standards. It was noted that although many of the studied bricks made from waste materials meet the various standard requirements and a number of patents have been approved, so far commercial production and application of bricks from waste materials was still very limited. The limited production and application of bricks from waste materials was also related to the absence of relevant standards and the slow acceptance by industry and public. Standardization plays an important role in disseminating knowledge, exploiting research results and reducing time to market for innovations (Zhang, 2013).

There were various research works have been done to find out the safe and environment friendly disposal of plastics. The inclusion of waste plastic in brick by replacing or adding it. The brick ingredients were one of the appropriate ways to dispose (Raju and Chauhan, 2014).

2.2. Definition of plastic

Plastic is a kind of material that was commonly known and used in everyday life. To define plastic at molecular level, plastic was a kind of organic polymer, which has molecules containing long carbon chains as their backbones with repeating units. The structure of these repeating units and types of atoms play the main role in determining the characteristics of plastics. These long carbon chains were well packed together by entanglements and Vander Waals forces between large molecules, and form a strong, usually ductile solid material. Also, additives were usually added when manufacturing of commercial plastics (Callister *et al*., 2008*)*. Generally, there were two kinds of commercial plastics, thermoplastic and thermosetting plastic. Thermoplastics can be reheated, melted, and molded into different shapes, while thermosetting plastic could degrade and turn into other substances if reheated after molding. The molecules of thermoplastics were packed together by entanglements and Van der Waals forces. A thermoplastic was heated up, it loses its entanglements and its molecules get farther away from each other, which causes the plastic changing from solid to liquid without breaking the bonds within the molecules. On the other hand, the molecules of thermosetting plastic are packed together not only by entanglements and Van der Waals forces, but also by the cross-links between molecules. When a thermosetting plastic was heated up, the cross-linking bonds between molecules break apart and the plastic turns into another substance when it melts, usually by decomposition (Shanmugavalli, 2017).

2.3. Types of Plastics

Today, there were many different types of plastics manufactured in the plastic industry. They were applied in different areas depending on their properties (Callister *et al*., 2008). The table below summarizes names of all commonly used plastics, their properties, and applications. It shows the importance of plastic materials, since they were used in many different areas. Most post-consumer waste contains a wide range of plastic polymer types, reflecting the variety of plastic polymers consumed in daily life (Camilla *et al*., 2019). The following table 2.1 illustrates about different types of waste polymer.

Table 2.1: Different Types of waste Polymers and their Applications (Yunping *et al*., 2003)

Short name	Scientific name	Used in
PET	Polyethylene Terephthalate	Water bottle , PET bottle
HDPE	High density polyethylene	Milk jugs, detergent bag, oil bottle
PVC	Poly vinyl chloride	Cooking oil bottles, cables, pipes
LDPE	Low density polyethylene	Grocery bags, shopping bags, squeezable bottles, films
PP	Poly propylene	Medicine bottle, cereal liners
PS	Poly styrene	Foam packaging, tea cups, ice cream cups
O	Other	Bakelite, nylon, melamine

2.3.1. PET bottle plastics waste

Plastic bottles which were the concern of this study were a lightweight, hygienic and resistant material which could be molded in a variety of ways and utilized in a wide range of applications unlike metal plastic not rust or corrode (Catt *et al*., 2004). Most plastics do not biodegrade, but instead they were slowly broken down into small fragments known as micro plastics. The fragmentation of large plastic items into micro plastics was common on land such as beaches because of high UV irradiation and abrasion by waves, while the degradation process was much slower in the ocean due to cooler temperatures and reduced UV exposure (Amit *et al*., 2012).

The assertions made in this document refer mostly to fossil-derived plastics and not to plastics of biogenic origins Single-use plastics, often also referred to as disposable plastics, are commonly used for plastic packaging and include items intended to be used only once before they were thrown away or recycled. These include, among other items, grocery bags, food packaging, bottles, straws, containers, cups and cutlery (Maneeth *et al.,* 2017).

Plastic bottles which were the concern of this study could be specific manufacturing and performance advantages over other packaging materials like aluminum, steel and glass that have helped plastics expand their market share of packaging materials. But with the growth of plastic bottling there was a heightened awareness of end-of-life (EOL) issues regarding their recycling and disposal. The plastics industry and the entire value chain have responded with sustainability efforts and educational endeavors. Plastic bottles have come a long way since their first commercial uses in the late 1940's. The introduction of high-density polyethylene (HDPE) and polyethylene Terephthalate (PET) polymers expanded plastic bottling applications. Plastics then surpassed glass as the go-to packaging choice for a wide array of product and brand. The importance of plastic bottles to Plastics membership (Alkunte *et al*., 2015).

2.4. Waste plastic characterization

A brief description of the key characteristics for end-of-waste is provided below, and discussion of the potential use of existing standards in the criteria is included (Punith *et al*., 2010).

2.4.1 Contaminants

Contaminants were materials present in waste plastic that are undesired for its further recycling. Contaminants could be classified in two groups: non-plastic material components, and plastic material components that were detrimental for recycling and further manufacturing (Punith *et al*., 2010).

2.4.2. Plastic material components

Plastic product quality was severely affected by the presence in waste plastic of more than one polymer of different structure. When a mix of polymers was melted for recycling, at the melting temperature of one of them, the polymers with lower fusion point could gasify and, while the higher fusion point polymers should stay intact. Both elements were undesirable in final products, as they interrupt the structure of the new product and reduce its mechanical properties. Normally, it is possible to separate physically most polymer types using their different properties. The degree of separation and purity achieved depends on the costs of the treatment and the marginal value added of the purified material (Hinislioglu *et al*., 2004). Density differences were widely used to effective separate polyolefin's (PE, PP) which are lighter than water, from PVC and PET, which are denser than water (See Table 2.2). The separation of plastics with close density values (e.g. PVC and PET) can also be undertaken by density, modifying the density of the separation liquid (e.g. adjusting the salt content in water). In a dry phase, optical separation with near-infrared (NIR) separators is also a widely used separation technique (Punith *et al*., 2010)

Table 2.2:-Density of some of the most common plastics (Little *et al*., 1993)

Plastic types	HDPE	LDPE	PP	PVC	PET	Teflon	PC
Density(g/cm^3)	0.95	0.92	0.91	1.44	1.35	2.1	1.2

2.5. Reasons for using plastics

Although plastic was not good for the environment and creating tons of trash around the world, it still plays a very important role in our everyday life. In fact, plastic was a very useful material that brings us convenience and makes many things possible. One of the well-known facts was its cheap price. Making packaging could cost 89% more to the consumers without the use of plastics. Except for some disadvantages, plastic was surprisingly beneficial in different aspects (Pramod *et al*., 2006). Plastic needs less energy in the production process. Foam polystyrene containers take 30 percent less amount of total energy needed to make paperboard container; by using plastic in packaging, European product manufactures annually save the equivalence of 101 million barrels of oil. Although plastic was not very environmental friendly, it does save energy and also lowers the amount of greenhouse gas emissions. Plastic was also durable and strong. Due to the way the plastics molecules arrange, it can stay intact for a long time as well as very strong but not brittle (Nadeesha *et al*., 2012).

2.6. Managing plastic waste

Today, the management of plastic wastes has become one of the most challenging problems in our society. It seems even serious if think about the future generation that has to deal with continuously growing amount of plastic wastes accumulated in the environment. In the course of this study, I could have an extensive amount of research on plastics and their types, their impacts on the environment, economy, and many other factors. The alternative that has the most potential in the future was biodegradable plastics. Even though the idea of biodegradable plastics was fairly new, with changing times and needs, they were most likely to be one of the most viable options to replace traditional plastics. There were a number of challenges related to biodegradability that need to be addressed like achieving complete biodegradation. By addressing some of these complications biodegradable plastics have along with creating awareness in people about their advantages over traditional plastics, biodegradable plastics could be introduced in all major areas of everyday life (Mehrabzadeh *et al*., 2008).

2.7. Problems of Plastics

2.7.1. Health hazards of Plastics

Plastics may be easy and convenient for everyday use. However, overlook their negative impacts on our health. In the long run, overuse of plastics and lack of proper recycling were going to yield many undesirable effects on our health. Plastics were harmful to manufacture, use, and pose a great challenge of recycling at the same time. Hence, when it comes to plastics, it was a full circle of problems and challenges that need to be resolved. In addition to Polycarbonate, breaking down the seven plastic resin codes and dangerous chemicals it leaches; let's look over with the following categories of resins (European Commission, 2018).

2.8. Properties of Plastic waste

Fatigue resistance: - the mix should not crack when subjected to repeated loads over a period of time.

Resistance to permanent deformation: - The mix should not distort or be displaced when subjected to traffic loads. The resistance to permanent deformation was more important at high temperatures.

Resistance to low temperature cracking: - this mix property was important in cold regions.

Durability:- the mix should contain sufficient asphalt cement to ensure an

Adequate film thickness around the aggregate particles: - The compacted mix should not have very high air voids, which accelerates the aging process.

Resistance to moisture-induced damage: -Using Plastic waste in road construction. An eco-friendly way of plastic waste disposal.

Workability: - the mix must be capable of being placed and compacted with reasonable effort.

2.9. Principles of Sound Plastic Waste Management

2.9.1 Conceptual and Analytical Framework

Waste management options were often arranged in a hierarchical manner to reflect their desirability. The first priority was waste avoidance that was not generating waste in the first place. If the waste must be generated, then the quantities should be minimized. Once that has been achieved, the next step was to maximize, recovery, reuse and recycling of suitable waste materials. Once the possibilities for waste prevention and minimization and recovery have been exhausted, the next step is to reduce waste by extracting useful resources or converting into energy or reducing bulk before the final disposal(EPA, 2006-A).

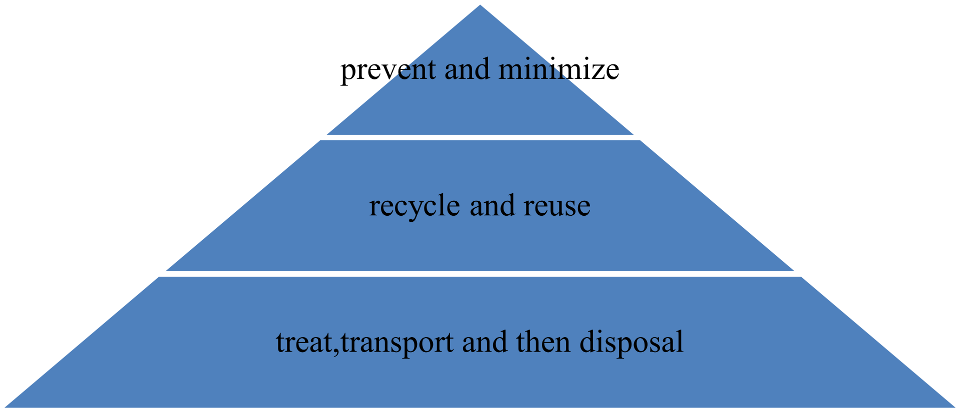

Figure 2.1: Solid Waste Management Hierarchies Upright Cone Shape

Figure 2.1 represents this hierarchy as an upright cone, with the most desirable option waste avoidance, at the apex. By coincidence, the volume of each of the layers in the cone was also roughly proportional to the relative quantities of waste currently being managed by each of the options in most countries around the world (UNlDO. UNEP. 1998). In other words, while there was general agreement on the order of desirability of the various options, in practice the current situation in terms of relative quantities was generally inversely proportional to desirability (EPA, 2006-A).

The attainment of sound waste management depends on capacity to attract and encourage investment on waste management service, implement the polluters pay principle (that was shifting the cost of bad waste management to the polluter him/herself from the public's. and facilitate and promote partnerships at all levels. In general, sound waste management system follows four steps to secure that waste was controlled well from its creation to its disposal (EPA, 2006-A) Such waste management steps could be valuable when applied in an economically viable, environmentally sustainable and socially acceptable way. The four steps were discussed in detail here under.

2.9.2 Prevention and/or Minimization of Waste Generation

Waste generators should use production systems, practices and processes that create the least minimum possible waste. Preventing waste from being generated was the first goal of any waste management program. The waste prevention and minimization approach encourages minimizing waste through proper organization and maintenance, changing inputs, process and product (EPA, 2006-A).

2.9.3. Reusing and/or Recycling

Waste generator (or any other user) must make the best use of the waste being generated. Reusing encourages users to reuse a product or pass it to those who can reuse products like, used plastic bottles, clothes, papers, bottles, tins, etc. Recycling program consist of recovery of recyclable wastes, processing into new materials or products and the marketing of these products (Shanmugavalli, 2017).

2.9.4 Treatment and Transportation

Once waste was produced, something should be done with it. Some wastes could be compacted to take up less space and could be treated covering and adding some chemicals that can suppress bad smell or blowing of dusty content) so that it becomes less dangerous. Wastes that were treated, physically, biologically or chemically were convenient to transport and dispose them in an acceptable way (EPA, 2006-A).

2.9.5 Disposal

The fourth step deals with all wastes remaining after taking the previous three steps. This step requires disposal of solid wastes in properly constructed, fenced and protected site. Such disposal should be taken in a manner that makes sure that the waste finally disposed does not negatively affect ground water. In addition not pollute the environment, be taken by wind or flood or be eaten by animals. Furthermore when the land fill was full and finishes its purpose, there should be a mechanism by which the area was used for another useful purpose, because landfills sites were essential components of any waste management (EPA, 2006-A).

2.10. Bricks

Bricks were a basic building unit which was in the form of rectangular block in which length to breadth ratio is 2 but height could be different.

2.10.1. Flyash Brick

Fly ash was a residue resulting from combustion of pulverized coal or lignite in thermal power plants. About 80% of the total fly ash was in finely divided form which was carried away with flue gases and collected by electrostatic precipitator or other suitable technology. The balance

20% of ash gets collected at the bottom of the boiler and is referred to as bottom ash. Fly ash got into a fine powder in the comparable to cement, however some particles have size less than 1 micron in equivalent diameter. Fly ash bricks/blocks technology has been developed successfully by National Thermal Power Corporation (NTPC), Bhanu International and Ahmadabad Electricity Company (AEC) for manufacturing bricks/blocks which can replace burnt clay bricks as walling material. It was also known as Fly Ash bricks. It was not a brand name but it was duct name, christened to the mix for easy identification of its ingredients (Bhogayata *et al*., 2012).

2.10.2. Brick Masonry

The art of laying bricks in mortar in a proper systematic manner gives homogeneous mass which can withstand forces without disintegration, called brick masonry (Mazenan *et al*., 2018).

