

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

DEPARTMENT OF CHEMISTRY

**INFLUENCE OF RECYCLED WASTE HIGH DENSITY POLYETHYLENE PLASTIC
AGGREGATE ON THE PHYSICO-CHEMICAL AND MECHANICAL PROPERTIES OF
CONCRETE**

**A THESIS SUBMITTED TO
THE DEPARTMENT OF CHEMISTRY IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE (MPHIL) IN
POLYMER SCIENCE AND TECHNOLOGY**

BY

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DECLARATION

I hereby declare that this thesis submitted to the Department of Chemistry, is as the result of my work towards the award of MPhil degree in Polymer Science and Technology and to the best of my knowledge, it contains neither any material previously published by any other person nor material which has been accepted for the award of any other degree or diploma at any institution or university, except where due acknowledgement has been made in the text.

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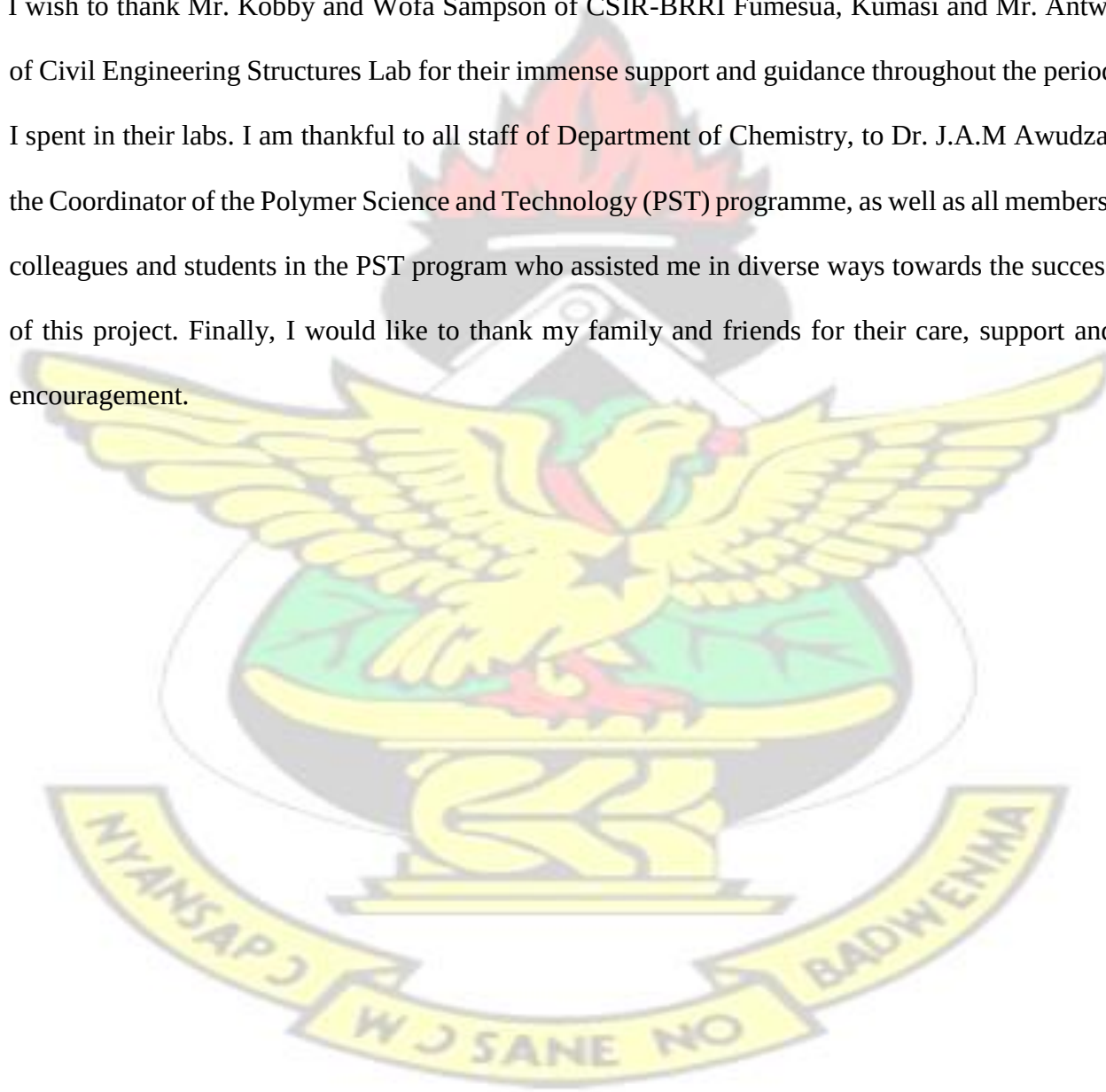
ABSTRACT

Utilisation of waste plastic materials as aggregates in concrete manufacturing is a partial solution to the environmental and ecological challenges associated with the use of plastics. The aim of this research is to reduce environmental pollution by using waste HDPE as a partial replacement of coarse aggregate in concrete. This study examines some mechanical and chemical effect of using waste High Density Polyethylene (HDPE) as a partial replacement for coarse aggregate in concrete at various plastic compositions (0%, 2%, 4%, 6% and 8% by weight of the coarse aggregate). The cleaned plastics were cut into flakes and then incorporated into the concrete. Particle size distribution (PSD) test was conducted on the aggregates and specific gravity test was also conducted for the plastic aggregates. The workability of the fresh concrete both for the control and concrete with plastic aggregates were determined using the slump cone test. Cube and prismatic beams of the samples were used to determine the compressive strength and flexural strength test of hardened concrete. The effect of water on the hardened properties was also determined for the various compositions. Finally, the effect of HNO_3 and H_2SO_4 on the compressive strength of the composite and the masses of the various compositions were also determined. The workability of the fresh concrete was found to decrease with increasing plastic content. From the results obtained it was revealed that the compressive strength for the normal concrete is higher than that of plastic concrete and the compressive strength of the concrete also decreases appreciably with increase in the plastic content. The 28th day flexural strength decrease marginally with increase in plastic content in the concrete. It was revealed from the acidic test that HNO_3 virtually had no effect on the strength properties of the concrete whereas H_2SO_4 had a deleterious effect on the concrete sample after 28 days of immersion. The mass of water absorbed by the concrete samples increased also with the increasing plastic content.

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DEDICATION

I dedicate this dissertation to each and every person who has offered me advice, love, care and support throughout this programme.



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LIST OF ABBREVIATIONS

UNEP	United Nations Environmental Programme
LDPE.....	Low Density Polyethylene
MSW.....	Municipal Solid Waste
ACI.....	American Concrete Institute
EPS.....	Expanded Polystyrene
HDPE.....	High Density Polyethylene
PET.....	Polyethylene Terephthalate

MMDA.....	Metropolitan Municipal and District Assemblies
ASTM.....	American Standard for Testing Material
GGBS.....	Ground Granulated Blast furnace Slag
PIC.....	Polymer Impregnated Concrete
PC.....	Polymer Concrete
PPCC.....	Polymer Portland Cement Concrete
PMC.....	Polymer Modified Concrete
LMC.....	Latex Modified Concrete
PMMA.....	Polymethyl Methacrylate
UV.....	Ultra Violet
MMA.....	Methyl Methacrylate
PP.....	Polypropylene
PE.....	Polyethylene
MDPE.....	Medium Density Polyethylene
LLDE.....	Linear Low Density Polyethylene
UHMWPE.....	Ultra High Molecular Weight Polyethylene
VLDPE.....	Very Low Density Polyethylene
GDP.....	Gross Domestic Product

NESSAP..... National Environmental Sanitation Strategy and Action Plan

PSD..... Particle Size Distribution

SG..... Specific Gravity

MPa..... Mega Pascal

SDF..... Strength Deterioration Factor



CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

The world's annual consumption of plastic materials has increased from 5 million tons in the 1950s to 100 million tons in the 2000s (UNEP, 2009). This has led to plastics forming a major chunk of the municipal solid waste after food waste and paper waste. The increasing use of plastic is now a major challenge for local authorities responsible for solid waste management. Lack of sustainable waste management techniques by our local authorities has led to most of the plastic waste not collected or disposed of properly in an appropriate manner. In most towns and cities in Ghana the waste plastics are thrown into municipal waste collection centers from where it is collected by the local authorities for further disposal into landfills and dumpsites. However, not all of these wastes gets collected and transported to the final dumpsites. This may be due to lack of resource as well as inefficient and insufficient infrastructure.

Ghana has no laws banning or enforcing the indiscriminate littering of plastic bags and containers of all sizes and shapes. Due to the unavailability of such enforcement policies the challenges associated with plastic waste in Ghana include;

- a) Plastics contribute to blockage of drains and gutters which can cause flooding
- b) The burning of waste plastic can release toxic gas into the atmosphere
- c) The waste plastic can choke livestock and aquatic species when they mistake them for food
- d) Plastic bags when filled with rainwater becomes breeding ground for mosquitoes
- e) Plastic takes several years to degrade and hence pose a disposal and ecological problem.

Fortunately, there are options there for dealing with this menace of waste plastic which include recycling, reduction, reuse of plastics and recovering of waste plastic which cannot be reduced, reused or recycled. In the developed countries, recycling technology has been the solution of choice but in developing countries, like Ghana it may not be economically viable since it is heavily capital intensive (UNEP, 2009).

Waste Low Density Polyethylene (LDPE) can be converted into high energy hydrocarbon fuels by a thermal degradation process (Sarker *et al.*, 2011). The fuel produced by recycling of waste plastic can be alternative to petrol, diesel etc.

Ghana and many developing countries are currently experiencing rapid urbanization and industrialization and as a result a lot of infrastructure developments are going on in these countries. However, infrastructure developments are plagued with problems such as acute shortage of construction materials, sky rocketing prices of construction materials and increased generation of waste. Plastic is one major component of Municipal Solid Waste (MSW) which is becoming a major research issue for its possible use in concrete. There have been successful replacement or partial replacement of aggregates or filler components of concrete with industrial waste such as fly ash and wood chips in concrete (Bignozzi *et al.*, 2000). Hence waste plastic can therefore, be mixed in the concrete mass in some form, without significant effect on its other properties or slight compromise in strength (Polymer Modified Concrete).

The American Concrete Institute (ACI) defines Polymer Modified Cementitious Concrete as a hydraulic cement combined at the time of mixing with organic polymers that are dispersed or redispersed in water, with or without the aggregates. Polymer modified concrete has applications in tile adhesion, floor leveling concrete, concrete patches and bridge deck overlays.

Waste plastics of various types can be used as partial replacements of aggregates in the manufacturing of concrete (Mostafizur *et al.*, 2012). For instance Expanded polystyrene (EPS) based waste, High Density Polyethylene (HDPE), Polyethylene Terephthalate (PET) waste bottles, Polypropylene fibers and Polyethylene bags have all been used in different forms by researchers in concrete. In this study high density polyethylene bottles which forms 19% of waste plastic in municipal solid waste (Sarker, 2010) was shredded into flakes and used as a partial replacement of coarse aggregate in concrete.

1.2 Problem Statement

Waste management in Ghana is the responsibility of the Ministry of Local Government and Rural Development which supervises the decentralized Metropolitan, Municipal and District Assemblies (MMDAs). However, the Environmental Protection Agency (EPA) is the regulatory authority under the auspices of the Ministry of Environment, Science and Technology Innovations. These MMDAs have contracted sanitation companies to clean the environment of the various waste generated from human activities. Despite the efforts of these agencies and departments solid waste management problem is prevalent everywhere in Ghana. Poor attitude of Ghanaians towards waste disposal such as littering and relying on traditional waste disposal techniques such as land filling and incineration have proven incapable of dealing with the increasing volumes of waste generated in the various municipalities and districts. The waste plastics consist of surplus, obsolete, broken, old plastic furniture, different household plastic materials, equipment, packaging materials, vehicle tire and devices made of plastic.

These polymer wastes are non degradable in the natural environment even after a long period of exposure. The slow degradation property of waste polymer materials causes a waste disposal crisis

from the environmental and ecological point of view. Therefore there is the need for an efficient and reliable method for solid waste management to curb the prevailing menace.

Ghana like any other developing country is currently experiencing rapid urbanization and industrialization and as a result a lot of infrastructure developments are going on. These developments are plagued with problems such as shortage of construction materials, high cost of building due to importation of cement and other building materials.

Waste plastic can be used as a complement to coarse aggregate or as a partial replacement of aggregates in the concrete (Mostafizur *et al.*, 2012; Al Bakri *et al.*, 2011; Sultana *et al.*, 2012).

There is little or no scientific work on the use of waste polymeric materials in concrete in Ghana. Elsewhere in Europe, Asia and the America's a lot of work exist on the subject. This work is to gain insight on the subject which has gain a lot of momentum in recent years beyond Ghana.

1.3 Research Aim

The aim of this research is to determine the suitability of waste HDPE as a partial replacement of coarse aggregate in concrete for construction.

1.4 Objectives

- To prepare various proportions of polymer modified concrete using recycled HDPE
- To determine the engineering properties (i.e. water demand, compressive strength, flexural strength) of samples of prepared polymer modified concrete
- To determine the effect of curing days on compressive strength and flexural strength on polymer modified concrete
- To determine water absorption and desorption content of polymer modified concrete
- To determine the durability of cube specimens in acidic media

- To use the data so generated to determine the optimum replacement of waste HDPE in the normal aggregate concrete

1.5 Scope of the Study

In this research HDPE waste bottles which constitute 19% of waste plastic in a waste stream were collected, washed and shredded into flakes and then used to replace coarse aggregate by weight percentage. In order to complement the current research and to gain a comprehensive perspective on the growing volume of research on polymer modified concrete, established fundamental and empirical laboratory tests such as slump test, compressive strength, flexural strength, water absorption and effect of acids on the mechanical properties were employed. High density polyethylene which is of interest in this study, identified by its recycling code (2) was processed into aggregates and used in the concrete manufacturing. Laboratory studies were conducted to determine the suitability of the concrete with waste plastic in the construction industry. This research is not intended to investigate and compare theories in polymer modified concrete but to embrace the application of this far fetching technology by taking cognizance of subsequent developments and general critique.

1.6 Justification

Despite the importance of plastics to Ghana's economy, its contribution to waste generation and management problems in the country has resulted in threats by some Municipal, Metropolitan and District Assemblies (MMDAs) and the central government to impose levies on its production or ban its production outright. These threats if carried out will increase the cost of production of plastic and worsen the unemployment situation in the country.

Some plastic waste are collected and disposed of at designated landfill and waste dump sites by public and private waste management companies. Polyethylene, polypropylene, polyethylene terephthalate and polystyrene forms a major chunk of the plastic waste in the environment. Therefore, there is the need for an economically viable recycling and value addition to the plastic waste generated.

Several studies have been carried out in countries like Egypt, India, Australia, and U.S.A where waste plastics have been reused to produce other products. Such reuses of plastics include incinerations for the production of electricity, as fuels and also as asphalt concrete. Ghana is yet to document a work done on the reuse of plastic into other products.

This study defines the potentials and benefits in the addition of plastic waste in the concrete mixture to produce a more flexible and durable concrete and at the same time being an alternative way to recycle the plastic waste. Plastics can be used to replace some of the aggregate in the concrete mixture. The fundamental advantage of plastics replacing aggregates would be reducing the bulk density of the composite and hence improved cost. Plastic replacing some of the aggregate in the concrete gives a good approach to reduce the cost of materials involved in making the concrete which in the long run help solve some of the waste problems posed by the plastics (Batayneh *et al.*, 2007).

Using plastics as partial replacement for coarse aggregate in concrete will eventually lead to less stones in the manufacturing process which means more chippings will remain in the natural environment.

CHAPTER TWO

LITERATURE REVIEW

2.1 Concrete

Concrete is a composite material which consists of aggregates, cement and water used in construction. The aggregates are generally coarse gravel or crushed rocks such as limestone or granite and the fine aggregate could be a material such as sand or can be manufactured such as slag. The cement commonly Portland cement and other materials such as fly ash and slag cement serve as binder for the aggregates. Water is then mixed with this dry composite which enables it to be shaped, which then solidified and hardened into hard rock strength material through a chemical process called hydration (Ogbonna, 2009).

The water reacts with the cement which bonds the other components together eventually creating a robust, compact stone like material. Concrete is an indispensable part of the fabric of modern society used for everything from road pavements to high rise building structures and is a versatile material that can easily be mixed to meet variety of special needs and formed to virtually any shape (Islam *et al.*, 2011). Hydraulic cement concrete has been defined according to the American Concrete Institute (ACI E1-99) as a cement and water paste in which aggregate particles are embedded. Aggregate is granular material such as sand, gravel, crushed stone, and blast furnace slag that usually occupies approximately 60% to 75% of the volume of concrete.

Various chemical admixtures can also be added to the concrete to achieve varied properties (Tomas, 2013). An admixture, according to the ASTM C-125-97a standard is a material other than water, aggregates or hydraulic cement that is used as an ingredient of concrete or mortar, and is added to the batch immediately before or during mixing. The widespread use of admixture is due to the many benefits made possible by their application. For example, chemical admixtures such

as superplasticizers can modify the setting and hardening characteristic of cement paste by influencing the rate of cement hydration (Tomas, 2013).

Water reducing admixture can plasticize fresh concrete mixtures by reducing surface tension of water, air entraining admixtures can improve the durability of concrete, and mineral admixtures such as fly ash, silica fume, pozzolan (materials containing reactive silica) can reduce thermal cracking (Naceri *et al.*, 2009) thereby improving strength. Based on the type of binder used there are many different kinds of concrete, Portland cement concrete, asphalt concrete, and epoxy concrete. For constructional purposes, the Portland cement concrete is utilized the most.

