JIMMA UNIVERSITY

INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES
ENVIRONMENTAL ENGINEERING CHAIR

TECHNICAL FEASIBILITY OF PET PLASTIC WASTES AS A PARTIAL REPLACEMENT FOR FINE AGGREGATES IN CONCRETE MIX

BY

ABREHAM BEKELE BAYU

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY FOR THE PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENVIRONMENTAL ENGINEERING

DECEMBER, 2016
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I, the undersigned, declare that this thesis entitled ‘’ Technical feasibility of PET plastic wastes as a partial replacement for fine aggregates in concrete mix” 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.

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As master research advisors, we hereby certify that we have read and evaluate this MSc research prepared under our guidance, by Mr. Abreham Bekele: Technical feasibility of PET plastic wastes as a partial replacement for fine aggregates in concrete mix.

We recommend that it can be submitted as fulfilling the MSc thesis requirements.

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ABSTRACT

The consumption of plastic has grown substantially all over the world in recent years and this has created huge quantities of plastic-based waste. The use of polyethylene terephthalate (PET, PETE) which is commonly used for carbonated beverage and water bottles (resin code 1) are increasing in day to day activities. The increase in use of plastics without recycling is going to yield environmental pollution as well as many undesirable effects on our health. Plastic waste is now a serious environmental threat to the modern way of living. In order to manage this environmental problem the plastic waste bottles (PET) should be recycled or reused.

The aim of this research was to examine the technical feasibility of PET plastic wastes as a partial replacement for fine aggregates with in a concrete mix for better environmental management.

The research was carried out by conducting tests on the raw materials to determine their properties and suitability for the experiment. Concrete mix designs were prepared using the DOE method and a total of 6 mixes with 72 samples were prepared consisting of concrete grade C-25. The specimens were produced with percentage replacements of the fine aggregate by 1, 2, 3, 4 and 5% of PET plastic waste aggregate. Moreover, a control mix with no replacement of the fine aggregate was used to make a comparative analysis. The prepared samples consist of concrete cubes, cylinders and beams. Furturemore, laboratory tests were carried out on the prepared concrete samples. The lists of tests conducted were; material property, slump, unit weight, compressive strength, splitting tensile strength and flexural strength tests. The data collection was mainly based on the tests conducted on the prepared specimens in the laboratory.

The test results were compared with the respective conventional concrete properties and show that there is slight increase in compressive strength of the concrete up to 3% replacement and reduction in Compressive strength increases beyond 3% replacement due to the inclusion of PET aggregates. Also like compressive strength there was an increase of tensile strength recorded with increasing PET bottle aggregate content up to 3% replacement. But more than 3% replacement of fine aggregate with PET bottle fiber results in reduction in tensile strength. Increased flexural strength was observed by replacing amount of PET bottle fiber with fine aggregate up to three percent (3%) used. But when percentage of PET bottle fiber increased more than three percent (3%) flexural strength becomes reduced was observed. Even though this may limit its use, it has few desirable characteristics such as lower density, enhanced ductility, and a slight increase in flexural strength. The overall results show that it is possible to use recycled PET bottles in concrete tile production as a partial replacement for fine aggregates. Nevertheless, the percentage of replacement should be limited to a specified amount.

Key words; *PET Plastic Waste, Environmental Management, Fine Aggregate Replacement and Technical Feasibility.*

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LIST OF ABBREVIATIONS

ABS	Acrylonitrile-butadiene-styrene
BBzP	Butyl benzyl phthalate
CCL_4	Carbon tetra chloride
CFT	Concrete floor tile
DEHP	Di ethyl hexa phthalate
DOE	Department of environment (British standard)
EPA	Environmental protection agency (World wide)
F.M	Fineness modules
g/cm^3	Gram per centimeter cube
ggbs	Ground granulated blast furnace slag
HDPE	High density polyethylene
mm	Milimeter
MOC	Magnesium oxychloride cement
MPa	Mega pascal
MSW	Municipal sold waste
NCA	Natural coarse aggregate
OPC	Ordinary Portland cement
PCA	Plastic coarse aggregate
PET	Polyethylene Terephalate
PETE	Polyesters
PPC	Pozzolanic portland cement
PVC	Polyvinyl chloride
SSD	Saturated surface dry
USA	United State of America
w/c	Water cement ratio
PA	PET aggregate

CHAPTER ONE

1. 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. 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. The informal private sector, represented by rubbish collectors, has been involved in waste recovery and recycling for many years because of the high value of recyclable materials (Willey, 2004).

Today plastics are an integral part of everyone's lifestyle with application varying from common place articles to sophisticated scientific and medical instruments. Designers and engineers readily turn to plastics because they offer combinations of properties not available in any other materials**.** However, there is a downside: plastic is one of the least environmentally friendly materials. Low-cost plastics such as single-use packaging appear more frequently in the waste stream than the polymers used in making durable goods. Some of the plastic products other than packaging enter the waste stream one year or more after production. It is advisable to recycle these plastics wastes in order to provide environmental management (Shirahama *et al.,* 2001).

Recycle process and reused of plastic waste products amount for vast manpower and huge processing cost resultantly very small amount of plastic waste is recycled and used and the rest going into landfills, incinerators and dumps. Many researchers have tried to utilize plastic waste and few have suggested its utilization in concrete 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 (Eldho *et al.*, 2012).

The consumption of plastic has grown substantially all over the world in recent years and this has created huge quantities of plastic waste. Plastic waste is now a serious environmental threat to the modern way of living. In Portugal, post-consumer packaging accounts for almost 40% of total domestic waste and it is therefore an important source for the recycled materials market (Magrinho *et al*., 2006). In a typical Portugal municipality about 10-14% of all generated waste is plastic (Magrinho *et al*., 2006). Recycling plastic waste to use as partial replacement in concrete could be one of the best solutions for disposing of it, given its economic and ecological advantages. The European aggregates demand is 3 billion tons per year, representing a turnover of around €20 billion. Some 90% of all aggregates are produced from natural resources. The other 10% come from recycled aggregates (6%), and marine & manufactured aggregates (2% each). Naturally, the use of waste materials as aggregate in concrete production reduces the pressure on the exploitation of natural resources (Choi *et al*., 2009).

Plastic aggregate (PA) is 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 (Raadal *et al*., 1999). 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 (Albano *et al*., 2009).

The incorporation of PA can significantly improve some properties of concrete because plastic has high toughness, good abrasion behavior, low thermal conductivity and high heat capacity compared to other materials (Eriksson *et al.*, 1999). PA is significantly lighter than natural aggregate (NA) and therefore its incorporation lowers the densities of the resulting concrete. This property can be used to develop lightweight concrete. The use of shredded waste PA in concrete can reduce the dead weight of concrete, thus lowering the earthquake risk of a building, and it could be helpful in the design of an earthquake-resistant building (Akcaozoglu *et al*., 2010).

However incorporation of PA in concrete has several negative effects such as poor workability and deterioration of mechanical behavior (Saikia *et al.*, 2012). The strength properties and modulus of elasticity of concrete containing various types of PA are always lower than those of the corresponding reference concrete containing NA only. The decrease in bond strength between PA and cement paste as well as the inhibition of cement hydration due to the hydrophobic nature of plastic are the reasons for the poor mechanical properties of concrete containing plastic wastes. Treating plastic chemically and coating plastics with slag and sand powders can improve the mechanical performance of concrete by improving the interaction between cement paste and PA (Choi *et al*., 2005). The prolonged curing of PET (polyethylene terephthalate) fiber in simulated cement pore-fluid can initiate the alkaline hydrolysis of PET, and form some organic compounds, which may increase the interaction between plastic aggregate and cement hydration products (Silva *et al*., 2005).

However, the information available on the use of plastic waste as aggregate in concrete is not always adequate. For example, the workability behavior of concrete containing similar type of PA is reported to be contradictory in different literatures. The shape and size of the aggregate have a significant influence on both fresh and hardened concrete properties. No thorough study is available on the effect of the shape of PA on the properties of the resulting concrete (Saikia *et al*., 2010).

Concrete PET strength is greatly affected by the properties of its constituents and the mix design parameters. Because aggregates represent the major constituent of the bulk of a concrete tile mixture, its physical properties affect the engineering properties of the final product. An aggregate has been customarily treated as inert filler in concrete. However, due to the increasing awareness of the role played by aggregates in determining many important properties of concrete, the traditional view of the aggregate as inert filler is being seriously questioned. Aggregate was originally viewed as a material dispersed throughout the cement paste largely for economic reasons. It is possible, however, to take an opposite view and to look on aggregate as a construction material connected into a cohesive whole by means of the cement paste. In fact aggregate is not truly inert and its physical, thermal, and sometimes chemical properties influence the performance of concrete PET (Neville *et al*., 1996).

Aggregate is cheaper than cement and it is, therefore, economical to put into the mix much of the former and as little of the latter as possible. Nevertheless, economy is not the only reason for using aggregate: it confers considerable technical advantages on concrete tile, which has a higher volume stability and better durability than hydrated cement paste alone (Neville *et al*., 1996).

The goal of sustainability is that life on the planet can be sustained for the foreseeable future and there are three components of sustainability: environment, economy, and society. To meet its goal, sustainable development must ensure that these three pillars remain healthy and balanced. Furthermore, it must do so simultaneously and throughout the entire planet, both now and in the future. At the moment, the environment is probably the most important component and an engineer or architect uses sustainability to mean having no net negative impact on the environment. Among the many threats that affect the environment are the wastes which are generated in the production process or discarded after a specific material ends its life time or the intended use. The wastages are divided as solid waste, liquid waste and gaseous wastes. There are many disposal ways for liquid and gaseous waste materials. Some solid waste materials such as plastic bottles, papers, steel, etc. can be recycled without significant impact on the environment. However, studies on how to dispose some solid wastes such as waste bottles in the most beneficial ways are not yet fully exhausted (Kumaran *et al*., 2008).

PET is a thermoplastic material that contains molecules of carbon, hydrogen elements and other chemicals. The process of mixing PET with other chemicals to form this thermoplastic material is commonly known as vulcanization. This makes postconsumer PET very stable and nearly impossible to degrade under ambient conditions. Consequently, it has resulted in a growing disposal problem that has led to changes in legislation and significant researches worldwide (Groom *et al*., 2005).On the other hand, disposal of the waste PET plastic waste all around the world is becoming higher and higher through time. This keeps on increasing every year with the number of needs, as do the future problems relating to the crucial environmental issues (Kumaran *et al*., 2008).

The increasing piles of waste PET will create the accumulation of used PET at landfill sites and presents the threat of uncontrolled fires, producing a complex mixture of chemicals harming the environment and contaminating soil and vegetation. This is considered as one of the major environmental challenges the World is facing because waste PET is not easily biodegradable even after a long period of landfill treatment. One of the solutions suggested was the use of PET bottle waste as partial replacement of fine aggregate in cement-based materials (Kumaran *et al*., 2008).

If the PET is burned, the toxic product from the PET will damage the environment and it creates air pollution. Since it is not a biodegradable material, this may affect the fertility of the soil and vegetation. Sometimes it may produce uncontrolled fire. Similarly, the other challenge to the human society is in the form of carbon dioxide emission a green house gas (Kumaran *et al*., 2008).

Recycled waste PET bottle fiber in asphalt fiber hot mix, was conducted to extend the use of crumb fiber in Portland cement concrete mixes. The intent was to use such mixes on urban development related projects. A list of feasible projects was identified. Examples are roadways or road intersections, sidewalks, recreational courts and pathways, and wheel chair ramps for better skid resistance. This collaboration has also expanded to include members from industry associations, concrete suppliers and consultants. Several crumb fiber in concrete test sections were built throughout the state of organization and are being monitored for performance (Kaloush *et al*., 2004).

Hence, all the above studies suggest that there is a strong need to use waste materials in concrete tile production and specifically waste PET should be used in an environmental friendly way. For this, concrete tile production can be considered as a very realistic and convenient area of application (Groom et *al*., 2004).

1.2 Statement of the problem

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 are going to yield many undesirable effects in the agricultural sector. The increase in use of plastics without recycling is going to yield environmental pollution and as well as many undesirable effects on our health like respiratory and skin irritation (Vanessa et al., 1995).

Over the years, they are broken down into smaller pieces that are not biodegraded by bacteria in soil. For example the breaking down of the seven plastic resin codes and dangerous chemicals it leaches and taken up with crops finally reach with nutrition to human beings. Their accumulation over the years leads to increase in toxicity of soil, which has many adverse effects on plant and animal life. Plastics are harmful to manufacture, use, and pose a great challenge of recycling at the same time. Hence, when it comes to plastics, it is a full circle of problems and challenges that need to be resolved. Waste plastic bottles are major cause of solid waste disposal. Polyethylene Terephthalate (PET, PETE or polyester) is commonly used for carbonated beverage and water bottles. This is an environmental issue as waste plastic bottles are difficult to biodegrade and involves processes either to recycle or reuse (Carol, 2004).

In Ethiopia, the amount of waste PET is expected to increase with the increase of social needs. The consumption rate in Ethiopia is 23 million tons per annum estimated in 2009. From this 1 million tons per annum was recycled, 1.8 million tons per annum was incernated and 20.2 million tones was disposed to the environment without landfill (Ethiopian waste plastic and Rubber Economy P.L.C, 2009). This is 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 is worn out beyond hope for reuse is recycling. Utilization of scrap PET should minimize environmental impact and maximize conservation of natural resources. The regulatory practices include landfill bans and scrap PET fees. One possible solution for this disposal problem is to incorporate PET particles into cement-based materials. Scrap PET can be shredded into raw materials for use in hundreds of crumb PET products (Prakash *et al*., 2006).

Here in our country concrete tile production so far is mainly based on the use of natural resources, like aggregates and other materials. But the conservation concepts of natural resources are worth remembering and it is very essential to have a look at the different alternatives. One is the re using waste material mechanism. This has two advantages. One is that it can prevent the depletion of the source of natural resources and the other will be the prevention of waste materials from their severe threats to the environment. The other part of the problem is that aggregate production for construction purpose is continuously leading to the depletion of natural resources. Moreover, some countries are depending on imported aggregate and it is definitely very expensive. For example, the Netherlands does not possess its own aggregate and has to import (Gintautas *et al*., 2007). This concern leads to a highly growing interest for the use of alternative materials that can replace the natural aggregates

Therefore, the use of waste PET bottle as an aggregate can provide the solution for two major problems: namely the environmental problem created by PET plastic waste and the depletion of natural resources by aggregate usage, consequently the shortage of natural aggregates.

1.3 Research Questions

The researcher has formulated the following statement of problems that this study will attempt to clarify.

- What are the physical properties of materials used for concrete production for PET plastic waste replacement?
- What will happen to the strength of final concrete mix as the percentage of PET waste plastic increases?
- What is the maximum allowable percentage of PET waste plastic in structural material produced which yields acceptable compressive strength?

1.4 Scope of the study

This study concentrated on the performance of a single gradation of crumb PET bottle. The bottles were collected from Jimma city local areas. Manually and using cutter machine cut into pieces to achieve a uniform size of river sand size, which is the minimum aggregate size in the mix design.

The waste plastic bottle collected were chosen from those used as packaging plastic bottle for water and beverage which are resin code one to avoid any inconsistent properties that may arise by mixing materials from different plastic resin code. The study was done on grades of concrete C-25. The percentage replacements were limited to five categories namely 1%, 2%, 3%, 4% and 5 % replacement of the natural fine aggregate.

1.5 Significance of the study

Results obtained from this study are expected to contribute to the construction industry as an alternative aggregate source. And more over to open concrete application areas in the construction industry. It is obvious that all the stake holders in the construction industry will definitely benefit from this study. And it will also encourage PET plastic factories to think of side business for PET plastic waste recycling as the economic benefit is obvious. It will also provide sustainable markets for recycled PET plastic waste and it will encourage material recovery of large amounts of PET bottles.