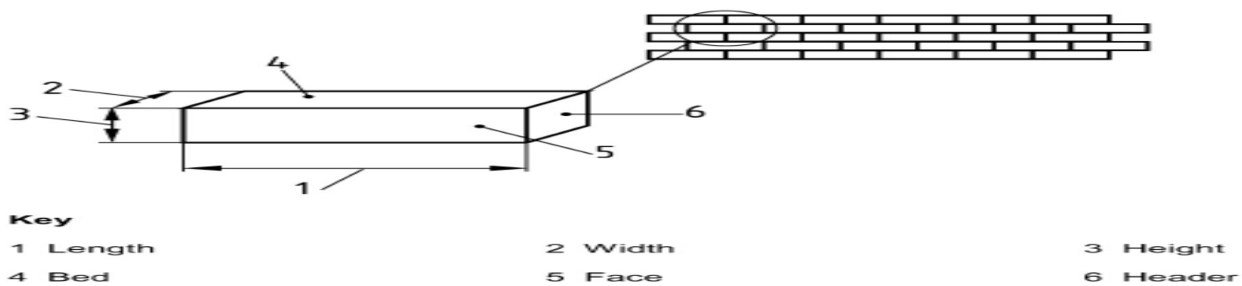

Figure 2.3: bricks masonry (Mazenan et al., 2018)

2.10.3. Brick Sizes

A standard metric brick has coordinating dimensions of 225x112.5x75mm called nominal size and working dimensions (actual dimensions)of 215 x 102.5 x 65 mm called architectural size (Mazenan *et al*., 2018).

2.10.4 Masonry Wall Requirements

The usual functional requirements of a masonry wall were adequate strength to support imposed loads, sufficient water tightness, sufficient visual privacy and sound transmission, appropriate fire resistance, ability to accommodate heating, air conditioning, electrical, and plumbing equipment, ability to receive various finish materials Cost, ability to provide openings such as doors and window (Mazenan *et al*., 2018).

2.11 The property of brick altered with plastic waste

The rutting resistance of the mixture has been observed to be increased by the improvement of stiffness in hot climates and the stiffness enhancement allows the use of relatively softer base bitumen, which sequentially, provides a better low temperature performance. The improved adhesion and cohesion property has also been observed in consequence of the applying polymer modified binders (Praveen *et al*., 2013). High density polyethylene (HDPE) can also be used as a modifier of asphalt concrete and this modified binder become more resistant to permanent deformation and it contributes to recirculation of plastic wastes as well as the solid waste disposal problem is relatively solved. Researchers have been found that, with the addition of some waste materials and certain polymers to brick binders can improve the performance of bricks (Poulakis *et al*., 2008).

2.12. Methods of Recycling PET Bottle

The numerous techniques and technologies available for processing postconsumer PET are enumerated below (Nagan *et al*., 2011).

- Shredding and Chipping: This was mechanical shredding of the PET bottle first in to bigger sizes and then into particles of 2 mm in size.
- Crumbing: It was the processing of the PET into fine granular or powdered particles using mechanical or cryogenic processes.
- Energy Recovery: It was the incineration of PET to generate energy.

The proposed benefits of using waste PET in construction were three-fold:

1. They can offer distinct engineering benefits over natural aggregates.
2. They could be used as an alternative to primary materials thereby reducing an environmental burden on extraction.

Their use can help to reduce burden of waste disposal (including illegal stockpiling and disposal, such as fly-tipping, with their associated risks) and the impacts on the environment associated with some other uses of PET. Waste PET have hardness and elasticity properties superior to those of sand, good resistance to weathering, could be used for preventing impact damage, and as a pavement making material, because of their low specific gravity which is lower than most construction materials (Mohammed *et al*., 2017).

2.13. Benefits of Recycled PET

A wide range of potential sectors which can benefit from using waste PET are identified. The areas were grouped into five classes (Groom *et al*., 2005). Civil engineering, non-road Sport, safety and outdoor surfaces Consumer and industrial products, and energy. The proposed benefits of using waste PET in construction were three-fold: They can offer distinct engineering benefits over traditional aggregates..They could be used as an alternative to primary materials thereby reducing an environmental burden on extraction. Their use can help to reduce burden of waste disposal (including illegal stockpiling and disposal, such as fly tipping, with their associated risks) and the impacts on the environment associated with some other uses of PET (Jayashankar, 2018).

In addition to the above from the literature the following listed researchers put their perspective on waste plastic as a constituent with bricks.

a) Jayaprakash M C1, Deeksha I M2 and Soumya M R, PET Bottles for Eco-friendly Building in Sustainable Development, International Journal of Current Trends in Engineering &Research (IJCTER)e-ISSN 2455–1392Volume 2 Issue 5, May 2016 pp. 318 – 326. This paper proposes the use of waste plastic PET (Poly-ethylene Terephthalate) bottles as constructions entity to standardized bricks. As plastics are non-biodegradable its disposal as always been a problem. This is an environmental issue as waste plastic bottles are difficult to biodegrade and involves processes either to recycle or reuse. Green building is one that may represent were generative process where there is actually an improvement and restoration of the site and its surrounding environment. The ideal "green" project preserves and restores habitat that is vital for sustaining life and becomes a net producer and exporter of resources, materials, energy and water rather than being a net consumer. Green building is the practice of constructing or modifying structures to be environmentally responsible, sustainable and resource-efficient throughout their lifecycle. Thus, to envisaged the sustainable development and energy consumption in the construction of green building for quality living concept to fulfill the paradigm of the development of country. The present work may give the same sort of solution in the construction of buildings by using waste plastic PET bottles which are dumped on the open land. It may solve the reuse of the waste plastic PET bottles as a benefit to minimize the solid waste in the form of environment friendly green building concept for living as a cost effective material.

b)Youcef Ghernouti et al, 2013. 1 The study present the partial replacement of fine aggregate in brick by using plastic fine aggregate obtained from the crushing of waste plastic wastes. Plastic bags waste was heated followed by cooling of liquid waste which was then cooled and crushed to obtained plastic sand having finesse modulus of 4.7. Fine aggregate in the mix proportion of brick was replaced with plastic bag waste sand at 10%, 20%, 30% and 40% whereas other brick materials remain same for all four mixes. In fresh properties of brick it was observed from the results of slump test that with increase of waste content workability of mortar increases which is favorable for brick because plastic cannot absorb water therefore excessive water is available. Bulk density decreases with increase of plastic bags waste. In harden state, flexural and compressive strength were tested at 28 days and reductions in both strengths with increasing percentage of plastic bag waste sand in brick mix. Plastic waste increases the volume of voids in brick which on other hand reduce the compactness of brick simultaneously speed of sound in brick is also decreased. Strength reduction in brick mix was prime concern; however they recommend 10 to 20% replacement of fine aggregate with plastic aggregate. Use of admixtures to address the strength reduction property of brick with addition of plastic aggregate is not emphasized.

c**) Muyen, TN Barna, MN Hoque (2012)**, Strength properties of plastic bottle bricks and their suitability as construction materials in Bangladesh, ISSN: 1017 – 8139. With global solid waste generation rates rising faster than ever, urban development specialists warn that the growth would peak this century and will not start to decline without transformational changes in how we use and reuse materials. The World Banks urban development specialists Daniel Hoornweg and PerinazBhada-Tata had placed the global Municipal Solid Waste (MSW) generation levels at approximately 1.3 billion tons per year in a 2012 report. They warned that the levels would increase to approximately 2.2 billion tons per year by 2025. This report also estimated the per capita global solid-waste generation rate would rise from more than 3.5 million tons per day in2010 to more than 6 million tons per day in 2025. The „bottle brick" is one such invention. Waste Polyethylene Terephthalate (PET) bottles packed with other dry solid wastes or sand and earth has been successfully used in a number of countries around the world. This study looked into the strength properties of waste PET bottles filled with fine sand. Five different sizes (250,500, 1250, 1500 and 2000ml) of waste PET bottle bricks were tested for compressive strength and the largest bricks give a compressive strength of 17.44Mpa. From the above literature review, I came to know that use of innovative materials with sustainable application such as plastic bottles can have considerable benefits including finding the best optimization in energy consumption of the region, reducing environmental degradation. Plastic bottles can cause the green construction by saving energy and also, recycling of the materials, minimizing the emission of CO2 etc. The study also suggests that waste materials which are fine in size, if handled in controlled condition well provide sustainable development. Walls constructed using plastic bottle block have been less costly as compared to the regular bricks and also they provide greater strength than bricks. But this research aims to partial replacement (not fully) of sand by grinding of PET Plastic Waste in order to get the standard compressive strength and adequately carry the expected load.

d) According to K. Ramaderi & R.Manju (2012): The study present that it was observed the compressive strength increased up to 2% replacement of the fine aggregate with PET bottle fibers and it gradually decreased for 4% and 6% replacements. Hence replacement of fine aggregate with 2% replacement will be reasonable. It was observed that the split tensile strength increased up to 2% replacement of the fine aggregate with PET bottle fibers and it gradually decreased for 4% and 6% replacements. Hence, the replacement of the fine aggregate with 2% replacement will be reasonable with high split tensile strength compared to the other specimens casted and tested. It was observed that the flexural strength increased up to 2% replacement of the fine aggregate with PET bottle fibers and it gradually decreased for 4% and remains the same for 6% replacements. Hence, the replacement of the fine aggregate with 2% of PET bottle fibers will be reasonable than other replacement percentages like 4% and 6% as the compression and split tensile strength reduces gradually (K. Ramader I & R.Manju, 2012).

e**) According to Ramesh et al., (2007):** They have used waste plastic of low density poly ethylene as replacement to coarse aggregate to determine its viable application in construction industry and to study the behavior of fresh and harden bricks properties. Different bricks mix were prepared with varying proportions (0%, 20%, 30% & 40%) of recycle plastic aggregate obtained by heat treatment of plastic waste (160-200 centigrade) in plastic granular recycling machine. A mix design with 1: 1.5: 3proportions was used having 0.5 water/cement ratio having varying proportion of plastic aggregate as replacement of crushed stone. Proper mixing was ensured and homogeneous mixture was prepared. A clear reduction in compressive strength was reported with increase in percentage of replacing plastic aggregate with crushed aggregate at 7, 14 and 28 days of casted cubes (80% strength achieved by replacing waste plastic up to 30%). The research highlights the potential application of plastic aggregate in light weight aggregate. Their research was narrowed down to compressive strength of bricks with no emphasis given to flexural properties of bricks. They suggest future research scope on plastic aggregate with regard to its split tensile strength to ascertain its tensile behavior and its durability aspects for beams.

2.14 Research Gap

All the researchers used the typical brick ingredients with plastic waste by melting it and no attention was given to admixtures and use of fly ash which can alter the properties of brick but this study used plastic waste by grinding it with required fine aggregate size and used fly ash as admixtures. The area of focus of all the researchers was limited to compressive strength and a wide gap is left for further research on other properties of brick produce by using plastic wasted. Plastic waste material requires detail investigation on behavior of its various types in brick, so this study investigate other properties of bricks such as water absorption, tensile strength, moisture content and oven test.

2.15. Properties of Hardened PET brick

2.15.1 Unit Weight

The replacement of natural aggregates with PET aggregates tends to reduce the density of the brick. This reduction was attributable to the lower unit weight of PET aggregate compared to ordinary aggregate. The unit weight of PET brick mixtures decreases as the percentage of PET aggregate increases (Danko *et al*., 2006).The unit weight (density) of bricks varies, depending on the amount and density of the aggregate, the amount of air that was entrapped or purposely entrained, and the water and cement contents, which in turn are influenced by the maximum size of the aggregate. Because of low specific gravity of PET particles, unit weight of mixtures containing PET decreases with the increases in the percentage of PET content. Moreover, increase in PET content increases the air content, which in turn reduces the unit weight of the mixtures. At 10% PET plastics content, the dry density diminished to about 9.5 % of the normal bricks. However, the decrease in dry density of PET was negligible when PET content is lower than 1-2% of the total aggregate volume (Ling et al., 2006). The reduction in the unit weight of the PET brick mix increases as the percentage crumb PET added increases (Groom *et al*., 2005).

2.15.2 Compressive Strength

Compressive strength tests were widely accepted as the most convenient means of quality control of bricks produced. Tests conducted on PET bricks behavior, using PET chips and crumb PET as aggregate substitute of sizes river sand exhibited reduction in compressive strength and increase water absorption of bricks but showed the ability to absorb a large amount of plastic energy under compressive loads (Anusuri *et al*., 2020). The compressive strength decreased as the PET content increased. Part of the strength reduction was contributed by the entrapped air, which increases as the PET content increases. Investigative efforts showed that the strength reduction could be substantially reduced by adding a de-airing agent into the mixing truck just prior to the placement of the bricks. In another study test results have shown that there was a systematic increase in the compressive strength with the increase in PET content from 0 % to 20% (The PET Manufacturers Association, 2009).

2.15.3 Tensile Strength

The tensile strength of PET containing brick affected by the size, shape, and surface textures of the aggregate along with the volume being used indicating that the strength of bricks decreases as the volume of PET aggregate increases (Danko *et al*., 2006). Tests conducted on PET brick behavior, using tire chips and crumb PET as aggregate substitute of river sand size exhibited reduction in splitting tensile strength by 20% but showed the ability to absorb a large amount of plastic energy under tensile loads (Kumaran *et al*., 2008).

2.15.4 Flexural Strength

The flexural strengths of PET brick decreased as the PET content in the mix increased (Kaloush *et al*., 2004).On the contrary, there was an improvement in flexural strength by the addition of PET aggregates in roller compacted brick. In comparison with the control brick, when the compressive strength was kept constant for roller compacted brick, the flexural strength, and ultimate tension elongation increased with the increase of PET content (Kang *et al*., 2008).

2.15.5 Water Absorption

It was a measure of the voids (reachable pore volume) within the net volume of the brick, including the voids within the aggregate itself. According to ASTM C140-70, the water absorption in utilization of waste plastic as a partial replacement of sand in brick production. absorption determined from five full-size units completely immersed in water at room temperature for 24 hours and they should be removed from the water and allowed to drain for one minute by placing them on a 10mm or coarser wire mesh. Visible surface water being removed with a damp cloth, and immediately weighed and then all specimens should be dried in a ventilated oven at 100°C to 115°C for not less than 24 hours and until two successive weightings at intervals of 2 hours show an increment of loss not greater than 0.2 percent of the last previously determined mass of the specimen and the recommended water absorption requirements of load bearing.