2.1.1 Classification of Concrete

Concrete can be classified based on many criteria's which can include weight, strength and additives used in the concrete manufacturing

A) Based on unit weight there are;

- a) Ultra light weight concrete whose density is less than 1200kgm^{-3}
- b) Light weight concrete whose density ranges from 1200kgm^{-3} — 1800kgm^{-3}
- c) Normal weight concrete whose density is approximately 2400kgm^{-3}
- d) Heavy weight concrete whose density is greater than 3200kgm^{-3}

B) Another criteria for distinguishing concrete is based on its strength and the varieties are ;

- a) Low strength concrete whose compressive strength is less than 20MPa
- b) Moderate high strength concrete for which the compressive strength lies between 20MPa to 50MPa
- c) High strength concrete whose compressive strength ranges from 50MPa to 200MPa
- d) Ultra high strength concrete whose compressive strength is above 200MPa

C) Additives added to the concrete can also be a criteria for categorising the concrete into;

- a) Normal concrete
- b) Fibre reinforced concrete
- c) Shrinkage compensating concrete
- d) Polymer concrete

2.1.2 Uses and Benefit of Concrete

Concrete is the most widely used construction material in the world used in many structures such as dams, pavements, buildings or bridges. Concrete is neither as strong nor as tough as steel even though it is believed to be widely used than steel because of certain advantages it has which include (Islam *et al.*, 2011);

a) Economical

Concrete is the most inexpensive and the most readily available material whose cost of production is low compared with other engineering construction materials. Its major components, water, aggregate and cement comparing with steel is inexpensive and available in every corner of the world. This enables concrete to be locally produced anywhere thus avoiding the transportation costs necessary for most other materials.

b) Ambient temperature hardened material

Since cement is a low temperature bonded inorganic material and its reaction occurs at room temperature concrete can gain its strength at ambient temperature.

c) Ability to be cast

Concrete can always be formed into different desired shape and sizes right at the construction site.

d) Excellent resistance to water

Concrete can harden in water and can withstand the action of water without serious deterioration unlike steel and wood. This property makes it an ideal material for building structures to control, store, and transport water.

e) High temperature resistance

Concrete is a poor conductor of heat, so is able to store considerable quantities of heat from the environment and thus can be used as protective coating for steel structure.

f) Ability to consume waste

Industrial wastes such as fly ash, slag and vehicle tire etc can be recycled as a substitute for cement or aggregates in concrete without significantly affecting its properties.

g) Ability to work with reinforcing steel

Concrete and steel possess similar coefficient of thermal expansion hence concrete provides good protection to steel. Therefore, while steel bars provide the necessary tensile strength, concrete provides a perfect environment for the steel, acting as a physical barrier to the ingress of aggressive species and preventing steel corrosion by providing a highly alkaline environment which passivates the steel.

2.1.3 Limitations of Concrete

Despite the mentioned benefits of concrete above, it also has certain limitation like any other engineering construction material (Islam *et al.*, 2011). The limitations include;

a) Quasi-brittle failure mode

Concrete is a type of quasi brittle material which can be reinforced

b) Low tensile strength

Concrete has an inherent low tensile strength which can be improved significantly by reinforcing with fibre (polymer concrete)

c) Low toughness

Its ability to absorb energy is low

d) Long curing time

Full strength development of a concrete needs about a month.

2.2 Polymers in Concrete

Concrete is a versatile material with the ability to get cast in any form and shape. Nonetheless the properties of concrete can be changed by adding some special natural or artificial ingredients. Concrete has advantages including good compressive strength, durability, impermeability, specific gravity and fire resistance. However, it is weak in tension, brittle, low resistant to cracking, lower impact strength, heavy weight, etc, but some remedial measures can be taken to minimize these limiting properties of concrete (Nibudey *et al.*, 2013).

Research concerning the use of waste products to augment the properties of concrete has been going on for many years and in the recent decades, efforts have been made to use industry waste products such as fly ash, silica fume, ground granulated blast furnace slag (GGBS), glass cullet, metakaolin etc, in construction (Puri *et al.*, 2013).

Many agencies, organizations and individuals have completed or are in the process of completing a wide variety of studies and research projects concerning the feasibility, environmental suitability and performance of using waste materials in concrete.

Polymer modified cementitious materials have been available for more than 70 years. The polymers are dispersed in water or redispersed in powders, then added to hydraulic cement, with or without aggregate or admixtures, depending on the desired results. The addition of a minor amount of a polymer to a cement mix can significantly enhance the properties of the resulting material (Bhikshma *et al.*, 2010).

Polymer mortars and concretes have obtained wide acceptance as materials for many applications due to their versatility in formulation and processing combined with high strength and rapid setting properties. Chemical and corrosion resistance, ease of placement, long durability, low permeability and thermal stability are some of the advantages that make these polymer composites suitable for precast components, bridge deck overlays, artificial marbles, repair materials for concrete structures and machine tool basements (Bignozzi *et al.*, 2000).

2.2.1 History of Polymers in Concrete

Portland cement concrete has been successful in many applications; however, since the 1960s technological investigations concerning modifications of concrete by polymeric materials have been conducted. The attention has been focused on concretes in which the continuous phase is some kind of polymeric resin and the discrete phase is some type of mineral aggregate (Barrera *et al.*, 2011).

The concept of a polymer hydraulic cement concrete system is not new (Ohama and Shiroishida, 1984) as reported in ACI 548. In 1923, the first patent of such a system was issued to Cresson which referred to paving materials with natural rubber latexes where cement was used as filler. Lefebure a year later in 1924 was granted the first patent of the modern concept of a polymer modified system. Lefebure appears to be the first person who intended to produce a polymer modified cementitious mixture using natural rubber latexes by proportioning latex on the basis of cement content in contrast to Cresson who based his mixture on the polymer content.

Then in 1925, Kirkpatrick patented a similar idea and throughout the 1920s and 1930s concrete using natural rubber latexes were developed. In 1932 Bond's patent recommended the use of synthetic rubber latexes, and Rodwell's patent in 1939 used synthetic resin latexes, including polyvinyl acetate latexes, to produce polymer modified systems.

In the 1940s, some patents on polymer modified systems with synthetic latexes, such as polychloroprene rubber latexes (Neoprene) (Cooke, 1941) and polyacrylic ester latexes (Jaenicke *et al.*, 1943) as was reported by ACI 548 were published. Also, polyvinyl acetate modified mortar and concrete were actively developed for practical applications.

Since the late 1940s, polymer modified mixtures have been used in various applications such as deck coverings for ships and bridges, paving, floorings, anti corrosives, and adhesives. In the United Kingdom, feasibility studies on the applications of natural rubber modified systems were

conducted by Stevens (1948) and Griffiths in 1951. Geist, Amagna, and Mellor in 1953 reported a detailed fundamental study on polyvinyl acetate modified mortar and provided a number of valuable suggestions for later research and development of polymer modified systems. A patent for the use of redispersible polymer powders as polymer modifiers for hydraulic cementitious mixtures was applied for in 1953 (Werk and Wirken, 1997).

The first use of epoxy resins to modify hydraulic cement was reported by Lezy and Pailere in 1967 (ACI 548). The use of polymer concrete pipes in public places and work started in the Middle East in the early 1990s (Mehdi, 2000).

2.2.2 Subdivisions of Polymers in Concrete

Concrete possesses high compressive strength but is relatively weak in tension and adhesion, and its porosity can lead to physical and chemical deterioration while polymers, on the other hand, are weaker in compression but can have higher tensile strength, and provide good adhesion to other materials as well as resistance to physical and chemical attack. A composite material of polymer and concrete can exploit the useful properties of both materials and yield a material with excellent strength and durability properties.

The combination of Portland cement concrete with polymers can result in extremely durable, tough, and strong building material. Polymers in concrete are categorized into three groups and they are Polymer Impregnated Concrete (PIC), Polymer Concrete (PC) and Polymer Modified Cementitious Concrete/ Polymer Portland Cement Concrete (PPCC) (Sivakumar, 2011).

2.2.2.1 Polymer Modified Cementitious Concrete (PMC)

Polymer Modified Cementitious mixtures (PMC), Polymer Portland Cement Concrete (PPCC) or Latex Modified Concrete (LMC) is defined as hydraulic cement combined at the time of mixing with organic polymers that are dispersed or redispersed in water, with or without aggregates (ACI

548). The polymer may be a homopolymer if it is made by the polymerization of one monomer or a copolymer when two or more monomers are polymerized. The organic polymer is supplied in three forms which may be dispersion in water (latex), as a redispersible powder or as a liquid that is dispersible or soluble in water.

Dispersions of polymers in water and redispersible polymer powders have been in use for many years as admixtures to hydraulic cement mixtures where these admixtures are called polymer modifiers. The dispersions of these polymer modifiers are called latexes, sometimes incorrectly referred to as emulsions (ACI 548). The improvements from adding polymer modifiers to concrete include increased bond strength, freezing and thawing resistance, abrasion resistance, flexural and tensile strengths, and reduced permeability and elastic modulus.

PMC can have increased resistance to penetration by water and dissolved salts, and reduce the need for sustained moist curing. The improvements are measurably reduced when PMC is tested in the wet state (Popovics 1987 as appears in ACI 548). The specific property improvement to the modified cementitious mixture varies with the type of polymer modifier used. Ohama as appeared in (Islam *et al.*, 2011) investigated on the principle of latex modified mortars and concrete and concluded that the latex modification improved the properties of the concrete. The hardened latex modified mortars and concretes developed good strength, adhesion, pore structure, impermeability, and durability (Islam *et al.*, 2011).

Bordeleau *et al.* (1992) as was reported by (Islam *et al.*, 2011), subjected Latex Modified Concretes (LMC) and normal concretes to freezing and thawing in the presence of a deicing salt and found that LMC had a better freeze thaw resistance and therefore concluded that the improvement in the properties depended on the quantity of styrene-butadiene rubber latex, the air void spacing factor, and the water cement ratio (Islam *et al.*, 2011).

2.2.2.2 Polymer Concrete (PC)

Polymer concrete (PC) became well known in the 1970s and it consists of aggregate with a polymer binder which contains no Portland cement or water. It is a composite material in which the binder consists entirely of a synthetic organic polymer. Thermosetting resins are used as additives for polymer concrete and some of the widely used liquid resins include unsaturated polyester resin, epoxy resin, vinyl ester resin and polyurethane, and tar modified resins and acrylic resins such as PolyMethyl Methacrylate (PMMA) and glycerol methacrylate-styrene (Ohama *et al.*, 2011).

The properties of Polymer Concrete depend on the interactions at the interface between the polymeric binder and the mineral aggregate. They have a longer maintenance free service life than normal concrete and possesses also other advantages such as increased bond strength, increased freeze thaw resistance, high abrasion resistance, increased flexural, compressive and tensile strengths, fast setting times (curing within 1 or 2 hours), good durability, improved chemical resistance in harsh environments. Moreover, they exhibit good creep resistance, and are highly UV resistant due to the very low polymer content and inert fillers. On the other hand, they exhibit reduced elastic modulus.

The loss of strength can be attributed to an increase of porosity in PC with increased capillary diffusion of solutions, which weakens the bond between the aggregate and the matrix.

PC has a variety of applications in highway pavements, underground wastewater pipes, manufacturing of thin overlays as precast components for bridge panels, overlay bridge decks, parking garage decks, industrial floors and dams (Martinez-Barrera *et al.*, 2011).

2.2.2.3 Polymer Impregnated Concrete (PIC)

Polymer impregnated concrete is made by impregnation of pre cast hardened Portland cement concrete with low viscosity monomers that are converted to solid polymer under the influence of

physical agents or chemical agents . It is produced by drying conventional concrete; displacing the air from the open pores, saturating the open pore structure by diffusion of low viscosity monomers or a pre polymer-monomer mixture and *in-situ* polymerization of the monomer or pre polymer monomer mixture, using the most economical and convenient method.

In the case of PIC, by effectively sealing the micro cracks and capillary pores, it is possible to produce a virtually impermeable product which gives an ultimate strength of the same order as that of PC. PIC has been used for the production of high strength precast products and for improving the durability of bridge deck surfaces.

The concept underlying PIC is that if voids are responsible for low strength as well as poor durability of concrete in severe environments, then eliminating them by filling with a polymer should improve the characteristics of the material. It is difficult for a liquid to penetrate it if the viscosity of the liquid is high and the voids in concrete are not empty but contain water and air. Therefore, for producing PIC, it is essential not only to select a low viscosity liquid for penetration but also to dry and evacuate the concrete before subjecting it to the penetration process.

Monomers such as Methyl Methacrylate (MMA) and styrene are commonly used for penetration because of relatively low viscosity, high boiling point and low cost. After penetration, the monomer has to be polymerized *in-situ* which can be accomplished in one of three ways. A combination of promoter chemical and catalysts can be used for room temperature polymerization, Gamma radiation can also induce polymerization at room temperature, and the third method, which is generally employed, consists of using a monomer catalyst mixture for penetration, and subsequently polymerizing the monomer by heating the concrete to 70°C with steam, hot water, or infrared heaters. Polymer impregnated concrete is rarely used in Japan despite its high performance because of the huge cost involved (Ohama and Bhutta, 2011).

2.2.3 Concrete with Recycled Polymer

A study by Sultana *et al.*, (2012), studied on the utilization of waste plastic on the strength of flexible and rigid pavements in which waste plastics in shredded form were added to heated coarse aggregates and mixed thoroughly with cement, sand and water to prepare concrete. They observed that there is a drastic change in the compressive strength of plastic coated concrete compared with plain cement concrete. This they attributed to weak bonding between the constituents of the concrete. They therefore concluded that by conducting compressive strength of cubes using plastic coated aggregates, there is no significant increase in the strength of cubes.

A related study conducted earlier on by Lakshmi *et al.*, (2010), on concrete containing electronic waste where electronic waste sources in the form of loosely discarded, surplus, obsolete, broken, electrical devices from commercial informal recyclers were ground to replace coarse aggregate in the concrete mix. Compressive strength test was conducted on them to evaluate the strength development of concrete containing various electronic waste contents at the age of 7, 14, 28 days respectively.

They concluded that the compressive strength and split tensile strength of concrete containing plastic aggregate is retained in comparison with controlled concrete specimens. However they noted that the strength noticeably decreased when the e plastic content was more than 20%. They also found out that the addition of fly ash in the mix considerably improves strength index of control mix as well as e waste concrete.

Mohan *et al.*, (2012), used post consumer polyethylene bags gathered from residential houses and from retail shops in India and shaped them as a ball with a diameter of 30 to 40 mm. They densified the plastic waste aggregates by heat which consisted of heating it at temperature of 160°C for 20 seconds in the Muffle Furnace. And spherical diameters of the sample plastic waste which shrunk to the range of 18 to 25 mm were used to replace conventional coarse aggregates to make the

concrete specimens. They concluded that the density and compressive strength of concrete decreased with the increase in the melt densified plastic aggregate content.

Another research by Batayneh *et al.*, (2007) investigated the performance of the ordinary Portland cement mix under the effect of using recycled waste materials, namely glass, plastics, and crushed concrete as a fraction of the aggregates used in the mix. This they demonstrated through experimental laboratory tests, using fine glass and plastic aggregates to substitute a certain percentage of the fine aggregates whilst using crushed concrete to substitute a certain percentage of coarse aggregates in the concrete.

The waste plastics were reused by grinding them into small sized particles and different percentages of cement, water, fine aggregates, and coarse aggregates were combined in order to produce concrete of the required workability and strength. Mixes of up to 20% of plastic particles were proportioned to partially replace the fine aggregates and fresh mix property tests, such as slump and unit weight tests, were performed immediately after mixing.

They observed that there is a decrease in the slump with the increase in the plastic particle content. This decrease in the slump value was attributed to the shape of plastic particles; i.e. the plastic particles have sharper edges than the fine aggregate. They also concluded that the addition of the plastic particles led to a reduction in the strength properties. For a 20% replacement, the compressive strength shows a sharp reduction up to 72% of the original strength. With 5% replacement the compressive strength shows a 23% reduction. Similar behavior, but in a lower effect, was observed in both the splitting and flexural strengths of the tested samples. This reduction in strength is due to the fact that the strength of the plastic particles is lower than that of the aggregate.

A work conducted by Alidoust *et al.*, (2007), was on cement based composite containing polypropylene fibers and finely ground glass exposed to elevated temperatures. Monofilament

fibers obtained from industrial recycled raw materials cut to 6 mm length and recycled clean glass windows were crushed and grinded in laboratory, sieved to the desired particle size. Partial replacements of cement with pozzolans include ground waste glass, silica fume, and rice husk ashes which were used to examine the effects of pozzolanic materials on mechanical properties of PP reinforced mortars at high temperatures. The amount of pozzolans which replaced was 10% by weight. The reinforced mixtures contained PP fiber with three designated fiber contents of 0.5%, 1% and 1.5% by total volume.

The specimens were positioned in heater and heated to desire temperature of 300⁰C and 600⁰C at a rate of 10-12 per min. They observed that the initial density of specimens containing polypropylene fibers was less than that of mixes without any fibers and that by increasing the amount of polypropylene fibers in matrix the compressive strength of specimens reduced. They also, concluded that the compressive strength of specimens decreased by increasing the temperature to 300⁰C and 600⁰C.

Another research conducted by Bandodkar *et al.*, (2011), on pulverized PET bottles as partial replacement for sand in which three different types of pulverized plastic wastes obtained from PET bottles, polythene bags and injection molded plastic were used as partial replacement for sand in concrete to the extent of 1%, 5% and 10% and its effect on 28 days compressive strength reported. They observed that at 1% of plastic content, the strength reduction was up to 3.5% for blow or injection molded plastic, 11% for PET bottles and 1.5% for polythene bags. For 5% plastic content, the strength reduction was up to 13.0% for blow or injection molded plastic, 12% for PET bottles and 0.5% for polythene bags. For 10% sand content, the strength reduction was up to 10.5% for blow or injection molded plastic, 13.5% for PET bottles and 3.5% for polythene bags was observed. They concluded that various plastic wastes can be used as replacement for natural sand to the extent of 10% without much appreciable reduction in 28 days compressive

strength.

Sivakumar, (2011), reported on the effect of polymer modification on mechanical and structural properties of concrete. They reported that a rapid strength development is obtained by increasing the latex polymer dosage from 5 to 15 % and similar trend was observed with styrene acrylic polymer also. Their experimental results evidently show that the characteristic compressive strength of polymer modified concrete increases with the increase of polymer dosage from 5% to 15%, after reaching its optimum percentage dosage around 15% it then starts to decrease. Also Raghatate, (2012), worked on the use of plastic in concrete to improve its properties where pieces of polythene bags were used in the concrete mix. It was reported that compressive strength of concrete was affected by addition of plastic pieces and it goes on decreasing as the percentage of plastic increased. He noticed that addition of 1 % of plastic in concrete causes about 20% reduction in strength after 28 days curing.

A later work by Mostafizur *et al.*, (2012), researched on waste polymeric materials as partial replacement for aggregates in concrete where post consumer waste polymer materials were collected, shredded, washed, dried and sieved. The concrete was prepared with the ratio of cement: sand: stone chips (1:2:4) and the waste polymer (EPS, HDPE and tire) varies from 10 to 40 percentage of total volume of the sample. They observed that compressive strength of modified concrete decreases with the three types of waste polymer content and density of the modified concretes also decreases significantly with the waste polymer content.

