JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

STRUCTURAL ENGINEERING STREAM

Study of Strength Characteristics of Concrete with Partial Replacement of High Density Polyethylene as Fine Aggregate

A Thesis Submitted to School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree Masters of Science in Structural Engineering

BY

ARARSA FEDESA

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STRUCTURAL ENGINEERING CHAIR

STUDY OF STRENGTH CHARACTERISTICS OF CONCRETE WITH PARTIAL REPLACEMENT OF HIGH DENSITY POLYETHYLENE AS FINE AGGREGATE

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DECLARATION

I ARARSA FEDESA, here by do declare that all the work done in this study entitled "Study of strength characteristics of concrete with partial replacement of HDPE as fine aggregate in concrete" originates from my own work and has not been presented by any other person for an award of a degree in JiT or other University. All secondary sources referred in this work have been duly acknowledged and cited.

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ABSTRACT

Concrete is the most widely used man made construction material in construction industries. It is mainly composed of cement, fine aggregate, coarse aggregate and water. The properties of concrete are mainly affected by its ingredients types, quantity and quality. The cement is used to bind the materials in concrete. Fine aggregate and coarse aggregate will fill the most of the spaces in concrete. There are numerous materials that can replace each constituent in concrete. In this study grinded HDPE waste plastic was used to partially replace fine aggregate at 0%, 3%, 6%, 9% and 12% dosage by volume proportion to evaluate various strength parameters like compressive strength, split tensile strength and flexural strength. Concrete is strong in compression but it is weak in tension, brittle, low resistant to cracking, lower impact strength and heavy weight. Waste HDPE plastic is one of the solid wastes in our surroundings which mostly pollute the environment condition. In order to overcome such types of problems related to pollution of environment the study deals the engineering property of concrete with waste HDPE plastic.

*Workability, compressive strength, split tensile strength and flexural strength test were performed to determine the competence of reusing waste HDPE plastic in the production of concrete. The average of three identical sample tests for each strength was used to determine the strength of concrete and tested at 7, 14, and 28 days of curing age. All cubes were made with 150mm*150mm*150mm, cylinders with 100mm diameter and 200mm height and beams with cross-section 100mm*100mm*and length of 500mm size.*

The study result revealed that the density decreases for all percentage replacement, mechanical strength of concrete decreases with increasing dosage of HDPE beyond 6% and workability increases with the increase of HDPE. The optimum dosage was found to be 6%. The compressive strength increases up to 10.18%, tensile strength increases by 18.28% and flexural strength increases by 24.01% for 6% HDPE replacement in the concrete mix when compared with control concrete.

***Keywords**: High Density Polyethylene (HDPE), compressive strength, tensile strength, flexural strength, fine aggregate, crack pattern*

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ACRONYMS

ABS	Acrylonitrile Butadiene Styrene
ACI	American Concrete Institute
ASTM	American Standard Test Materials
CA	Coarse Aggregate
CCB	Coal Combustion By-Products
CCBs	Coal Combustion By-products
FM	Fineness Modulus
GGBS	Ground Granulated Blast Furnace Slag
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
LDPP	Low Density Polypropylene
MSW	Municipal Solid Wastes
NCA	Natural Coarse Aggregate
OD	Oven Dry
OPC	Ordinary Portland Cement
PC	Polycarbonate
PCA	Plastic Coarse Aggregate
PCC	Polymer Cement Concrete
PE	polyethylene
PET	Polyethylene Terephthalate
PETE	Polyethylene Terephthalate
PH	Power of Hydrogen
PP	Polypropylene
PS	Polystyrene
PSD	Particle Size Distribution
PVC	Polyvinyl Chloride

RAC	Recycled Aggregate Concrete
RCC	Reinforced Cement Concrete
SSD	Saturated Surface Dry
UPV	Ultrasonic Pulse Velocity
UPVC	Unplasticised Polyvinyl Chloride
w/c	Water Cement Ratio

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Concrete is the most widely used man made construction material in construction industries. When concrete members are subjected to external load there are tensile stresses on one side and compressive stresses on the other side. Concrete is mainly composed of cement, fine aggregate, coarse aggregate and water. The cement is used to bind the materials in concrete. Fine aggregate and coarse aggregate will fill the most of the spaces in concrete. There are numerous materials that can replace each constituent in concrete. Each constituent in concrete can be partially or fully replaced by different materials. Various waste materials are generated from manufacturing industries, house hold service process and municipal solid wastes. The disposal of wastes is one of the major problems related to the environment. The solid waste management is the main problem due the availability of land area. Many research works are carried out by inclusion of waste products in concrete. Some of waste products include discarded tires, plastic, and coal combustion by-products (CCBs). These waste products effect the properties of fresh and hardened concrete if added in concrete mix as an ingredient replacement. The use of waste products in concrete helps in its disposal and it also make economical. Reuse of these wastes in bulk quantity is considered as the best environmental alternative for solving the problem of disposal.