Ethiopian standard (ES 596:2001) specify water absorption 290 kg/m3 (25%) for load bearing brick and 320 kg/m3 (30%) for the non-load bearing brick while Indian standard recommended 10 percent.

2.16. Cost Considerations in PET fly ash bricks

The use of recycled PET in brick production was an infant technology and the number of used PET that was recycled in environmental engineering applications was very low at the current time. However, any new bricks products developed for the market need to be feasible in terms of cost, including material costs and production processes or the resulting advantage of improved properties should surpass any cost increment that might occur. The different factors associated with the cost of PET brick were discussed below.

2.16.1 Cost Savings due to Material substitution

The other approach was to consider the replacement value of virgin materials used in current products. This calculates the acceptable price for PET aggregate based upon the current price of virgin materials less an allowance for the cost of process changes. In this approach, the principle was that the use of PET aggregate should be cost neutral. The acceptable price for PET aggregate can then be compared with the actual price. The process change costs were dependent on the particular application therefore difficult to estimate at present. The cost of PET aggregates also varies widely depending on the source of the PET and the amount of processing during production (Cairns *et al*., 2004).Taking the UK government as an example, its policy was to reduce demand for virgin materials and encourage the use of recycled materials by promoting a market solution through a mixture of statutory regulation and economic measures. The Landfill Tax was introduced in October 1996 to discourage the land filling of inert and active waste and the value of the tax was set to increase over time. The European Union legislation currently bans the disposal of whole tires in landfill sites. The implementation of the landfill ban would undoubtedly improve the viability and economics of PET recycling. It was possible that the PET retailers would need to pay more to the PET recyclers to take the used PET and that this cost would be passed on to PET purchasers (Wallis *et al*., 2005).Cost savings could be made by substituting aggregates for PET. PET weighs less than most other options. The cost of transporting the equivalent m^3/km in PET would be less than for other aggregates, however, the distance differential should also be considered carefully to ensure that any additional distance required to deliver PET or PET materials does not negate the advantage (Kumaran *et al*., 2018).

2.16.2 Whole life Cost reductions

The cost savings potentially afforded by PET through material substitution and performance (lower construction, maintenance and renewal costs) could over the lifetime of a structure significantly reduce its „whole-life cost". The objective of whole life costing was to minimize long-term expenditure by taking all costs associated with the provision of a structure into account including initial construction and subsequent maintenance, and monitoring and selecting the approach that offers the best value in the longer term (Wallis *et al*., 2005).

2.16.3 Cost Savings by Protecting the Environment

One of the sustainability targets set by some governments for the construction industry was replacing natural aggregates with secondary or recycled alternatives while also reducing waste disposal. However, for use of alternative aggregates to be sustainable, there must be an economic supply of sufficient quantity. There must also be methods of quality assurance plus specification and a market appropriate to the costs of the processed wastes, as well as good technical performance (Groom *et al*., 2005). The accumulation of used tires at landfill sites presents the threat of uncontrolled PET, producing a complex mixture of chemicals harming the environment and contaminating soil and vegetation. Reuse and recycling generally costs the environment less in resources to the benefit of wider society (Groom *et al*.,2005). Additional benefits from using ground PET fiber in landscaping applications include benefits related to avoided disposal space savings (landfill space, land space), reduced risks to human health from PET piles, and avoided emissions from PET pile fires. The need for quarrying and waste disposal was reduced with the associated environmental impacts as well (Stutz *et al*., 2013).Provided that the cost of PET aggregate could be kept to the lower end of the range, it could be seen that the cost increase should not be onerous for manufacturers. The less stringent processing requirements for PET aggregate used in bricks were likely to further reduce the cost of PET aggregate in this application. Simultaneously, environmental concerns were increasing all over the world. The recent Copenhagen summit of different nations has demonstrated how big and critical were the environmental issues and the problem our world was facing due to it. A growing fraction of the public in many modern societies would not hesitate to favor the environmental protection. And that implies a certain willingness to pay more for a commodity that was clearly identified as environmentally friendly or to contain recycled materials. Recycling was associated with a number of cost items, like collection, separation, processing transportation, and the required capital investments. On the other hand, solid waste that was not recycled or reused needs to be disposed in landfills, with direct costs in the form of tipping fees and indirect costs in the form of environmental impact and depletion of suitable landfill capacities. Hence, the successful use of waste tire chips and fibers in brick could provide one of the environmentally responsible and economically viable ways of converting this waste into a valuable resource (Groom *et al*., 2005). So far, a review of the characteristics and constituents of brick in general has been done. Following that, the use of recycled materials in bricks construction was discussed with recycling PET as the main subject. Previous works on PET fiber brick were also presented in this chapter. In addition, the production of fiber aggregates and the different surface treatment methods utilized by other researchers were clearly seen. Moreover, in the final parts of this chapter, the fresh and hardened properties of fly ash were thoroughly reviewed. As to the knowledge of the author of this study, there was no reported research in Ethiopia in the use of recycled PET in bricks construction until now. Thus, the research was aimed at evaluating the fresh and hardened properties of bricks produced by partial replacement of the natural fine aggregates with PET bottle plastic aggregates that were obtained from local sources and physically reprocessed for the purpose of this research (Groom *et al*., 2005).

All the information in this literature review have provided with a sufficient knowledge to go to the next part of the research. In the subsequent chapter, the different tests conducted and the properties of the ingredient materials from the test results were presented. Moreover, the mix proportioning procedure utilized was also explained.

CHAPTER THREE

Materials and Methods

3.1. Description of the study area

Debre Birhan is located in North Shewa Zone of ANRS. It is astronomically located in an approximate geographical coordinates between 9º 38’00’’North Latitudes and 39º 30’00’’East Longitudes. In relative terms, it is situated at about 120kms road distance from Addis Ababa (the capital of Ethiopia) and at about 696kms from Bahir Dar (the regional capital) on the main highway to Dessie and/or to Mekele. The town is bounded by wereda of North Shewa Zone of ANRS. Currently, it was divided in to 9 kebeles under municipal status and wereda level and serves as a center for North Shewa Zone. The total area of Debre Birhan under the municipal (*wereda* level) jurisdiction (including the surrounding rural areas) was estimated to be about 18,000 hectares. Debre Birhan was classified under Dega agro-climatic zone. With an average maximum temperature of 20.1ºc and average minimum temperature of 6.5º c., with mean annual rainfall of 965.25mm.

This study area is selected because in this area there is no designed land fill, litter bins, and there are no any industries which recycles the plastic waste.

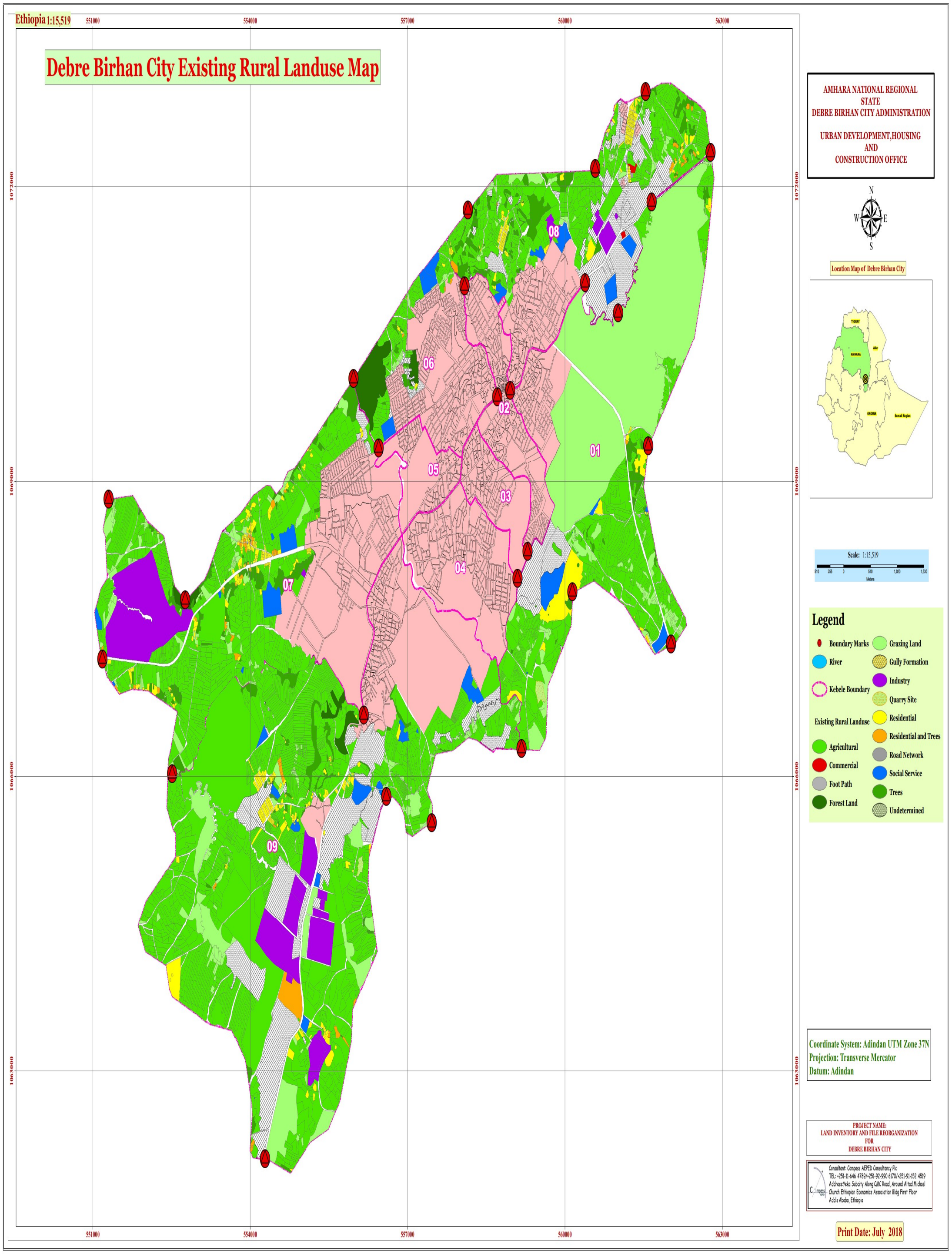

Figure 3.1: Map showing the relative position of the study area

3.2. Material Selection of Ingredient for Plastic fly ash Bricks

The materials used for this study were:-plastic waste (PET), cement (PPC), sand (river sand), water, fly Ash.

3.2.1. Waste plastic bottles

Plastic bottles which were the concern of this study were a lightweight, hygienic and resistant material which could be molded into a variety of ways and utilized in a wide range of applications unlike metal plastic not rust or corrode Most plastics do not biodegrade, but instead they were slowly break down into small fragments known as micro plastics. The fragmentation of large plastic items into micro plastics was common on land such as beaches because of high UV irradiation and abrasion by waves, while the degradation process was much slower in the ocean due to cooler temperatures and reduced UV exposure The assertions made in this document refer mostly to fossil-derived plastics and not to plastics of biogenic origins Single-use plastics, often also referred to as disposable plastics were commonly used for plastic packaging and include items intended to be used only once before they were thrown away or recycled. These include, among other items, grocery bags, food packaging, bottles, straws, containers, cups and cutlery (Maneeth *et al*., 2017).

Waste plastic bottles for this study were collected from waste disposal site of Debre Birehan town, collected with three round and the total collected plastics weigh 110Kg. The collected plastics were washed properly before crushing it, in order removal other impurities.

Figure 3.2:-PET plastic waste (5/2/2021)

3.2.2. Cement

Cement was a generic name that can apply to all binders. The chemical composition of the cements could be quite diverse but by far the greatest amount of bricks used today was made with Portland cements (IRJET, 2019).

For this reason, the discussion of cement in this study was mainly about the Portland cement. Portland cement, the basic ingredient of bricks were a closely controlled chemical combination of calcium, silicon, aluminum, iron and small amounts of other ingredients to which gypsum is added in the final grinding process to regulate the setting time of the brick. Lime and silica make up about 85% of the mass. Common among the materials used in its manufacture were limestone, shells, and chalk or marl combined with shale, clay, slate or blast furnace slag, silica sand, and iron ore. Each step in the manufacturing of Portland cement was checked by frequent chemical and physical tests in plant laboratories. The finished product was also analyzed and tested to ensure that it complies with all specifications (The Portland Cement Association, 2009). For this study Dangote cement is used, the cement was purchased from the local cement shop of Debre Birehan town and weighs 100kg.

3.2.3. Sand

Natural river sand could be used as a fine aggregate. This material was one ingredient of brick and the appropriate particle size were determined by sieve analysis. Sieve analysis of sand helps to determine the particle size distribution of the coarse and fine aggregates. This was done by sieving the aggregates as per IS: 2386 (Part I) – 1963. In this study different sieves used as standardized by the IS code and then pass aggregates through them and thus collect different sized particles left over different sieves. The silica material was utilized as a fine aggregate in brick and mortars. Natural river sand was the most preferred choice as a fine aggregate material. River silica sand was a product of natural weathering of rocks over a period of millions of years. It was mined from the river beds. River sand was becoming a scarce commodity now. River sand was the clean water of superior sand was far superior for construction purposes than any other sand used in construction. Quarrying of river sand was an important economic activity in Ethiopia with river sand forming a crucial raw material to the construction industry (IRJET, 2019).

.In this study river sand was used, which collected from local area originally come from shewarobit. The collected sand washed properly in order remove debris which affect the strength and quality of brick and sieve it with the standard size (the sand passed 4.75mm and retained on 60um sieve are used). The collected sand weighs 120Kg.

3.2.4.Water

Water used for mixing and curing of bricks should be clean and free from oils, acids, alkalis, salts and organic materials or other substances the might be deleterious to bricks. Portable water should be used for mixing of brick. Suspended solid matter in the water should not exceed more than 200mg/l. The pH value of the water should not be less than 6 **(**IRJET, 2019).

For this study tap water was used from Debre Birehan town.

3.2.5. Fly Ash

Fly ash was a residue resulting from combustion of pulverized coal or lignite in thermal power plants. About 80% of the total fly ashwas in finely divided form which is carried away with flue gases and is collected by electrostatic precipitator. The specific gravity of fly ash was 2.67 and the fineness must be near about 84%. This ash was called as dry ash or chimney or hopper ash. The balance 20% of ash gets collected at the bottom of the boiler and was referred to as bottom ash. Fly ash was very fine comparable to cement, however some particles have size less than 1micron in equivalent diameter. The fly ash was the product from the burning of younger lignite in addition of younger lignite as in addition to pozzolanic properties. It was also have self-made cement properties. Generally, it contains more than 20% lime (CaO) (Conference Paper, 2011).