Large amount of plastic waste produced every year. Plastics which are used for carrying goods become a waste after use and create environmental problems. For example the use of Polyethylene Terephthalate (PET, PETE or polyester) which is commonly used for carbonated beverage and water bottles are increased in day to day activities. The increase in use of plastics without recycling is going to yield environmental pollution and as well as many undesirable effects on our health. Plastic waste is now a serious environmental threat to the modern way of living. In order to manage this environmental problem the plastic waste bottles (PET) should be recycled or reused. Reuse of PET plastic waste has a dual advantage cost of material is low also it solves the problem of disposal of plastic waste to the environment. Finally this will alleviate environmental pollution to some extent and which will save nature diminishing resources.

CHAPTER TWO

2. LITRATURE REVIEW

2.1 Definition of plastic

Plastic is a kind of material that is commonly known and used in everyday life. To define plastic at molecular level, plastic is 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 the plastic. These long carbon chains are well packed together by entanglements and Vander Waals forces between large molecules, and form a strong, usually ductile solid material. Also, additives are usually added when manufacturing of commercial plastics is carried on, in order to improve the strength, durability or grant the plastic specific characteristics. Generally, there are two kinds of commercial plastics, thermoplastic and thermosetting plastic. Thermoplastics can be reheated, melted, and molded into different shapes, while thermosetting plastic will degrade and turn into other substances if reheated after molding. The molecules of thermoplastics are packed together by entanglements and Van der Waals forces (Callister *et al*., 2008).

When a thermoplastic is 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 is heated up, the cross-linking bonds between molecules break apart and the plastic turns into another substance when it melts, usually by decomposing (Asanuma *et al*., 2004).

2.2 Types of Plastics

Today, there are many different types of plastics manufactured in the plastic industry. They are applied in different areas depending on their properties. The table below summarizes names of all commonly used plastics, their properties, and applications. It shows the importance of plastic materials, since they are 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 (Callister *et al*., 2008).The following table 2.1 illustrates about different types of waste polymers.

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

Chemical Name	Abbreviation	Code	Properties	Typical Uses
Polyethylene terephthalate	PET,PETE	1	✣ Clear and optically smooth surfaces for oriented films and bottles ✣ Excellent resistance to most solvents Capability for hot-filling ✣ Excellent barrier to oxygen, water, and carbon dioxide	Soffit drink bottles
High-density polyethylene	HDPE	2	✣ Excellent resistance to most solvents ✣ Higher tensile strength compared to other forms of Polyethylene	Milk bottles
Polyvinyl Chloride	PVC	3	✣ Resistance to grease, oil and chemicals ✣ High impact strength, brilliant clarity, excellent processing performance	Food packaging, wire insulation and pipe
Low-density polyethylene	LDPE	4	✣ Excellent resistance to acids, bases and vegetable oils ✣ Toughness, flexibility and relative transparency	Plastic film used for food wrapping trash bags, grocery bags and baby diapers
Polypropylene	PP	5	✣ Excellent optical clarity in biaxial oriented films, stretch blow molded containers	Automobile battery casings and bottle caps
Polystyrene	PS	6	✣ Excellent moisture barrier for short shelf life products ✣ Low thermal conductivity and excellent insulation properties in foamed form	Food packaging, foam cups and plates and eating utensils
Mixed plastic	PLA	7	✣ Dependent on resin or combination of resins	Fence posts, benches, pallets and compostable packaging

2.3 Plastic Waste

Plastic takes up large part of society, from plastics used for furniture, electronics, to small households needs like containers and grocery bags. Since plastic first became available to consumers, it became widely used, due to the advantages it provides, such as lightweight, durability and its ability to mold into any products with chemicals and additives. However, there are also a number of disadvantages that plastic poses, including health problems starting from manufacturing to consumption and negative environmental impacts created by accumulation of plastic wastes (Catt *et al*., 2004).

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 are materials present in waste plastic that are undesired for its further recycling. Contaminants can be classified in two groups: non-plastic material components, and plastic material components that are detrimental for recycling and further manufacturing.

2.4.2 Non-plastic material components

These are materials not bound to the polymer matrix, but are part of the products where plastic is present. Examples:

- Metals (Ferro-magnetic and non-Ferro-magnetic)
- Non-metal non-glass inorganic:
- Ceramics, Stones and Porcelain
- Glass.
- Organics (non-hazardous) (paper, rubber, food remains, wood, textiles, organic plastic additive
- Hazardous (hazardous materials contained in plastic packaging, such as medicines, paint, Solvents and in general chemical waste).

2.4.3 Plastic material components

Plastic product quality is severely affected by the presence in waste plastic of more than one polymer of different structure. When a mix of polymers is melted for recycling, at the melting temperature of one of them, the polymers with lower fusion point will gasify and, while the higher fusion point polymers will stay intact. Both elements are 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. Density differences are 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 below).

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 (Hinislioglu *et al*., 2004).

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

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

Non-plastic material components are in most cases also relatively easy to separate through mechanical techniques, some in dry phase (metals, glass and stones), some in wet phase (paper, liquid contents of packaging such as food remains or detergents). Some materials such as rubber and wood are reported to be more complicated to separate, as their physical properties are closer to plastics. In most cases, removal of non-plastic materials requires size reduction (Arora, 2012).

2.4.4 Plastic additives

Plastic monomers alone are typically not stable enough to withstand use conditions without losing useful properties. Additives are therefore essential to compensate for this. Additive compounds are ubiquitously present in most plastics, sometimes in large amounts, and bound to the matrix structure of the plastics, so they cannot be removed using dry or wet physical methods. Actually, the presence of additives in plastics can alter significantly some of the properties used for separation (e.g. flame retardants and fillers in percentages above 10% can notably alter density) (Okada *et al*., 2000).

2.5 Reasons for using plastics

Although plastic is not good for the environment and is creating tons of trash around the world, it still plays a very important role in our everyday life. In fact, plastic is a very useful material that brings us convenience and makes many things possible. One of the well-known facts is its cheap price. Making packaging will cost 89% more to the consumers without the use of plastics. Except for some disadvantages, plastic is surprisingly beneficial in different aspects (Pramod *et al*., 2006).

Plastic needs less energy in 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 is not very environmental friendly, it does save energy and also lowers the amount of greenhouse gas emissions.

Plastic is also durable and strong. Plastic lumber, made with recycled plastic, holds nails and screws better than wood and is virtually maintenance free. Due to the way the plastics molecules arrange, it can stay intact for a long time as well as is very strong but not brittle (Nadeesha *et al*., 2012).

2.6 Plastic waste Collection

PET plastics collected from the disposal area were sorted to get the superior one. These were crushed into small fraction and washed to remove the foreign particles. Then it was heated at a particular temperature so that the necessary brittleness was obtained. After extrusion the molten plastic was cooled down and collected in boulders of 100 mm size approximately. These plastic boulders crushed down to the size of aggregates (Dinish *et al*., 2013).

Figure 2.1: PET plastic waste (Dinish *et al*., 2013)

According to environmental conservation laws, the recycling of wastes constitute 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. The informal private sector, represented by rubbish collectors, has been involved in waste recovery and recycling for many years because of the high value of recyclable materials (Khilesh, 2014).

2.7 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 we 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 project, we will 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 is biodegradable plastics. Even though the idea of biodegradable plastics is fairly new, with changing times and needs, they are most likely to be one of the most viable options to replace traditional plastics. There are 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 can soon be introduced in all major areas of everyday life (Mehrabzadeh et al., 2008).

2.8 Applicability of plastic waste

Even though biodegradable plastics might appear to have promising future, from our researches we determined that it cannot replace all the areas where plastics are currently used. One of such reasons is that in some places where plastics are expected to have a long lifetime, biodegradable plastics may pose problems because their biodegradability is not always controllable. In addition, for some areas where plastics are used, other solutions can produce better results than biodegradable plastics. For example, biodegradable plastics are not tolerable to heat and cannot replace all plastic silverwares and dishes. However, there are other options of reducing the use of plastics by replacing them with china dishes and metal silverware (Suarez *et al*., 2000).

Also, one of the areas where most plastics are used is probably in grocery bags. Biodegradable plastics can eventually replace the traditional plastic grocery bags. However, from interviews and other researches, we concluded that the use of plastic grocery bags can be reduced more easily by using financial incentives and encouraging people to bring reusable tote bags. Lastly, one other area where use of plastics can be reduced easily without using biodegradable plastics would be bottled beverage containers. Bottle beverage containers can be recycled easily if people are educated and aware that they need to be placed in proper recycling containers. However, there are other obstacles to recycling water bottles as the bottles and caps are usually made with different types of plastics (Zainab, 2003). Also, additives are usually added when the bottles are manufactured, and labels and glue are also used in packaging. Such impurities in water bottles might contaminate the recycling streams and therefore cause down cycling. Thus, if the manufacturers take appropriate steps and make the containers easier to be recycled by recycling companies, it would help reduce the plastic waste in the environment. Combinations of these solutions will definitely help reduce plastic wastes in areas where biodegradable plastics cannot or do not have to replace traditional plastics and will also help reduce the plastic wastes until biodegradable plastics are good enough to be used extensively (Nagan *et al*., 2011).

The proportion as well as the properties of the components (binder, aggregate and additive) into the design mix of Asphalt concrete greatly depends on its performance. Among them, the binder is of relatively more important which can be normal penetration grade bitumen as well as it can be modified by adding an optimum proportion of different additives. Recently, many studies have been attempted by adding different materials as an additive to improve the mechanical and physical properties of asphalt concrete. Polymer is one of these additives. Bitumen can be improved by the addition of polymers in stiffness and the temperature susceptibility point of view (Bhogayata *et al*., 2012).

2.9 Problems of Plastics

2.9.1 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 are going to yield many undesirable effects on our health. Plastics are harmful to manufacture, use, and pose a great challenge of recycling at the same time. Hence, when it comes to plastics, it is 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.

I) Polyethylene Terephalate (PETE or PET):

It is commonly used in soft drinks, mouthwash, and detergent containers. It is known to leach “antimony trioxide” which causes respiratory and skin irritation, increased incidences of miscarriages in women and other menstrual problems under exposure for a long period of time (Okada *et al*., 2000).

II) Polystyrene

It is commonly used in egg cartons, Styrofoam containers, plastic cutlery, and take out containers. It is known to leach styrene, which is also an endocrine disruptor just like BPA, known to mimic female hormone estrogen. It has the potential to cause reproductive and developmental problems in women, nervous system disorders (Okada *et al*., 2000).

III) Polyvinyl chloride (PVC)

It is commonly used in toys, squeeze bottles, shampoo bottles, cooking oil bottles and even in medical tubing. PVC has been described as one of the most hazardous consumer products ever made. It leaches phthalate (DEHP) or (BBzP). Just like BPA, these chemicals act as endocrine disruptors mimicking female hormone estrogen. They have also been associated with causing asthma and allergic symptoms in children, effects on spleen and kidneys, bone formation and body weight. In Europe, the use of DEHP or BBzP has been banned for making toys for kids since 1999 (Okada *et al*., 2000).

2.9.2 Other health problems

Health hazards of plastics result not only from the manufacturing process and consumption, but also from their destruction by incineration. Incineration pollutes air, water, and land exposing workers to toxic chemicals including carcinogens. Their recycling is a challenge in itself, and the fact that used plastics tossed into land never degrade ads to the problem. Over the years, they are broken down into smaller pieces that are not biodegraded by bacteria in soil. Their accumulation over the years leads to increase in toxicity of soil, which has many adverse effects on plant and animal life that are dependent on soil reduction, recycling, composting, landfills, and combustion in order of preference (Guoxi *et al*., 1999).

2.10 Characteristics of Concrete PET

Concrete PET is a composite material composed of fine granular material of plastic fiber (the aggregate or filler) embedded in a hard matrix of material (the cement or binder) that fills the space between the aggregate particles and glues those together. In its simplest form, concrete tile is a mixture of paste and aggregates. The paste, composed of Portland cement and water, coats the surface of the fine and coarse aggregates. Through a chemical reaction called hydration, the paste hardens and gains strength to form the rock-like mass known as concrete PET (Asokan *et al*., 2010).The main concrete making materials are discussed below.

2.11 Constituents of Concrete

2.11.1 Cement

Cement is a generic name that can apply to all binders. The chemical composition of the cements can be quite diverse but by far the greatest amount of concrete used today is made with Portland cements (Sidney et *al*., 2003). For this reason, the discussion of cement in this thesis is mainly about the Portland cement.

Portland cement, the basic ingredient of concrete, is 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 concrete. Lime and silica make up about 85% of the mass. Common among the materials used in its manufacture are 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 is checked by frequent chemical and physical tests in plant laboratories. The finished product is also analyzed and tested to ensure that it complies with all specifications (The Portland Cement Association, 2009).

The term "Portland" in Portland cement originated in 1824 when an English mason obtained a patent for his product. This was because his cement blend produced concrete that resembled the color of the natural limestone quarried on the Isle of Portland in the English Channel (Sidney *et al*., 2003).

2.11.2 Types of Portland Cements

Different types of Portland cement are manufactured to meet different physical and chemical requirements for specific purposes. The American Society for Testing and Materials (ASTM) Designation C 150 provides for eight types of Portland cements (ASTM International Standards, 2009).

TYPE I

Type I is general-purpose Portland cement suitable for all uses where the special properties of other types are not required. It is used where cement or concrete is not subject to specific exposures, such as sulfate attack from soil or water, or to an objectionable temperature rise due to heat generated by hydration. Its uses include pavements and sidewalks, reinforced concrete buildings, bridges, railway structures, tanks, reservoirs, culverts, sewers, water pipes and masonry units (ASTM International Standards, 2009).

TYPE II

Type II Portland cement is used where precaution against moderate sulfate attack is important, as in drainage structures where sulfate concentrations in ground waters are higher than normal but not unusually severe. Type II cement will usually generate less heat at a slower rate than Type I. With this moderate heat of hydration (an optional requirement), Type II cement can be used in structures of considerable mass, such as large piers, heavy abutments, and heavy retaining walls. Its use will reduce temperature rise which is especially important when the concrete is placed in warm weather (ASTM International Standards, 2009).

TYPE III

Type III is a high-early strength Portland cement that provides high strengths at an early period, usually a week or less. It is used when forms are to be removed as soon as possible, or when the structure must be put into service quickly. In cold weather, its use permits a reduction in the controlled curing period. Although richer mixtures of Type I cement can be used to gain high early strength, Type III, high early-strength Portland cement, may provide it more satisfactorily and more economically (ASTM International Standards, 2009).

TYPE IA, IIA, IIIA

Specifications for three types of air-entraining Portland cement (Types IA, IIA, and IIIA) are given in ASTM C 150. They correspond in composition to ASTM Types I, II, and III, respectively, except that small quantities of air-entraining materials are inter ground with the clinker during manufacture to produce minute, well distributed, and completely separated air bubbles. These cements produce concrete with improved resistance to freeze-thaw action (ASTM International Standards, 2009).

TYPE IV

Type IV is a low heat of hydration cement for use where the rate and amount of heat generated must be minimized. It develops strength at a slower rate than Type I cement. Type IV Portland cement is intended for use in massive concrete structures, such as large gravity dams, where the temperature rise resulting from heat generated during curing is a critical factor (ASTM International Standards, 2009).

TYPE V

Type V is sulfate-resisting cement used only in concrete exposed to severe sulfate action principally where soils or ground waters have high sulfate content (ASTM International Standards, 2009).

2.11.3 Properties of the cement

2.11.3.1 Normal consistency of cement

Cement is finely ground powder of chemically combined argillaceous materials (silica, alumina) and calcareous materials (lime) with iron oxide, gypsum and small amount of other ingredients. When mixed with water, cement sets and hardens in to a solid mass up on hydration. The normal consistency of hydraulic cement refers to the amount of water required to make a neat paste of satisfactory workability. It is determined using Vicat apparatus. This apparatus measures the resistance of the paste to the penetration of a plunger or needle of 300gm related at the surface of the paste. The amount of water required for normal consistence is then expressed as a percentage by weight of the dry cement (Abebe, 2002).

$$\text{Calculation:} \qquad \%\text{Water} = \frac{\text{weight of water} * 100\%}{\text{Weight of cement}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.1)}$$

Thus the usual range of water-cement ratio for normal consistency is between 26% and 33% and from the experiment the percentage by weight of dry used water is between the ranges with penetration of 10 ±1.