The most common waste materials are Metal and plastic which are available in enormous quantities in the world. The modern lifestyle, alongside the advancement of technology has led to an increase in the amount and type of waste being generated, leading to a waste disposal crisis (Jaivignesh B. and Sofi, 2017). The productive use of waste material represents a means of alleviating some of the problems of solid waste management. Therefore the use of this waste is very important from environment and sustainability aspects. This leads to saving of natural resources and resulting in decrease in environmental pollution. The wastes generated during various operations and their byproduct is one of major problem arising in the world today. Plastic waste is one of the major contributing agents for polluting the environment. (Jaivignesh, B. and Sofi, A., 2017).

Aggregates are the vital constituents of the concrete. The mining of aggregates in rivers has led to deterioration of river basins, also increase in pollution and changes in pH level. In the extraction of aggregates from the river, it causes the river to cut its channel through the bottom of the valley floor in both upstream and downstream of the removal place. The sand mining in rivers had gone up to such an extent that in many countries, there is a legal prohibition on sand mining. Even In places where there is no debar, nowadays satisfactory sand is not promptly available which is required to transport sand over a long distance. The search for an alternate source is of high- priority. Artificially manufactured sands are used as a substitute to the natural sands but are uneconomical. If an appropriate industrial or agricultural by-product, which is a waste material, is used to replace sand partially it will diminish the problems and complications due to the inadequacy of sand. On the other hand, it will also be an environment friendly technique of disposal of huge quantities of materials that would otherwise contaminate land, air and water. If this waste can be used as a partial sand replacement material in concrete, it will be an extremely valuable resource, (Sudharsan A. and Balamurugan G., 2017).

Fine aggregate can also be replaced by different materials. Plastic is one of such material that can replace fine aggregate. The concept of using recycled plastics in the production of new construction materials is important to both improve concrete properties and the plastic recycling industries. The disposal of plastic is very difficult job. So recycling of plastic is more advantageous and it will reduce the pollution due the plastic wastes. The plastic themselves contribute approximately 10% of the total discarded waste. So introduction of plastic waste in concrete is one of the logical methods to reduce the plastic waste problems. (Shyam S. and Drishya P., 2018).

The different types of plastic materials are Polyethylene Terephthalate (PET or PETE), High Density Polyethylene (HDPE), Polyvinyl Chloride (PVC), Low Density Polyethylene (LDPE), Polypropylene (PP), Polystyrene (PS), Polycarbonate (PC), and Acrylonitrile Butadiene Styrene (ABS). In this study grinded HDPE was be used.

Rapid industrial development causes quantities of polymer wastes to increase these recent years due to the boost in industrialization and the rapid improvement in the standard of living. Numerous polymer wastes are available on the environment and not used for household for by recycling. This situation causes serious problems such as wastage of natural resources and environmental pollution. Polymer products such as synthetic fibers, plastics and rubber are not easily biodegradable and it takes long period of time to degrade. Using this waste plastic material for the purpose of concrete production is one way of reducing the environmental problem due to waste plastics. Use of waste plastics in concrete as an ingredient helps in getting them utilize construction materials, reducing the cost of concrete manufacturing and also has indirect benefits such as reduction in land-fill cost, saving in energy and protecting the environment from possible pollution problems.

The utilization of waste HDPE in concrete and to enhance the properties of concrete achieved if the plastic waste used in concrete and not only reduces the pressure on the environment but also improves the compressive, tensile and flexural behavior of concrete, because the disposal of plastic is a very major problem, which requires huge area and also the plastic takes hundreds of years to degrade.

1.2 Statement of the problem

The potentials 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 concept 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 to solve some of the waste problems posed by the plastics (Batayneh *et al.,* 2007).

Concrete is the most used construction material in building construction. In civil Engineering construction the mechanical strength properties of concrete in capability of carrying load is a major concern. Improving the ductility of concrete by modifying ingredient property to some extent can increase strength of concrete. The properties of concrete are mainly affected by its ingredients types, quantity and quality. Concrete is strong in compression but it is weak in tension, brittle, low resistant to cracking, lower impact strength and heavy weight.

The problem of disposing and managing solid waste materials has become one of the major environmental, economic, and social issues. Waste HDPE plastic is one of the solid wastes in our surroundings which mostly pollute the environment condition. In order to overcome such types of problems related to pollution of environment we have to re-use waste HDPE plastic instead of throwing to the surrounding environment for different purpose; using HDPE as partial replacement of fine aggregate in concrete is one of the advantageous.

1.3 Research Questions

- ✓ What is the effect of partially replacing fine aggregate by HDPE on the workability of fresh concrete?
- ✓ In partially replacing of fine aggregate by HDPE what is the significant effect on the strength characteristics of concrete?
- ✓ What is the optimum percentage partial replacement of HDPE as fine aggregate in concrete strength characteristics?
- ✓ What is the relationship of concrete stress and strain in the partial replacement of fine aggregate with HDPE in concrete mix?