The fly ash used in this study was purchased from Habesha cement manufacturing P.L.C which located around Addis Ababa, Ethiopia and the fly ash weighs 100Kg.

Figure 3.3:-Fly ash (17/2/2021)

3.3. Independent variables

Physical properties of materials, compressive strength, water absorption, moisture content, unit weight, tensile strength, flexural strength and oven test.

3.4. Dependent variables

Utilization of PET plastic waste as fine aggregate (sand).

3.5. Data quality assurance

The material used in this study properly prepared in order to keep the quality of the specimen, river sand was washed and sieved with the standard size ,the crushed plastics also washed and sieved with required size in order to avoid reduction of strength and quality of specimen.
Laboratory test procedures manual were prepared in order to avoid error of data. Laboratory instruments were calibrated; for the quality of the data triplicate experiments was carried out during each set of experiments and average of the triplicate measurements was reported. At each set of experiments calibration (standardization) was conducted for analysis.

3.6. Data analysis

The data analysis were performed by using Microsoft excel 2007, scientific calculator and Minitab. The test results of the samples were compared with the respective control bricks properties and the results are presented using tables, pictures and graphs.

3.7. Experimental design

3.7.1. Design the Proportion of Sand and Plastic

For the fabrication of plastic fly ash bricks, plastic and sand were mixed in different proportions and bricks containing different amount of plastic and sand were made. Plastic and river sand were mixed in different ratios of plastic sand were 10%:90%, 20%:80%, 40%:60% and 50%: 50% bottle plastic waste and sand respectively (Jalagon, 2017). The reason behind taking different proportions of plastic and sand was to find the optimum proportion which gives the desired results. The bricks made of these ratios could further be investigated for various desired properties.

Table 3.1: Mixing Proportions (Jalagon, 2017)

Bricks type	Plastic percentages	Sand percentages
Control brick	0%	100%
Brick 2	10%	90%
Brick 3	20%	80%
Brick 4	40%	60%
Brick 5	50%	50%

3.7.2. Mix design of plastic bricks

Mix Proportioning (Pre-Mix Design)

In order to find the plastic bricks that they possess high compressive strength with various mix proportions were made and they were tested using compressive testing machine (CTM). The mix proportions were in the ratio of 10%; 90%, 20%:80%, 40%:60%, 50%:50% (Jalagon , 2017). These are the ratio which represents the plastic, river sand respectively and 50% 0f fly ash, 30% of sand and 20% cement (ASTM standard for first class brick) have to be used in the production of fly ash bricks.

Table 3.2: Mixing Proportions in gram

Brick No	Plastic (%)	Flyash(gm)	Cement(gm)	Sand(gm)	PET bottle plastic waste(gm)
1	0	1500	634	960	0
2	10	1500	634	864	96
3	20	1500	634	768	192
4	40	1500	634	576	384
5	50	1500	634	480	480

3.8. Specimen preparation

The bricks specimens were prepared in the debre Birehan pole technical college, in construction department, material testing laboratory. The prepared sample consists of 45 brick, beam and cylindrical shaped samples for compressive and tensile strength test.

3.8.1. Procedure of Casting Plastic Sand Bricks

The procedure of casting plastic sand bricks was a simple one. The first step was batching in which sand and plastic waste, PET bottles were weighed. Then different proportions according to the weight are taken for casting the bricks.

3.8.2. Grinding of plastics wastes

PET bottles crushing machine could convert used PET bottles Plastics into shreds readily available for recycling. PET bottles Plastic crushing machine was that which performs the function of crushing PET bottles or plastic materials into granules or shreds for recycling and production of new products rather than using virgin raw materials for production (European Commission, 2013). This mechanical a crushing machine used for grinding of PET bottles Plastics. From the aforementioned points of view, crushing of PET bottles for recycling was cheaper than manufacturing the bottles from virgin raw material, and could also help in controlling the waste disposal problems ravaging the environment particularly in developing countries. The grinding machine used for this study were the following characteristics: - Model name of Suraj G12, semi- automatic type, body material of mild steel, plastic type grinded by this model machine were PET, PVC and PP and produced in 2011.

Figure 3.6: Grinding Machine (source: Sino flavor Manufacturing PLC, in Bishefito) (3/7/2021)

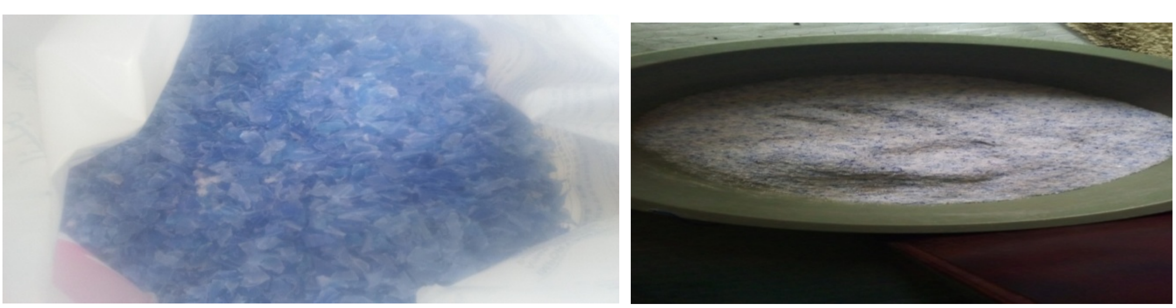

Figure 3.7: Crushed PET plastic waste by Grinding Machine (3/7/2021)

3.8.3. Preparation of Brick Mould

The moulds used for this study was wooden mould and made in the carpentry shop. All the sides and surfaces of the mould should be even for the brick to have better surface finish. Both fixed and movable moulds could be used for this purpose. Wooden mould could be cost effective and serve the purpose whereas if better surface finish was needed then cast iron moulds could be used. Mould size this study would be (215*105*65) mm.

Figure 3.5: Mould preparation in the carpentry shop (3/12/2021)

3.8.4. Batching

Measurement of materials was known as batching .The waste bottles were washed with water and then dried after which the weights of bottles were measured. Sieving of sand was done by 60 micron sieve and this sand would be used for making bricks .Various proportions of plastic bottles with sand was taken for bricks. The different ratios used for this study (10:90, 20:80, 40:60, and 50:50) %, plastic waste and sand respectively (Jalagon, 2017).

Figure 3.8: Batching (Measuring) of plastic waste, fly ash, cement and sand (3/14/2021)

3.8.5. Mixing

Mixing of materials was essential for the production of uniform and strengthens brick. The mixing should ensure that the mass becomes homogeneous, uniform in color and consistency. Generally there are two types of mixing, Hand mixing and machine mixing. In this study, I adopted hand mixing. The percentage of fly ash should be 50%, 30% of sand and 20% of cement (ASTM standard for first class brick) and the plastic wastes were added to mix with the ratio of (10%:90%, 20%:80%, 40%:60% and 50%: 50%), this ratio represents the plastic, river sand respectively (Jalagon, 2017).

Figure 3.9: Mixing (3/16/2021)

3.8.6. Moulding

In molding process the prepared mixture was then filled into wooden mould and then compressed by tamping rod. The pressure was applied by the tampering rod so as the mixture gets filled properly in the mould. Then it was left for cooling in air but before filling the mould apply oil on the walls of mould so that at last brick can be removed easily. The application of oil on the inner surfaces of the mould was must as after solidification the brick would not come out easily and to remove the mould some pressure must be applied that would wear the edges of the brick. So proper oiling was needed before filling the mixture in the mould. The brick then could be removed from mould after 24 hours.

The mould used for this study was wood mould with the standard size of 215mm*105mm*65mm and prepared in local furniture.

Figure 3.10: Casting the mixed material in mould (16/3/2021)

3.8.7. Curing

The test specimens after compaction could allow drying for a period of 24 hours. The specimens would be kept in ordinary curing tank and allowed to cure for a period of 28 days (Chauhan., 2019).

Figure 3.11: Plastic fly ash Brick after removing it from the mould (14/4/2021)

3.9. Laboratory Testing of Specimens

Laboratory tests were carried out on the prepared brick samples. The tests which conducted were compressive strength, unit weight and water absorption. The Schematic flow diagram for the study which was recycling of PET is shown in figure 3.12. Washed PET Plastic waste Cement, water and sand sized PET Test sample product.

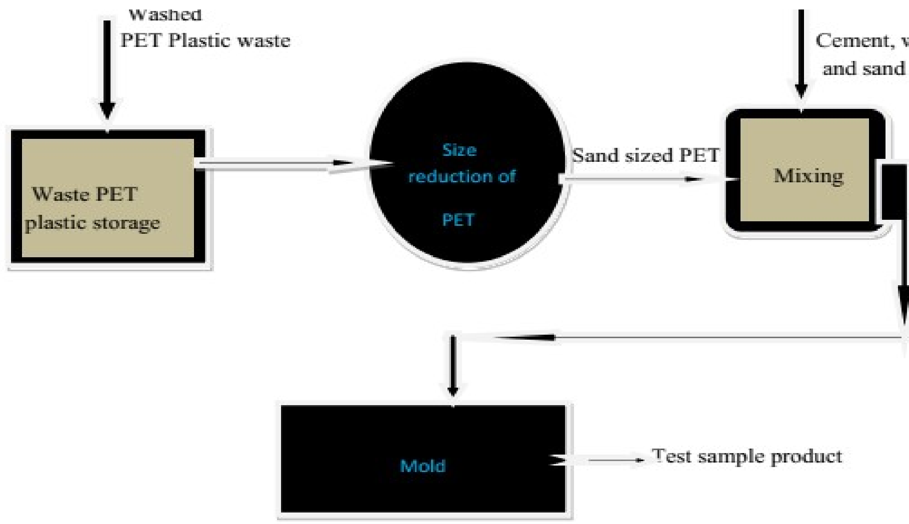

Figure 3.12: Process of Casting Plastic fly ash Bricks

3.9.1. Unit Weight

The unit weight of brick mix containing PET with the increasing the percentage of fiber content was evaluated. This measurement was done in Debre birehan poly technical collage construction engineering laboratory. The replacement of natural aggregates with PET aggregates tends to reduce the density of the bricks. This reduction was attributable to the lower unit weight of PET aggregate compared to ordinary aggregate. The unit weight of PET brick mixtures decreases as the percentage of PET aggregate increases (Danko *et al*., 2006).The unit weight (density) of bricks varies, depending on the amount and density of the aggregate, the amount of air that was entrapped or purposely entrained, and the water and cement contents, which in turn were influenced by the maximum size of the aggregate, because of low specific gravity of PET particles, unit weight of mixtures containing PET decreases with the increases in the percentage of PET content. Moreover, increase in PET content increases the air content, which in turn reduces the unit weight of the mixtures (Ling *et al*., 2006). The reduction in the unit weight of the PET bricks mix increases as the percentage crumb PET added increases (Groom *et al*., 2005).

3.9.2. Compression Strength test

Compressive strength tests were widely accepted as the most convenient means of quality control of the bricks produced. In this test, the brick specimen was placed in the compression strength testing machine. After placing it, applying the load on the brick without any shock. The load could be increased at a rate of140kg/cm2 min continuously till the specimen's resistance to increasing load breaks down and it could not withstand any greater load further (Loukham *et al*., 2017). Recording the maximum load applied to the brick specimen the appearance and type of failure was also noted along with any unusual features (sina *et al*., 2016).

Compressive strength machine used for this study were the following characteristics:- model number BSC280 and produced in 2009.

$$\text{Compressive strength} = \frac{\text{Max.loaad applied}}{\text{Specimen area}} \quad (1)$$

=F/A Where, F -Maximum load applied (KNA – Specimen Area (mm2)

Procedures: On the 28th day the bricks were taken out from the curing tank, then dried in open air, then after the bricks were placed in the digital compression testing machine between both the plates and the results were recorded, the load at which the bricks break out was the maximum loading bearing capacity of that bricks and lastly recording the maximum load applied to calculate the compressive strength of each bricks by equation 1.

Figure 3.13: Compression strength test on brick to determine the load carrying capacity of bricks under compression (4/14/2021)

3.9.3. Tensile and Flexural Strength Tests

The strength tests for tensile and flexural were checked for test brick specimens in Debre Birehan Poly Technical Collage Construction laboratory.

Experiment for Flexural Strength

Beam samples measuring 500×100×100mm were molded and stored in water for 28days before the test for flexural strength. Three similar samples were prepared for each mix proportion. The casting was made by filling each mold with freshly mixed brick and compacted in table vibrator for 30 seconds. To determine the flexural strength of brick ASTM C-78 (Standard Test Method for Flexural Strength of brick using Simple Beam with Third-Point Loading) was used. The hardened beam was placed on the modified compressive testing machine simply supported over a span on a pair of supporting rollers. Two additional loading rollers were placed on top of the beam as shown in Figure 3.14.

Table 3.3: Specifications for testing machines

S/N	Test machine name	Model No	Capacity
1	tensile strength test machine	ADR 36-0720/01	1560KN
2	Flexural test machine	37-6140	100KN

Figure 3.14 the strength tests for tensile and flexural respectively (4/14/2021)

3.9.4. Water Absorption and moisture content test

In this test at first the bricks were weighed after oven dry the bricks. Then they would be allowed to be dipped in fresh water for about 24 hours in a container. The bricks were taken out of the water after 24 hours and wiped with a cloth. The wet brick was weighed using a weighing machine. For the calculation of water absorption, the difference between wet brick and dry brick was done. The difference was the amount of water absorbed by the brick, after that the percentage of water absorption is calculated using the data (Aiswaria *et al.,* 2018). Water absorption of bricks tells about the bonding of bricks with mortar, although other factors such as grooves and design on bricks also improve the bonding. For fly ash bricks which have less water absorptive leaner mortar layer were used for bonding bricks and mortar (Is1905, 1987).Greater quality bricks absorb less amount of water. For a good quality brick the water absorption should not be greater than 20% of its own weight.

$$\text{Water absorption} = \frac{[\text{Weight of wet brick} - \text{Weight of dry brick}]}{(\text{Weight of dry brick}\}} * 100 \qquad (2)$$

Procedures: Dry the specimen in a ventilated oven at a temperature of 105°C to 115°C till it attains substantially constant mass, then Cool the specimen to room temperature and obtain its weight (M1) specimen too warm to touch should not be used for this purpose, after that immerse completely dried specimen in clean water at a temperature of 27°C for 24 hours, next remove the specimen and wipe out any traces of water with damp cloth and weigh the specimen after it has been removed from water (M2) and lastly water absorption % by mass was calculated by equation 2.