Also Baboo *et al.*, (2012), reported on waste plastic mix concrete with plasticizer where the waste material used in this study was virgin plastic which was then used as a partial replacement for fine aggregate with superplasticizer CONPLAST SP 320. Four different volume percentages of plastic pellets (0%, 5%, 10%, and 15%) were cast for each percentage of plastic pellets without superplasticizer, and also for each varying percentages with superplasticizer CONPLAST SP320.

They reported that dry densities at each curing age tend to decrease with increasing waste plastic ratio in each concrete mixture. They observed that degree of workability was low when superplasticizer was not mixed in the concrete mixture.

When superplasticizer was used, the degree of workability becomes medium till the water plastic content was 10%. The increase in workability was around 10 to 15% when superplasticizer was mixed in the waste plastic mix concrete. They also reported that by increasing the waste plastic ratio, the compressive strength values of waste plastic concrete mixtures decrease at each curing age. The flexural strength of waste plastic mix concrete was prone to decrease with the increase of the waste plastic ratio in these mixtures.

Prahallada *et al.*, (2013), reported on the strength and workability characteristics of waste plastic fiber reinforced concrete produced from recycled aggregates where the waste plastic fibbers were obtained by cutting waste plastic pots, buckets, cans, drums and utensils. Their concrete was prepared by using design mix proportion of 1: 1.374: 2.42 with water to cement ratio of 0.46, which correspond to M30 grade of concrete. The different percentages of waste plastic fibre 0%, 0.5%, 1%, 1.5%, 2%, 2.5% and 3% (by volume fraction) was adopted. They observed that the compressive strength, tensile strength, flexural strength of waste plastic fibre reinforced concrete using recycled aggregates goes on increasing until 1% addition of waste plastic fibres. After 1%, these mechanical properties starts decreasing i.e. the maximum compressive strength of waste plastic fibre reinforced concrete were obtained with 1% addition of waste plastic fiber. They observed that the workability of waste plastic fibre reinforced concrete using recycled aggregates as measured from slump, compaction factor and percentage flow was maximum when 1% fibres were used. Addition of more than 1% of waste plastic fiber decreases the workability. Thus they concluded that 1% addition of waste plastic fibres yielded good workability. They also reported that higher strength and workability characteristics of waste plastic fibre reinforced concrete using

recycled aggregates and conventional aggregates could be obtained with 1% addition of fibres into it and the strength properties of waste plastic fibre reinforced concrete produced from recycled aggregates were slightly lower than waste plastic fibre reinforced concrete produced from conventional aggregates.

Furthermore Bhogayata *et al.*, (2012), reported on the feasibility of waste metalized polythene used as concrete constituent in which metalized polythene waste bags were shredded to the macro flakes form. The materials were mixed with the standard practice of mixing them in a mixer and the plastic fibers were added to the mix with different proportions from 0%, 0.5%, 1% to 1.5% of the volume of concrete and fly ash was added in proportion of 0%, 10%, 20% and 30% by volume. They concluded that the addition of fibers reduced the compressive strength and the addition of plastic fibers along with fly ash showed good combination as far as strength gain was concerned. They also noticed that the addition of fibers with the combination of fly ash showed relatively good chemical resistant without any significant loss in the strength.

Ramadevi *et al.*, (2012), worked on the properties of concrete with plastic PET (bottle) fibers as fine aggregates where 0.5%, 1%, 2%, 4% and 6% of traditional fine aggregate was replaced for M25 grade concrete. They concluded that the concrete with PET fibers reduced the weight of concrete and thus mortar with plastic fibers can be made into light weight concrete based on unit weight. They also observed that 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. Also the split tensile strength increased up to 2% replacement of the fine aggregate with PET bottle fibers and it gradually decreased for 4% and 6% replacements.

Another research conducted by Kandasamy *et al.*, (2012), was on fiber reinforced self compacting concrete using domestic waste plastics as fibers where fly ash, superplasticizer (TMB 233) was used for the manufacture of M30 grade concrete. For the same mix 0.5% waste polyethene plastic

in the form of fiber by weight of cement was added for the manufacturing of the fiber reinforced cement concrete. They concluded that based on concrete with sand, concrete with manufactured sand and fiber reinforced concrete with manufactured sand with addition of 0.5% polyethylene fiber, there was no much difference in the compressive strength of fiber reinforced self compacting concrete and that of fiber reinforced concrete or normal concrete. Flexural strength of fiber reinforced self compacting concrete was more than that of fiber reinforced concrete and normal concrete and also the tensile strength of fiber reinforced self compacting concrete was higher than of normal concrete.

A related study by Ganirun, (2013), was to find the feasibility of using polymer fiber as a superplasticizer admixture in concrete. A superplasticizer admixture in concrete may result in lower rate of water adsorption, high range water reducer, greater strength and excellent in elasticity. Polymer fiber (polyvinyl alcohol, polyvinyl acetate) dissolved in water with five different proportions ranging from 2%, 4%, 6%, 8% and 10% by weight of cement was used in the concrete with mix proportion of 1:2:4 (cement: sand: stone). Cylindrical specimens were cast and compressive strength tested for 7, 14 and 28 days. It was concluded from the results that the concrete mix with polymer fiber gave greater strength results than the standard mix.

Herki *et al.*, (2013), in a separate study presented work on light weight concrete made with waste polystyrene and fly ash. The composite aggregate was formed with 70% waste polystyrene which was shredded to coarse and sand sizes, 10% of a natural material to improve the resistance to segregation of expanded polystyrene and 20% Portland cement. Nine different mixtures with water to binder ratio of 0.8 with varying expanded polystyrene content ratios of 0%, 60% and 100% as partial replacement of natural fine aggregate by equivalent volume at the fly ash replacement levels of 0%, 20% and 40% with Portland cement were prepared and tested. Compressive strength and ultrasonic pulse velocity at the age of 28 day indicated that there was a decrease in compressive

strength and ultra pulse velocity with increasing amounts of expanded polystyrene and fly ash in concrete.

A related work by Praveen *et al.*, (2013) used recycled waste plastic as coarse aggregate in structural concrete, indicated a 100% replacement of natural coarse aggregate with plastic aggregates was not possible. They concluded that 22% replacement of natural coarse aggregate with plastic aggregate gave a superior compressive strength. They also observed a substantial reduction in split tensile strength and elastic modulus.

Nibudey *et al.*, (2013), worked to optimize the benefits of post consumed waste PET bottles in the fibre form in concrete. They employed several design concrete mixes with different percentages (0 to 3 %) of waste plastic fibres for two aspect ratios casted and cured for 28 days. The workability (slump, compaction factor), compression strength, split tension and flexural strength tests was carried and they observed an improvement in mechanical properties of concrete. They observed that workability decreased when the fibre percentage increases and concluded that the waste plastic fibre reinforced concrete showed ductility due to the inclusion of fibres.

2.2.3.1 Benefits of Using Recycled Plastics in Concrete

Polymers with different kinds of fillers are used as construction materials since they have good binding properties and good adhesion with aggregates. Their long chain structure helps in developing long range network structure of bonding. On the flip side, cement materials provide short range structure of bonding. As a result, some polymer materials usually provide superior compressive, tensile and flexural strength to the concrete compared to Portland cement. Some other polymer materials may provide good adhesion to other materials as well as resistance to physical damage (abrasion, erosion, and impact) and chemical attack. Conventional concrete materials

combined with polymers could yield composites with excellent mechanical and physical properties (Sivakumar *et al.*, 2010).

Synthetic fibers benefit the concrete in both the plastic and hardened states which includes reduction in plastic settlement cracks, reduced plastic shrinkage cracks, lowered permeability, increased impact and abrasion resistance and providing shatter resistance. Natural and other synthetic fibers are added to cement as secondary reinforcement to control plastic shrinkage

(Alidoust *et al.*, 2007).

Some concrete structures have failures due to crushing of the aggregates; plastic aggregates which have low crushing values will not be crushed as easily as the coarse aggregates and hence will not fail (Praveen *et al.*, 2013). As indicated in Elzafraney *et al.*, (2005), insulation materials such as polystyrene and polyethylene can be used in building construction for the purpose of saving energy (Budaiwi *et al.*, 2002, Al-Hammad *et al.*, 1994). Polymer mortars and concretes have received wide acceptance as materials for many applications thanks to their versatility in formulation and processing combined with high strength and rapid setting properties. Chemical and corrosion resistance, ease of placement, long durability, low permeability, high damping and thermal stability are some of the advantages that make these polymer composites suitable for precast components, bridge deck overlays, artificial marbles, repair materials for concrete structures and machine tool basements (Bignozzi *et al.*, 2000).

Proper addition of selected waste materials such as polyethylene terephthalate (PET) bottles into concrete can significantly reduce heat loss or improve thermal insulation performance (Yesilata *et al.*, 2009).

Utilization of waste polymer material in making concrete or mortar can be good solution to the environmental hazard which is posed by waste plastics (Mostafizur *et al.*, 2012).

2.2.3.2 Interaction between Polymer and Cement

Polymer Modified Concrete or mortar is a composite material consisting of two solid phases: the aggregates which are discontinuously dispersed through the material and the binder which itself consists of a cementitious phase and a polymer phase. According to the volume fraction of the polymer in the binder phase the material shifts from Polymer Cement Concrete (PCC), to Polymer Concrete (PC). In the case of PCC, the binder consists of a polymer-cement co-matrix.

The polymer is added to the fresh mixture as an emulsion or as redispersible polymer powders. During hardening and curing, cement hydration and polymer film formation take place resulting in a co-matrix in which polymer film is intermingled with cement hydrates.

A special group of materials in which polymers are used in combination with concrete is Polymer Impregnated Concrete, (PIC). Here, the polymer is injected in the pores of the hardened concrete and forms a second matrix if the pores are interconnected throughout the material.

The hardened concrete may be cement concrete, a PCC or a PC. Cement hydration in polymer modified material is influenced by the presence of the polymer particles and polymer film in the fresh state, during hydration as well as in the hardened state.

The properties of the fresh mixture are influenced to a large extent by the surfactants, present at the surface of the polymer particles. The cement particles are better dispersed in the mixture and a more homogeneous material is formed. The hydration of the cement is reflected in the strength evolution of the material. The influence of the polymer modification is in twofold. Due to the polymer and the surfactants, a retardation of the cement hydration can be noticed. This is especially visible in the compressive strength of the mortar beams.

On the other hand, due to the film formation or due to the interaction between the cement hydrates and the polymer particles, the tensile strength of the binder matrix as well as the adhesion strength between the aggregate and the binder increase. This is especially seen in the flexural strength of

the mortar beams. Immediately after mixing, the cement particles and polymer particles are dispersed in the water. The first hydration of the cement takes place, which results in an alkaline pore solution.

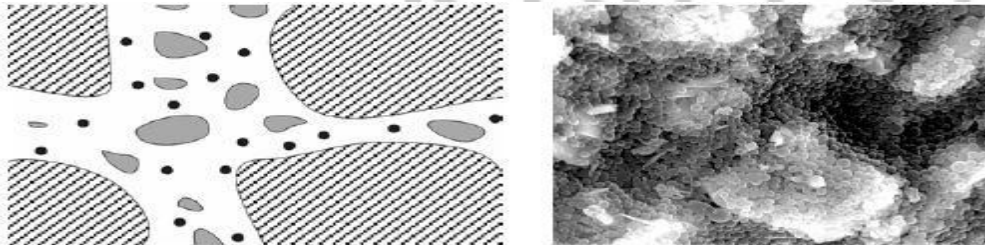


Fig 2.1 Interaction between aggregates, cement, polymer and water immediately after mixing (Van Gemert *et al.*, 2004)

The second step proceeds where a portion of the polymer particles is deposited on the surface of the cement grain and the aggregate. The polymer cement ratio determines the amount of polymers present in the pore solution and present at the aggregate surface. Part of the polymer particles may coalesce into a continuous film. This preferably takes place at the surface of the cement hydrates where extra forces are exerted on the polymer particles due to the extraction of water for cement hydration. The polymer film can partly or completely envelop a cement grain, which results in a retardation or even a complete stop of the hydration of the cement grain.

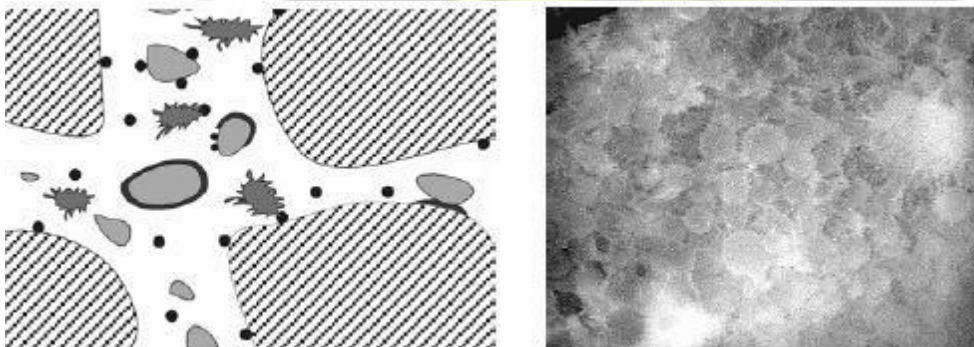


Fig 2.2 Interaction at the second stage (Van Gemert et al., 2004)

The proceeding stage consists of cement hydration, polymer flocculation and possibly polymer coalescence into a film. The processes that take place depend on the curing conditions. If a dry curing period is included, polymer film formation takes place during this step, which influences the cement hydration process as well as the strength development at early ages. In the bulk liquid phase, hydrate precipitations are present, which form a combined inorganic and organic product. The fractions of the different types of product formed depend on the polymer to cement ratio used. The polymer fractions included in these hydration products do not contribute to the strength development of the specimen.

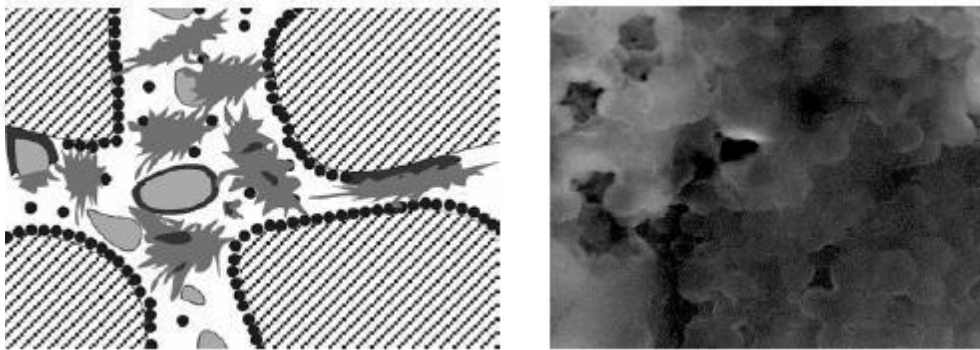
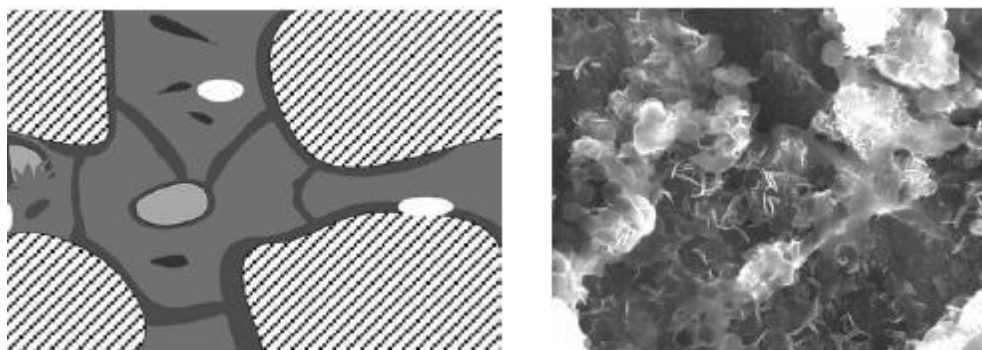


Fig 2.3 Cement hydration proceeds, polymer film formation starts at specific spots (Van Gemert et al., 2004)

The final stage includes further hydration and final film formation. Through the cement hydrates, a continuous polymer film forms as water is further removed from the pore solution. The part of the polymer particles, that is still present in the dispersion, is restricted to the capillary pores and at the interface of the aggregates and the bulk polymer cement phase. It is this part which contributes the most to the elastic and final strength properties. The continuity of the polymer phase through the binder matrix is more pronounced in the case of a higher polymer cement ratio (Van Gemert et al., 2004).



**Fig 2.4 Cement hydration continues, the polymer particles coalesce into a continuous film
cement particles are hydrated (Van Gemert *et al.*, 2004)**

2.2.4 Properties of Polyethylene

Polyethylene (PE) resins are a general class of thermoplastics produced from ethylene gas.

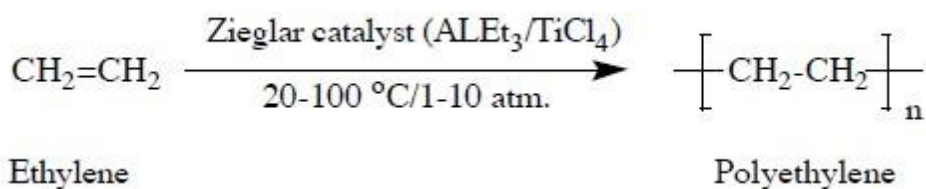
Ethylene gas is derived from the cracking of natural gas feedstock or petroleum by products. Under broad ranges of pressures, temperatures and catalysts (depending PE type), ethylene generally polymerizes to form very long polymer chains. Polyethylene is the world's most common plastic which finds innumerable applications in everything from bottles and jugs to shopping bags and children's toys. Ethylene is a simple hydrocarbon with a pair of double bonded carbon atoms and four hydrogen atoms.

All polyethylenes are long polymers of ethylene with central chain of carbon atoms, each of which is bonded to the carbon ahead of it and the carbon behind it and two hydrogen atoms. Some polyethylenes have secondary chains that branch out from the first chain; HDPE, however, is unbranched. This structural difference between HDPE and other polyethylene is important for determining its function.

Historically, polyethylene was made using very high pressure and temperature which resulted in forming many short chains branching that prevents the molecules from packing closely together, leading to low density polyethylene (LDPE).