2.11.3.2 Setting time

Cement forms a solid and hard mass when mixed with water upon hydration. The duration of a cement paste requires undergo setting is its setting time. Cement pastes with different water-cement ratio will, generally, have different setting times. Therefore it seems confusing at first, which setting time to use. As a convention, it is the setting time of cement paste with normal consistency that is referred to as the setting time of cement (Abebe, 2002).

Generally there are two types of setting time to determine in the laboratory, initial and final setting times. The initial setting time is the duration of cement paste related to 25mm penetration of the Vicat needle in to the paste in 30 seconds after it is released while the final setting time is that related to zero penetration of the Vicat needle in to the paste (Abebe, 2008).

Ethiopian standard recommends that, the initial setting time for Portland cement is not to be less than 45minutes and the final setting time is not exceed 10hours (Ethiopian central statics agency, 2007).

2.12 Aggregates

Aggregates generally occupy 70 to 80 % of the volume of concrete floor tile and can therefore be expected to have an important influence on its properties. They are granular materials derived for the most part from natural rock and sands. Moreover, synthetic materials such as slag and expanded clay or shale are used to some extent, mostly in lightweight concrete. In addition to their use as economical filler, aggregates generally provide concrete with better dimensional stability and wear resistance. Based on their size, aggregates are divided into coarse and fine fractions. The coarse aggregate fraction is that retained on the 4.75 mm sieve (Sidney *et al*., 2003). Based on their origin, aggregates can be classified as natural aggregates and non-natural aggregates (Cairns *et al*., 2004).

The relevant tests to identify the properties of the aggregates that were intended to be used in this research were carried out. After that, corrective measures were taken in advance before proceeding to the mix proportioning. In general, aggregates should be hard and strong, free of undesirable impurities, and chemically stable. Soft, porous rock can limit strength and wear resistance; it may also break down during mixing and adversely affect workability by increasing the amount of fines. Aggregates should also be free from impurities: silt, clay, dirt or organic matter. If these materials coat the surfaces of the aggregate, they will isolate the aggregate particles from the surrounding concrete, causing a reduction in strength. Silt, clay, and other fine materials will also increase the water requirements of the concrete, and organic matter may interfere with cement hydration. To proportion suitable concrete mixes, certain properties of the aggregate must be known. These are; shape and texture, size gradation, moisture content, specific gravity and bulk unit weight (Sidney et *al*., 2003).

2.12.1 Natural Aggregates

Mineral aggregates consist of sand and gravel, stones and crushed stone. Construction aggregates make up more than 80 percent of the total aggregates market, and are used mainly for road base, rip-rap, cement concrete, and asphalt. In 1998, roughly 3,400 U.S. quarries produced about 1.5 billion tons of crushed stone, of which about 1.2 billion tons was used in construction applications (Meyer *et al*., 2004). The sources of mineral aggregates are by directly extracting from the original sources like river basins or by manufacturing them into a desired shape from the parent rock in a crasher mill**.** It was also found out that manufactured sand offers a viable alternative to the natural sand by providing a higher compressive strength and delivering environmental benefits (Shewaferaw, 2006).

All natural aggregate particles are originally formed as part of a larger parent mass. This may have been fragmented by natural processes of weathering and abrasion or artificially by crushing. Thus, many properties of the aggregate depend entirely on the properties of the parent rock, e.g. chemical and mineral composition, specific gravity, hardness, strength, physical and chemical stability, pore structure, and color. On the other hand, there are some properties possessed by the aggregate but absent in the parent rock: particle shape and size, surface texture and absorption. All these properties may have a considerable effect on the quality of the concrete, either in the fresh or in the hardened state (Neville *et al*., 1996).

2.12.2 Non Natural Aggregates

This category consists of aggregates that are artificial in origin. The reasons for their advent in concrete construction are:

- Environmental considerations are increasingly affecting the supply of aggregate.
- There are strong objections to opening of pits as well as to quarrying.
- At the same time, there are problems with the disposal of construction demolition waste and with dumping of domestic waste.

However, these types of waste can be processed into aggregate for use in concrete and this is increasingly being done in a number of countries, for example, in the Netherlands (Neville *et al*., 1996).Wide varieties of materials come under the general heading of solid wastes. These range from municipal and household garbage, or building rubble, such as brick and concrete, through unwanted industrial byproducts such as slag and fly ash or discarded or unused materials such as mine tailings (Nyland *et al.,* 2003). Recycled PET bottle fibers can be categorized under municipal wastes. Table 2.3 below shows the different solid wastes that have been considered as aggregates for concrete with their composition and the associated industry.

Table 2.3: Typical solid wastes that have been considered as aggregate for Concrete (Sidney *et al.*, 2003).

Material	**Composition**	**Industry**
Mineral wastes	Natural rocks	Mining and mineral processing
Blast furnace slags	Silicates or alumino silicates of calcium and magnesium	Iron and Steel
Metallurgical slags	Silicates, aluminosilicates	Metal refining
Bottom ash	Silica glasses	Electric power
Fly ash	Silica glasses	Electric power
Municipal wastes	Paper, glass, plastics, metals	Commercial and house hold waste
Incinerator residues	Container glass and metal and silica Glasses	Municipal and industrial wastes
Building rubble	Brick, concrete, reinforcing steel	Demolition

2.13 Water

Water is a key ingredient in the manufacture of concrete. Attention should be given to the quality of water used in concrete. The time-honored rule of thumb for water quality is “If you can drink it, you can make concrete with it.” A large amount of concrete is made using municipal water supplies. However, good quality concrete can be made with water that would not pass normal standards for drinking water. Mixing water can cause problems by introducing impurities that have a detrimental effect on concrete quality. Although satisfactory strength development is of primary concern, impurities contained in the mix water may also affect setting times, drying shrinkage, or durability or they may cause efflorescence. Water should be avoided if it contains large amounts of dissolved solids, or appreciable amounts of organic materials (Sidney *et al.*, 2003).

2.14 Methods of Recycling PET Bottle

The numerous techniques and technologies available for processing postconsumer PET are enumerated below (Groom *et al*., 2005).

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

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

1. They can offer distinct engineering benefits over natural aggregates.
2. They can be used as an alternative to primary materials thereby reducing an environmental burden on extraction.
3. 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 (Stutz *et al*., 2003).

Waste PET have hardness and elasticity properties superior to those of sand, good resistance to weathering, can 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 (U.S. Army Engineer Research and Development Center, 2004). Crumb PET particles from shredded PET have been successfully added to asphalt and is widely used. The following section discusses the application of recycled PET in concrete tile.

2.15 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

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- They can offer distinct engineering benefits over traditional aggregates.

- They can 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 (Wallis *et al*., 2005).

2.16 Material constituents of PET Concrete Tile

2.16.1 General

The production of concrete using waste PET bottle waste added in different volume proportions is a very infant technology. Partially replacing the coarse or fine aggregate of tile with some quantity of small waste PET mix cubes can improve qualities such as low unit weight, high resistance to abrasion, absorbing the shocks and vibrations, high ductility and so on to the tile. Moreover, the inclusion of fiber into tile results in higher resilience, durability and elasticity. In constructions that are subject to impact effects the use of PET concrete tile will be beneficial due to the altered state of its properties (Kumara *et al*., 2008).

2.17 The property of concrete 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 asphalt binders can improve the performance of asphalt concrete (Poulakis *et al*., 2008).

In this investigation, waste polyethylene and PVC as the sort of polymers is used to investigate the potential prospects to enhance asphalt mixture properties and to check the design criteria of asphalt mixture using this two modifier at optimum binder content. The amount of waste polyethylene and PVC is increasing day by day as the availability of these two wastes is enormous. More or less all the solid waste is being mixed with Municipal Solid Waste over land area after some nominal sorting and thus thrown over the land area named landfill. Since the plastic, polyethylene and PVC is non-biodegradable, it remains at the site for uncertain time causing the appreciable amount of waste increase into the landfill, ultimately increasing amount of cost for waste disposal. Since the present disposal method is either by land filling or by incineration, the waste plastic is owed dispose likely that causing adverse impact on the environment. To encounter this trend, considerable effort is being put into recycling waste, turning it into re-usable by products (Awwad *et al*., 2007).The following table 2.4 shows the effect of waste plastic percentage on the density of samples.

Table 2.4: Effect of waste plastic percentage on the density of the samples (Little *et al*., 1993).

Particle size(mm)	Waste plastic%	Density (g/cm^3)
0.2	10	1.9
	20	1.75
	30	1.7
	40	1.6
	50	1.51
0.65	10	1.9
	20	1.71
	30	1.63
	40	1.5
	50	1.39
1.3	20	1.88
	30	1.8
	40	1.7

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

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 fibres 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.Ramaderi & R.Manju , 2012**)**

According to **Youcef et al., (2008)**: The study present the partial replacement of fine aggregate in concrete by using plastic fine aggregate obtained from the crushing of waste plastic bags. 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 concrete was replaced with plastic bag waste sand at 10%, 20%, 30% and 40% whereas other concrete materials remain same for all four mixes. In fresh properties of concrete it was observed from the results of slump test that with increase of waste content workability of concrete increases which is favorable for concrete 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 concrete mix. Plastic waste increases the volume of voids in concrete which on other hand reduce the compactness of concrete simultaneously speed of sound in concrete is also decreased. Strength reduction in concrete 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 concrete with addition of plastic aggregate is not emphasized (Youcef *et al*., 2008).

According to **Raghatate Atul M. (2002):** The paper is based on experimental results of concrete sample casted with use of plastic bags pieces to study the compressive and split tensile strength. He used concrete mix by using Ordinary Portland Cement, Natural River sand as fine aggregate and crushed granite stones as coarse aggregate, portable water free from impurities and containing varying percentage of waste plastic bags (0%, 0.2%, 0.4%, 0.6% 0.8% and 1.0%). Compressive strength of concrete specimen is affected by the addition of plastic bags and with increasing percentage of plastic bag pieces compressive strength goes on decreasing (20% decrease in compressive strength with 1% of addition of plastic bag pieces). On other hand increase in tensile strength of concrete was observed by adding up to 0.8% of plastic bag pieces in the concrete mix afterward it start decreasing when adding more than 0.8% of plastic bags pieces. He concluded that utility of plastic bags pieces can be used for possible increase in split tensile strength. This is just a basic study on use of plastic bags in concrete. More emphasis was required by varying the shape and sizes of plastic bags to be use in concrete mixes (Raghatate, 2002).

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 concrete properties. Different concrete 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 concrete mix design with 1: 1.5: 3 proportions 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 concrete with no emphasis given to flexural properties of concrete. 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 and columns (Ramesh *et al*., 2007).

According to **Pramod et al., (2006)**: This study presents the use of plastic recycled aggregate as replacement of coarse aggregate for production of concrete. They used forty eight specimen and six beams/cylinders casted from variable plastic percentages (0, 10, 20, 30, 40 and 50%) used as replacement of coarse aggregate in concrete mixes. They have conducted various tests and observed decrease in density of concrete with increase percentage of replacement of aggregate with recycle plastic concrete. They also reported decrease in compressive strength for 7 and 28 days with increase in percentage of replacement of coarse aggregate with recycle plastic aggregate. They have recommended feasibility of replacing 20 % will satisfy the permissible limits of strength. Again these researchers limited their research to only compressive strength property and no work was carried out to study the other important properties of concrete. Their research also lacks use of various admixtures in concrete to cater for the loss in strength (Pramod *et al*., 2006).

According to **Elzafraney et al., (2005)**: This study has incorporated use of recycled plastic aggregate in concrete material for a building to work out its performance with regards to thermal attributes and efficient energy performance in comparison with normal aggregate concrete. The plastic content concrete was prepared from refined high recycled plastics to meet various requirement of building construction like strength, workability and finish ability etc. Both buildings were subject to long and short term monitoring in order to determine their energy efficiencies and level of comfort. It was observed that recycled plastic concrete building having good insulation used 8% less energy in comparison of normal concrete; however saving in energy was more profound in cold climate in building with lower insulation. They recommended that efficiency of energy can further be increase if recycle plastic of high thermal capacity is used. They have suggested the use of recycle plastic aggregate concrete being economical and light weights are having high resistance to heat. The author should also incorporate the comparison of both buildings with regards to durability and strength (Elzafraney *et al*., 2005).

2.18 Properties of Hardened PET Concrete

2.18.1 Unit Weight

The replacement of natural aggregates with PET aggregates tends to reduce the density of the concrete. This reduction is attributable to the lower unit weight of PET aggregate compared to ordinary aggregate. The unit weight of PET concrete mixtures decreases as the percentage of PET aggregate increases (Danko *et al*., 2006).The unit weight (density) of concrete varies, depending on the amount and density of the aggregate, the amount of air that is 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 3% rubber content, the dry density diminished to about 9.5 % of the normal concrete. However, the decrease in dry density of PET is 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 concrete mix increases as the percentage crumb PET added increases (Groom *et al*., 2005).

2.18.2 Compressive Strength

Compressive strength tests are widely accepted as the most convenient means of quality control of the concrete produced. Tests conducted on PET concrete behavior, using PET chips and crumb PET as aggregate substitute of sizes river sand exhibited reduction in compressive strength by 8.5% and tensile splitting strength by 5% but showed the ability to absorb a large amount of plastic energy under tensile and compressive loads (Kumaran *et al*., 2008). 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 concrete (Kaloush *et al*., 2004).

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 2 % (The PET Manufacturers Association, 2009).

According to Felipe J.A. and Jeannette Santos, a maximum strength reduction of 5% was noted for a mix with 6% substitution in their studies (Felipe *et al*., 2004). Nevertheless, in a very different approach, Hanson aggregates achieved higher compressive strength in crumb PET concrete by reducing entrapped air in the mix (Carol, 2004).

In most of the previous studies, a reduction in compressive strength was noted with the addition of PET aggregate in the concrete mix but there is still a possibility of greatly improving the compressive strength by using de-airing agents (Naik *et al*., 2002).

2.18.3 Tensile Strength

The tensile strength of PET containing concrete is affected by the size, shape, and surface textures of the aggregate along with the volume being used indicating that the strength of concretes decreases as the volume of PET aggregate increases (Danko *et al*., 2006). Tests conducted on PET concrete behavior, using tire chips and crumb PET as aggregate substitute of river sand size exhibited reduction in splitting tensile strength by 5% but showed the ability to absorb a large amount of plastic energy under tensile loads (Kumaran *et al*., 2008).

2.18.4 Flexural Strength

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

2.19 Applications of PET Concrete Tile

There is a growing evidence for the feasibility of substituting waste PET fiber with a portion of natural aggregate in concrete production. While very little fiber from used PET goes into the production of new PET, hosts of other products made from recycled PET fiber have come to market in many areas of applications. Chips of shredded PET fiber are used as a fill in engineering projects. More finely cut and screened PET bottle fiber is used in playground and landscaping areas. Crumb PET is used to make better concrete production (Prakash *et al*., 2006).

Among the largest projects that utilized higher contents of crumb fiber in concrete was an experimental outdoor tennis court in Phoenix. Leading to the final construction of this tennis court, a series of experimental test slabs (0.61m x 1.22m in size, with a thickness of 5 to 8 cm) were built in January 2003 with fiber content varying between 20 to 130 kg of crumb PET fiber per m3 of concrete. The experimental testing program included compressive strength, flexural strength, indirect tensile strength, and thermal coefficient of expansion tests. The preliminary results were very encouraging (Kaloush *et al*., 2004).

The introduction of waste PET fiber considerably increased toughness, impact resistance, and plastic deformation of concrete, offering a great potential for it to be used in sound/crash barriers, retaining structures and pavement structures. A study revealed that it is possible to fabricate block containing PET up to 2 % by sand volume using chemical and mineral admixtures, which gives better bonding characteristics to rubber and significantly improves the performance of crumb PET fiber concrete paving block (Ling *et al*., 2006).. New Zealand does have some current waste PET processors that shred PET either to render them acceptable for land filling or to provide PET chips for such purposes as playground surface cover, drainage material, horse arena surfaces, embankment construction and land erosion control (Emiroglu *et al*., 2002).