Moisture content of bricks were the natural water content of brick before immersing it into water and highly dependent with water cement ratio. For this study the water cement were 0.5 (ASTM, 2001). Moisture content in brick cause differential shrinkage between the top and the bottom of the brick. This leads to curling stresses in which the top of the brick was in tension while the bottom is in compression. The magnitude of these stresses was determined by the moisture distribution and it was determined in laboratory measurements.

$$\text{\% of moisture content of sample} = \frac{(\text{weight of brick} - \text{weigh of oven dryed brick}}{\text{weight of oven dryed brick}}) * 100 \qquad (3)$$

Figure 3.15: oven drying, immersing in to water and weighing of bricks (4/15/2021)

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Physical Properties of the Fine Aggregate and compressive strength of brick samples

4.1.1 Physical Properties of the Fine Aggregate

To investigate properties and suitability of sand for intended application, the following tests were carried out.

- Sieve analysis for fine aggregate.
- Sieve analysis for PET plastic waste.
- Specific gravity and absorption capacity for fine aggregate
- Moisture content for fine aggregate
- Silt content for fine aggregate

Sieve Analysis for Fine Aggregate (River sand)

The fine aggregates used for this study were washed and dried before conducting the tests and Sieve analysis was done in order to determine the fineness modulus of aggregate and the relative amount of various sizes of particles present in the aggregate using sieve series of square or round openings starting with the largest. Fine aggregate were passed through 9.5mm sieve along with almost entirely passed through 4.75mm sieve and predominantly retained on the 60µm sieve. The strength and quality of Brick produced was very much influenced by the sizes of its aggregate. Aggregate grain size distribution or gradation was one among these properties and should be given due consideration. The standard fineness modules for fine aggregate are between 2.2 and 2.6 (Abebe, 2002).

Table 4.1 shows the percentage of fine aggregates passed and retained in each sieve size and shown the corresponding graph.

Table 4.1: The percentage passing each sieve size for fine aggregate

Sieve size(mm)	Wt of selves(gm)	Wt of sieves and retained(gm)	Wt of retained (gm)	Cum. Wt of retained(gm)	Cum. % retained	% passing	Lower limit	Upper Limit
9.5	585	585	0	0	0	100	100	100
4.75	566	566	0	0	0	100	95	100
2.36	522	529	7	7	1.4	98.6	80	100
1.18	530	590	60	67	13.40	86.6	50	90
0.06	505	685	180	247	49.40	50.6	25	60
0.03	476	701	225	472	94.40	5.6	0	30
Pan	422	450	28	500	100	0	0	0
Sum			500		258.6		`	

Calculation of fineness modulus:

Fineness modulus (F.M) = $\frac{(\Sigma \text{ Cum.\% of retained})}{100}$ %……………………..… (1)

= 258.6/100

=2.586

The distribution of fine aggregate was well because it was in the range of between 2.2 and 2.6 (Abebe, 2002). The corresponding relationship between sieve size and percent passing for fine aggregate was shown graphically with figure 4.1.

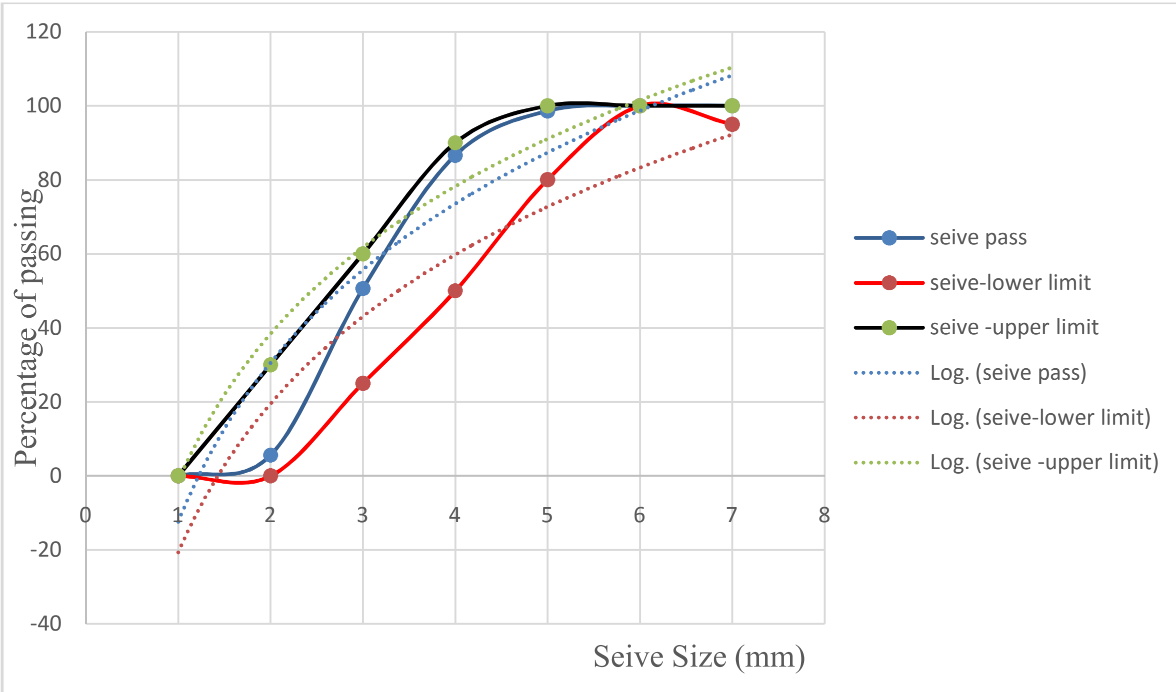

Figure 4.1: Sieve analysis of fine aggregate

Sieve Analysis for PET plastic waste

The fine PET plastic waste used for this study were washed and dried before conducting tests. Sieve analysis was done in the same procedure with fine aggregate in order to determine the relative amount of various sizes of particles present in the aggregate using sieve series of square or round openings starting with the largest PET plastic waste were passed through 4.75mm sieve and predominantly retained on the 60µm sieve with the same size to fine aggregate (River sand).

Specific gravity and absorption capacity of fine aggregate

The specific gravity of an aggregate was considered to be a measure of strength or quality of the material. The specific gravity of a substance was the ratio between the weight of the substance and that of the same volume of water (Ethiopian waste plastic and Rubber Economy Plant P.L.C, 2009). The following table 4.2 shown the results found for the fine aggregate sample.

Table 4.2 Specific gravity and absorption capacity of fine aggregate test results

No.	Description	Test Results
1	Bulk Specific gravity	2.41
2	Apparent specific gravity	2.68
3	Absorption capacity	4.16%

4	Moisture content	2.66%

Silt content of fine aggregate

Sand was a product of natural or artificial disintegration of rocks and minerals. Sand was obtained from glacial, river, lake, marine, residual and wind-blown deposits. These deposits however do not provide pure sand. They often contain other materials such as dust, loam and clay that were finer than sand. The presence of such materials in sand used to make brick or mortar decreases the bond between the materials to be bound together and hence the strength of the mixture. The finer particles do not only decrease the strength but also the quality of the mixture produced resulting in fast deterioration.

Therefore, it was necessary that one make a test on the silt content and check against permissible limits (Abebe, 2002). From the silt content test performed on the sand, it was found that the original silt content was 9%. According to the Ethiopian standard, it was recommended to wash the sand or reject if the silt content exceeds a value of 6 % (Abebe, 2002). Therefore, it was necessary to wash the sand to improve the property. Finally, the silt content reached 3% that was within the acceptable range.

4.1.2 Compressive strength Test

The compressive strengths of plastic Flyash bricks specimens were determined after 28th days of standard curing (Chauhan., 2019). For PET bricks, the results show that the addition of PET aggregate resulted in appreciable increase in the compressive strength was observed up to 10% replacement of the fine aggregate with PET bottles fibers and then the compressive strength was gradually reduced compared with the control Flyash bricks the result in table 4.3 and figure 4.2 shown the results of the 28th day compressive strength tests.

Mean Compressive strength of Plastic waste Brick at 10% replacement and 20% replacement were satisfied as per Ethiopian and ASTM standard Class A and SW grade respectively.

$$\text{Compressive strength} = \frac{\text{Max.loaad applied}}{\text{Specimen area}} \quad (2)$$

=F/A Where, F -Maximum load applied (KN A – Specimen Area (mm2)

Table 4.3: Compressive strength tests results for 28 days

Samples	Number of samples per test	% PET plastics waste	Individual sample compressive strength(MPa)	Average compressive strength(MPa)
B1	B11	0	20.83	20.32
	B12		19.85	
	B13		20.27	
B2	B21	10	20.76	21.1
	B22		21.18	
	B23		20.52	
B3	B31	20	18.23	17.71
	B32		17.77	
	B33		17.13	
B4	B41	40	10.34	10.4
	B42		10.62	
	B43		10.25	
B5	B51	50	7.49	7.66
	B52		7.68	
	B53		7.83	

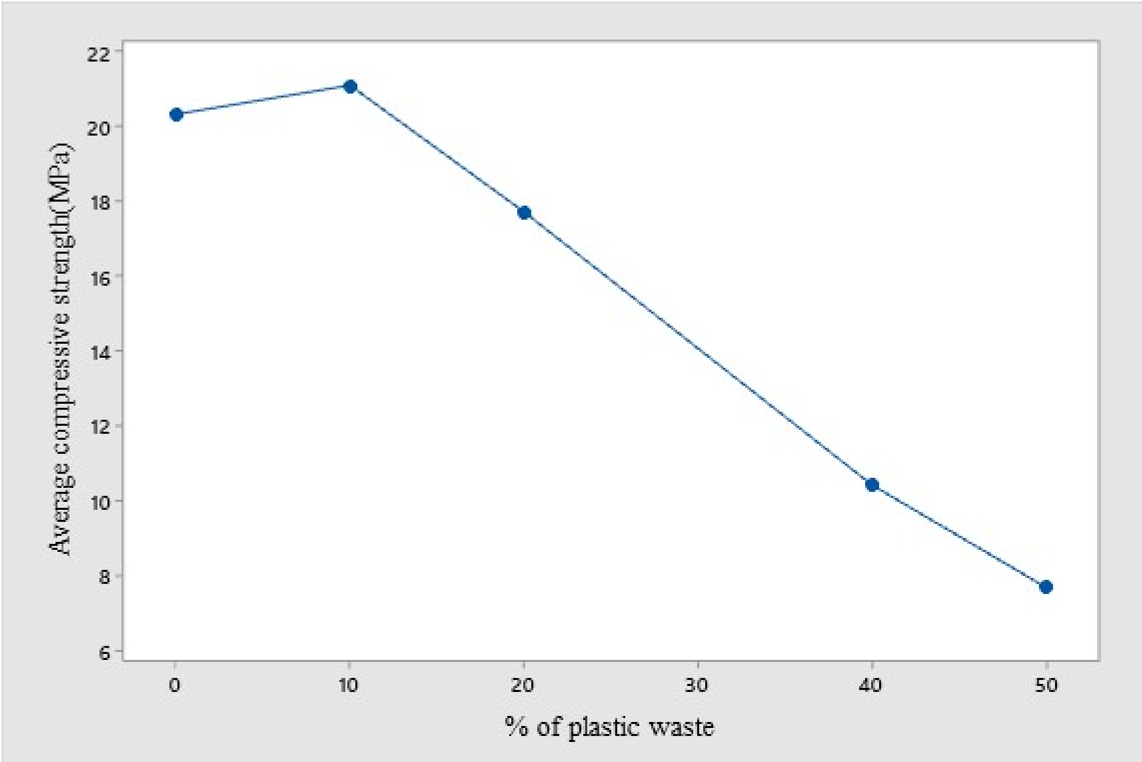

Figure 4.2: Compressive strength comparisons of samples

As shown in the figure 4.2 when 10% of the fine aggregate was replaced by an equivalent volume of PET plastic waste aggregate increasing in compressive strength of 21.11MPa (B2) as compare to the control fly ash bricks of 20.32MPa (B1) were observed, while 20% of the fine aggregate was replaced by an equivalent volume of PET plastic waste aggregate, there was slight decrease in compressive strength of 17.71MPa (B3) as compare to the control fly ash bricks of 20.32MPa (B1) was observed. whereas 40% of the fine aggregate was replaced by an equivalent volume of PET plastic waste aggregate, shown high decrease in compressive strength of 10.4MPa (B4) as compare to the control fly ash bricks of 20.32MPa (B1) was observed and 50% of the fine aggregate was replaced by an equivalent volume of PET plastic waste aggregate, there was high reduction in compressive strength of 7.66MPa (B5) as compare to the control fly ash bricks of 20.32MPa (B1) was observed.

Generally as 10% PET plastic waste replace the fine aggregate (sand), slight increment of compressive strength observed as shown in the table 4.3 and figure 4.2. While 20% of plastic waste replace the fine aggregate, the compressive strength slightly decrease as compared to the control sample and whilst it's beyond 20% replacement of fine aggregate by PET plastic waste, it shown high decrement in compressive strength as compare with the control sample. All results shown reduction in compressive strength exceeds 20% substitution.

Ethiopian Standard Specification

Bricks were classified according to the laboratory test results and individuals of compressive strength, water absorption and saturation coefficient, according to Ethiopian standard ES 86 given in the Table 4.4 (ES, 2001).

Table 4.4:-compressive strength of different class of brick according to Ethiopia standard

class	Average minimum compressive strength of individual bricks (MPa)
A	17.5
B	12.5
C	7.5
D	5.5

According to ES specification, as 10% of the fine aggregate was replaced by an equivalent volume of PET plastic waste aggregate the compressive strength was 21.11MPa (B2) which was greater than the minimum compressive strength of class A brick (17.5MPa) and similarly when 20% of the fine aggregate was replaced by an equivalent volume of PET plastic waste aggregate, the compressive strength was 17.71MPa (B3) which was greater than the minimum compressive strength of class A brick (17.5MPa) but when 40% and 50% of the fine aggregate were replaced with an equivalent volume of PET plastic waste aggregate, the compressive strength were 10.4MPa and 7.66MPa respectively which was less than the minimum compressive strength of class A brick (17.5MPa).