If ethylene however, is polymerised at a lower temperature and pressure, in a solvent and in the presence of a complex catalyst, Ziegler catalyst (AlEt_3 and TiCl_4), high density polyethylene is formed, which has longer chains than the low density form. In this form there are few side branches, which allow the molecules to pack together more tightly. Thus because they take up less space the density of the polymer is increased. The high density polyethylene has higher degree of crystallinity and rigidity than the low density polyethylene.

Polymerisation of High Density Polyethylene



High density polyethylene (HDPE) ($0.941 < \text{density} < 0.965$) is a thermoplastic material composed of carbon and hydrogen atoms joined together forming high molecular weight products with the application of heat and pressure, into polyethylene. The polymer chain may be 500,000 to 1,000,000 carbon units long. Short or long side chain molecules exist with the polymer's long main chain molecules. The longer the main chain, the greater the number of atoms, and consequently, the greater the molecular weight. The molecular weight, the molecular weight distribution and the amount of branching determine many of the mechanical and chemical properties of the end product. Other common polyethylene (PE) materials are medium density polyethylene (MDPE) ($0.926 < \text{density} < 0.940$) used for low-pressure gas pipelines; low density polyethylene (LDPE) ($0.910 < \text{density} < 0.925$), typical for small-diameter water-distribution pipes: Linear low density polyethylene (LLDPE), which retains much of the strength of HDPE and the flexibility of LDPE, has application for drainage pipes. Less common PE materials are ultra high molecular weight

polyethylene (UHMWPE) (density > 0.965) and very low density polyethylene (VLDPE) (density < 0.910). High density polyethylene resin has a greater proportion of crystalline regions than low density polyethylene. The size distributions of crystalline regions are determinants of the tensile strength and environmental stress crack resistance of the end product (Lester).

2.2.5 Solid Waste Management in Ghana

The 18th session of the United Nations commission on sustainable development report on waste management reveals that most of the concern for waste management in Ghana is with the urban areas than the rural areas. Urban areas in this country produce a variety of waste that are predominantly domestic solid waste, industrial waste and construction waste. These wastes are sent to a few dumpsites, but majority end up in drains, streams and open places. Waste is disposed of by open dumping, open burning, and controlled burning at dumpsites. Effective delivery of environmental sanitation services remains one of the major intractable challenges facing Metropolitan, Municipal and District Assemblies (MMDAs).

The impact of poor environmental sanitation is immediate which include unsightly littering, foul smelling excreta laden and choked gutters, stagnant pools of water and flooding during rains, vermin and rodents on mounds of refuse dumps, and the attendant prevalence of malaria, cholera, diarrhoea and typhoid in many communities. Ghana is aspiring to reach higher middle income status by 2020, with expected threefold increase in gross domestic product (GDP) from levels of US\$450 to US\$650. The enlarged Ghanaian economy and improved incomes will lead to increases in all types of waste streams and further deterioration of services if effective strategies and plans are not put in place (NESSAP, 2010).

The traditional methods applied in dealing with wastes have been unsuccessful, and the resulting contamination of water and land has led to growing concern over the absence of an integrated

approach to waste management in the country. Combustion of the waste releases carbon dioxide to the atmosphere, leaching of toxic chemicals from landfills contaminates ground water and littering results in the blocking of drains and gutters, which contribute to flooding and serving as breeding sites for mosquitoes.

Plastic products are used in most packaging foods and goods of every household and as such constitute a vast majority of municipal solid waste. Despite the significance of plastics production to Ghana's economy, its contribution to plastic waste generation and management problems in the country has resulted in threats by some MMDAs and Central Government to impose levies on its production or ban its production completely.

These threats if carried out will increase the cost of production of plastic or worsen the unemployment situation in the country. In developed societies the practise often employed in dealing with the menace of waste plastic is recycling. This method is environmentally friendly, as compared to the other means of plastic waste disposal aforementioned even though it is capital intensive. The recycling of plastics generates a means of employment and brings about a massive economic potential to the nation. The recovery and reuse of once waste material creates the avenue for the generation of new energy sources and materials for diverse applications.

CHAPTER THREE

METHODOLOGY

3.1 Materials

3.1.1 Cement

Ordinary Portland limestone cement manufactured by Ghacem CEM II/BL 33.5R was used for casting the cubes and beams for all the concrete mixes. The cement was of uniform grey colour and free from any hard lumps and was bought from a local vendor.

Table 3.1 Oxides composition of Portland limestone cement (Sam *et al.*, 2013)

Concentration of oxides (% weight)			
OXIDES	CEM A	CEM B	CEM C
CaO	61.74 ± 0.4	62.19 ± 0.4	57.37 ± 0.3
SiO ₂	18.77 ± 0.6	21.90 ± 0.6	21.69 ± 0.2
Al ₂ O ₃	5.41 ± 0.2	2.50 ± 0.9	6.40 ± 0.2
Fe ₂ O ₃	3.01 ± 0.1	2.92 ± 0.3	3.10 ± 0.1
SO ₃	3.89 ± 0.6	4.03 ± 0.1	4.05 ± 0.1
MgO	3.13 ± 0.4	2.23 ± 0.1	3.34 ± 0.1

3.1.2 Fine Aggregates

Ordinary pit sand used for the experimental program was procured locally from Fumesua, a town in the Ejisu Municipality. The sand was first dried, passed through a 5mm sieve to remove any particles greater than 5mm including roots and debris. Sieve analysis was conducted to determine the particle size distribution using Malest Auto sieve shaker.

3.1.3 Coarse Aggregates

Locally available coarse aggregates/granite supplied by Consar Gh. Ltd having maximum size of 19mm were used in this work. Particle size distribution of the coarse aggregate was also obtained using Malest Auto sieve shaker.

3.1.4 Polymeric Material

High density Polyethylene (HDPE) bottles identified using its recycled code was collected from KNUST environment and used in the work. The labels on the bottles were removed and the bottles were then washed, cleaned, dried and cut or shredded into smaller flake sizes manually using table knife and scissors. The recycled plastic wastes were used to replace coarse aggregate for making the concrete specimens. The specific gravity test was conducted on the plastic aggregates and the Malest Auto sieve shaker was also used for the particle size distribution of the plastic aggregates.



Fig 3.1 Plastic Aggregates

3.1.5 Water

Generally water that is satisfactory for drinking is also suitable for use in concrete. In this work portable water suitable for human consumption was employed in the experimental procedures.

3.1.6 Sulphuric Acid, H_2SO_4

A Philip Harris laboratory acid (AnalaR grade) with the following properties was used

Assay 98%

Wt per ml 1.84g

Maximum limit of impurity

Chloride 0.007%

Arsenic 0.0002%

Lead 0.001%

Non – volatile 0.01%

3.1.6 Nitric Acid, HNO_3

A Philip Harris laboratory (AnalaR grade) acid 70% W/W was also employed

Purity % 69 – 70

Wt per ml 1.42g

Arsenic 0.0001%

Lead 0.0002%

3.2 Equipment

Tools and equipment employed in this experimental work include;

- a) Concrete mixer for mixing homogeneously the aggregates and the water
- b) Electronic balance for measuring mass of aggregates and cube specimen
- c) Volumetric flask for measuring volume of water
- d) Cube and beam moulds for casting the concrete
- e) A tamping rod for tamping sides of the moulds during casting
- f) Curing tanks
- g) Oven for drying the samples at constant temperature
- h) Sieves for sieving impurities from the aggregates
- i) Malest auto sieve shaker for sieve analysis
- j) Slump cone for determining the workability of the fresh concrete
- k) Hydraulic compressive strength machine

- l) Blackhawk flexural strength testing machine

3.3 Preparation of Samples

3.3.1 Mix Proportion

The control mix has a mix ratio of 1:2:3 (cement: fine aggregate: coarse aggregate) which was adapted for this work with a constant water- cement ratio of 0.55. For making mixes containing plastics, the amount of plastic were calculated as 2%, 4%, 6% and 8% by weight of the coarse aggregate in the control concrete. The mix proportion for the control and the other mixes for the cube and beam specimens are shown in Table 3.2 and Table 3.3 (Appendix A).

3.3.2 Mixing, Casting, Curing

The fine aggregate, coarse aggregate and plastic aggregates were weighed first and mixed homogeneously for about two minutes in the concrete mixer. This was followed by the addition of cement and one third of total mixing water. After two minutes of mixing, remaining mixing water was added subsequently. Mixing was ceased after five minutes for all mixes when a homogenous mixture has been obtained.

Before casting, all the cubic moulds and beam moulds were cleaned and oiled properly. The moulds were secured tightly to ensure that there were no gaps left on the mould which could lead to a possibility of a slurry leakage. Clean and oiled mould for each category was filled with the concrete in three layers and tamped 25 times with the tamping rod.

After tamping the moulds they were then vibrated from side to side using Kango hammer type F vibrator. The vibration was stopped as soon as the cement slurry appeared on the top of the moulds.

The specimens were left in the steel moulds covered with wet sack for 24 hours. After 24 hours the specimens were remove from the moulds then kept in the curing tank containing clean water till the stipulated day of testing of mechanical and other properties.



Figure 3.2 Concrete Mixer



Figure 3.3 Hammer Vibrator

3.4 Test Conducted

3.4.1 Aggregates Test

3.4.1.1 Particle Size Distribution (PSD)

The shredded plastic waste (166g) was weighed and then placed on the first sieve of the arranged series of sieves of the Malest Auto sieve shaker and the machine was turned on. The sieve shaker shook the plastic aggregates with some aggregates passing through some sieves and others retained. After 10 minutes the sieve shaker automatically stops and plastic aggregates retained in the respective sieves were weighed for their masses. The same process was repeated with 378g of

sand and 296g of the coarse aggregates respectively. The sieve analysis tables are displayed in Table 3.4, Table 3.5, and Table 3.6 (Appendix A).

The particle size distribution curves for all the aggregates are displayed in Figure 3.5, Figure 3.6, Figure 3.7 and Figure 3.8 (Appendix B).



Figure 3.4 Malest Auto Sieve Shaker

3.4.1.2 Specific Gravity

An empty relative density bottle was weighed and then filled with HDPE aggregates and then weighed again. Since HDPE is less dense than water and floats in water, kerosene was used as the liquid for this experiment. The bottle containing the plastics was then filled with kerosene and reweighed. The kerosene was poured away and the specific gravity bottle then filled with water and reweighed. The same procedure was repeated with a different bottle and the average specific gravity obtained from the results.

The specific gravity (SG) is obtained using the formula

$$SG = \frac{\text{mass of any vol of substance}}{\text{mass of equal volume of liquid}}$$

The various parameters and the results obtained for the specific gravity test is displayed in Table 3.7 (Appendix B).

3.4.2 Workability, Slump Test, ASTM C143 (2005)

Fresh concrete is defined as concrete at the state when its components are fully mixed but its strength has not yet developed. The properties of fresh concrete directly influence the handling, placing and consolidation, as well as the properties of hardened concrete. Workability is defined in ASTM C 125 as the property determining the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity.

The primary characteristics of workability are consistency (or fluidity) and cohesiveness. Consistency is used to measure the ease of flow of fresh concrete and cohesiveness is used to describe the ability of fresh concrete to hold all ingredients together without segregation and excessive bleeding. The consistency or the ease of flow of the concrete is determined using the slump test.

The interior of the slump cone was dampened and the cone was put on a flat level surface. The mould was then held firmly in place by standing on the two foot pieces on either side of the mould after which the slump cone was filled with the freshly prepared concrete in three layers with a trowel. The cone was tamped 25 times with tamping rod for each level of filling after which the cone was removed vertically upwards and the slump was measured using a rod and a rule.

The slump measured was the vertical distance between the top of the mould and the displaced original center of the top surface of the specimen.

The slump results are shown in Table 3.8 (Appendix A).



Figure 3.9 Measuring slump using the Slump Cone

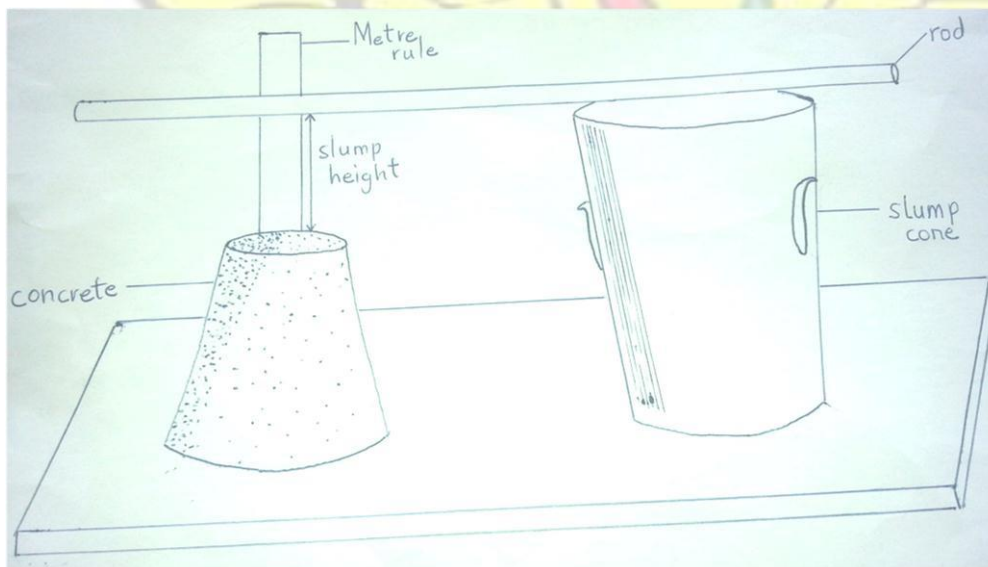


Figure 3.10 Schematic diagram for measuring Slump height

3.4.3 Compressive Strength, ASTM C39 (2014)

When stress is applied on a hardened concrete the response of the concrete depends on the stress type and on various factors which include, properties and proportions of materials that are used for concrete mixture design, degree of compaction, and conditions of curing (Janković *et al.*, 2011). The compressive strength of concrete is the most common measure for judging not only the ability of the concrete to withstand load, but also the quality of the hardened concrete. This test method consists of applying a compressive axial load to moulded cylinders or core at a rate which is within a prescribed range until failure occurs.

Specimens for the testing of mechanical properties such as compressive strength was prepared by filling 100mm×100mm×100mm lubricated cubical moulds. After 24 hours the specimens were removed from the moulds and placed on curing tanks containing water. Three samples were taken from each percentage replacement of HDPE waste plastic content and their compressive strength determined after 7, 14 and 28 days of curing in clean water.

The compressive strength was calculated from the formular;

$$\text{Compressive strength} = \frac{\text{maximum applied load}}{\text{cross sectional area of the specimens}}$$

$$\text{Compressive strength} = \frac{\text{load}}{L_1 \times L_2}$$

Where L_1 is the length of the cube specimen

L_2 is the height of the cube specimen

ELE hydraulic compressive strength machine



Hardened cube concrete

Figure 3.11 Determining Compressive strength of Cube Sample

The average of the two most consistent compressive strength values for each

curing day was used for the analysis. The compressive strength results obtained for all the samples at each curing date for different mix ratios are displayed in Table 3.9 (Appendix A).

3.4.4 Flexural Strength, ASTM C78 (2002)

Flexural strength is the ability of a beam or slab to resist failure in bending. It is measured by loading a concrete beam with a span length at least three times the depth and the flexural strength measured is expressed as modulus of rupture.

A lubricated 100mm×100mm×500mm was filled with the fresh concrete using a trowel and then the specimen was covered with wet sack cloth and left for 24 hours. After 24 hours the specimens were removed from the mould and put into a curing tank containing clean water and left for 28 days before determining the modulus of rupture or flexural strength of the concrete. Ten beams were cast for this test with two samples for each percentage replacement. The average value for the two samples for each percentage replacement was taken for the analysis.

Figure 3.11 below shows Ele Blackhawk flexural strength testing machine use for testing a sample. Table 3.10 (Appendix A) shows the results obtained for the flexural strength for the beam specimens.

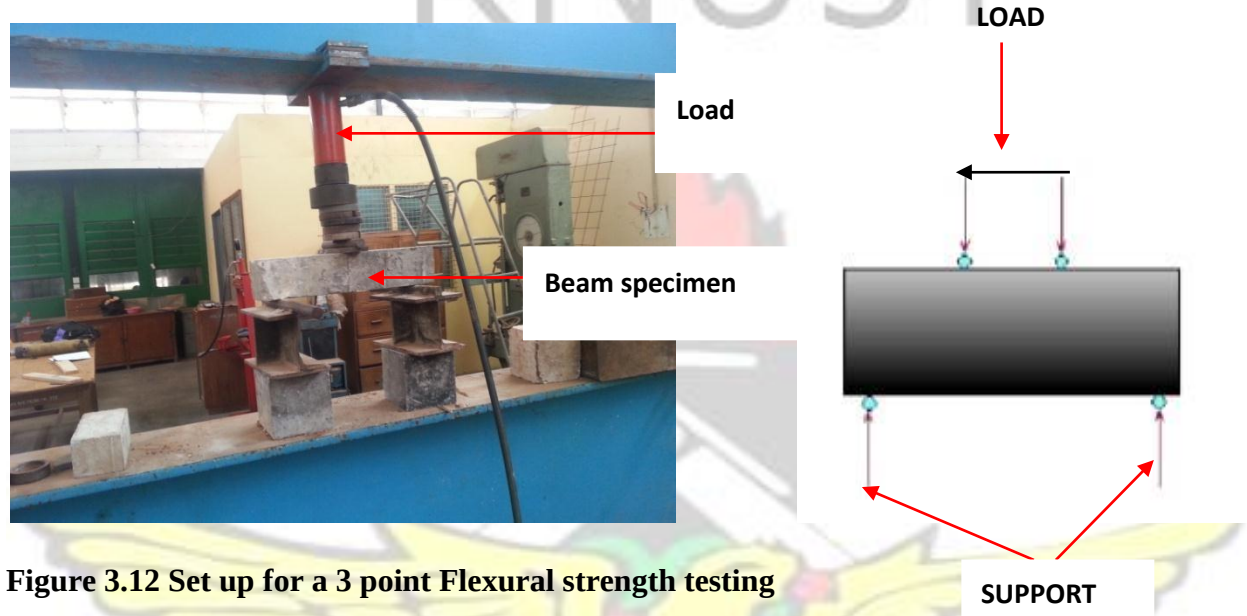


Figure 3.12 Set up for a 3 point Flexural strength testing

The modulus of Rupture or flexural strength of a concrete using the 3 point loading is calculated using the formulae:

$$R = \frac{PL}{bd^2}$$

Where R is flexural strength or modulus of rupture in kPa,

P is the applied load in kN, L is the

span length of beam in mm, b is the

width of beam in mm and d is the

thickness of beam in mm



Fig 3.13 Fractured Beam Specimen after flex

3.4.5 Effects of HNO_3 and H_2SO_4 on Hardened Cubes

Concrete is highly vulnerable to acid media, this is because none of its hydration products (calcium silicate hydrates with different C/S ratios) is stable. Cement and concrete products can be subjected to attack by various inorganic and organic acids including sulfuric, nitric, hydrochloric, and phosphoric. However, sulfuric acid can be considered as the most common cause of deterioration of these products (Allahverdi *et al.*, 2005).