There are also uses of rubberized concrete in building applications. It has been shown that crumb rubber additions in structural high strength concrete slabs improved its fire resistance, reducing its spelling damage under fire. This material provides a good mechanical behavior under static and dynamic actions and is being used for road pavement applications. The results of recycled tire rubber-filled concrete (RRFC) under fatigue loads show the feasibility of using this composite material as a rigid pavement for roads on elastic sub grade (Barnet *et al*., 2004).Landscaping applications like playground surface cover, athletic field turf amendment, and running track construction is a potential market. Rubber strips can also be partially embedded into concrete surfaces, such as in paving slabs, concrete floors, highway crash barriers, bollards, etc. to soften tread or dampen any impact (Barnet *et al*., 2004).

Applications in the areas of horse arenas and playgrounds and landscape materials show that crumb rubber can bring some improved qualities to concrete. For it absorbs force and bounces back, does not freeze, and is not biodegradable. Small proportions of rubber are also used as an energy absorbing material in children's play areas to prevent injury. In January 2003, Hanson's Aggregates built the first of several test slabs. The slab contained around 180 kg of crumb rubber per m^3 (representing 25 percent of the concrete mix by volume) and was placed without any joints. No shrinkage cracks have been observed after a period of more than a year. This slab serves as a truck parking facility (Carol, 2004). Currently, the waste PET fiber concrete is used in precast sidewalk panel, non-load bearing walls in buildings and precast roof for green buildings. It can be widely used for development related projects such as roadways or road intersections, recreational courts and pathways and skid resistant ramps. With this new property, it is projected that these concretes can be used in architectural applications such as nailing concrete, where high strength is not necessary, in wall panels that require low unit weight, in construction elements and Jersey barriers that are subject to impact, in railroads to fix rails to the ground. Roofing tiles and other concrete products can now be made lighter with PET concrete (Naik *et al*., 2005). Benefits from using recycled PET fiber in landscaping projects include project cost savings, and improved product performance and safety. Greenhouse gas and public health benefits result from diverting tires from landfills and PET piles (Stutz *et al*., 2003).

Looking at the possibilities for crumb PET fiber in future concrete products, one can visualize high-rises that are lighter in weight and more resistant to cracking. Moreover, concrete bases for heavy pounding machinery that absorb the sound and withstand the pressure can be achieved. All the applications discussed above show that there is a huge potential advantage that can be exploited from the use of PET concrete. It is a very promising technology that can deliver various outstanding benefits to the construction sector.

2.20 Cost Considerations in PET Concrete Tile

The use of recycled PET in concrete tile production is an infant technology and the number of used PET that is recycled in environmental engineering applications is very low at the current time. However, any new concrete 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 may occur. The different factors associated with the cost of PET concrete are discussed below.

2.20.1 Cost Savings due to Material substitution

The other approach is 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 is 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 are dependent on the particular application and are 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 is 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 is 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 will undoubtedly improve the viability and economics of PET recycling. It is possible that the PET retailers will need to pay more to the PET recyclers to take the used PET and that this cost will be passed on to PET purchasers (Wallis *et al*., 2005).

Cost savings can 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 will thus 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*., 2008).

2.20.2 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 is 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).

2.20.3 Cost Savings by Protecting the Environment

One of the sustainability targets set by some governments for the construction industry is 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 is reduced with the associated environmental impacts as well (Stutz *et al*., 2003).

Provided that the cost of PET aggregate can be kept to the lower end of the range, it can be seen that the cost increase should not be onerous for manufacturers. The less stringent processing requirements for PET aggregate used in concrete are likely to further reduce the cost of PET aggregate in this application. Simultaneously, environmental concerns are increasing all over the world. The recent Copenhagen summit of different nations has demonstrated how big and critical are the environmental issues and the problem our world is 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 is clearly identified as environmentally friendly or to contain recycled materials. Recycling is associated with a number of cost items, like collection, separation, processing, transportation, and the required capital investments. On the other hand, solid waste that is 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 concrete 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 concrete in general has been done. Following that, the use of recycled materials in concrete construction was discussed with recycling PET as the main subject. Previous works on PET fiber concrete 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 rubberized concrete were thoroughly reviewed. As to the knowledge of the author of this research, there is no reported research in Ethiopia in the use of recycled PET in concrete construction until now. Thus, the research is aimed at evaluating the fresh and hardened properties of concrete produced by partial replacement of the natural fine aggregates with PET aggregates that are 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 are presented. Moreover, the mix proportioning procedure utilized is also explained.

CHAPTER THREE

3. OBJECTIVE OF THE STUDY

3.1 General objective of the study

- The general objective of this study is to examine technical feasibility of PET plastic wastes as a partial replacement for fine aggregate in concrete mix for better environmental management.

3.2 Specific objective of the study

- To check physical properties of materials used for PET plastic waste concrete mix production.
- To determine hardened or strengthen properties of concrete with and without PET plastic waste.
- To optimize the PET plastic waste content in a concrete mix.

CHAPTER FOUR

4. MATERIALS AND METHODS

4.1 The study setting area

The study was conducted in Jimma Town, Oromia National Regional State, and South West Ethiopia which was located at 346 Km from Addis Ababa. The total coverage of the city was estimated to be 19,506.24m^2. The climatic condition of the Jimma town constitutes three major climates. It belongs to subtropical, temperate and tropical zones, respectively. Jimma town is mainly wet season in the period of June to October and the rest was dry season extends from November to May. The maximum temperature of the area is 28^{o}C and the minimum is 12^{o}C, which occurs in November, where the maximum is in May. In general, rainfall in the area increases with altitude but the pattern is considerably modified by local topography (Chaffey, 1982). The GIS generated map for Jimma town is shown with figure 4.1.

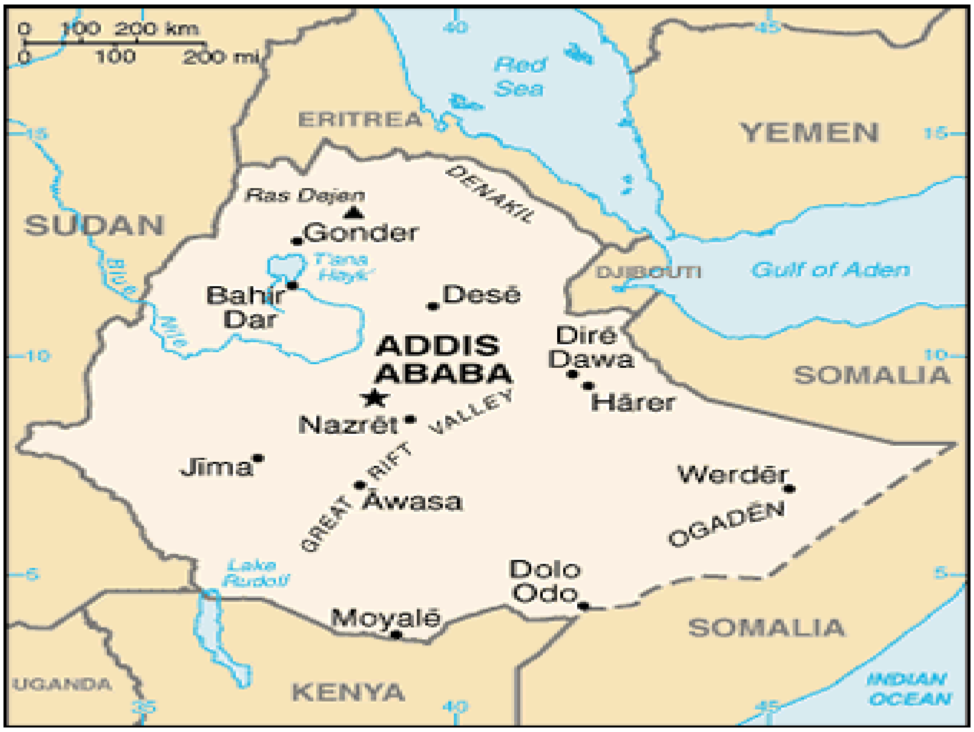

Figure 4.1: Map showing the relative position of the study area.

4.2 Study period

The research have taken four months and started on March 2016 and it ends on June 2016.

4.3 Study design

i. Material Tests

Tests were conducted on the raw materials to determine their properties and suitability for this experiment. After all the materials like cement, sand, coarse aggregate and waste PET plastic waste delivered to laboratory. The PET plastic wastes were washed with water in order to remove impurities before gradation. After washing the PET plastic waste, gradation (size reduction) was done using cutter machine in the chemical engineering laboratory. The test was done on the raw materials to adjust physical properties of material and suitability, like sieve analysis, silt content of sand, moisture content of aggregate, setting time and consistency of cement and etc.

ii. Mix Proportioning (Pre-Mix Design)

Total of 6 mixes with 72 samples for concrete grade of C-25 were produced. It was prepared with fine aggregate replacements by 0, 1, 2, 3, 4 and 5% of the fine PET plastic waste aggregate; this was set depending on the previous work of different researcher. A control mix with no fine PET plastic waste aggregate replacement should be produced to make a comparative analysis which is 0% replacement.

iii. Specimen preparation

The concrete specimens were prepared in the Jimma University, Institute of Technology, under civil engineering department, material testing laboratory. The prepared samples consist of concrete cubes, cylinders and beams.

iv. Testing of Specimens

Laboratory tests were carried out on the prepared concrete samples. The tests which conducted were compressive strength, split tensile strength and flexural strength.

The Schematic flow diagram for the study which is recycling of PET is showen in figure 4.2 below.

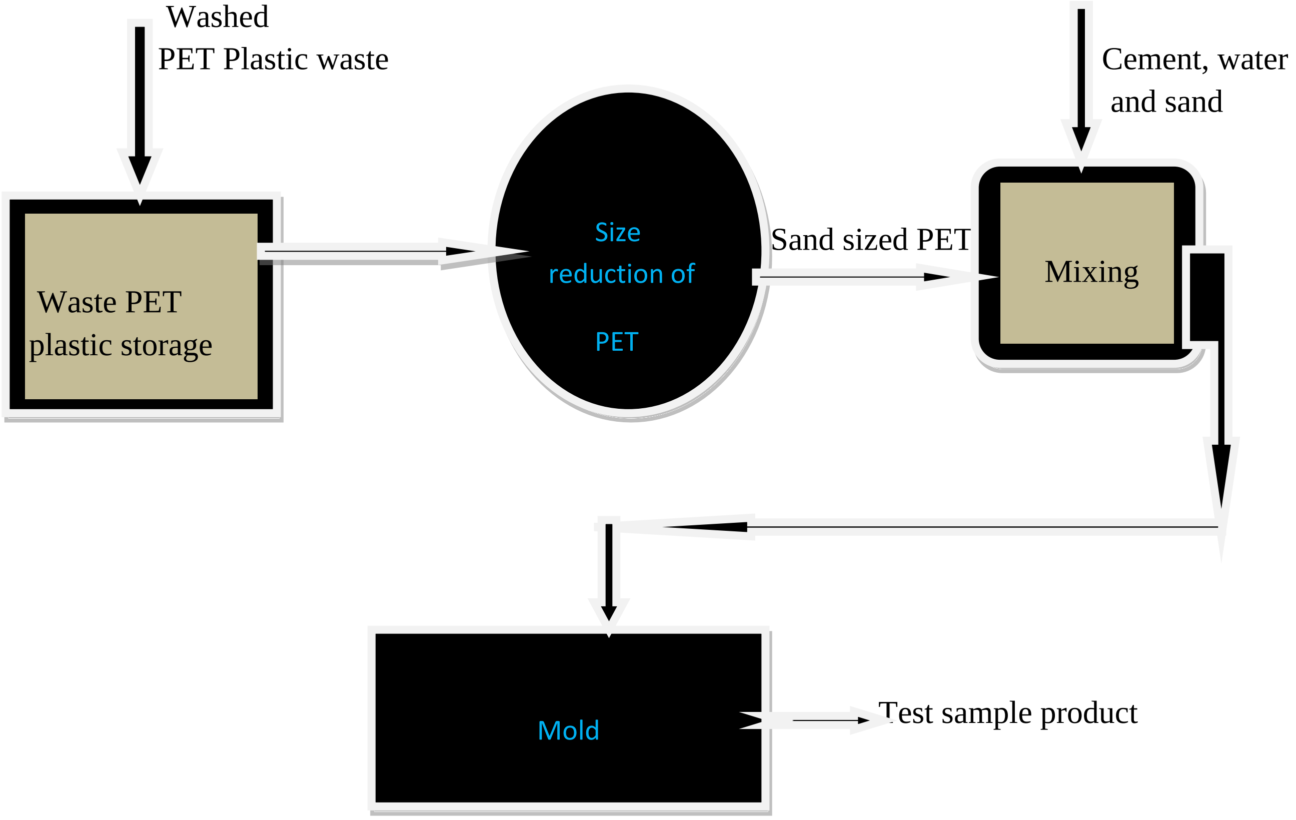

Figure 4.2: Schematic process flow diagram for the study design.

4.4 Collection of samples

It includes collection of raw materials**;** all the required materials were collected and delivered to the laboratory. These are; cement (ordinary Portland cement), fine aggregate from Gambela which is river sand(to the size which ranges from 0.06 up to 2 mm), coarse aggregate from Agaro which is 20 mm size and waste PET plastic wastes (bottles) from Jimma town and JiT which is reduced to the size of 2mm. The cement type used in this research was OPC cement from capital manufactured in Ethiopia. The main reason for using Ordinary Portland Cement (Type I) in this study is that, this is by far the most common cement in use and is highly suitable for use in general concrete construction when there is no exposure to sulphates in the soil or groundwater (Neville *et al*., 1996). The choice of OPC from PPC also avoids any uncertainties in the results of the test.

4.5 Study variables

1. Independent variables

- Optimization of PET plastic waste
- Physical properties of materials, compressive strength, split tensile strength, flexural strength.

2. **Dependent variables**

- Utilization of PET plastic waste as fine aggregate

4.6 Data quality assurance

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.

4.7 Data analysis

The data analysis were performed by using Microsoft excel 2007, scientific calculator and Minitab 16.The test results of the samples were compared with the respective control concrete properties and the results are presented using tables, pictures and graphs.

4.8 Sample preparation

4.8.1 Preparation of PET plastic waste

The source of the PET plastic aggregate was waste plastic bottle which were collected from the local Jimma city and JiT campus. For uniformity of the concrete PET production and convenience, all the plastic wastes collected were from those which were used as carbonated beverage and water bottles, which is shown as the following figure 4.3.

This study has concentrated on the performance of PET plastic waste which is prepared by manual cutting for shredding and by cutting machine. The minimum size of the PET plastic waste aggregate was river sand size as shown in figure 4.3. The PET plastic waste aggregates used in the present investigation were made by manually and using cutting machines. It was very difficult, time consuming and was not easy to handle at the initial stages. However, all this complications can be easily sorted out if a large scale production is devised and proper cutting tools and machineries are made for this particular usage.

Figure 4.3: Size reduction of PET plastic waste bottles to river sand size (2mm) at chemical engineering laboratory **(**Photo taken by Merid Teshome).

4.8.2 Trial Mixes/Pre Mixes

To attain the stated objectives, the research basically focuses on laboratory investigations of concrete samples prepared. The specimens were prepared with changing amount of PET plastic waste aggregate. The DOE method was used in determining the mix proportions after all the required parameters have been obtained a priori. These include the studying physical properties of materials, sieve analysis of both the fine and coarse aggregates and their specific gravity.

Concrete grades C-25 strength concretes were selected and trial mixes were prepared. Trial mixes were conducted to check amount of water required or to avoid the use of admixtures. Normal tap water was used for all the mixes.