Generally according to ES specification the compressive strength result at 10% and 20% replacement satisfy Class A bricks but the compressive strength result at 40% and 50% replacement could not satisfy Class A bricks.

American Society for Testing and Materials; Standard Specification for Building Bricks

According to ASTM, standard specifications for building bricks were classified based on their compressive strength, water absorption and saturation coefficient as shown in the Table 4.5 *(*ASTM, 1999).

Table 4.5:-compressive strength of different class of brick according to ASTM

Designation	Minimum compressive strength of individual bricks((MPa)
Grade SW	17.2
Grade MW	15.2
Grade NW	8.6

SW=Sever weathering, MW= Moderate weathering, NW= Negligible Weathering

According to ASTM standard, there were three grade brick, Grade SW (Sever weathering) - bricks intended for use where high and uniform resistance to damage caused by cyclic freezing desired and where the brick might be frozen when saturated with water. Grade MW (Moderate weathering) bricks intended for use where moderate resistance to cyclic freezing damage was permissible or where the brick might be damp but not saturated with water when freezing occurs. Grade NW (Negligible weathering).

According to ASTM standard, at 10% of the fine aggregate was replaced by an equivalent volume of PET plastic waste aggregate the compressive strength was 21.11MPa (B2) which was greater than the minimum compressive strength of grade SW brick (17.2MPa) and similarly while 20% of the fine aggregate was replaced by an equivalent volume of PET plastic waste aggregate, the compressive strength was 17.71MPa (B3) which was greater than the minimum compressive strength of grade SW brick (17.2MPa) but when 40% and 50% of the fine aggregate were replaced with an equivalent volume of PET plastic waste aggregate, the compressive strength were 10.4MPa and 7.66MPa respectively which was less than the minimum compressive strength of grade SW brick (17.2MPa).

Generally according to ASTM standard the compressive strength result at 10% and 20% replacement satisfy grade SW brick but the compressive strength result at 40% and 50% replacement could not satisfy grade SW brick.

4.2 Split tensile strength and Flexural strength Tests

4.2.1 Split tensile strength test

No standard tests have been adopted to provide a direct measurement of tensile strength of brick. The problem of secondary stresses induced through gripping makes the test results difficult either to interpret or produce. The splitting tensile strength test was an indirect tension test for brick and concrete. It was carried out on a standard cylinder, tested on its side in diametric compression.

The split tensile strength of the cylinder specimen was calculated using the following formula.

Split Tensile Strength, $f_{sp} = \frac{2p}{ld}$ N/mm2 ………………………………………………. (3)

Where, P = Load at failure in N

L = Length of the Specimen in mm

d = Diameter of the Specimen in mm

It was not practical to apply a true line load along the top and bottom of the specimen, partly because the sides were not smooth enough and partly because this would include extremely high compressive stresses near the points of load application. Therefore, the load was usually applied through narrow bearing strips of relatively soft material (Sidney *et al*., 2003). The test was carried out on cylindrical specimens using a bearing strip of 3 mm thick plywood that was free of imperfections and about 25 mm wide. The splitting tensile strength test result was shown with table 4.6.

Table 4.6: Split tensile strength test results after 28 days

Sample	No of sample per test	% plastic waste	Splitting load (KN)	Individual splitting strength(MPa)	Average splitting strength(MPa)
B1	B11	0	39.34	1.25	1.23
	B12		38.79	1.24	
	B13		37.4	1.19	
B2	B21	10	37.18	1.19	1.25
	B22		39.86	1.27	
	B23		40.1	1.28	
B3	B31	20	34.35	1.09	1.06
	B32		32.34	1.03	

	B33		33.1	1.05	
B4	B41	40	18.88	0.6	0.59
	B42		18.71	0.6	
	B43		17.7	0.56	
B5	B51	50	13.26	0.42	0.45
	B52		14.02	0.45	
	B53		14.65	0.47	

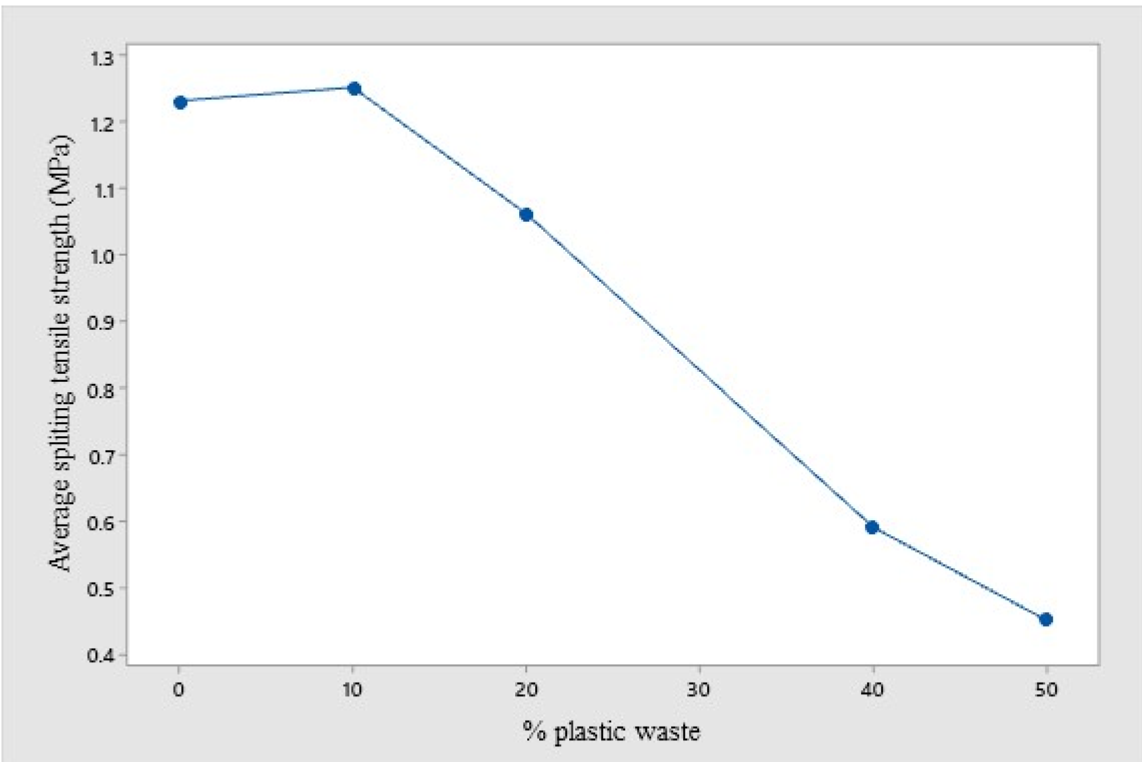

Figure 4.3 splitting tensile strength comparisons of samples

As shown in the figure 4.3 when 10% of the fine aggregate was replaced by an equivalent volume of PET plastic waste aggregate increasing in Split tensile strength of 1.25MPa (B2) as compare to the control fly ash bricks of 1.23MPa (B1) were observed, while 20% of the fine aggregate was replaced by an equivalent volume of PET plastic waste aggregate, there was small decrease in Split tensile strength of 1.06MPa (B3) as compare to the control fly ash bricks of 1.23MPa (B1)) was observed. whereas 40% of the fine aggregate was replaced by an equivalent volume of PET plastic waste aggregate, shown high decrease in Split tensile strength of 0.59MPa

(B4) as compare to the control fly ash bricks of.0.59 MPa (B1) was observed and 50% of the fine aggregate was replaced by an equivalent volume of PET plastic waste aggregate, there was high reduction in Split tensile strength of 0.45MPa (B5) as compare to the control fly ash bricks of 1.23MPa (B1) was observed.

As the results show that the Split tensile strength increased with increasing PET bottle aggregate content in a similar manner to that observed in the splitting load up to 10% replacement comparing with consecutive control mix samples. Slight decrement up to 20% of the fine aggregate was replaced by PET bottle aggregate. Whilst exceed 20% replacement of fine aggregate by PET plastic waste, it shown high decrement in Split tensile strength as compare with the control sample.

4.2.2 Flexural strength Tests

This test gives another way of estimating tensile strength of brick. During pure bending, the member resisting the action was subjected to internal actions or stresses (shear, tensile and compressive). For a bending force applied downward on a member supported simply at its two ends, fibers above the neutral axis were generally, subjected to compressive stresses and those below the neutral axis to tensile stresses. For this load and support system, portions of the member near the supports were subjected to relatively higher shear stresses than tensile stresses. In this test, the brick member to be tested was supported at its ends and loaded at its interior locations by a gradually increasing load to failure. The failure load (loading value at which the brick cracks heavily) was then recorded and used to determine the tensile stress at which the member failed, i.e. its tensile strength.

The prepared beam samples were tested after 28 days of standard curing (Youcef., 2013) and the results of flexural strength tests for the control bricks and the PET bottle concretes were summarized in Table 4.7 The flexural strength of the prism specimen was calculated using the following formula.

$C = \frac{D}{2}$cm; $M = \frac{PL}{3}$N.m; $I = \frac{BD3}{12}m^4$; $\sigma = \frac{ML}{I}$ MPa (4)

Where: P = Failure Load

σ = Bending Strength

M = Maximum Moment

L = Span of Specimen

I = Moment of Inertia

D = Depth of specimen

C = Centroid depth

B = Width of the specimen

Table 4.7: Flexural strength Tests results after 28 days

Sample	No of sample per test	% plastic waste	Splitting load (KN)	Individual flexural strength(MPa)	Average flexural strength(MPa)
B1	B11	0	39.34	1.96	1.97
	B12		38.79	1.98	
	B13		37.4	1.96	
B2	B21	10	37.18	2.89	2.9
	B22		39.86	2.86	
	B23		40.1	2.95	
B3	B31	20	34.35	2.9	2.85
	B32		32.34	2.79	
	B33		33.1	2.85	
B4	B41	40	18.88	1.61	1.6
	B42		18.71	1.66	
	B43		17.7	1.52	
B5	B51	50	13.26	1.16	1.24
	B52		14.02	1.25	
	B53		14.65	1.3	

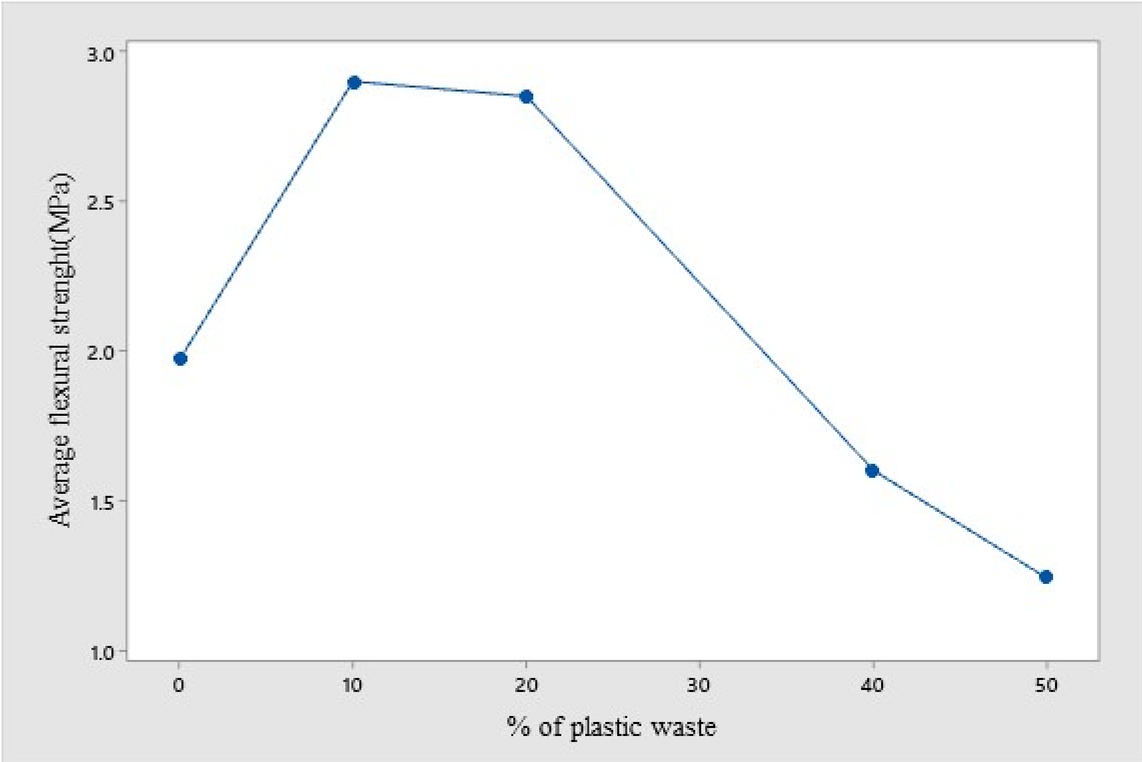

Figure 4.4 Flexural strength comparisons of samples

As shown in the figure 4.4 when 10% of the fine aggregate was replaced by an equivalent volume of PET plastic waste aggregate increasing in flexural strength of 2.9MPa (B2) as compare to the control fly ash bricks of 1.97MPa (B1) were observed, while 20% of the fine aggregate was replaced by an equivalent volume of PET plastic waste aggregate, there was increasing flexural strength of 2.85MPa (B3) as compare to the control fly ash bricks of 1.97MPa (B1) was observed. whereas 40% of the fine aggregate was replaced by an equivalent volume of PET plastic waste aggregate, shown decrement in flexural strength of 1.6MPa (B4) as compare to the control fly ash bricks of 1.97MPa (B1) was observed and 50% of the fine aggregate was replaced by an equivalent volume of PET plastic waste aggregate, there was high reduction in flexural strength of 1.24MPa (B5) as compare to the control fly ash bricks of 1.97MPa (B1) was observed

As the results show that the flexural strength increased with increasing PET bottle aggregate content up to 20% replacement comparing with consecutive control mix samples. Whilst exceed 20% replacement of fine aggregate by PET plastic waste, it shown high decrement in flexural strength as compare with the control sample.

This shown that improvements in flexural strength were limited to a relatively small amount of PET aggregate contents. As the test result shows there was an advantage of increasing in flexural strength to some extent replacing fine aggregate with PET bottle aggregate. It could be concluded that as the amount of PET bottle fiber content increases more than 20% the reduction in the flexural strength also increases.