The source of sulphate attack on concrete may either be due to external or internal sources. External sources are natural occurring sulphates in the environment or those that are the product of industrial processes or various human activities.

This method in determining the effect of acids on concrete involves the immersion of dry concrete specimens in selected chemical solutions after 28 days of water curing then their unit weight, colour change and their compressive strength determined after the specific number of days of immersion in the chemical solution (Sekta *et al.*, 2012).

After 28 days of curing cube specimens in clean and portable water, the specimens were removed from the curing tank. The cube specimens were then left to dry in air for 24 hours in laboratory conditions. Then the unit mass of the dried cubes were taken after which two solutions one containing 5% of HNO_3 and the other containing 5% H_2SO_4 by volume or weight of water were prepared. The dried specimens were then totally immersed in the respective solutions for 28 days. After 28 days of immersing the cube specimens in acidic solutions they were then removed and their new mass, new compressive strength, colour changes and the percentage loss in mass was determined.

The loss in mass is determine using the formula

$$\% \text{ loss in mass} = \frac{M_1 - M_2}{M_1} \times 100\%$$

Where M_1 = mass of specimen before immersion

M_2 = mass of specimen after immersion

The loss in mass and compressive strength after immersion in H_2SO_4 is displayed in Table 3.11 (Appendix A) whiles that of HNO_3 is shown in Table 3.12 (Appendix A).



Figure 3.14 Cube Specimens after 28 days in HNO_3



Figure 3.15 Fractured Cube Specimen after 28 days in H_2SO_4

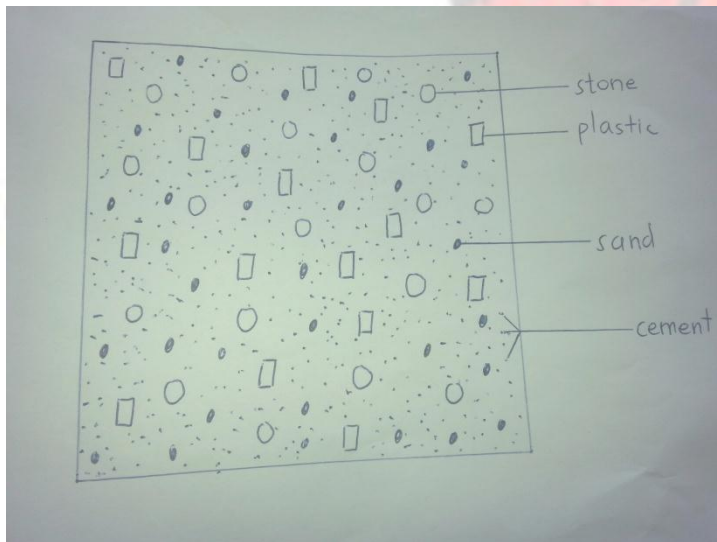


Figure 3.16 Schematic diagram of the composition of the fractured surface of Polymer modified concrete

3.4.6 Water Absorption of Hardened Specimen

The water absorption of a concrete surface depends on factors including mixture proportions, the presence of chemical admixtures and supplementary cementitious materials, the composition and physical characteristics of the cementitious component and that of the aggregates. It also depends on the type and duration of curing, the degree of hydration or age and the presence of micro cracks.

Water absorption is also strongly affected by the moisture condition of the concrete at the time of testing.

Air dried cubes specimens were weighed for their masses and then the dried samples were placed in an oven at a constant temperature of 107°C for 24 hours to ensure the samples were completely dried with a constant mass. After 24 hours the cube specimens were removed and their masses noted and recorded. The samples were allowed to cool in the laboratory and then immersed in clean water for 24 hours. After 24 hours of immersion in water the specimens were removed and their masses weighed.



Figure 3.17 Cube Samples in the oven



Figure 3.18 The Oven

The percentage absorption of water was then calculated using the formular`

$$\% \text{Water absorption} = \frac{W_2 - W_1}{W_2} \times 100\%$$

Where W_1 is the oven dry mass of the test specimen

W_2 is the wet mass of the test specimen

The mass of water absorbed and the percentage mass of water absorbed is shown in Table 3.11 (Appendix A).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Fresh State Test (Slump Test)

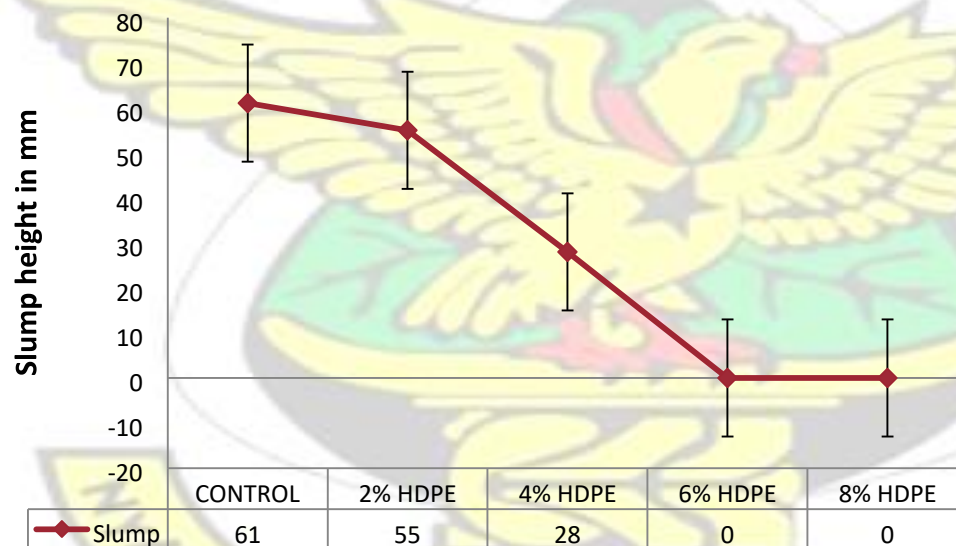


Figure 4.1 Slump test results for control and replacement concrete

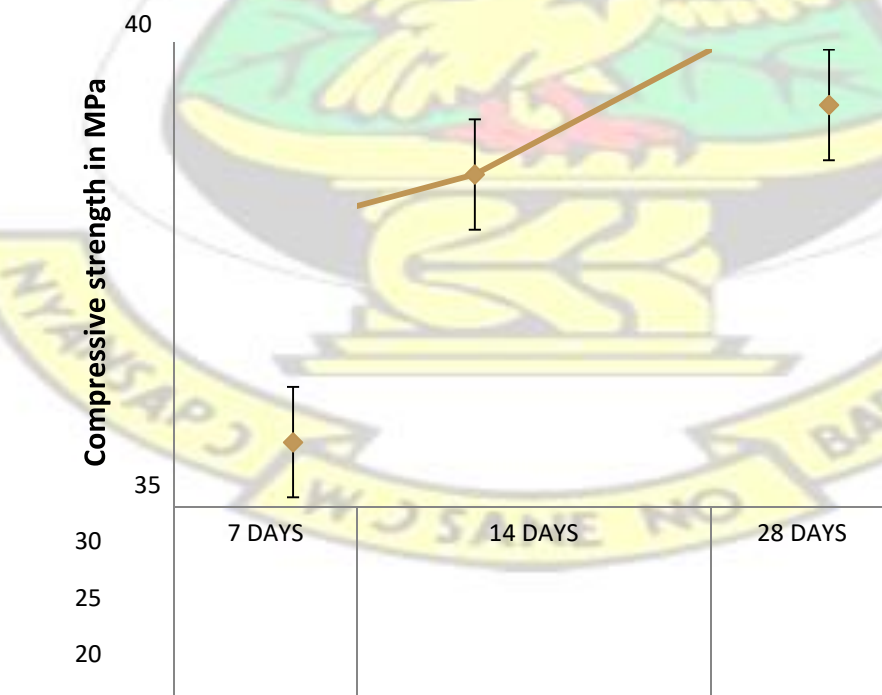
The results obtained from the slump cone test as shown in Figure 4.1 shows that the concrete workability or ease of flow for the control was 61mm while no slump was obtained for 8% HDPE replacement. The general trend of the slump height decreases as the percentage replacement of

coarse aggregate with waste HDPE increases. With 2% HDPE replacement the slump measured reduced appreciably from 61mm for the control to 55mm. A more drastic decrease in the slump was observed with 4% HDPE replacement which was 28mm. A further increase in the plastic waste content yield no slump as observed from the results obtained for the 6% and 8% HDPE waste replacement respectively which indicates difficulty with which the concrete will flow. It therefore means that more water is required to make the concrete workable with 6% and 8% HDPE inclusion in the concrete.

Slump is prone to decrease sharply with increasing waste plastic ratio (Baboo *et al.*, 2012). Prahallada *et al.*, 2013 explained this trend as due to the addition of waste plastic fibres obstructing the flow and reducing the workability of the concrete.

4.2 Hardened State

4.2.1 Compressive Strength



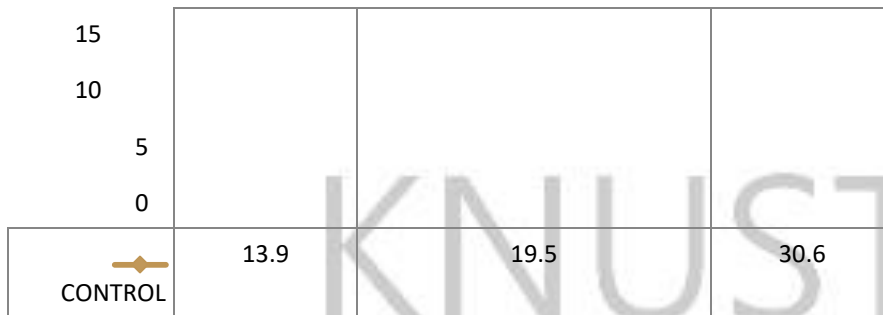
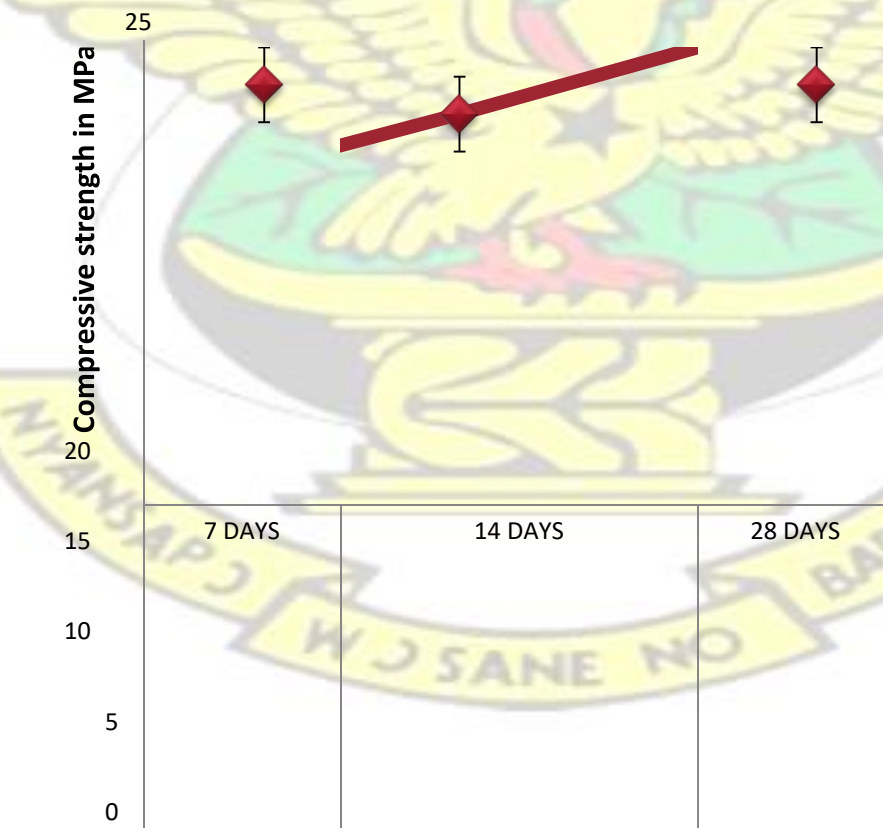


Figure 4.2 Compressive strength results for Control Specimen

As depicted by Figure 4.2 the compressive strength for the control concrete increases with increasing curing age. The minimum compressive strength was obtained at the early days of curing which was 13.9MPa for 7 days. As expected the compressive strength of concrete increases as the curing age increases with 14 days recording a compressive strength of 19.5MPa. The 28 day compressive strength obtained was 30.6MPa which shows a remarkable leap in strength of the control concrete.



2% HDPE	12.6	16.1	19.8
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Figure 4.3 Compressive strength for 2% HDPE replacement

Figure 4.3 shows the compressive strength results obtained with replacing 2% coarse aggregate with HDPE waste. The 7 days compressive strength was 12.6MPa lesser than what was obtained for the control at the 7 days. The compressive strength obtained for the 14 days was 16.1MPa which increased to 19.8MPa after 28 days of curing. Thus the general increase in compressive strength as the curing day's increases was also observed with 2% replacement of coarse aggregate with waste HDPE.

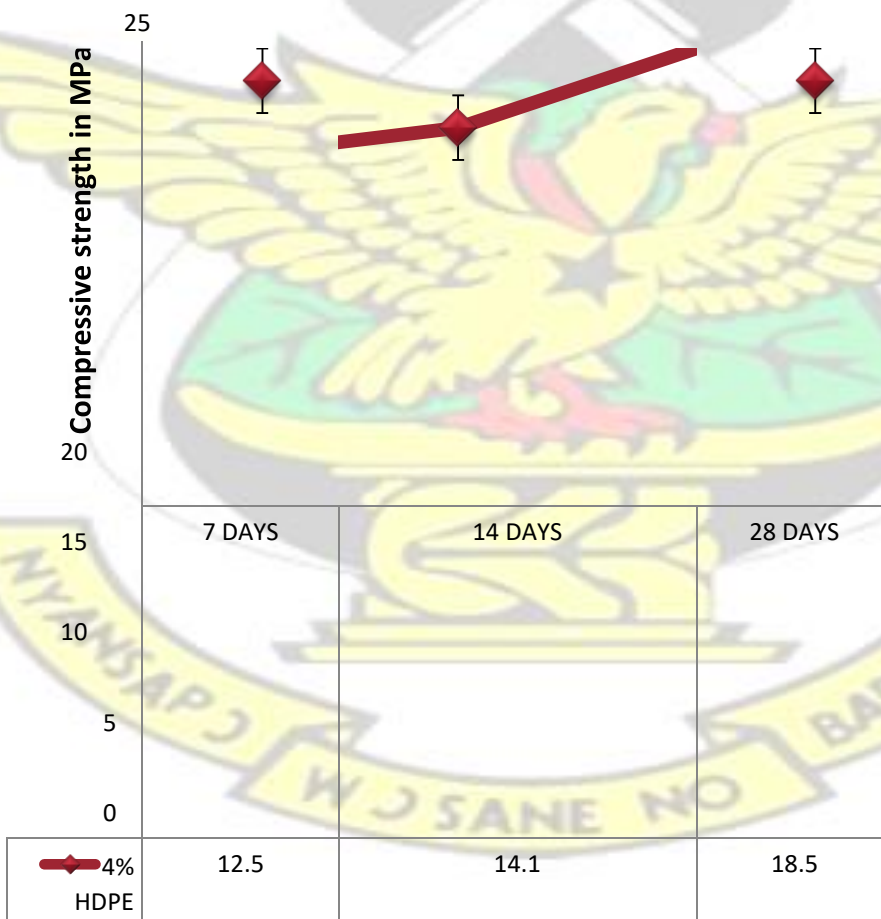


Figure 4.4 Compressive strength for 4% HDPE replacement

From Figure 4.4 with replacement of 4% coarse aggregate with waste HDPE, the 7 days compressive strength was 12.5MPa but there wasn't a significant increase in strength for the 14 days which was 14.1MPa. However there was a leap in compressive strength for the 28 days which was 18.5MPa.

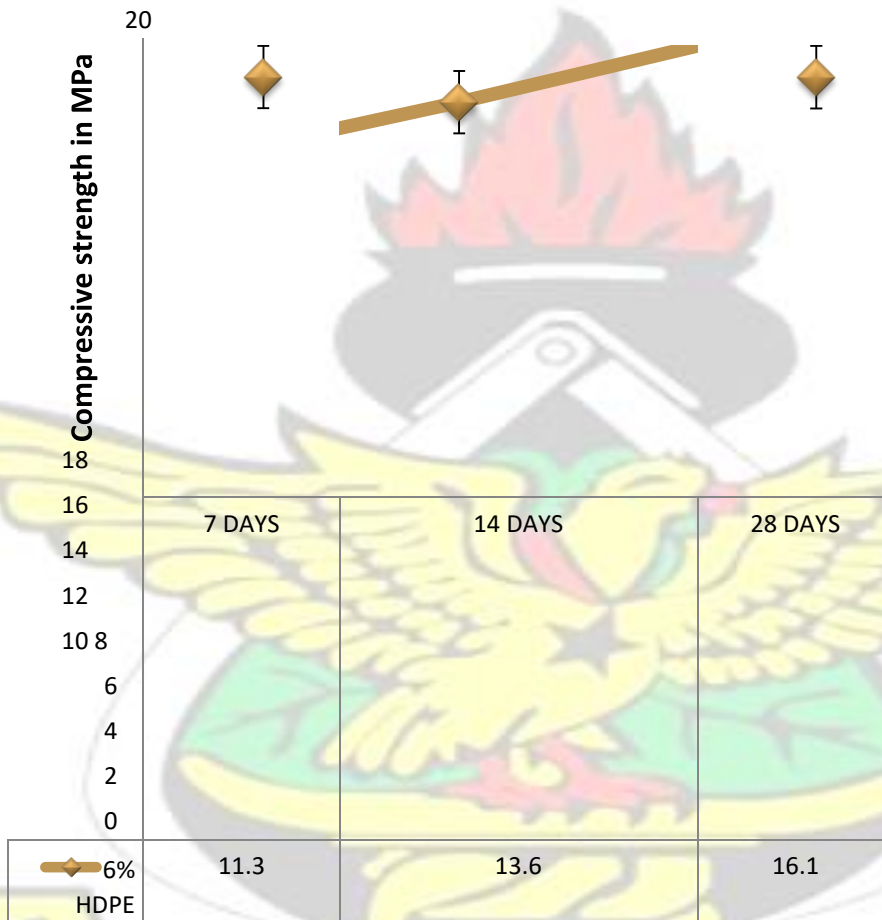


Figure 4.5 Compressive strength results with 6% HDPE replacement

Figure 4.5 shows the results obtained with replacing 6% coarse aggregate with waste HDPE, 7 days recorded a compressive strength of 11.3MPa. As expected there was an upward increase

in the compressive strength with 14 days being 13.6MPa and 28 days compressive strength being 16.1MPa.