Subsequent curing was carried out in a curing tank to avoid minor discrepancies from the shortening of the curing period. The specimens are then kept inside the laboratory till the tests are conducted. Parallel to preparing the specimens and conducting the laboratory tests, background study was also conducted in the form of literature reviews so as to correlate the expected results with their actual physical significance. In view of this, a number of textbooks and researches conducted in related areas have been reviewed

Before proceeding to the preparation of the main mix design of the research, trial mixes were prepared for each of the control mixes. A particular mix design method determines a set of mix proportions for producing a concrete that has approximately the required properties of strength and workability. The method however is based on simplified classification for type and quality of the materials and it remains to check whether or not the particular aggregates and cement selected for use in a given case will behave as anticipated. This is the object of making the trial mix, and the subsequent feedback of information from the trial mix is an essential part of the mix design process (ASTM International Standards, 2009). Table 4.1 below shows the material constituents of the trial mix.

Table 4.1: Material constituents of the trial (pre) mixes.

Grade (Mix ratio)	Comp. strength (MPa)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	water (kg)
C25	25	346	647.02	1259.44	180

The compressive strength tests are conducted at 7 day for the trial mixes and the result is extrapolated to possible 28-day strength. The ratio of the 28-day strength to the 7-day strength lies between 1.3 and 1.7 but it is usually less than 1.5 and it depends on the cement type and curing temperature (Sidney,*et al*.,2003). In other words, the 7 day strength will be on the range between 60 and 75 % of the 28 day strength. For this study, considering the relative early strength development of OPC cement, the maximum value of 75 % of strength achievement at the 7 day was assumed to forecast the 28-day strength of the trial mixes. After that, it was found out that the compressive strength test results of the final mixes have shown a similar trend of relationship between the 7th and the 28th day strengths.

Table 4.2: Slump and Compressive Strength Test results of the Trial mix

Grade	Slump(mm)	Comp. Strength(MPa)	
		7 day	Estimation for 28 day
C25	12	40	50

The designed slump was 10-30 mm. Hence, all the slump results are within the intended range. To proceed for the final preparation of the final mix design, it was necessary to evaluate the compressive strength test results of the trial mix. The 7th and the estimated 28th day compressive strength test results revealed that the attained results have exceeded the original intended values. This lead to the understanding that there is still much more adjusting the mix design and a more economical mix can be produced. Based on this, the mix design was readjusted and the final proportioning for the main concrete samples was prepared. The designations Y indicate the concrete grades of 25 compressive strengths. Whereas A1,A2, A3, A4, A5 and A6 indicate the corresponding concrete grades with percentage PET waste plastic aggregate replacements of 0, 1, 2, 3, 4 and 5% of the fine aggregate respectively.

Table 4.3: Mix Proportioning for 1m³ of Concrete.

Type	Grade	Cement (Kg/m^3)	Water (kg/ m^3)	Fine agg. (kg/ m³)	Coarse agg. (kg/ m³)	PET agg. (kg/ m³)
Control (YA1)	C-25	295	180	590	1180	0.00
YA2	C-25	295	180	590	1180	5.90
YA3	C-25	295	180	590	1180	11.80
YA4	C-25	295	180	590	1180	17.70
YA5	C-25	295	180	590	1180	23.60
YA6	C-25	295	180	590	1180	29.50

For 0.15 m³ capacity mix the corresponding mix proportioning is shown with table 4.4 below.

Table 4.4: Mix Proportions for 0.15 m³ of concrete.

Type	Grade	Cement (Kg/m3)	Water (kg/ m³)	Fine agg. (kg/ m³)	Coarse agg. (kg/ m³)	PET agg. (kg/ m³)
Control (YA1)	C-25	44.25	26.99	88.5	177.00	0
YA2	C-25	44.25	26.99	88.5	177.00	0.89
YA3	C-25	44.25	26.99	88.5	177.00	1.77
YA4	C-25	44.25	26.99	88.5	177.00	2.66
YA5	C-25	44.25	26.99	88.5	177.00	3.54
YA6	C-25	44.25	26.99	88.5	177.00	4.43

In this study, a total of 72 mixes consisting of C-25 of concrete grades were produced with partial replacements of the fine aggregate by 0, 1, 2, 3, 4 and 5% of the PET plastic waste aggregate. Moreover, a control mix with no replacement of the fine aggregate was produced to make a comparative analysis which is 0% replacement. The mix design process adopted was the Department of Environment (DOE) method.

The mixture proportions of the basic ingredients like cement, water, and fine aggregate, were the same for the control concrete and PET plastic waste concrete. However, a certain amount of the fine aggregate was replaced by an equal volume of PET plastic waste aggregate to form PET fiber concrete. Control mix designs, C-25 were prepared for this investigation. The main reason for selecting this concrete grades is that they are known as medium concrete grades.

The following tests were performed on the different materials and concrete samples produced in this study.

- Slump test
- Unit weight test
- Compressive strength test at 7th and 28th day
- Splitting tensile strength test
- Flexural strength test

4.9. Slump and Unit weight tests

4.9.1 Slump tests

Slump test is the simplest test for workability and is most widely used on construction sites. In the slump test, the distance that a cone full of concrete slumps down is measured when the cone is lifted from around the concrete. In order to check the workability of concrete mix the slump test was done. This is shown with the following figure 4.4.

Figure 4.4: Slump test in civil engineering laboratory (Photo taken by Merid Teshome)

4.9.2 Unit weight tests

The specific gravity of PET plastic waste particles, unit weight of concrete mix containing PET with the increase in the percentage of fiber content was evaluated. This measurement was done in Jimma Institute of Technology civil engineering laboratory.

4.10 Compressive, Tensile and Flexural Strength Tests

The strength tests for compressive, tensile and flexural were checked for test concrete specimens in Jimma Institute of Technology civil engineering laboratory.

Table 4.5: Specifications for testing machines

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

Figure 4.5: The strength tests for compressive, tensile and flexural respectively (Photo taken by Merid).

4.11 Ethical Consideration

Ethical consideration was taken in to account for the study to be sound and ideal. Each and every of data collection, processing, and analysis was followed scientific methods and procedures. Furthermore all concerned bodies was informed prior to the study get started. Finally, the result of laboratory analysis honestly recorded and interpreted based on scientific procedures.

CHAPTER FIVE

5. RESULTS AND DISCUSSIONS

5.1 Physical Properties of the Fine Aggregate

In this research different materials used for the production of concrete PET where prepared like cement, fine aggregate, coarse aggregate, PET aggregate, and water. The mixtures are with and without PET aggregates for different amount of PET content. The materials used to develop the concrete mixes in this study were a total of 6 mixes with 72 samples were prepared with concrete grades of C-25, without PET and with PET replacements of the fine aggregate by 1, 2, 3, 4 and 5% of the PET aggregate. Moreover, a control mix with no replacement of the fine aggregate was produced to make a comparative analysis. The fine aggregate sample used in this experiment was purchased from local sand suppliers at Jimma Town around „Yetababarut area‟, which it is originally from Gambella region. To investigate its properties and suitability for the intended application, the following tests were carried out.

- Sieve analysis for fine aggregate
- Specific gravity and absorption capacity for fine aggregate
- Moisture content for fine aggregate
- Silt content for fine aggregate
- Unit weight of fine aggregate

5.1.1 Sieve Analysis for Fine Aggregate

Sieve analysis is 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 shall mean aggregate passing 9.5mm sieve and almost entirely passing the 4.75mm sieve and predominantly retained on the 63µm sieve. The strength and quality of concrete tile to be produced is very much influenced by the properties of its aggregates. Aggregate grain size distribution or gradation is one among these properties and should be given due consideration. The standard finness modules for fine aggregate is between 2.2 and 2.6 and for coarse aggregate it is in the range of 5.5 to 8.5 (Abebe, 2002).

The fine aggregates used for this research was washed and dried before the start of the tests. Then followed by sieve analysis. Table 5.1 below shows the percentage passing each sieve size and Figure 5.1 shows the corresponding graph.

Table 5.1: The percentage passing each sieve size for fine aggregate.

Sieve Size (mm)	**Wt. of Sieve (gm)**	**Wt.of Sieve and Retained (gm)**	**Wt. of Retained (gm)**	**Cumul.Wt Retained (gm)**	**Cumm. % 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:

$$\text{Fineness modulus (F.M)} = \frac{\Sigma\,\text{Cumulative \% Retained}}{100}\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5.1)}$$

$$= 258.6/100$$

$$= 2.586$$

The distribution of fine aggregate is well because it is in the range of between 2.2 and 2.6. The corresponding relationship between sieve size and percent passing for fine aggregate is shown graphically with figure 5.1 below.

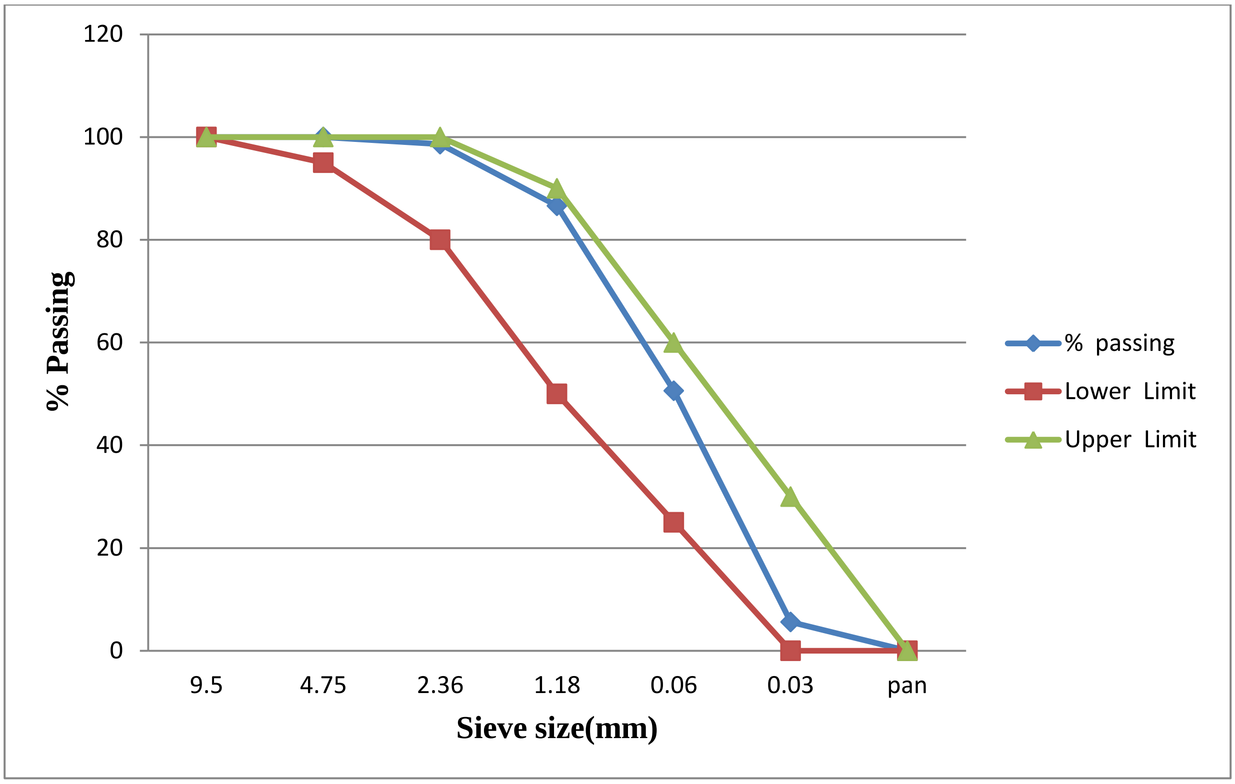

Figure 5.1: Sieve analysis of fine aggregate.

5.1.2 Specific gravity and absorption capacity of fine aggregate

The specific gravity of an aggregate is considered to be a measure of strength or quality of the material. The specific gravity of a substance is the ratio between the weight of the substance and that of the same volume of water. This definition assumes that the substance is solid throughout. Aggregates, however, have pores that are both permeable and impermeable. The structure of the aggregate (size, number, and continuity pattern) affects water absorption, permeability, and specific gravity (Ethiopian waste plastic and Rubber Economy Plant P.L.C, 2009). The following table 5.2 shows the results found for the fine aggregate sample.

Table 5.2: Specific gravity and absorption capacity of fine aggregate test results

No.	Description	Test Results
1	Bulk Specific gravity	2.41
2	Bulk Specific gravity (SSD basis)	2.51
3	Apparent specific gravity	2.68
4	Absorption capacity	4.16%
5	Moisture content	2.66%

5.1.3 Moisture content of fine aggregate

A design water cement ratio is usually specified based on the assumption that aggregates are inert (neither absorb nor give water to the mixture). But in most cases aggregates from different sources do not comply with this i.e. wet aggregates give water to the mix and drier aggregates take water from the mix affecting in both cases, the design water cement ratio and therefore workability and strength of the mix. In order to correct for these discrepancies, the moisture content of aggregates has to be determined (Abebe, 2002). As shown in table 5.2 the moisture content of fine aggregate is 2.66.

5.1.4 Silt content of fine aggregate

Sand is a product of natural or artificial disintegration of rocks and minerals. Sand is 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 are finer than sand. The presence of such materials in sand used to make concrete 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 is 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 is 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 is within the acceptable range.

5.1.5 Unit weight of fine aggregate

Unit weight can be defined as the weight of a given volume of graded aggregate. It is thus a density measurement and is also known as bulk density. But this alternative term is similar to bulk specific gravity, which is quite a different quantity, and perhaps is not a good choice. The unit weight effectively measures the volume that the graded aggregate will occupy in concrete and includes both the solid aggregate particles and the voids between them. The unit weight is simply measured by filling a container of known volume and weighing it. Clearly, however, the degree of compaction will change the amount of void space, and hence the value of the unit weight. Since the weight of the aggregate is dependent on the moisture content of the aggregate, constant moisture content is required. Oven dried aggregate sample is used in this test. 5.25 Kg of samples was taken and put within oven at temperature of 75c for 24 hour. The unit weight of the fine aggregate sample used was found to be 1560 kg/m^3.

5.2 Properties of the coarse aggregate

Coarse aggregate for concrete shall consist of natural gravel or crushed rock or a mixture of natural gravel and crushed rock. Coarse aggregate used in this research was purchased from Jimma Town Yetebaberut area. Like the fine aggregate, laboratory tests were carried out to identify the physical properties of the coarse aggregate and to investigate its properties and suitability for the intended application. The following tests were carried out.

- Moisture content
- Unit weight of coarse aggregate
- Bulk Specific gravity
- Bulk specific gravity(SSD basis)
- Apparent specific gravity
- Absorption capacity
- Crushing value of aggregate
- Los Angeles Abrasion Test

Table 5.3: Physical properties of coarse aggregate and results.

No.	**Description**	**Test Results**
1	Bulk Specific gravity	2.82
2	Bulk specific gravity(SSD basis)	2.85
3	Apparent specific gravity	2.93
4	Absorption capacity	1.39%
5	Moisture content	1.31%
6	Unit weight of coarse aggregate	1.542g/cm³
7	Crushing value of aggregate	18 .05%
8	Los Angeles Abrasion Test	14.72 %

The sieve analysis for the coarse aggregate is shown with the following table (Table 5.4).

Table 5.4: Sieve Analysis for the Coarse Aggregate.

Sieve Size (mm)	Wt. of Sieve (gm)	Wt.of Sieve and Retained (gm)	Wt. of Retained (gm)	Cumu.Wt Retained (gm)	Cumul. % Retained	% Passing	Lower Limit	Upper Limit
37.5	1187	1187	0	0	0	100	100	100
19	1420	1420	0	0	0	100	90	100
13.2	1166	4144	2978	2978	45.70	54.30	40	80
9.5	1171	3180	2009	4987	76.53	23.47	10	50
4.75	1195	2724	1529	6516	100	0	0	10
2.36	1080	1080	0	6516	100	0	0	10
1.18	1102	1102	0	6516	100	0	0	10
0.6	1098	1098	0	6516	100	0	0	10
Pan	1060	1060	0	6516	100	0	0	10
Sum			6516		622.23			

$$\text{Fineness modulus (F.M)} = \frac{\Sigma\,\text{cumulative \% retained}}{100}\,\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (5.2)$$

$$= 622.23/100$$

$$= 6.22$$

The distribution of coarse aggregate is well because it is in the range between 5.5 and 8. The corresponding relationship between sieve size and percent passing for coarse aggregate is shown graphically with figure 5.2 below.