4.3 Water absorption, Moisture content, unit weight and oven test

4.3.1 Water absorption test

Water absorption of brick specimens were tested and shown in Figure 4.8. The plastic fly ash bricks specimen exhibits very high water absorption; however the values were between the ranges specified by ASTM Specification for first class bricks (ASTM, 1999). Since the water absorption values of plastic Flyash bricks were much higher than those of normal Flyash bricks.

$$\text{Water absorption} = \frac{[\text{Weight of wet brick} - \text{Weight of dry brick}]}{(\text{Weight of dry brick}\}} * 100 \quad (5)$$

Table 4.8: Water Absorption tests results

Samples	Number of samples per test	%PET plastic waste	Brick weight after oven dry(Kg)	Weight of bricks before immersed into water(Kg)	Weight of Bricks after immersed into water for 24 hr(Kg)	Individual water absorption (%)	Average water absorption(%)
B1	B11	0	2.34	2.36	2.48	6	5.95
	B12		2.32	2.35	2.45	3.4	
	B13		2.24	2.26	2.44	8.44	
B2	B21	10	2.15	2.2	2.29	6.51	6.78
	B22		2.33	2.36	2.46	6.1	
	B23		2.21	2.24	2.36	6.78	
B3	B31	20	2.2	2.25	2.25	9.75	8.95
	B32		2.08	2.14	2.23	7.21	
	B33		2.15	2.2	2.22	9.9	
B4	B41	40	1.56	1.62	1.71	12.54	11.46

	B42		2.01	2.08	2.22	10.14	
	B43		1.78	1.85	1.92	11.69	
B5	B51	50	1.42	1.48	1.6	12.68	12.6
	B52		1.66	1.75	1.91	11.51	
	B53		1.47	1.52	1.59	13.6	

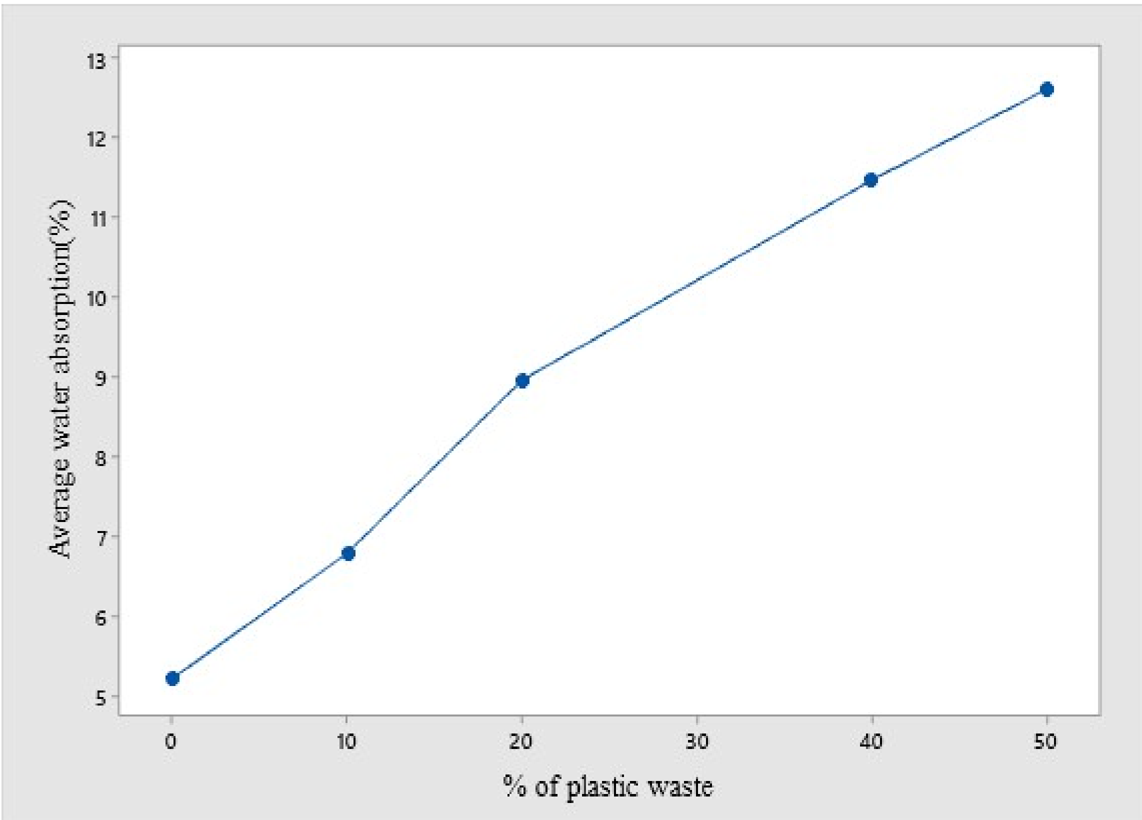

Figure 4.5: Water Absorption comparisons of samples

For a good quality brick the water absorption should not greater than 20% of its own weight (ASTM, 1999).The test values range from 12.6% to 5.21% which shown excellent performance of the plastic waste brick, as shown in the figure 4.6, so all sample water absorption result satisfy ASTM standard specification, which mean all result values were less than 20% of its weight. The virgin bricks shown good performance since it absorbs 5.21% of water. Good quality of bricks was not absorbs more than 20% of water. When 0% PET plastic wastes replace the fine aggregate , the water absorption was 5.21%, while 10% of fine aggregate replaced with PET plastic waste, the water absorption was 6.78% which was increased as compare to the control sample ,as 20% of fine aggregate replaced with PET plastic waste, the water absorption was 8.95% which was increased as compare to the control sample, when 40% of fine aggregate replaced with PET plastic waste the water absorption was 11.46% which shown high increment as compare to the control sample and finally 50% of fine aggregate replaced with PET plastic waste, the water absorption was 12.6% which also show high increment as compare to the control sample.

Generally the plastic waste content in the brick increased, as the percentage of water absorption increased as shown in the figure 4.5 and table 4.8, this was because as the plastic content increased the void spaces between the bricks increased, it could absorb more water due to this the high plastic in the brick mix, the high value of water absorption. The highest water absorption, the less the performances the bricks.

Form this study conclude that the presence of highest percentage of plastic waste in the bricks reduce the performance of the bricks.

4.3.2 Moisture content test

Moisture content of bricks were the natural water content of brick before immersing it into water and highly dependent with water cement ratio. For this study the water cement were 0.5 (ASTM, 2001). The compressive strength of brick decreases with increasing porosity. When the moisture content decreases, the strength first increase, and then decrease. Furthermore, the brick specimens are found to be stronger in dry condition than in saturated condition. The moisture content at the time of testing was found to be on brick specimens of moisture retention after drying and solidification shown in the figure 4.6 and table 4.9.

$$\text{\% of moisture content of sample} = \frac{(\text{weight of brick} - \text{weigh of oven dryed brick}}{\text{weight of oven dryed brick}}) * 100 \qquad (6)$$

Table 4.9: Moisture content tests results

Samples	Number of samples per test	%PET plastic waste	Brick weight after oven dry(Kg)	Weight of bricks before immersed into water(Kg)	Weight of Bricks after immersed into water for 24 hr(Kg)	Individual Moisture content (%)	Average Moisture content (%)
B1	B11	0	2.34	2.36	2.48	0.9	1.03
	B12		2.32	2.35	2.45	1.3	
	B13		2.24	2.26	2.44	0.89	
B2	B21	10	2.15	2.2	2.29	2.3	1.67
	B22		2.33	2.36	2.46	1.3	
	B23		2.21	2.24	2.36	1.4	
B3	B31	20	2.2	2.25	2.25	2.4	2.55
	B32		2.08	2.14	2.23	2.9	
	B33		2.15	2.2	2.22	2.34	
B4	B41	40	1.56	1.62	1.71	3.8	3.73
	B42		2.01	2.08	2.22	3.5	
	B43		1.78	1.85	1.92	3.9	
B5	B51	50	1.42	1.48	1.6	4.2	4.47
	B52		1.66	1.75	1.91	5.1	
	B53		1.47	1.52	1.59	4.1	

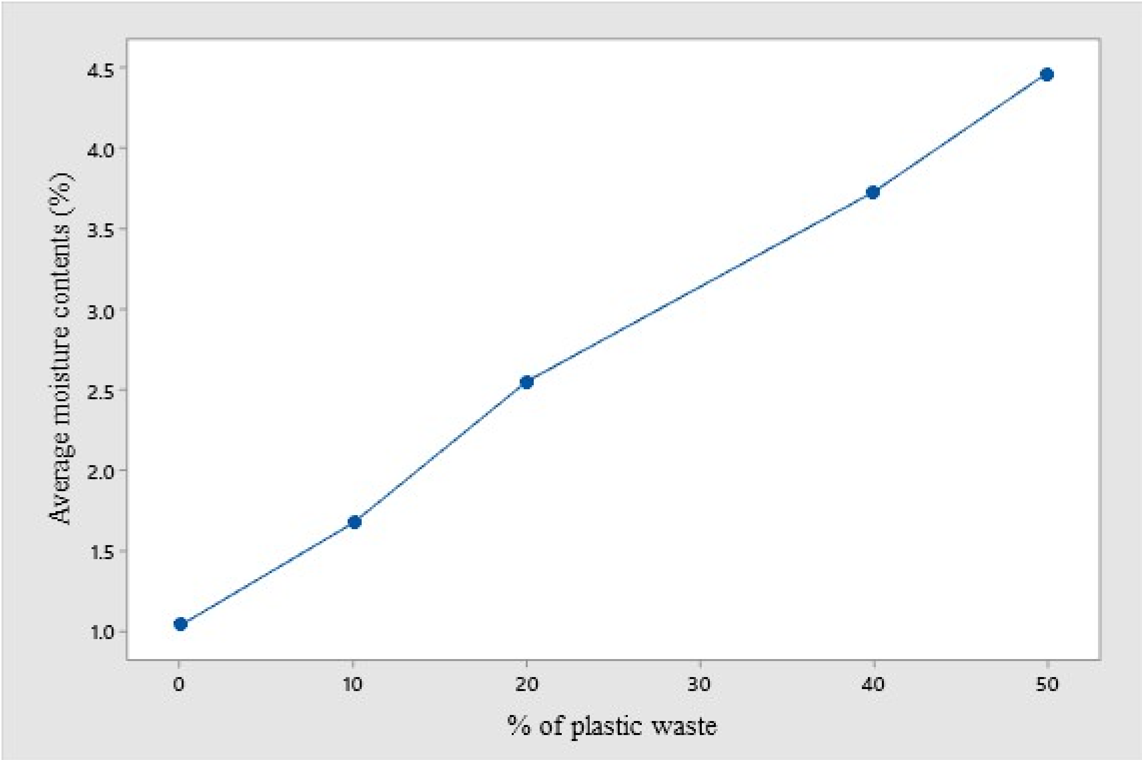

Figure 4.6: Moisture content comparisons of samples

The plastic waste content in the brick increased, as the percentage of moisture content increased as shown in the figure 4.6 and table 4.9, this was because as the plastic content increased the porosity between the bricks increased, it could absorb more water due to this the high plastic in the brick mix, the high value of moisture content. With increasing moisture content, the strength increased initially and then increased. The distribution of water and the stresses in porous materials is highly dependent on the moisture content. As shown the result in figure 4.7 the moisture content increased with plastic replacement increased so the strength decreased with respect to increment of percentage of plastic replacement.

4.3.3 Unit weight determination

The unit weight values were measured for the plastic bricks samples after 28 days of standard curing. From the result, it was found out that a reduction of unit weight for 28 day curing time were 1548kg/m_3, 1520.11 kg/m^3, 1461.03kg/m^3, 1206.54 kg/m^3 and 1033..85kg/m^3were observed, when 0%, 10%, 20%, 40%, and 50% by volume of the fine aggregate(sand) was replaced by PET plastic waste aggregate in sample B1,B2,B3,B4 and B5 respectively, because of the PET fiber aggregate was lighter than around two and half times of fine aggregate, it was expected that the mass density of the mix would be suggestively reduce. This leads to the reduction of unit weight as the content of PET plastic aggregate increased as shown in the table 4.10 and by using equation (2). Dry unit weight of specimen was determined in the table 4.10.

$$\text{Dry unit weight} = \frac{\text{Dry weight (Kg)}}{\text{Volume of specimen (m3)}} \quad (7)$$

Table 4.10: A 28 day dry unit weight results

Samples code	Number of samples	% of PET plastic waste	Individual dry weight after oven dry(Kg)	Volume of bricks (m_3) with size (0.215*0.105*0.065) m^3	Individual dry unit weight (Kg/ m^3)	Average dry unit weight (Kg/ m^3)
B1	B11	0	2.34	0.001467	1595.09	1548
	B12		2.32		1581.46	
	B13		2.15		1465.58	
B2	B21	10	2.15	0.001467	1465.58	1520.11
	B22		2.33		1588.28	
	B23		2.21		1506.48	
B3	B31	20	2.2	0.001467	1499.66	1461.03
	B32		2.08		1417.86	
	B33		2.15		1465.57	
B4	B41	40	1.56	0.001467	1036.13	1206.54
	B42		2.01		1370.14	
	B43		1.78		1213.36	
B5	B51	50	1.42	0.001467	967.96	1033..85
	B52		1.66		1131.56	
	B53		1.47		1002.04	

As shown in table 4.10 the dry unit weight of specimen decreased as the PET Plastic waste content used in the mix increased. This was because of PET plastic was lighter than river sand, low specific gravity and dry weight than fine aggregate (sand)