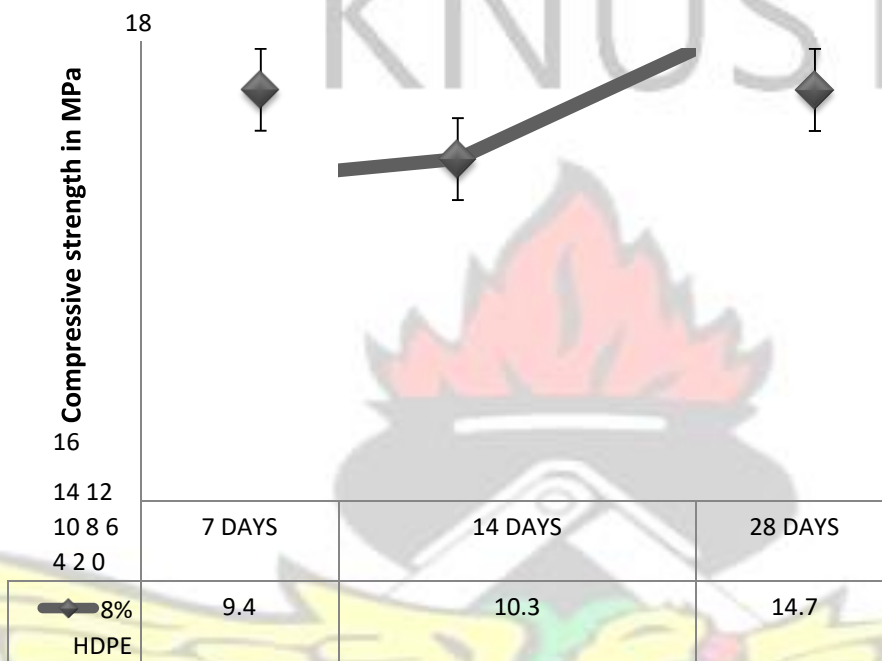


Figure 4.6 Compressive strength for 8% HDPE

From Figure 4.6, 7 days compressive strength with 8% HDPE replacement was 9.4MPa which is the minimum obtained in the 7 days for all the replacement samples. There was as usual an increase in the 14 days compressive strength which was 10.3MPa which is also the minimum obtained compared with other replacement samples. The compressive strength of 14.7MPa was also recorded for the 28 days.

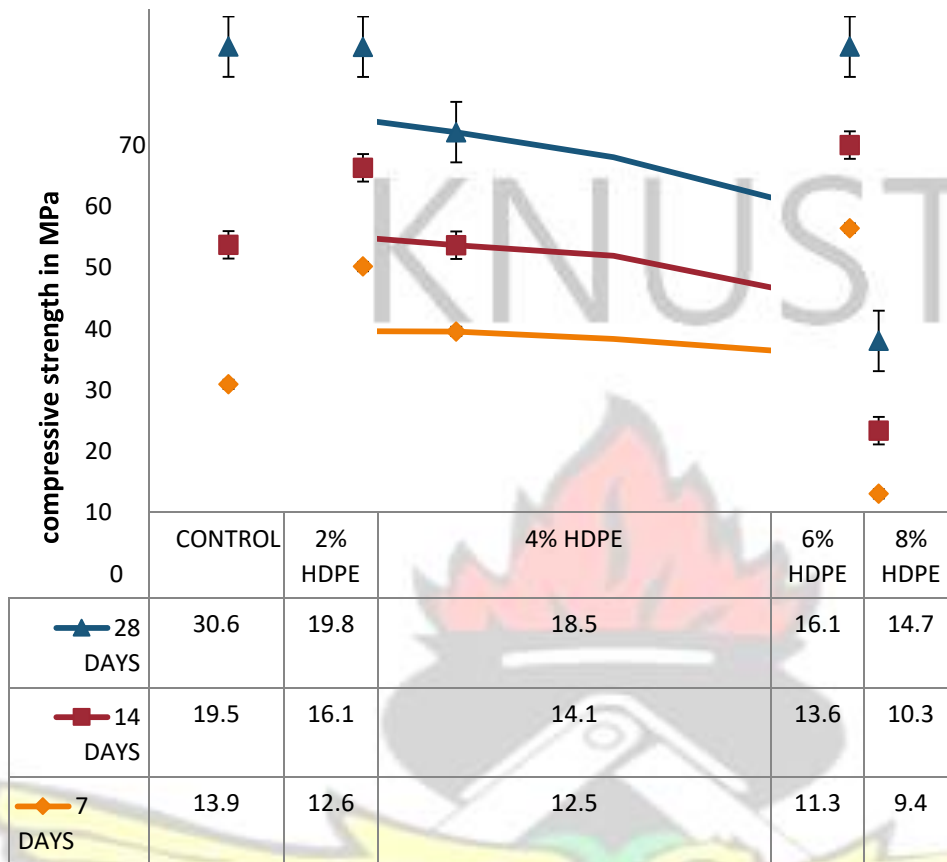


Figure 4.7 Compressive strength results for all Concrete Samples

The combined results of the compressive strength of the cube specimens for all the mix proportions are displayed in Figure 4.7. From the graph it could be deduced that the compressive strength of each mix ratio increases with increase in curing age.

Youcef *et al.*, (2012) attributed this increase to the increase in hydration of cement which causes the evolution of compactness. The control concrete had the greatest compressive strength at the maximum curing age of 28 days which was 30.6MPa. With 2% replacement of coarse aggregate with HDPE the maximum 28 days compressive strength was 19.8MPa. A compressive strength of 18.5MPa was recorded for 4% HDPE replacement which reduced to 16.1MPa with 6% HDPE replacement and 14.7MPa for 8% HDPE replacement.

However, the value obtained for the 7 days compressive strength for each of the mix ratio decrease linearly from each other with the control being 13.9MPa, 12.6MPa for 2% HDPE, 12.5MPa for 4% HDPE, 11.3MPa for 6% and 9.4MPa for 8% HDPE replacement. It can be deduced from Figure 4.7 that with the addition of plastic waste content in the concrete there is a systematic decrease in the compressive strength of the hardened concrete.

The decrease in the compressive strength may be due to decrease in the content of natural coarse aggregate in the concrete mixture.

Raghatate *et al.*, (2012) attributed the reduction in strength to the reduction in bond strength between the aggregates with the introduction of plastic aggregates.

Baboo *et al.*, (2012) also explain this trend to the decrease in adhesive strength between the surface of the waste plastic and the cement paste as well as the particles size of the waste plastic. Bhogyata *et al.*, (2013) also gave a reason to the decrease in compressive as a result of the presence of the macro fibres in the concrete which may have interrupted the bonding and the complete hydration of the cement paste and aggregates.

4.2.2 Flexural Strength

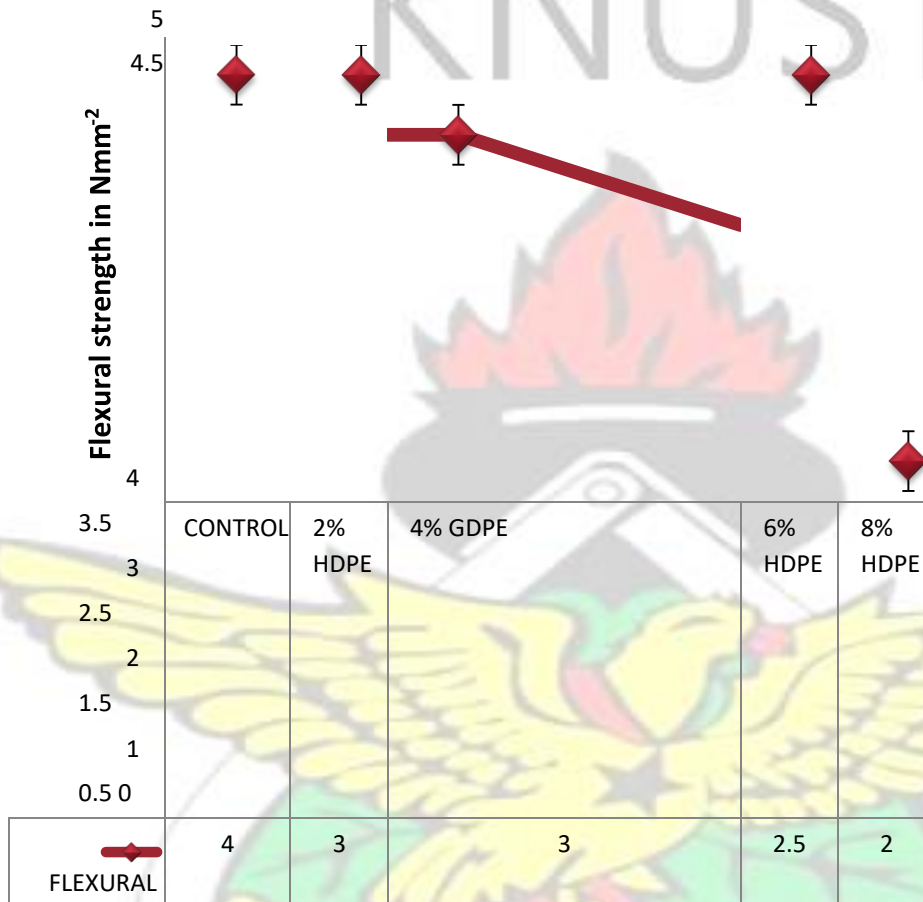


Figure 4.8 Flexural strength of mix proportions after 28 days

The 28 days flexural strength of the beams is displayed with the control beam having a flexural strength of 4Nmm^{-2} . The flexural strength decreased systematically with increasing percentage of plastic content but addition of 2% and 4% HDPE in the concrete yielded the same flexural strength of 3Nmm^{-2} . With 6% addition of waste HDPE into the concrete the flexural strength reduced to 2.5Nmm^{-2} and further to 2.0Nmm^{-2} with 8% addition of waste HDPE content.

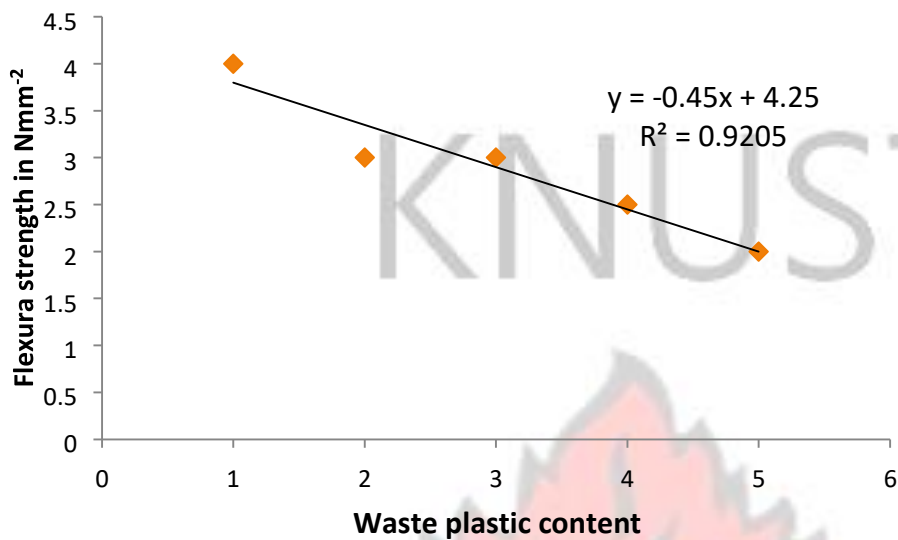


Figure 4.9 Linear relationships between flexural strength and waste plastic content

From Figure 4.9 there is strong correlation between the decrease in flexural strength and the increase in HDPE content in the concrete as indicated by the strong correlation coefficient of 0.9205. Youcef *et al.*, (2012) also notices a reduction in the flexural strength according to the increase in percentage of plastic waste in mortars.

The flexural strength of waste plastic concrete is prone to decrease with an increase in the waste plastic ratio (Baboo *et al.*, 2012, Al Bakri *et al.*, 2011).

Nitish *et al.*, (2013) observed a decrease in flexural strength when natural aggregates were replaced with PVC aggregates.

Baboo *et al.*, (2012) attributed the decrease in the flexural strength to a decrease in adhesive strength between the surface of waste plastic and the cement paste.

4.2.3 Effect of Acids on Strength and Mass

4.2.3.1 Effect of HNO_3

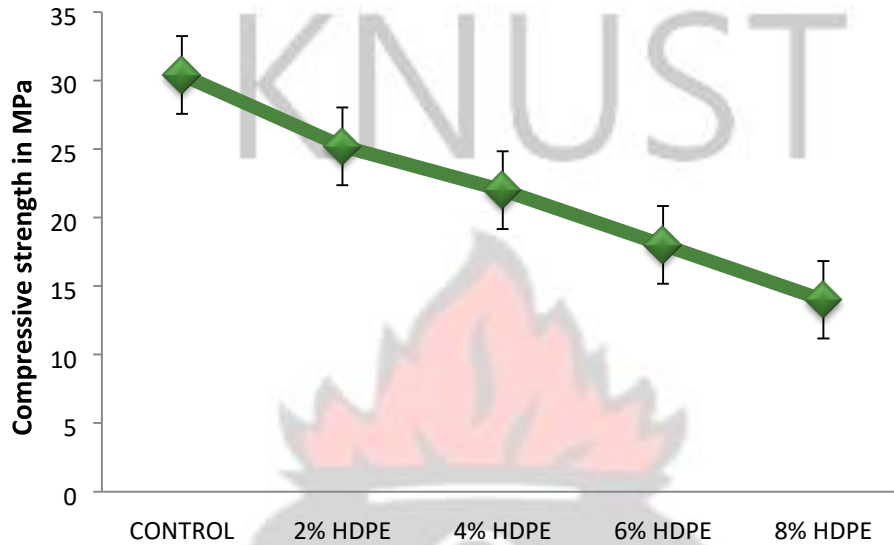


Figure 4.10 Compressive strength of samples immersed in HNO_3

After 28 days of immersing the cube specimens into the HNO_3 solution, the ash colour of the concrete changed into brownish yellow.

As displayed from Figure 4.10 the compressive strength of the specimen decreases with increasing waste plastic content. The control concrete had the maximum strength of 30.4MPa closely followed by 2% HDPE replacement which had 22.5MPa as its compressive strength. With 4% HDPE the compressive strength was 22MPa, 18MPa for 6% HDPE and 14MPa with 8% HDPE replacement in the concrete. The decrease in compressive strength in HNO_3 medium was not severe as clearly depicted by Figure 4.11 with a slope of -4.

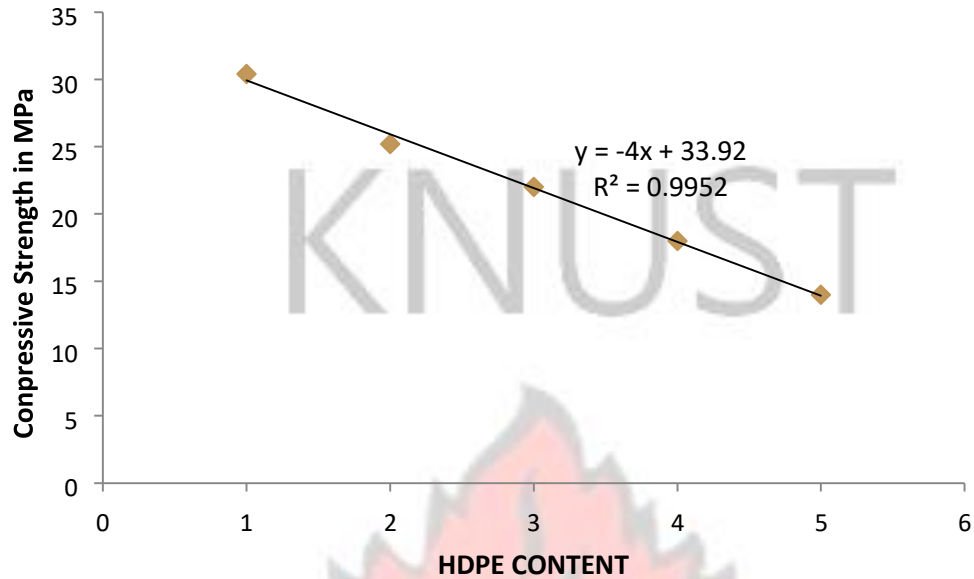


Figure 4.11 Trend line between compressive strength and HDPE content in HNO₃ immersion

The lost in mass of the concrete also increased with the increment in plastic content in the concrete as depicted in Figure 4.12. The control concrete lost mass of 0.044kg, 2% HDPE concrete lost 0.056kg, 0.057kg was lost by the concrete containing 4% HDPE waste plastic. With 6% HDPE waste plastic replacement the sample lost a mass of 0.059kg and 0.058kg with 8% HDPE replacement of coarse aggregate in the concrete as shown in Table 3.12.