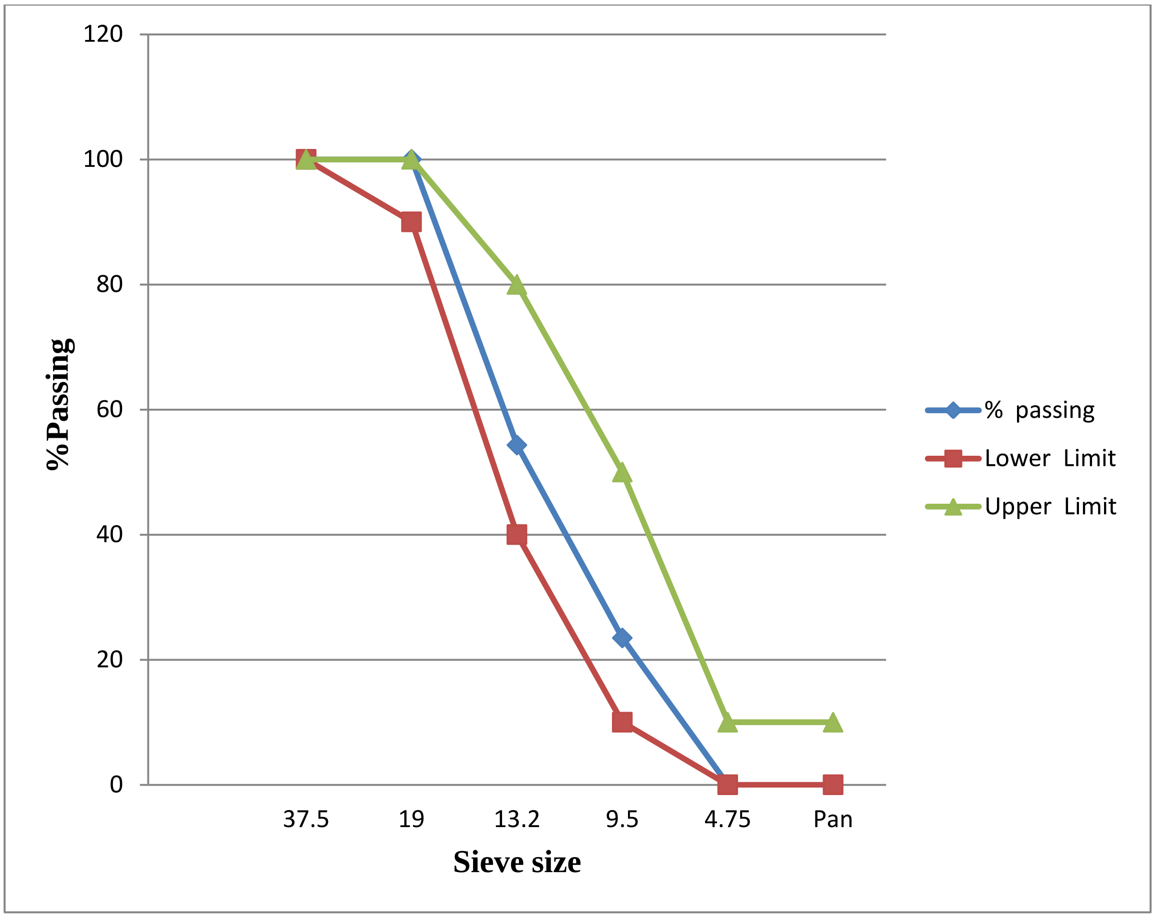

Figure 5.2: Sieve analysis of coarse aggregate

To get the required surface of the PET plastic waste aggregate, surface treatment was done washing thoroughly the sample to remove dusts and impurities from the surface of the PET, the PET aggregates were then immersed in water for 24 hours until all particles were fully saturated (wetted both inside and on the surface). The plain PET aggregates were then taken to the saturated surface dry (SSD) condition by spreading them in a thin layer on a clean surface free from dust and rolled in a towel until all visible films of water are removed. In this condition, the PET aggregate reached the saturated surface dry condition and thus requiring no alteration to the quantity of mixing water.

5.3 Water

The quality of the water plays a significant role in concrete tile production. Impurities in water may interfere with the setting of the cement, may adversely affect the strength of the concrete or cause staining of its surface. For these reasons, the suitability of water for mixing and curing purposes should be considered. In this research, tap water supplied by Jimma water and sewerage authority at room temperature was used in all mixes.

5.4 Property of aggregate test results

The relevant tests to identify the properties of the aggregates that were intended to be used in this research were carried out. After that, corrective measures were taken in advance before proceeding to the mix proportioning. In general, aggregates should be hard and strong, free of undesirable impurities, and chemically stable. Soft, porous rock can limit strength and wear resistance; it may also break down during mixing and adversely affect workability by increasing the amount of fines. Aggregates should also be free from impurities: silt, clay, dirt or organic matter. If these materials coat the surfaces of the aggregate, they will isolate the aggregate particles from the surrounding concrete, causing a reduction in strength. Silt, clay, and other fine materials will also increase the water requirements of the concrete, and organic matter may interfere with cement hydration. To proportion suitable concrete mixes, certain properties of the aggregate must be known. These are; shape and texture, size gradation, moisture content, specific gravity and bulk unit weight (Sidney *et al*., 2003).The table 5.5 shows the test results for fine aggregate and table 5.6 shows the results for coarse aggregate.

Table 5.5: Test results found for fine aggregate.

No.	Description	Test Results
1	Bulk Specific gravity	2.41
2	Bulk Specific gravity (SSD basis)	2.51
3	Apparent specific gravity	2.68
4	Absorption capacity	4.16%

The test result for coarse aggregate is shown with following table 5.6

Table 5.6: Test results found for coarse aggregate.

No.	**Description**	**Test Results**
1	Bulk Specific gravity	2.82
2	Bulk specific gravity(SSD basis)	2.85
3	Apparent specific gravity	2.93
4	Absorption capacity	1.39%
5	Moisture content	1.31%
7	Crushing value of aggregate	18.05 %
8	Los Angeles Abrasion Test	14.72 %

5.5 Fresh Properties of concrete test results

5.5.1 Workability Test result

A concrete mix must be made of the right amount of cement, aggregates and water to make the concrete workable enough for easy compaction and placing and strong enough for good performance in resisting stresses after hardening. If the mix is too dry, then its compaction will be too difficult and if it is too wet, then the concrete is likely to be weak. During mixing, the mix might vary without the change very noticeable at first. For instance, a load of aggregate may be wetter or drier than what is expected or there may be variations in the amount of water added to the mix. These all necessitate a check on the workability and strength of concrete after producing. Slump test is the simplest test for workability and are most widely used on construction sites. In the slump test, the distance that a cone full of concrete slumps down is measured when the cone is lifted from around the concrete. The slump can vary from nil on dry mixes to complete collapse on very wet ones. One drawback with the test is that it is not helpful for very dry mixes (Ethiopian waste plastic and Rubber Economy Plant P.L.C, 2009).The slump test and results were listed in the table blow (Table 5.7).

Table 5.7: Slump Test Results.

S/N	Samples	Grade	%PET	w/c ratio	Slump(mm)
1	YA1	C-25	0	0.52	13
2	YA2	C-25	1	0.52	15
3	YA3	C-25	2	0.52	18
4	YA4	C-25	3	0.52	24
5	YA5	C-25	4	0.52	27
6	YA6	C-25	5	0.52	29

As observed from Table 5.7 slump and workability increased as percentage of PET increased with the same water cement ratio. All the test results show that the slumps are between the designed ranges (10-30 mm). In general, PET plastic waste concrete mixes did not pose any difficulties in terms of finishing, casting, or placement and can be finished to the same standard as plain concrete.

5.6 Hardened Properties of Concrete results

The different tests that have been carried out to establish the hardened properties of the concrete samples produced were; determination of unit weight, compressive strength, splitting tensile strength, and flexural strength tests.

5.6.1 Unit weight Determination

The unit weight values used for the analysis of this section were measured from the concrete cube samples after 28 days of standard curing. From the results, it was found out that a reduction of unit weight for 28 curing time in table 5.9 as 3.92, 9.01, 20.78, 22.35 and 26.66 % was observed when 1 %, 2%, 3%, 4% and 5% by volume of the fine aggregate was replaced by PET plastic waste aggregate in sample YA2, YA3, YA4, YA5 and YA6 respectively. As the laboratory result shows (Table 5.2) specific gravity of the PET plastic waste aggregate is lower than that of fine aggregates, this leads to the reduction of unit weight. Because of the PET fiber aggregate is lighter than around two and half times of fine aggregate, it was expected that the mass density of the mix would be suggestively reduced.

Table 5.8: A7 day unit weight determination.

NO	**Specimen**	**Sample No.**	**Grade**	**% PET**	**Samples Unit wt.(gm/cm^3)**	**Average Unit wt.(gm./cm³)**	**%Reduction**
1	YA1	1	C-25	0	2.53	2.54	0.00
		2			2.53		
		3			2.57		
2	YA2	1	C-25	1	2.42	2.48	2.36
		2			2.45		
		3			2.56		
3	YA3	1	C-25	2	2.24	2.27	10.62
		2			2.30		
		3			2.27		
4	YA4	1	C-25	3	2.18	2.15	15.35
		2			2.12		
		3			2.15		
5	YA5	1	C-25	4	2.15	2.12	16.53
		2			2.09		
		3			2.12		
6	YA6	1	C-25	5	2.12	2.09	17.71
		2			2.06		
		3			2.09		

The unit weight determination for 28 day is shown with table 5.9.

Table 5.9: A 28 day unit weight determination.

NO	Specimen	Sample No.	Grade	% PET	Samples Unit wt.(gm/cm^3)	Average Unit wt.(gm./cm^3)	%Reduction
1	YA1	1	C-25	0	2.59	2.55	0.00
		2			2.54		
		3			2.53		
2	YA2	1	C-25	1	2.45	2.45	3.92
		2			2.41		
		3			2.48		
3	YA3	1	C-25	2	2.28	2.32	9.01
		2			2.38		
		3			2.29		
4	YA4	1	C-25	3	1.98	2.02	20.78
		2			2.09		
		3			1.99		
5	YA5	1	C-25	4	1.98	1.98	22.35
		2			2.01		
		3			1.95		
6	YA6	1	C-25	5	1.87	1.87	26.66
		2			1.85		
		3			1.89		

5.6.2 Compressive strength Test

The compressive strengths of concrete specimens were determined after 7th and 28th days of standard curing. For PET concrete, the results show that the addition of PET aggregate resulted in appreciable increase in the compressive strength is observed up to 3% replacement of the fine aggregate with PET bottles fibers and then the compressive strength is gradually reduced compared with the control concrete. Increase in compressive strength of 13.16% (YA2) was observed when 1% of the fine aggregate was replaced by an equivalent volume of PET plastic waste aggregate. Increase of compressive strength 15.58 % (YA3) were observed when 2% of fine aggregate was replaced by PET aggregate. The observed increments of strength when 3 % of the fine aggregate was replaced by PET aggregate were 21.53% (YA4). Increases of 9.22% (YA5) were observed when 4% of fine aggregate was replaced by PET aggregate. Finally increases of strength 2.73 % (YA6) were observed for PET concrete containing 5% by volume of PET aggregate replacement with comparing control mix. Table 5.10 and Table 5.11 below show the results of the 7th and 28th day compressive strength tests.

Table 5.10: Compressive strength tests results for 7 days.

No.	Samples	No. of Samples per test	Grade	%PET	Individual samples Comp.str (M Pa)	Comp.str. (M Pa) (Average)	
						7 Days	%Str. Increment
1	YA1	1	C-25	0	23.30	22.60	0.00
		2			22.20		
		3			21.10		
2	YA2	1	C-25	1	26.02	25.03	10.75
		2			24.01		
		3			25.07		
3	YA3	1	C-25	2	28.04	27.05	19.69
		2			27.03		
		3			26.07		
4	YA4	1	C-25	3	28.40	28.00	23.89
		2			28.50		
		3			27.10		
5	YA5	1	C-25	4	26.30	25.23	11.63
		2			24.10		
		3			25.10		
6	YA6	1	C-25	5	23.02	23.04	1.94
		2			24.04		
		3			22.05		

The 28 day the compressive strength test result is shown with the following table (Table 5.11).

Table 5.11: Compressive strength tests results for 28 days.

No.	Samples	No. of Samples per test	Grade	%PET	Individual samples Comp.str(M Pa)	Comp.str. (M Pa) (Average)	
						28 Days	%Str. Increment
1	YA1	1	C-25	0	32.40	31.44	0.00
		2			30.50		
		3			31.43		
2	YA2	1	C-25	1	35.90	35.58	13.16
		2			36.30		
		3			34.55		
3	YA3	1	C-25	2	36.30	36.34	15.58
		2			37.42		
		3			35.29		
4	YA4	1	C-25	3	38.32	38.21	21.53
		2			39.10		
		3			37.21		
5	YA5	1	C-25	4	35.22	34.34	9.22
		2			34.37		
		3			33.43		
6	YA6	1	C-25	5	33.40	32.30	2.73
		2			32.01		
		3			31.50		

Figure 5.3 below illustrates the trend of strength development in the different concrete Specimens prepared and the comparison of the strength achieved in contrast with the control concrete for 7 and 28 day result.

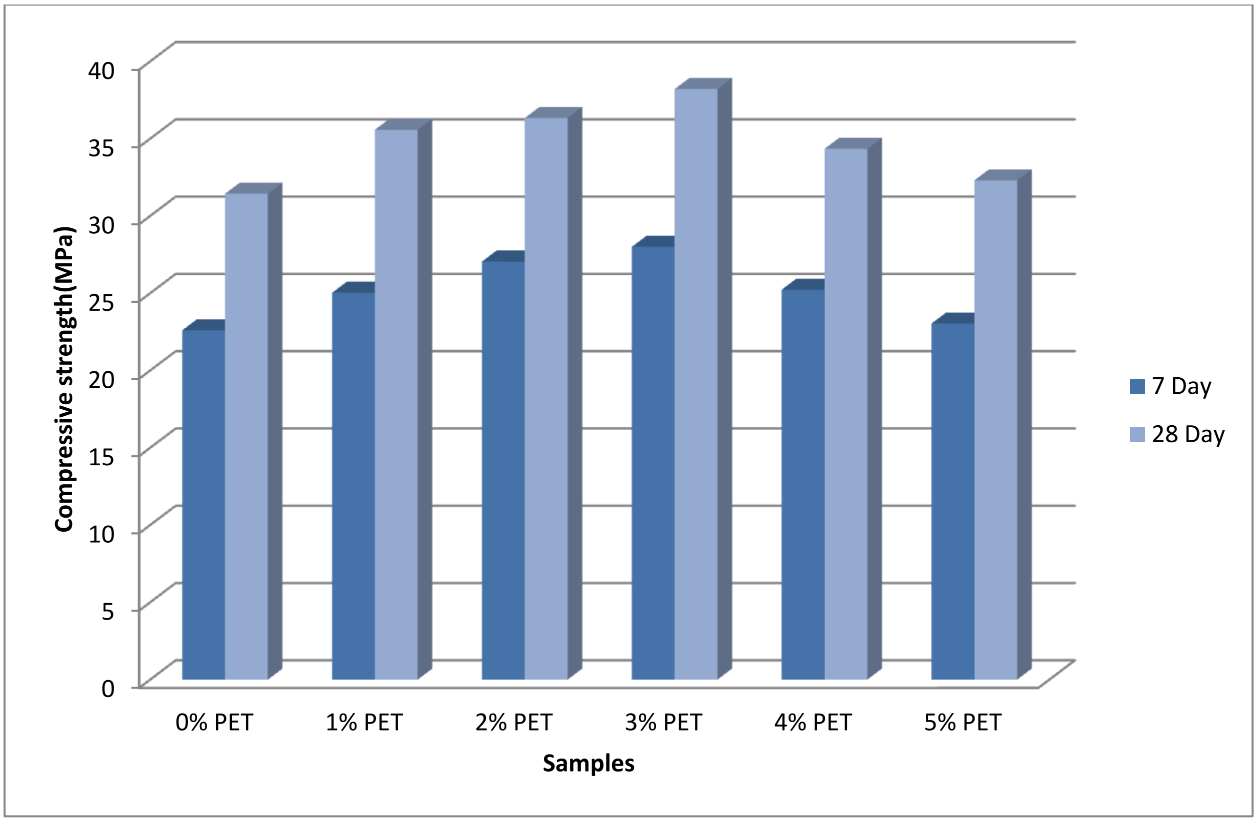

Figure 5.3: Compressive strength comparisons of samples.