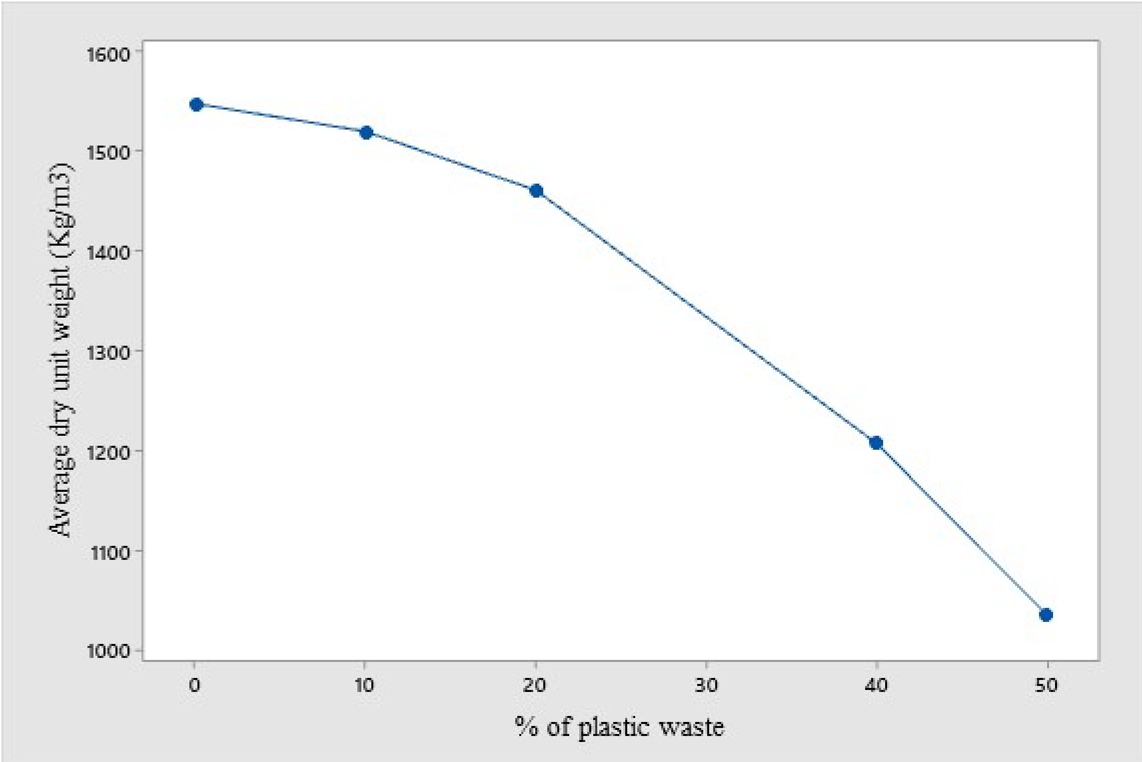

Figure 4.7: Unit Weight comparisons of samples

The unit weight of specimens was presented in Figure 4.7. It was observed that the plastic Flyash brick specimen (bricks made from sand and waste plastic bottles) has the minimum unit weight as compare to the normal fly ash brick(B1).When 0% PET Plastic wastes used, the unit weight of specimens was 1548Kg/m^3, whereas 10% PET Plastic wastes used, the unit weight of specimens was 1520.11Kg/m^3, while 20% PET Plastic wastes used, the unit weight of specimens was 1461.03Kg/m^3,as 40% PET Plastic wastes used, the unit weight of specimens was1206.54Kg/m^3 and 50% PET Plastic wastes used, the unit weight of specimens was 1033..85Kg/m^3. The unit weight of specimen highly reduced as the percentage PET plastic wastes used in the mix increased.

Generally plastic Flyash bricks were lighter when compared to normal Flyash bricks of the five different specimens. The bricks made from 50% PET Plastic bottled waste give the lowest unit weight. Lower unit weight of plastic Flyash bricks could help in reduction of dead loads of structures, reduction of dead loads of structures could lower construction costs and hence improve economy but the unit weight could not lower than the permissible lower limit, the unit weight of bricks was between 1450Kg/m^3- 1600Kg/m^3(ES, 2001). But B4 and B5 unit weight were below the lower limit, so these bricks were not acceptable.

4.3.4 Oven Test

Table 4.11 shown the result of the over test of the samples. The oven test was carried out to ascertain the temperature at which each pavement block fails.

Table 4.11 comparisons temperature falling point for plastic fly ash brick (˚C)

Samples	% of plastic waste	Temperature of failure (˚C).
B2	10	185
B3	20	180
B4	40	150
B5	50	150

The results obtained from the oven test shows that there was no visible change in the shape, size and rigidity of all the plastic derived pavement blocks at a temperature below 150˚C. the oven test shows that at 10% of fine aggregate replaced with PET plastic waste, there was visible change in the shape, size and rigidity (start melt) at a temperature of 185˚C.when 20% of fine aggregate replaced with PET plastic waste, there was visible change in the shape, size and rigidity (start melt) at a temperature of 180˚C and 40% and 50% of fine aggregate replaced with PET plastic waste, there was visible change in the shape, size and rigidity (start melt) at a temperature of 150˚C.

Generally the plastic waste content in the brick increased, temperature resistance (visible change in the shape, size and rigidity) decrease, start melt with less heat as the plastic content increase in the brick matrix as shown in the table 4.11.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

As the suitability of the materials was checked and adjusted there was no constraint with the materials used for this study and it was possible focusing on the hardened properties of materials. The unit weight reduction was observed as percentage of PET bottle aggregate increased, because of the specific gravity of the PET bottle aggregate was lower than that of fine aggregates, this leads to the reduction of unit weight. The test results shown that the addition of PET bottle aggregate resulted in a substantial increase in brick compressive strength up to 10% partial replacement of fine aggregate with PET bottle aggregate compared with the control brick and the compressive strength satisfy ES and ASTM standard up to 20% replacement. As observed from the test results there was a reduction of strength as percentage of PET increased and beyond 20% comparing with control brick mix sample. The reason for the compressive strength reductions could be attributed both to a reduction of quantity of the solid load carrying material and to the lack of adhesion at the surfaces of the PET bottle aggregate. Also like compressive strength there was an increase of tensile strength and flexural strength recorded with increasing PET bottle aggregate content up to 20% replacement. But more than 20% replacement of fine aggregate with PET bottle fiber results in reduction in tensile strength. Because of the bond between cement and PET bottle fiber particles was poor, the reduction indicates that improvements in flexural strength and tensile strength were limited to relatively small PET bottle aggregate contents and as the content of PET plastic increase in the bricks mix, water absorption and moisture content shown high increment because of. PET bottle particles behave as voids in the brick matrix and porosity. Good quality of bricks should not absorb more than 20% of water lastly; B2 and B3 start to melt at temperature of 180ºc and 185ºc respectively while B4 and B5 start to melt at temperature of 150ºc. This indicated that plastic content increased melting temperature of brick decreased.

Generally the advantage of using PET bottle fiber aggregates from waste plastic were; reduction of the environmental threats caused by waste plastic bottles, an alternative source to aggregates and reduces bio disturbance which caused by during quarry of aggregates and this study shows that it was possible to use waste (used) PET bottle fiber in brick production as a partial replacement for fine aggregates. But the percentage should be limited (not beyond 20% of its wight).

5.2 Recommendations

- Hence, there was a potential accumulation of waste plastic PET bottles in Debre Birehan town. So far, the Administration has made an attempt by declaring the solid waste management proclamation on the Negarit gazette prohibiting the import of waste plastics.
- The country should also enforce laws regarding the management of waste plastic before the problem expands and reaches to an uncontrollable level. Since town administration motivate the use of PET bottle aggregates in brick.
- Many studies and research works need to be carried out in this area and academic institutions should play a major role and PET plastic bottle manufacturers and importers in the country should be aware of the environmental consequences of waste plastic and they should have research centers that promote an environmentally friendly way of plastic reprocessing.
- It is observed that designers and contractors go to a high strength and expensive brick to get few improved properties such as impact resistance in parking areas and light weight structures for particular applications. Nevertheless, these properties can be achieved through the application of PET brick by first conducting laboratory tests regarding the desired properties. Therefore, the use of PET brick as an alternative brick making material needs an attention.
- Other researchers do other properties of plastic bricks such as fire resistance and durability.
- These brick applicable in the area where light weight and low load carry brick was needed such as parking area, road side and water tanker.

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ANNEXES

Annex 1: Mix design data sheet

1.1: Trial Mix

No	Items	reference	values
1	Cement type	specified	PPC
	Aggregate type		River sand
2	Aggregate size	specified	60µm
3	Unit weight of cement	specified	1440kg/m3
	Unit weight of sand		1450kg/m3
	Unit weight of fly ash		1380kg/m3

Quantities	Cement(Kg)	Sand(Kg)	Fly ash(Kg)
For 1m3	432	652.5	1035
Per trial mix of 0.0015m3	0.634	0.96	1.5

1.2. The amount of PET required for 0.0015m3 capacity (final mix)

Sample	Fly ash(gram)	Cement(gram)	Sand(gram)	%of PET	PET(gram)
B1	1500	634	960	0	0
B2	1500	634	864	10	96
B3	1500	634	768	20	192
B4	1500	634	576	40	384
B4	1500	634	480	50	480

Annex 2: Compressive strength, Unit weight result

2.1: A 28 Day Compressive Strength Test Result

Sample	No of sample per test	% of PET plastic waste	Area of specimen(mm2)	Maximum load (KN)	Individual compressive strength(MPa)	Average compressive strength(MPa)
B1	B11	0	22575	470.237	20.83	20.32
	B12			448.11	19.85	
	B13			457.6	20.27	
B2	B21	10	22575	470.24	20.76	21.1
	B22			478.14	21.18	
	B23			465.5	20.52	
B3	B31	20	22575	411.54	18.23	17.71
	B32			401.16	17.77	
	B33			386.71	17.13	
B4	B41	40	22575	233.43	10.34	10.4
	B42			239.75	10.62	
	B43			231.39	10.25	
B5	B51	50	22575	169.09	7.49	7.66
	B52			173.38	7.68	
	B53			176.76	7.83	

2.2. Dry Unit weight test results

sample	No of sample per test	% of PET Plastic waste	Individual dry weight after oven dry(Kg)	Volume of specimen(m3)	Individual unit weight(Kg/m3)	Average unit weight(Kg/m3)
B1	B11	0	2.34	0.001467	1608.73	1548
	B12		2.32		1595.09	
	B13		2.15		1629.18	
B2	B21	10	2.15	0.001467	1465.58	1520.11
	B22		2.33		1431.49	
	B23		2.21		1424.68	
B3	B31	20	2.2	0.001467	1397.41	1461.03
	B32		2.08		1417.86	
	B33		2.15		1376.96	
B4	B41	40	1.56	0.001467	1036.13	1206.54
	B42		2.01		1008.86	
	B43		1.78		1049.76	
B5	B51	50	1.42	0.001467	967.96	1033..85
	B52		1.66		947.51	
	B53		1.47		954.33	
	B53		1.4	1.59	13.6	

Annex 3: photos

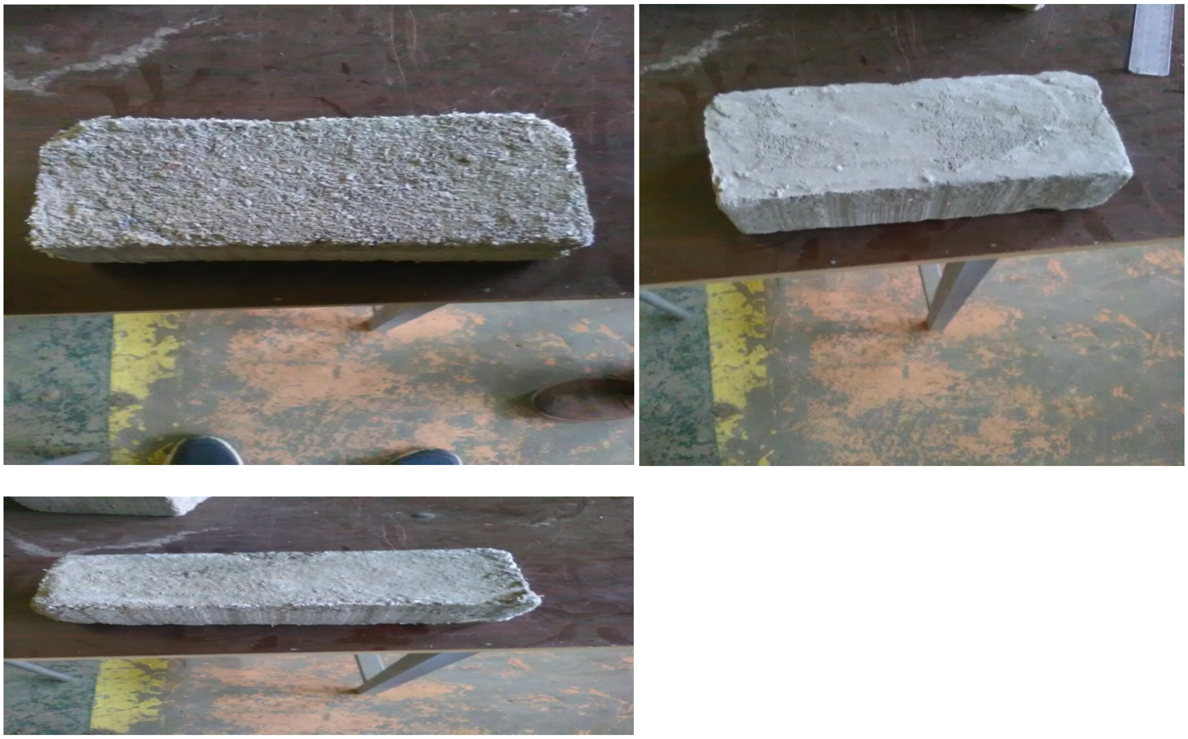
Shredding and cutting Machine (Photo taken by me)

Shredding and cutting of PET and fly ash (Photo taken by me)

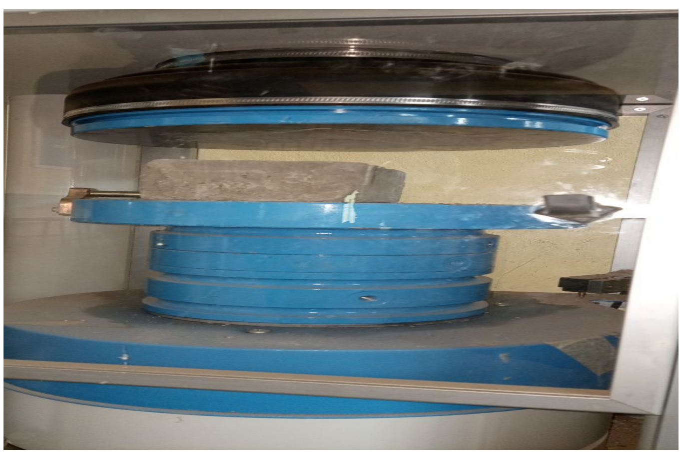
Weighing or Batching of PET plastic waste, cement, Flyash and sand(photo taken by Belete Asegdew)

Mixing of ingredient of plastic fly ash bricks (photo taken by me)

Casting and Moulding of bricks (photo taken by Belete Asegdew)



Bricks after removing from mould (photo taken by me)



Compressive strength test (photo taken by Belete Asegdew)

Bricks immersed in to water and dried in oven dry (photo taken by me)

Weighing of bricks (photo taken by me)

Curing of samples