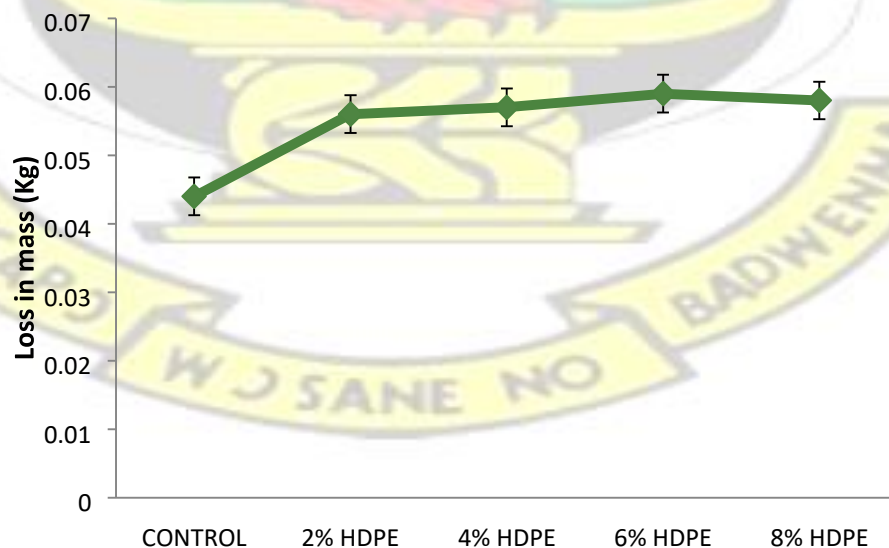


Figure 4.12 Loss in mass of cube samples after HNO₃ immersion

4.2.3.2 Effect of H₂SO₄

The cube specimens after immersion in H₂SO₄ solution showed severe deterioration on all sides of the specimens. The compressive strength of the samples was severely reduced with the control sample recording a compressive strength of 17.6MPa. 14.6MPa was recorded for 2% HDPE content while 10.8MPa was recorded for 4% HDPE waste replacement in the concrete. The compressive strength decreased with the increase in plastic content with 9.4MPa recorded for 6% HDPE and 8.6MPa recorded for 8% HDPE replacement of coarse aggregate content in the concrete. The effect of H₂SO₄ on the control is stronger than on the polymer modified concrete with the control having higher strength deterioration factor compared with the replacement concrete as shown in Table 4.1.

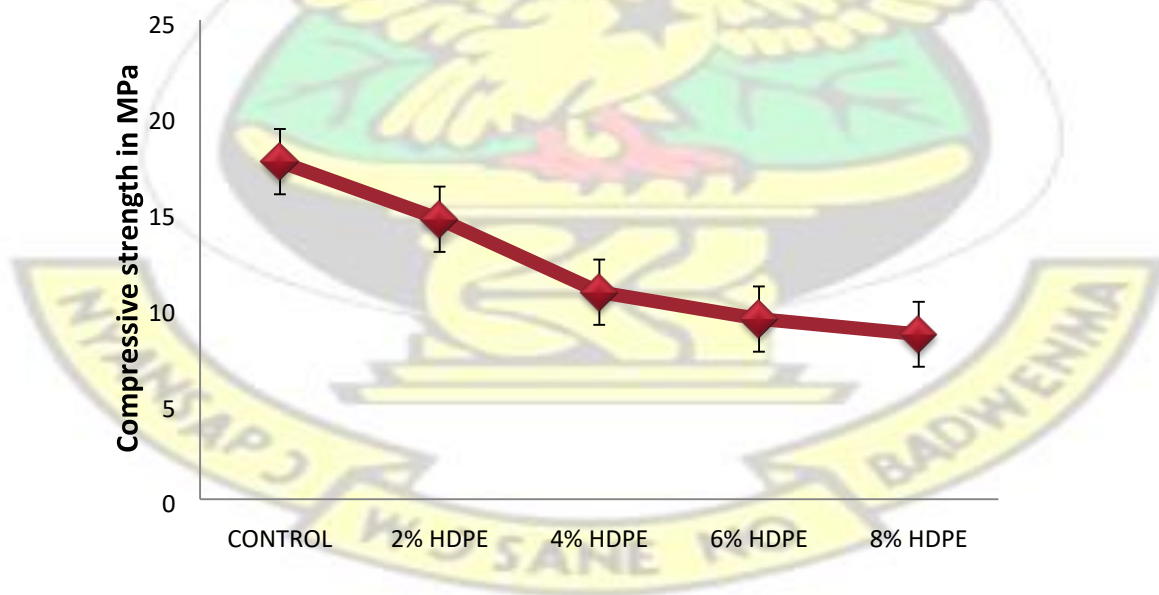


Fig 4.13 Compressive strength of cube samples after H₂SO₄ immersion

The loss in mass of the concrete increases with increasing plastic content as displayed in Figure 4.14. The control lost a mass of 0.124kg which increased to 0.144kg with 2% HDPE content and 0.185kg with 4% HDPE content. The lost in mass of the concrete increases further to 0.204kg with 6% HDPE waste replacement and then 0.224kg lost in mass with 8% HDPE waste plastic content.

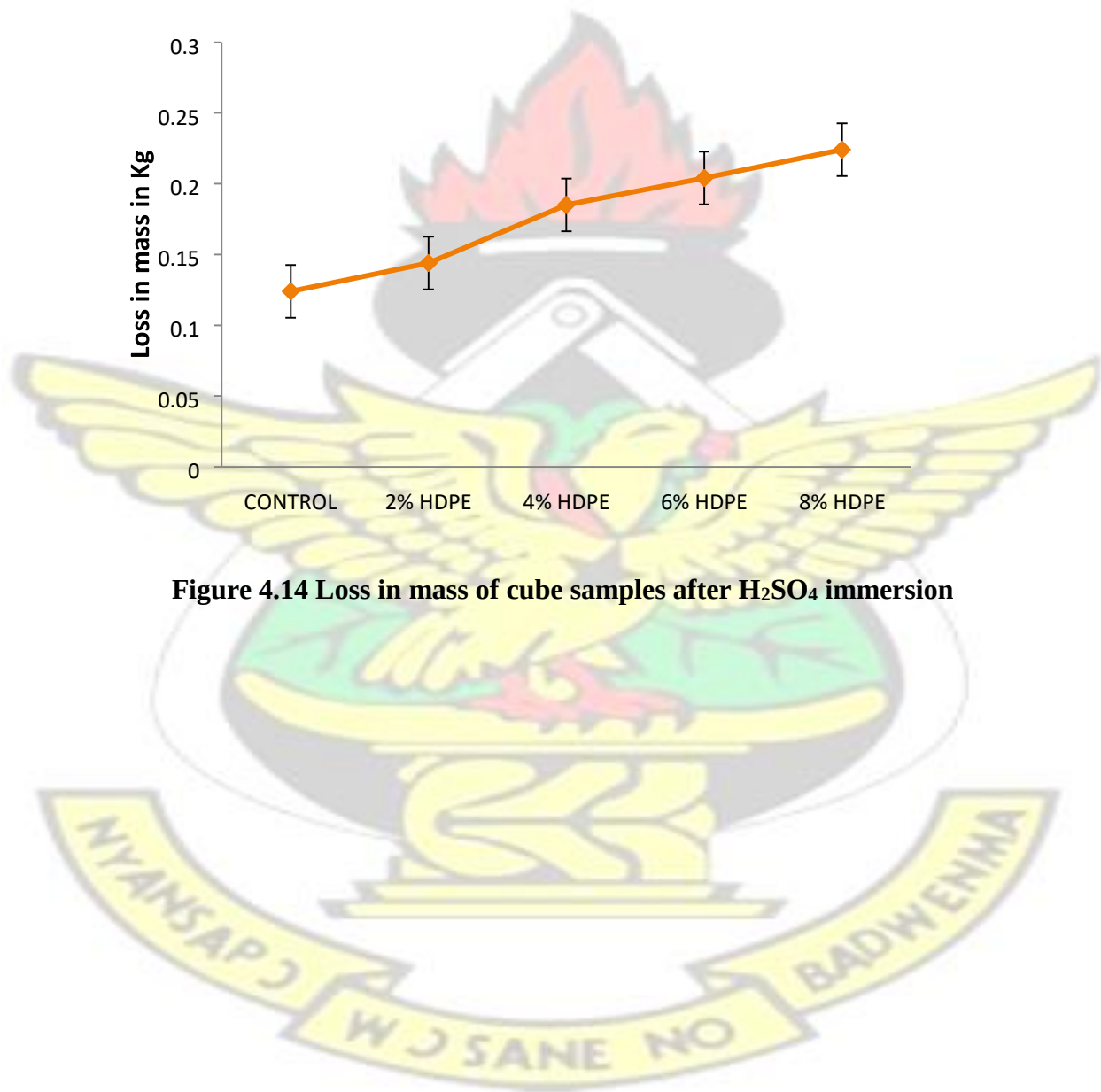


Figure 4.14 Loss in mass of cube samples after H_2SO_4 immersion

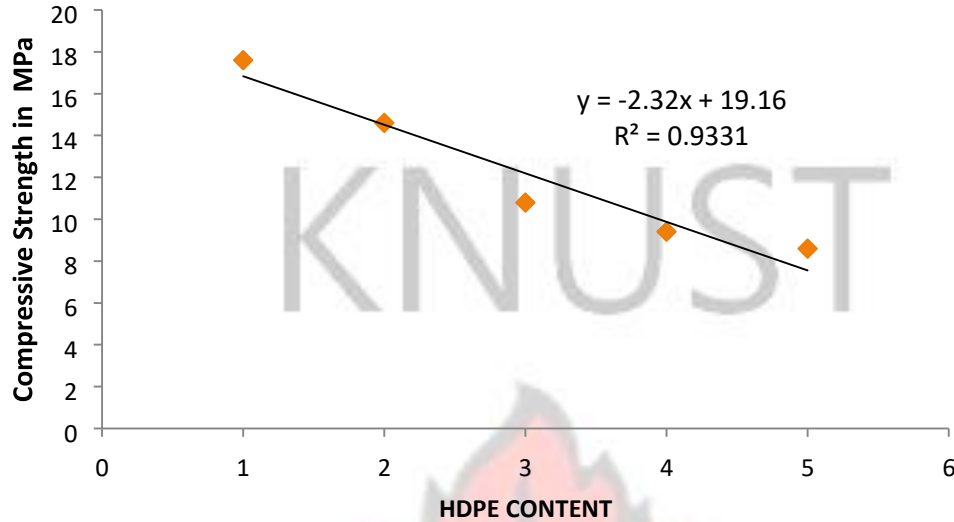


Figure 4.15 Trend line between Compressive strength and HDPE content in H₂SO₄ solution

From Figures 4.11 and 4.15 respectively, it can be deduced that H₂SO₄ has a deleterious effect on the compressive strength compared with H₂SO₄ having a slope of -2.32 compared with -4 for HNO₃.

This loss is due to the deposit of the gypsum which is formed following the action between the portlandite and sulfuric acid (Youcef *et al.*, 2012).



The strength deterioration factor (SDF) was calculated for concrete cubes immersed in H₂SO₄ solution using the equation,

$$\text{Strength reduction factor} = \frac{R_{co} - R_{ca}}{R_{co}} \times 100\%$$

Where

R_{C0} is the compressive strength after concrete was cured in water for 28 days

R_{Ca} is the compressive strength after the concrete was cured in acidic solution for 28 days

The results are displayed in Table 4.1

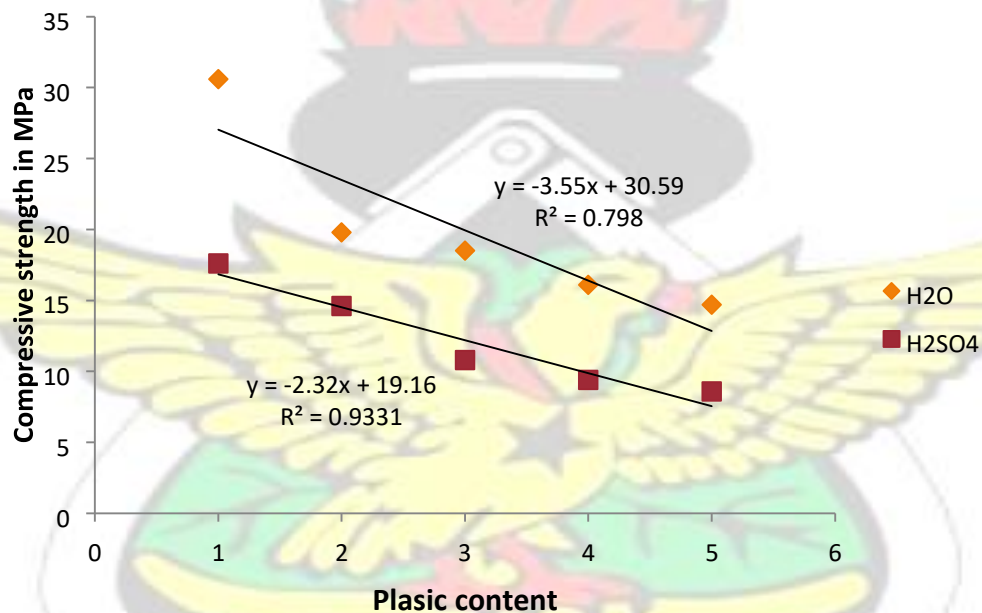


Figure 4.16 Strength comparisons of samples in H₂O and H₂SO₄ medium

From the Figure 4.16 it is obvious that the concrete sample suffers more deterioration in compressive strength in H₂SO₄ medium compared to H₂O medium. The slope of the compressive strength against waste plastic content gave -2.32 for H₂SO₄ medium and -3.55 for H₂O medium.

This means that the decrease in compressive strength with increase in waste plastic is greater in H_2SO_4 medium than in H_2O medium.

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4.2.3 Water Absorption Test

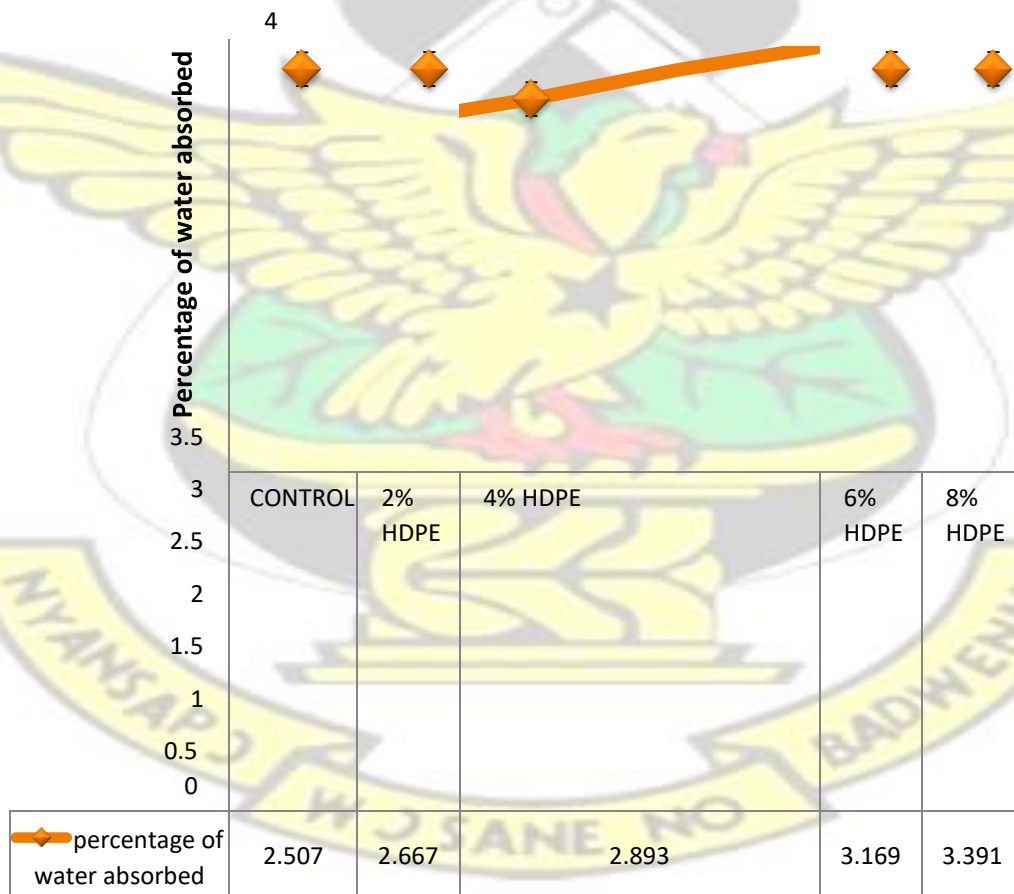


Figure 4.17 Percentage mass of water absorbed by various mix proportions.

From Figure 4.17 the percentage of water absorbed by the concrete specimens increased linearly with the increase in waste plastic content. The control sample absorbed the least with percentage mass of water absorbed being 2.507%. The plastic aggregates concrete absorbed a little more than the control sample. With 2% HDPE content the concrete sample absorbed 2.667% water which might mean there was not much void in the concrete. A percentage mass of 2.893% was absorbed by 4% HDPE content in the concrete which then increased to 3.169% with 6% HDPE and 3.391% with 8% HDPE replacement in the concrete which may be due to more spaces created with increase in plastic content.

Lack of interface bonding between the plastics and the other aggregates could be a reason for the increase in percentage mass of water absorbed by the polymer modified concrete

Another possible reason is due to higher waste plastic content which occupies the space in the concrete and as the water evaporates it leaves voids thus increase the absorption value (Kartina *et al.*, 2010).

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CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The main objectives of this research proposal was to evaluate the possibility of using shredded waste HDPE plastic waste materials as partial replacement for the coarse aggregate (stone) in concrete composites here in Ghana. To determine the percentage of plastic waste which gives more strength when compared to control concrete was an important parameter to be determined by this investigation. This experimental investigation was intended to find out the effect of addition of waste HDPE on the workability and strength characteristics (mechanical behaviour) of waste plastic concrete.

This would provide a basis for the reuse of HDPE waste in the construction industry and to gain insight into the performance of polymer modified concrete and its mechanism.

After using waste HDPE as a partial replacement for coarse aggregate and examining the properties and doing mechanical test on the concrete and comparing to that of the normal concrete, the following conclusions were deduced:

- There was decrease in the workability of the concrete with increase in the percentage of waste plastic content in the concrete.
- The compressive strength of all the concrete samples increase with increasing curing days.
- The compressive strength also decreases with increase in plastic content in the concrete.
- The increase in mass of water absorbed by the concrete samples with increasing plastic content is insignificant compared to the reduction in the compressive strength with increasing plastic content. It can therefore be deduced that the dominant factor in the reduction of compressive strength of the concrete samples is the percentage HDPE replacement.
- The compressive strength for the normal concrete is higher than the compressive strength of concrete samples containing HDPE plastic.
- With 2% replacements of coarse aggregate in the concrete the 28 day compressive strength reduced by 35.2%, 39.5% for 4% replacement, 47.38% for 6% replacement and 51.96% for 8% replacement.
- The flexural strength of the specimens after 28 days decreases marginally with increase in waste plastic content.
- HNO_3 virtually had no effect on the 28 days compressive strength comparing with concrete cured in water.
- H_2SO_4 had a deleterious effect in the concrete which increases with increasing HDPE content.