As observed from the test results, there was a reduction of compressive strength as percentage of PET increased beyond 3% replacement of fine aggregates with PET aggregate for consecutive concrete mix samples. 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 aggregate. PET fiber particles behave as voids in the concrete matrix. Considering the very different mechanical properties of mineral aggregates and PET aggregates, mineral aggregates usually have high crushing strength and they are relatively incompressible, whereas PET aggregates are, compressible and resilient. PET has a very low modulus of elasticity of about 6.5 MPa and a Poisson"s ratio of 0.5 (Cairns,*et al*.,2004). Therefore, PET aggregates tend to behave like weak inclusions or voids in the concrete, resulting in a reduction in compressive strength. It is well known that the presence of voids in concrete greatly reduces its strength. The existence of 5 % of voids can lower strength by as much as 30 % and even 2 % voids can result in a drop of strength of more than 10% (Abbott *et al*., 2001).

5.6.3 Split tensile strength Test

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

Split Tensile Strength, $f_{sp} = \frac{2P}{\pi L d}$ N/mm^2 …………………………………………………. (5.3)

Where, P = Load at failure in N

L = Length of the Specimen in mm

d = Diameter of the Specimen in mm

It is not practical to apply a true line load along the top and bottom of the specimen, partly because the sides are not smooth enough and partly because this would include extremely high compressive stresses near the points of load application. Therefore, the load is usually applied through narrow bearing strips of relatively soft material (Sidney *et al*., 2003). The test is carried out on cylindrical specimens using a bearing strip of 3 mm thick plywood that is free of imperfections and is about 25 mm wide. The splitting tensile strength test result is shown with table 5.12 below.

Table 5.12: Splitting Tensile Strength Test Results.

No.	Samples	No. of samples per test	Grade	%PET	Splitting Load(kN)	Indivdual splitting streng(MPa)	Splitting Streng.(MPa) (Average)	% Streng. Increament
1	YA1	1	C-25	0	61.20	1.95	1.90	0.00
		2			59.60	1.90		
		3			58.00	1.85		
2	YA2	1		1	64.30	2.05	2.12	11.57
		2			67.80	2.16		
		3			67.50	2.15		
3	YA3	1		2	68.40	2.18	2.17	14.2
		2			67.80	2.16		
		3			68.10	2.17		
4	YA4	1		3	70.00	2.23	2.22	16.84
		2			69.00	2.20		
		3			70.00	2.23		
5	YA5	1		4	67.50	2.15	2.10	10.52
		2			64.30	2.05		
		3			65.90	2.10		
6	YA6	1		5	64.30	2.05	2.04	7.36
		2			63.70	2.03		
		3			64.00	2.04		

As the results show that the splitting tensile strength increased with increasing PET bottle aggregate content in a similar manner to that observed in the compressive strength tests up to 3% replacement comparing with consecutive concrete mix samples. The increases of strength up to 11.57% (YA2) when 1% of the fine aggregate was replaced by PET bottle aggregate. Increases of up to 14.2% (YA3) observed when 2% of the fine aggregate was replaced by PET bottle aggregate. The increase of strength 1.68 % (YA4) observed when 3% of fine aggregate replaced by PET bottle aggregate. The increase of tensile strength 10.52% (YA5) and 7.36% (YA6) were observed for 4 % and 5% replacement of fine aggregate with PET bottle aggregate comparing with control mix. The comparison was shown by using Figure 5.4 graphically.

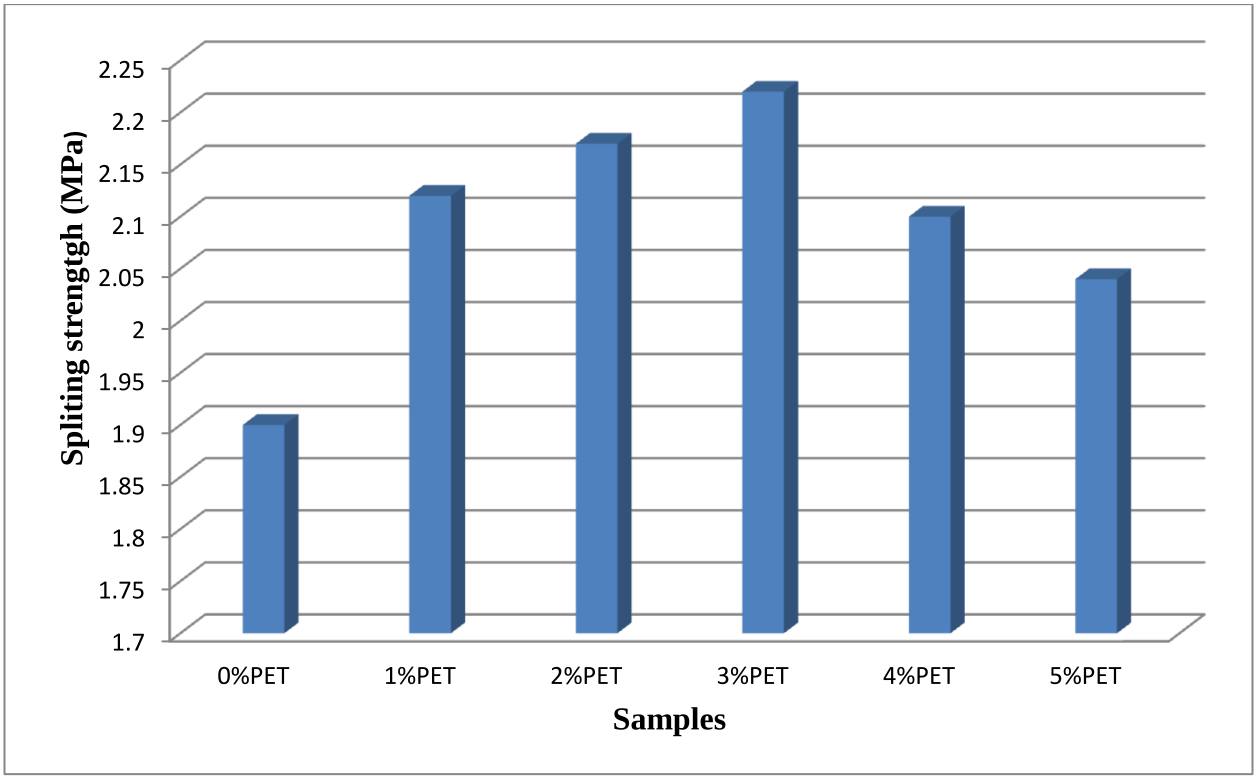

Figure 5.4: Comparisons of splitting tensile strength test results

5.6.4 Flexural strength Tests

This test gives another way of estimating tensile strength of concrete. During pure bending, the member resisting the action is 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 are, 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 are subjected to relatively higher shear stresses than tensile stresses. In this test, the concrete member to be tested is 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 concrete cracks heavily) is 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 and the results of flexural strength tests for the control concretes and the PET bottle concretes are summarized below in Table 5.13. The flexural strength of the prism specimen is calculated using the following formula

$C = \frac{D}{2}$ cm; $M = \frac{PL}{3}$ N.m; $I = \frac{BD^3}{12}$ m^4; $\sigma = \frac{MC}{I}$ MPa …………………………………. (5.4)

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 5.13: Flexural strength tests results

No.	Samples	No. of samples per test	Grade	%PET	Fluxeral Streng of Samples(MPa)	Average Fluxeral Streng of Samples(MPa)	% Streng. increase
1	YA1	1	C-25	0	3.06	3.05	0.00
		2			3.04		
		3			3.05		
2	YA2	1		1	4.98	4.93	61.63
		2			4.87		
		3			4.95		
3	YA3	1		2	5.80	5.85	91.80
		2			5.85		
		3			5.90		
4	YA4	1		3	6.00	6.05	98.36
		2			6.10		
		3			6.05		
5	YA5	1		4	5.91	5.88	92.78
		2			5.72		
		3			5.80		
6	YA6	1		5	5.79	5.80	90.16
		2			5.82		
		3			5.81		

Comparing this result with the control one from Table 5.13 there was an increased flexural strength up to three percent (3%) of the fine aggregate was replaced by PET bottle aggregate but becomes reduced of flexural strength observed when more than three percent (3%) of fine aggregate replaced by PET bottle aggregate compared with consecutive control mix samples. This shows that improvements in flexural strength are 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 by 3% of PET bottle aggregate. It can be concluded that as the amount of PET bottle fiber content increases, by more than 3% the reduction in the flexural strength also increases. But there was increase with flexural strength from 61.63 to 98.36 comparing with control mix. Comparisons of flexural strength test results are shown below as figure 5.5 graphically.

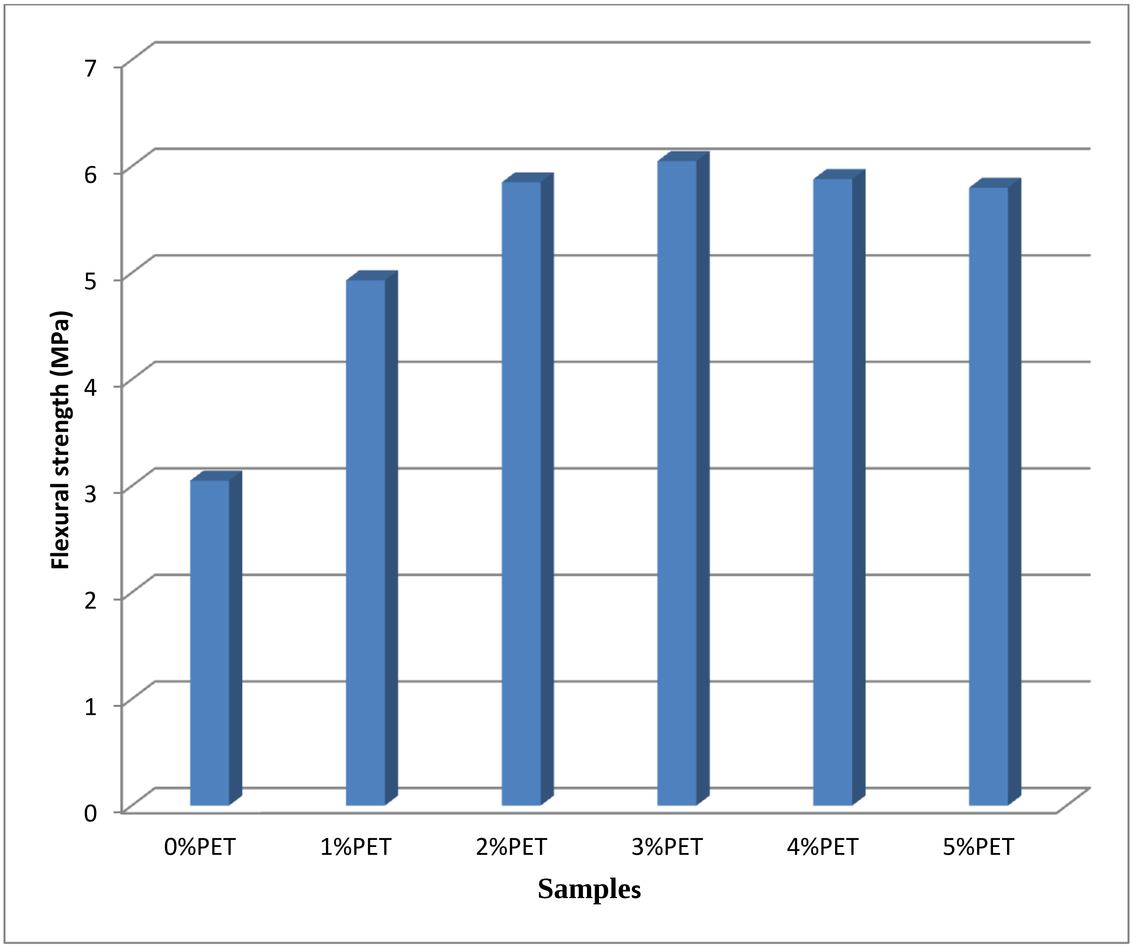

Figure 5.5: Comparisons of Flexural strength test results

CHAPTER SIX

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

As the suitability of the materials are checked and adjusted there was no constraint with the materials used for this research and it is possible focusing on the hardened properties of materials. From the test results slump and workability increased as percentage of PET increased with the same water cement ratio. All the test results show that the slumps are between the designed ranges (10-30 mm). In general, PET concrete mixes did not pose any difficulties in terms of finishing, casting, or placement and can be finished to the same standard as plain concrete.

The unit weight reduction was observed as percentage of PET bottle aggregate increased. Because of the specific gravity of the PET bottle aggregate is lower than that of fine aggregates, this leads to the reduction of unit weight. PET bottle aggregate is lighter than around two and half times of fine aggregate, it was expected that the mass density of the mix would be suggestively reduced. PET bottle concrete can be used in the production of concrete which used for side walk, recreational areas or the areas which there is no heavy loads, thus the PET bottle concrete could give a feasible alternative to the normal weight concrete.

The test results show that the addition of PET bottle aggregate resulted in a substantial increase in concrete compressive strength up to 3% partial replacement of fine aggregate with PET bottle aggregate compared with the control concrete. As observed from the test results there was a reduction of strength as percentage of PET increased beyond 3% comparing with consecutive concrete 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. PET bottle particles behave as voids in the concrete matrix. Therefore, PET aggregates tend to behave like voids in the concrete, resulting in a reduction in compressive strength. It is well known that the presence of voids in concrete greatly reduces its strength.

Also like compressive strength there was an increase of tensile strength recorded with increasing PET bottle aggregate content up to 3% replacement. But more than 3% replacement of fine aggregate with PET bottle fiber results in reduction in tensile strength. Because of the bond between cement paste and PET bottle fiber particles is poor.

Increased flexural strength was observed by replacing amount of PET bottle fiber with fine aggregate up to three percent (3%) used. But when percentage of PET bottle fiber increased more than three percent (3%) flexural strength increases and starts to decline were observed. The reduction indicates that improvements in flexural strength are limited to relatively small PET bottle aggregate contents. It can be concluded that as the amount of PET bottle fiber content increases, the reduction in the flexural strength also increases. The advantage of using PET bottle fiber aggregates from waste plastic are; 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.

There was an advantage of increasing in flexural strength to some extent replacing fine aggregate by 3% of PET bottle fiber aggregate only. It can be concluded that as the amount of PET bottle fiber content increases, by more than 3% the reduction in the flexural strength also increases.

Using PET bottle aggregates from waste plastic discourses many issues, like reduction of the environmental threats caused by waste plastic bottles, an alternative source to aggregates in concrete production, reduces the conservation of natural resources and reduces the disturbance of bio diversity of occurred during quarrying of aggregates.

From literature according to K.Ramaderi & R.Manju (2012): The study present that it was observed the compressive, tensile and flexural 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 was reasonable. According to K.Ramaderi & R.Manju (2012): The percent of PET bottle fiber replacement for fine aggregate was done within 2% gap. But my research was done with 1% gap; this makes a difference and finally reached to replacement of fine aggregate with 3% of PET bottle fiber replacement was reasonable.

Generally this study shows that it is possible to use waste (used) PET bottle fiber in concrete production as a partial replacement for fine aggregates. But the percentage should be limited.

6.2 Recommendations

Hence, there will be a potential accumulation of waste plastic PET bottles especially in the larger cities of the country. So far, the Government has made an attempt by declaring the solid waste management proclamation on the Negarit gazette prohibiting the import of waste materials. Moreover, the country should also enforce laws regarding the management of waste plastic before the problem expands and reaches to an uncontrollable level.