- The strength reduction of concrete samples in acidic medium was greater in the control concrete compared with the polymer modified concrete.
- The percentage mass of water absorbed by the concrete samples also increased with increasing plastic content.

From the above findings it can then be concluded that concrete with HDPE waste as partial replacement for coarse aggregates can be used in situations which requires concrete with lower strength up to 20MPa (light reinforced concrete).

Also the benefits of using openly dumped plastic waste in concrete as aggregates resulting in reduction in waste and the problems it creates cannot be ignored.

5.1 RECOMMENDATIONS

From this work and its findings the following recommendations will be suggested for future work

- Chemical admixtures such as superplasticizers can be used to improve the bonding properties of the concrete.
- Electrical properties, insulating or thermal properties and impact strength of HDPE waste plastic concrete can be evaluated to further understand the behavior of such a concrete.
- Different types of post consumer plastics such as Low Density Polyethylene, Polypropylene etc can also be used and studied for their properties and inference as to which one gives the better strength behavior.
- This polymer modified concrete can be used for works which requires lower strength up to 20MPa (driveways, walkways, slabs and footings).

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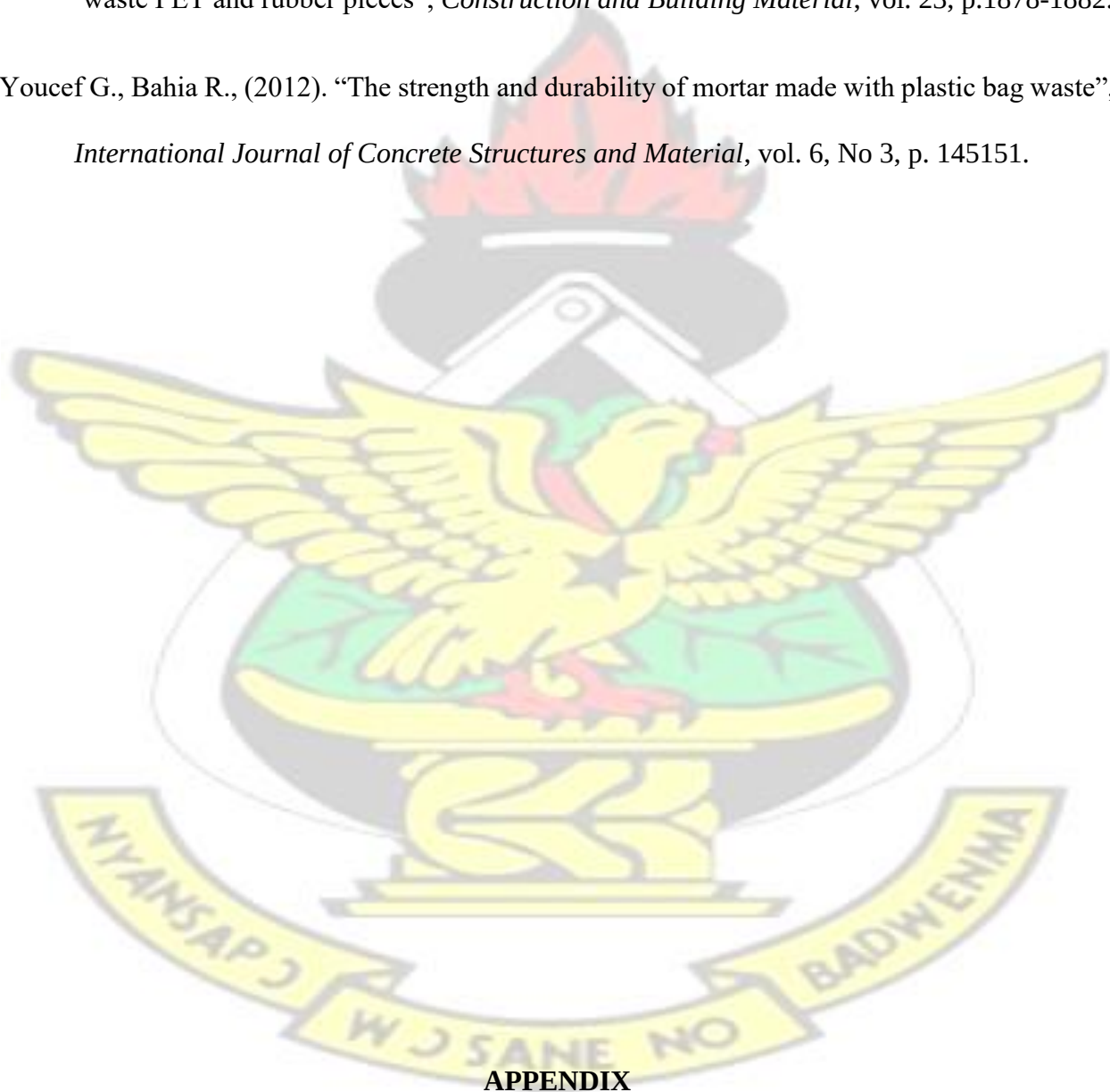
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APPENDIX

A. Miscellaneous Tables

Table 3.2 Mix Proportion for the Control and other Mixes (cube specimens)

	Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Plastic aggregate (kg)	Water (litres)
CONTROL	4.5	9.0	13.5	0.0	2.475
2% HDPE	4.5	9.0	13.23	0.27	2.475
4% HDPE	4.5	9.0	12.96	0.54	2.475
6% HDPE	4.5	9.0	12.69	0.81	2.475
8% HDPE	4.5	9.0	12.42	1.08	2.475

Table 3.3 Mix proportion for the Control and other Mixes (flexural beams)

	Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Plastic aggregate (kg)	Water (litres)
CONTROL	4	8	12	0.0	2.2
2% HDPE	4	8	11.76	0.24	2.2
4% HDPE	4	8	11.52	0.48	2.2
6% HDPE	4	8	11.28	0.72	2.2
8% HDPE	4	8	11.04	0.96	2.2

Table 3.4 Sieve Analysis of Coarse Aggregates

Total Dry Weight (g)		296.0	
Sieve size	Weight	Percentage	Percentage

Metric	retained	retained	passing
(mm)	(g)	(%)	(%)
37.5	0.0	0.00	100.00
19.00	0.0	0.00	100.00
13.20	4.32	1.46	98.54
9.50	2.90	0.98	97.56
4.75	43.90	14.83	82.73
2.36	104.08	35.16	47.57
1.18	56.22	18.99	28.57
0.600	56.11	18.96	9.62
0.300	10.14	3.43	6.19
0.150	6.23	2.10	4.09
DUST	12.10	4.09	

Table 3.5 Sieve Analysis of Fine Aggregate

Total Dry Weight (g)		378.0	
Sieve size	Weight	Percentage	Percentage

Metric	retained	retained	passing
(mm)	(g)	(%)	(%)
37.5	0.0	0.00	100.00
19.00	0.0	0.00	100.00
13.20	0.0	0.00	100.00
9.50	0.0	0.00	100.00
4.75	0.38	0.10	99.90
2.36	80.55	21.31	78.59
1.18	81.06	21.44	57.15
0.6	99.29	26.27	30.88
0.300	47.32	12.52	18.36
0.150	34.81	9.21	9.15

Table 3.6 Sieve Analysis for HDPE

Total Dry Weight (g)		166.0	
Sieve size			Percentage passing

Metric	Weight retained	Percentage retained	
(mm)	(g)	(%)	(%)
26.5	0.0	0.00	100.00
19	0.0	0.00	100.00
13.20	1.55	0.52	99.48
9.50	90.40	30.54	68.94
6.7	63.37	21.41	47.53
4.75	9.56	3.23	44.30
2.36	1.12	0.38	43.92
0.150	0	0.00	43.92
WASTE	0.00	0.00	

Table 3.7 Specific Gravity of HDPE

BOTTLE NO.	A	B
Mass of empty glass Jar + lid	87.79	88.77

Mass of glass Jar + plastic + lid	106.06	105.57
Mass of glass Jar + Plastic +kerosene + lid	181.63	182.83
Mass of glass Jar + kerosene + lid	179.01	180.42
Mass of plastic	18.27	16.8
Mass of kerosene	91.22	91.65
Mass of kerosene used	75.57	77.26
Volume of particles	15.65	14.39
Mass of bottle + water only	200.61	202.45
Density of kerosene	0.81	0.81
Average Specific Gravity	0.81	
Bulk Specific Gravity	0.95	0.93
Average Specific Gravity	0.94	

Table 3.8 Slump Height Measured Results

CONCRETE	SLUMP HEIGHT (mm)
CONTROL	61.0
2% HDPE	55.0
4% HDPE	28.0
6% HDPE	0.0
8% HDPE	0.0

Table 3.9 Compressive Strength for three samples in each curing day

	CONTROL (MPa)	2% HDPE (MPa)	4% HDPE (MPa)	6% HDPE (MPa)	8%HDPE (MPa)
7 DAYS	13.6	12.0	13.0	11.6	10.0
	14.2	14.2	12.4	11.0	9.2
	16.2	13.2	12.6	12.2	9.6
14 DAYS	20.0	18.0	14.0	15.0	9.6
	19.0	14.2	15.4	13.6	13.0
	21.2	13.0	14.2	13.4	11.0
28 DAYS	23.4	19.0	17.6	17.0	15.0
	31.0	20.6	19.4	16.6	14.8
	30.2	24.4	21.0	16.2	14.6

Table 3.10 Flexural Strength for beams after 28 days

	Load failure (kN)	Flexural strength (Nmm⁻²)	Load failure (kN)	Flexural strength (Nmm⁻²)	Average flexural strength (Nmm⁻²)
CONTROL	8.0	4.0	8.0	4.0	4.0
2% HDPE	6.0	3.0	6.0	3.0	3.0
4% HDPE	6.0	3.0	6.0	3.0	3.0
6% HDPE	6.0	3.0	4.0	2.0	2.5
8% HDPE	4.0	2.0	4.0	2.0	2.0

Table 3.11 Loss in Mass and Compressive Strength in H₂SO₄ solution

	Initial mass (Kg)	Final mass (Kg)	Loss in mass (Kg)	Percentage loss in mass	28 Day compressive strength (MPa)
CONTROL	2.560	2.436	0.124	4.843	17.6
2% HDPE	2.527	2.383	0.144	5.698	14.6
4% HDPE	2.663	2.478	0.185	6.947	10.8
6% HDPE	2.662	2.458	0.204	7.663	9.4
8% HDPE	2.726	2.502	0.224	8.217	8.6

Table 3.12 Loss in Mass and Compressive Strength after HNO₃ immersion

	Initial mass (Kg)	Final mass (Kg)	Loss in mass (Kg)	Percentage loss in mass	28 Day compressive strength (MPa)
CONTROL	2.756	2.712	0.044	1.596	30.4
2% HDPE	2.615	2.559	0.056	2.141	25.2
4% HDPE	2.608	2.551	0.057	2.186	22.0
6% HDPE	2.622	2.563	0.059	2.250	18.0
8% HDPE	2.560	2.502	0.058	2.265	14.0

Table 3.13 Mass of Cube Specimen after water absorption

	Before oven (kg)	After oven (kg)	After immersion in water (kg)	Water absorbed (kg)	Percentage of water absorbed (%)
CONTROL	2.551	2.512	2.575	0.063	2.507
2% HDPE	2.631	2.587	2.656	0.069	2.667
4% HDPE	2.554	2.506	2.591	0.085	2.893
6% HDPE	2.568	2.524	2.604	0.080	3.169
8% HDPE	2.636	2.524	2.667	0.075	3.391

Table 4.1 Strength Reduction for cubes immersed in H₂SO₄ solution after 28 days

CONTROL	2% HDPE	4% HDPE	6% HDPE	8% HDPE
42.28	40.16	41.62	41.61	41.49

B. Miscellaneous Graphs

Figure 3.5 Particle Size Distribution (PSD) curve for HDPE only

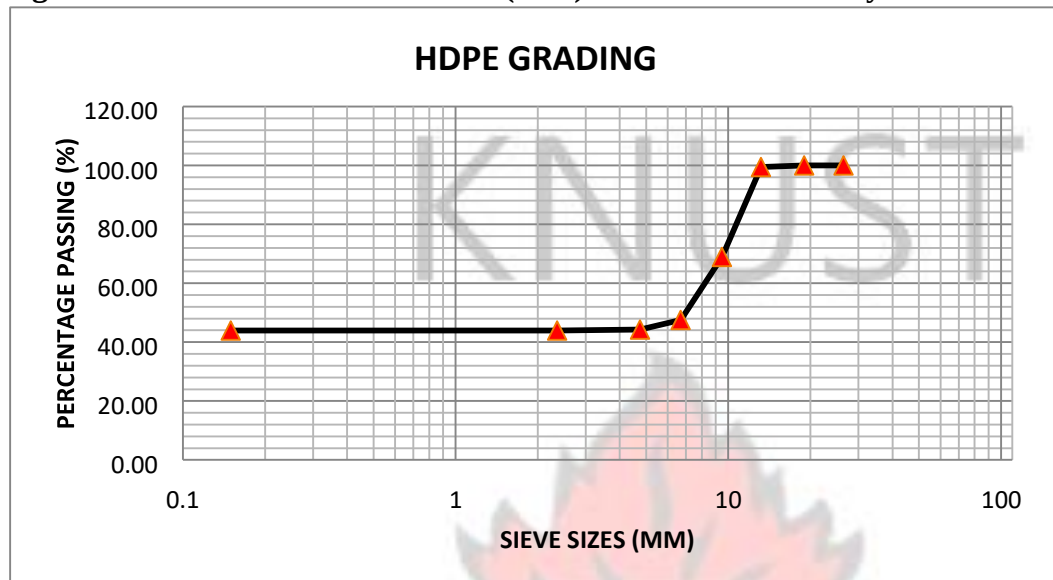


Figure 3.6 Particle Size Distribution (PSD) curve for Coarse aggregate

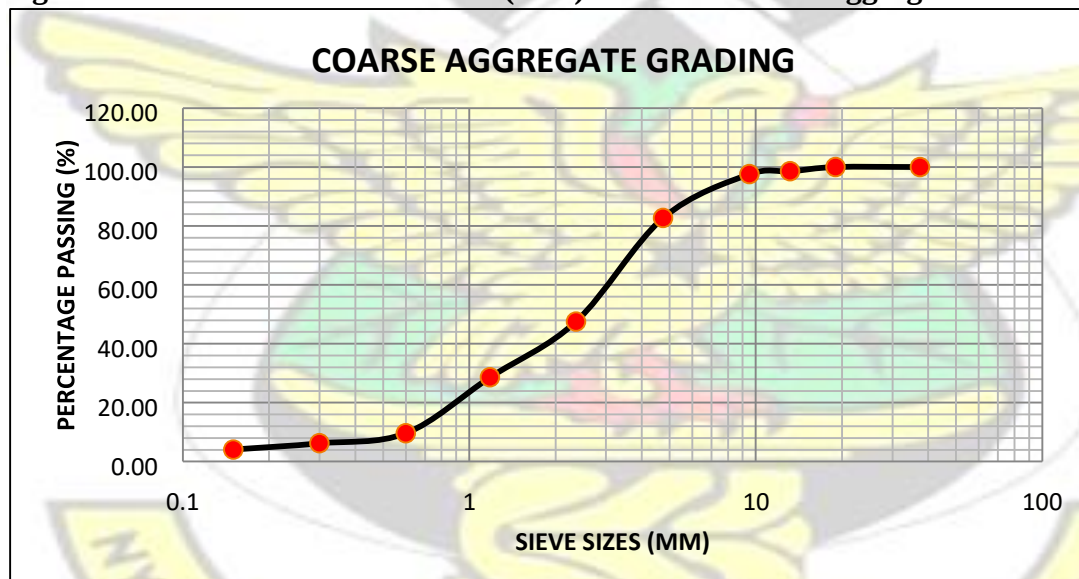


Figure 3.7 Particle Size Distribution (PSD) curve for Sand

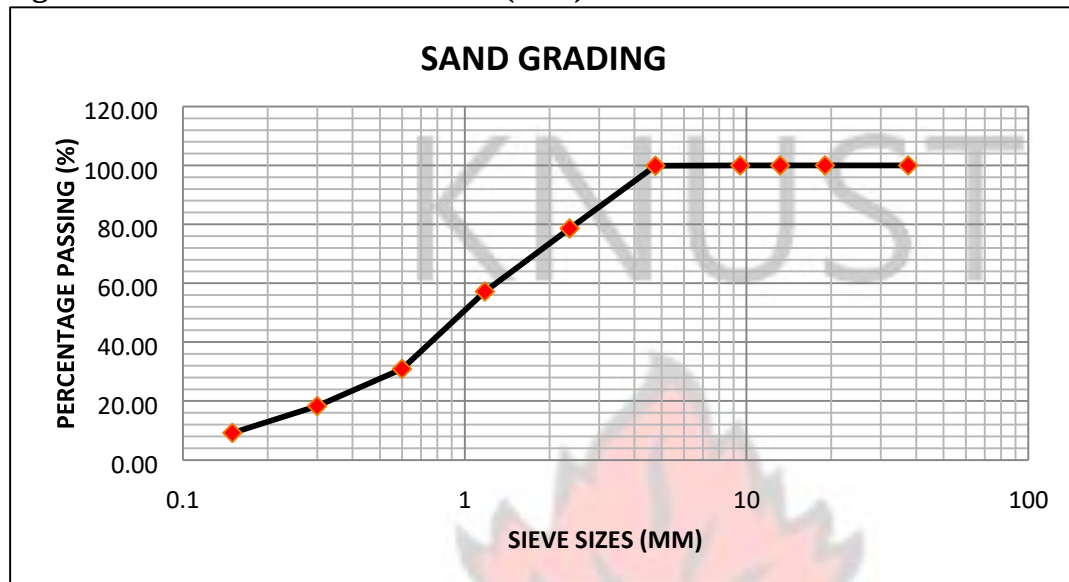


Figure 3.8 Particle Size Distribution (PSD) curve for combined aggregates