Since the use of PET bottle aggregates in concrete construction is not a common trend in our country. Many studies and research works need to be carried out in this area and academic institutions should play a major role.

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 environmental friendly way of plastic reprocessing.

Most of the time, it is observed that designers and contractors go to a high strength and expensive concrete 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 concrete by first conducting laboratory tests regarding the desired properties. Therefore, the use of PET concrete as an alternative concrete making material needs an attention.

Since the long-term performance of these mixes was not investigated in the present study, the use of such mixes is recommended in places where high strength of concrete is not as important as the other properties.

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ANNEXES

ANNEX 1: MATERIAL PROPERTIES

1.1: Physical Properties of the Fine Aggregate

Description	**Result**
1. Specific Gravity and Absorption test Pycnometer Procedure	
Weight of original sample in air	500 gm.
A=weight of oven-dry sample in air (gm.)	480 gm
B= weight of pycnometer filled with water	1268
C=weight of pycnometer with sample and water to calibration mark	1569
Bulk Specific gravity= A/(B+500-C)	2.41
Bulk Specific gravity(SSD basis) = 500/(B+500-C)	2.51
Apparent Specific Gravity= A/(B+A-C)	2.68
Absorption(%)= 100*(500-A)/A	4.16%
2. Moisture Content	
A- Weight of original sample	500 gm.
B- Weight of oven dry sample	487 gm.
Moisture content w (%) = $\frac{(A-B)*100}{B}$	2.66 %

1.2: Physical Properties of the coarse Aggregate

Description	**Result**
1. Specific Gravity and Absorption Capacity of Coarse Aggregate	
A= weight of oven dry sample in air	4951 gm.
B = Weight of SSD sample in air	5020 gm.
C= weight of saturated sample in water	3261 gm.
Bulk Specific Gravity= A/(B-C)	2.82
Bulk Specific Gravity(SSD basis) = B/(B-C)	2.85
Apparent Specific Gravity = A/(A-C)	2.93
Absorption Cap.(%)= 100*(B - A)/A	1.39 %
2. Moisture Content	
A- Weight of original sample	2000 gm
B- Weight of oven dry sample	1974 gm.
Moisture content w (%)= 100*(A-B)/B	1.31%
4. Crushing Value of Aggregate The test is done on agg. that passes 12.5mm sieve and retained on 10.0mm ASTM sieve	
A= the mass of surface dry sample (gm.) =	2830 gm
B= mass of the fraction passing =	511 gm
Percentage fineness = **B/A**	18 .05
5.Los Angeles Abrasion Test The Los Angeles Abrasion value is the % of fineness passing 1.18mm that gives the Abrasion resistance.	
A= the mass of specimen before abrasion	5000 gm
B= the mass of specimen after abrasion	4264 gm
Abrasion Value= 100*(A-B)/A	14.72 %

ANNEX 2: MIX DESIGN DATA SHEET (DOE METHOD)

2.1: Trial Mix

<table>
<tr><th>Stage</th><th>Item</th><th colspan="2">Reference or calculation</th><th colspan="2">values</th></tr>
<tr><td>1</td><td>1.1 Cement Type
1.2 Aggregate type
1.3 Free water/cement ratio
1.4 Maximum free water/ cement ratio</td><td colspan="2">Specified</td><td colspan="2">OPC
Coarse = crushed Fine = uncrushed
Use the lower value
0.52</td></tr>
<tr><td>2</td><td>2.1 Slump
2.2 Max. aggregate size
2.3 Free-water content</td><td colspan="2">Specified
specified</td><td colspan="2">10-30mm
2mm
180kg/m3</td></tr>
<tr><td>3</td><td>3.1 Cement content
3.2 Maximum Cement Content
3.3 Minimum Cement Content
3.4 Modified FW/C</td><td colspan="2">[Free water÷(w/c)]
Specified
specified</td><td colspan="2">180/0.52 = 346 kg/m3</td></tr>
<tr><td>4</td><td>4.1 Relative density of aggregate (SSD)
4.2 concrete density
4.3 Total aggregate content</td><td colspan="2">Specified
[concrete density - water content -cement content]</td><td colspan="2">2.7 known
2435 Kg/m3
1909Kg/m3</td></tr>
<tr><td>5</td><td>5.1 Proportion of fine aggregate
5.2 Fine aggregate content
5.3 Coarse aggregate content</td><td colspan="2"></td><td colspan="2">take 35%
668.15 Kg/m3 take 669 kg/m3
1240 Kg/m3</td></tr>
<tr><th colspan="2">Quantities</th><th>Cement (kg)</th><th>Water (kg)</th><th>Fine aggr. (kg)</th><th>Coarse aggr. (kg)</th></tr>
<tr><td colspan="2">Per m^3(to nearest 5 kg)</td><td>346</td><td>180.00</td><td>669.00</td><td>1240.00</td></tr>
<tr><td colspan="2">Per trial mix of 0.011m^3</td><td>3.80</td><td>1.98</td><td>850.00</td><td>1579.00</td></tr>
</table>

2.2: Final Mix

Stage	**Item**	**Reference or calculation**	**Values**
1	1.5 Cement Type 1.6 Aggregate type 1.7 Free water/cement ratio 1.8 Maximum free water/ cement ratio	specified	OPC Coarse aggregate = crushed Fine aggregate = uncrushed 0.61 Use the lower value
2	2.1 Slump 2.2 Max. aggregate size 2.3 Free-water content	Specified specified	10-30mm 2mm 180kg/m3
3	3.1Cement content 3.2 Maximum Cement Content 3.3 Minimum Cement Content 3.4 Modified FW/C	[Free water÷(w/c)] Specified specified	180/0.61 = 295 kg/m3
4	4.1 Relative density of aggregate (SSD) 4.2 concrete density 4.3 Total aggregate content	[concrete density - water content -cement content]	2.7 known 2435 kg/m3 **1960 kg/m3**
5	5.1 Proportion of fine aggregate 5.2 Fine aggregate content 5.3 Coarse aggregate content		Take 35 % 686.00 Kg/m3 1274 Kg/m3

Quantities	**cement (kg)**	**Water (kg)**	**Fine aggr. (kg)**	**Coarse aggr. (kg)**
Per m3(to nearest 5 kg)	295.00	180.00	686.00	1274.00
Per trial mix of 0.15m³	44.25	26.99	827.00	1537.00

2.3: The amount of PET required for 0.15m3 capacity (final mix)

Sample	Cement (Kg)	Fine Agg. (Kg)	%PET	PET (Kg)	Water (Kg)	Coarse Agg (Kg)
YA1	44.25	827	0	0	26.99	256.16
YA2	44.25	827	1	8.27	26.99	256.16
YA3	44.25	827	2	16.54	26.99	256.16
YA4	44.25	827	3	24.81	26.99	256.16
YA5	44.25	827	4	33.08	26.99	256.16
YA6	44.25	827	5	41.35	26.99	256.20
Total Required	265.5	827-124 =703		124	161.94	1537

ANNEX 3: COMPRESSIVE STRENGTH AND UNIT WEIGHT TESTS

3.1: A 7 Day Compressive Strength & Unit Weight Test Results

Sample No.	**Specimen**	**Grade**	**% PET**	**Dimensions [cm]**			**Volume [cm3]**	**Weight [gm]**	**Failure Load [kN]**	**Area[m2]**	**Comp. Strength [Mpa]**	**Unit Weight [gm/cm^3]**
				L	W	H						
1	YA1	C-25	0	15	15	15	3375	8,538.00	524.20	0.15*0.15 =0.0225	23.30	2.53
2				15	15	15	3375	8,548.00	499.50		22.20	2.53
3				15	15	15	3375	8,667.00	474.70		21.10	2.57
Mean				**15**	**15**	**15**	**3375**	**8584.33**	**499.4**		**22.60**	**2.54**
1	YA2	C-25	1	15	15	15	3375	8,166.00	585.40	0.0225	26.02	2.42
2				15	15	15	3375	8,259.00	540.20		24.01	2.45
3				15	15	15	3375	8,654.00	564.00		25.07	2.56
Mean				**15**	**15**	**15**	**3375**	**8359.67**	**563.20**		**25.03**	**2.48**
1	YA3	C-25	2	15	15	15	3375	7,564.00	630.90	0.0225	28.04	2.24
2				15	15	15	3375	7,759.00	608.10		27.03	2.30
3				15	15	15	3375	7,651.00	586.50		26.07	2.27
Mean				**15**	**15**	**15**	**3375**	**7658.00**	**608.5**		**27.05**	**2.27**
1	YA4	C-25	3	15	15	15	3375	7,342.00	639.00	0.0225	28.40	2.18
2				15	15	15	3375	7,153.00	641.20		28.50	2.12
3				15	15	15	3375	7,252.00	609.70		27.10	2.15
Mean				**15**	**15**	**15**	**3375**	**7249.00**	**629.97**		**28.00**	**2.15**
1	YA5	C-25	4	15	15	15	3375	7,242.00	591.70	0.0225	26.30	2.15
2				15	15	15	3375	7,059.00	542.20		24.10	2.09
3				15	15	15	3375	7,152.00	564.70		25.10	2.12
Mean				**15**	**15**	**15**	**3375**	**7151.00**	**566.20**		**25.23**	**2.12**
1	YA6	C-25	5	15	15	15	3375	7,162.00	517.90	0.0225	23.02	2.12
2				15	15	15	3375	6,959.00	540.90		24.04	2.06
3				15	15	15	3375	7,052.00	496.10		22.05	2.09
Mean				**15**	**15**	**15**	**3375**	**7057.67**	**518.30**		**23.04**	**2.09**

3.2: A 28 Day Compressive Strength & Unit Weight Test Results

Sample No.	**Specimen**	**Grade**	**% PET**	Dimensions (cm)			Volume (cm3)	**Weight (gm)**	**Failure Load [kN]**	**Area[m2]**	**Comp. Strength [Mpa**	**Unit Weight [gm/cm^3]**
				L	W	H						
1	YA1	C-25	0	15	15	15	3375	8,746.00	729.00	0.15*0.15 =0.0225	32.40	2.59
2				15	15	15	3375	8,582.00	686.20		30.50	2.54
3				15	15	15	3375	8,524.00	707.10		31.43	2.53
Mean				**15**	**15**	**15**	**3375**	**8617.33**	**707.43**		**31.44**	**2.55**
1	YA2	C-25	1	15	15	15	3375	8,252.00	807.70	0.0225	35.90	2.45
2				15	15	15	3375	8,117.00	816.70		36.30	2.41
3				15	15	15	3375	8,371.00	777.30		34.55	2.48
Mean				**15**	**15**	**15**	**3375**	**8246.67**	**800.57**		**35.58**	**2.45**
1	YA3	C-25	2	15	15	15	3375	7,684.00	816.70	0.0225	36.30	2.28
2				15	15	15	3375	8,046.00	841.90		37.42	2.38
3				15	15	15	3375	7,736.00	794.00		35.29	2.29
Mean				**15**	**15**	**15**	**3375**	**7822.00**	**817.53**		**36.34**	**2.32**
1	YA4	C-25	3	15	15	15	3375	6,684.00	862.20	0.0225	38.32	1.98
2				15	15	15	3375	7,049.00	879.70		39.10	2.09
3				15	15	15	3375	6,738.00	837.20		37.21	1.99
Mean				**15**	**15**	**15**	**3375**	**6823.67**	**859.70**		**38.21**	**2.02**
1	YA5	C-25	4	15	15	15	3375	6,677.00	792.40	0.0225	35.22	1.98
2				15	15	15	3375	6,786.00	793.30		34.37	2.01
3				15	15	15	3375	6,591.00	752.10		33.43	1.95
Mean				**15**	**15**	**15**	**3375**	**6684.67**	**779.27**		**34.34**	**1.98**
1	YA6	C-25	5	15	15	15	3375	6,321.00	751.50	0.0225	33.40	1.87
2				15	15	15	3375	6,252.00	720.20		32.01	1.85
3				15	15	15	3375	6,406.00	708.70		31.50	1.89
Mean				**15**	**15**	**15**	**3375**	**6326.33**	**726.80**		**32.30**	**1.87**

ANNEX 4: SPLITTING TENSILE STRENGTH TESTS

4.1: Splitting Tensile Strength Test Results

No.	Samples	No. of samples per test	Grade	%PET	Splitting Load(P) at failure(KN)	Indivdual splitting streng(MPa)	Dimensions Of specimen(m)	Splitting Streng.(MPa) (Average) $f_s=2P/\pi LD$
1	YA1	1	C-25	0	61.20	1.95	D=0.1 L=0.2	**1.90**
		2			59.60	1.90		
		3			58.00	1.85		
2	YA2	1		1	64.30	2.05		**2.12**
		2			67.80	2.16		
		3			67.50	2.15		
3	YA3	1		2	68.40	2.18		**2.17**
		2			67.80	2.16		
		3			68.10	2.17		
4	YA4	1		3	70.00	2.23		**2.22**
		2			69.00	2.20		
		3			70.00	2.23		
5	YA5	1		4	67.50	2.15		**2.10**
		2			64.30	2.05		
		3			65.90	2.10		
6	YA6	1		5	64.30	2.05		**2.04**
		2			63.70	2.03		
		3			64.00	2.04		

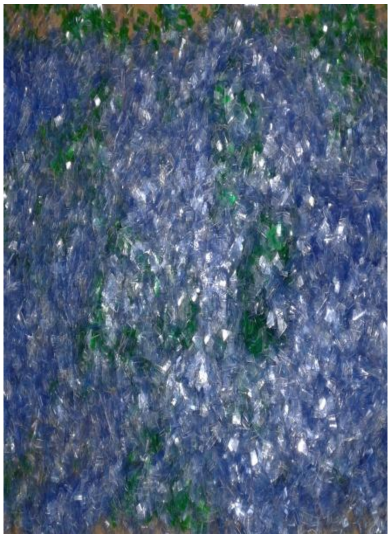
ANNEX 5: FLEXURAL STRENGTH TESTS

5.1: Flexural Strength Test Result

No.	Samples	No. of samples per test	Grade	%PET	Dimensions (cm)			P [kN]	M [N.m]	I [m4]	C [cm]	Fluxeral Streng (**σ)** of Samples(MPa)	Average σ [Mpa]
					L	B	D						
1	YA1	1	C-25	0	50	10	10	3.06	510	833.3	5	3.06	**3.05**
		2			50	10	10	3.04	506.6	833.3	5	3.04	
		3			50	10	10	3.05	508.3	833.3	5	3.05	
2	YA2	1		1	50	10	10	4.98	830	833.3	5	4.98	**4.93**
		2			50	10	10	4.87	811.6	833.3	5	4.87	
		3			50	10	10	4.95	825	833.3	5	4.95	
3	YA3	1		2	50	10	10	5.80	966.6	833.3	5	5.80	**5.85**
		2			50	10	10	5.85	975	833.3	5	5.85	
		3			50	10	10	5.90	983.3	833.3	5	5.90	
4	YA4	1		3	50	10	10	6.00	1000	833.3	5	6.00	**6.05**
		2			50	10	10	6.10	1016.6	833.3	5	6.10	
		3			50	10	10	6.05	1008.3	833.3	5	6.05	
5	YA5	1		4	50	10	10	5.91	985	833.3	5	5.91	**5.88**
		2			50	10	10	5.72	953.3	833.3	5	5.72	
		3			50	10	10	5.80	966.6	833.3	5	5.80	
6	YA6	1		5	50	10	10	5.79	965	833.3	5	5.79	**5.80**
		2			50	10	10	5.82	970	833.3	5	5.82	
		3			50	10	10	5.81	968.3	833.3	5	5.81	

ANNEX 6: PHOTOS

Aggregate, Washed and drying Sand samples



Aggregate tests (Photo taken by me)

Shredding and cutting of PET (Photo taken by Merid Teshome)

Sieve analysis tests

Mixing of aggregates and molding (Photo taken by Merid Teshome).

Mixing and molding

Slump and form work (Photo taken by Merid Teshome)

Curing tank

Cube crushing and samples (Photo taken by me)

Beam samples and crushing

Tensile strength tests (Photo taken by Teklu Amenu)