1.4 Objectives

1.4.1 General Objective

- ✓ The main objective of the study was to study the strength characteristics of concrete in which fine aggregate is partially replaced by HDPE.

1.4.2 Specific Objectives

- ✓ To investigate the suitability of replacing HDPE as fine aggregate in concrete.
- ✓ To evaluate the various strength parameters like compressive strength, split tensile strength and flexural strength test.
- ✓ To determine the optimum percentage partial replacement of HDPE as fine aggregate in concrete in terms of concrete workability and strength.
- ✓ To find out the basic relationship of concrete stress and strain.

1.5 Significances of the Study

The importance of this study deals with the effect of using partial replacement of HDPE waste plastic as fine aggregate in concrete mix to increase the mechanical strength of concrete which specifically considered for concrete compressive, split tensile and flexural strength value of the concrete in construction industries. From laboratory test result, the determination and comparison of stress-strain in the concrete section based on partially replacing fine aggregate or not partially replacing fine aggregate with HDPE was considered. The other importance was to decrease waste of HDPE plastic which is non-bio degradable and causes environmental pollution that comes from hotels and households.

It allows the researcher to gain knowledge on the effect of HDPE in concrete by building academic knowledge and provide base for further career improvement and also benefit Jimma Institute of Technology (JIT) in attaining its objective as a center of academic excellence and accelerate the national development through provision of problem solving research output to the policy and decision makers.

1.6 Scope of the Study

In this research, HDPE waste plastic was collected, washed, shredded into flakes and then grinded to replace fine aggregate in concrete by volume percentage proportion. In order to complement the research and to gain a comprehensive perspective on the growing volume of research on polymer modified concrete laboratory tests such as workability test, compressive strength, tensile strength, flexural strength and the effect of HDPE on the mechanical properties of concrete with and without partial replacement of fine aggregate with HDPE was employed. A laboratory study was conducted to determine the suitability of the concrete with partial replacement of waste HDPE plastic as fine aggregate in the construction industry. This research was intended to investigate and compare strength characteristic of concrete in polymer modified concrete and the physical property of HDPE was taken from the literature that other researchers used.

All beams, cubes and cylinders have similar geometry and the same water cement mix ratio. The total length of the test beam was 500mm and the cross section of 100mmx100 mm, for the cubes 150mm x 150mm x 150mm and a cylinder of 100mm x 200mm for split tensile tests. In all concrete mix the row material was consist of: ordinary Portland cement, sand and crushed coarse aggregate with the volume proportion.

CHAPTER TWO

RELATED LITERATURE REVIEW

The main objective of this chapter is to present description of related studies, investigated by different researchers that may support this study. The main areas this topic covered include concrete properties, application of waste high density polyethylene (HDPE) used as aggregate in concrete mix properties and types of plastics.

2.1 Concrete

Concrete is the most widely utilized man-made material globally for construction of different types of structure in many developing countries in all types of civil engineering works. Also concrete is an environmental friendly material and in areas of growing environmental related awareness that is of prime importance. It is construction material due to its many advantages such as high compressive strength, availability of ingredient at reasonable cost, mold- ability to any shapes giving aesthetic appearance and resistance to fire and weathering. (M.C.Guru et al., 2016). One of the rapidly growing industries is construction, concrete play an inherent role in this construction industry as it is the most widely used manmade construction material due to its versatile advantageous properties such as good compressive strength, impermeability, fire resistance and durability (Bandodkar L. et al., 2011).

2.2 Polymers in Concrete

Concrete is a construction material with the ability of getting any shape and form when casted. 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 R. 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. 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 cementetious 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 V. 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. The advantages of using recycled polymers is do not easily attacked by chemical and corrosion resistance, long durability, low permeability and thermal stability so that it is suitable for precast components, bridge deck overlays, artificial marbles and machine tool basements (Bignozzi M. et al, 2000).

(Vasudevanet al., 2009) Studied the utilization of waste polymers in production of flexible pavements. In the presented studies, authors coated the stone aggregates with molten waste plastics. They concluded that the coating of aggregates with plastics reduced the porosity, absorption of moisture and improved soundness. They found that the use of waste plastics for flexible pavement was one of the best methods for easy disposal of waste plastics.

Regarding the use of polymer (plastic) wastes for asphalt modification, high density polyethylene (HDPE), polypropylene (PP), Acrylonitrile-butadiene-styrene (ABS), polyethylene terephthalate (PET) and polyvinyl chloride (PVC) have investigated the improvement of asphalt modified with polyethylene (PE). The studies have been also carried out to determine the best type of PE to be used and its proportion in the asphalt mixture. HDPE and LDPE were added to coat the aggregate. The observed result shows that grinded HDPE polyethylene modifier provided better engineering properties. The optimum proportion of the modifier was 12% by weight of asphalt content. It was also found to increase the stability, reduce the density and slightly increase the air voids and the voids of mineral aggregate. (E. Hinislioglu et al, 2004).

2.3 Benefits of Using Recycled Plastics in Concrete

A study was conducted on concrete properties with Polymers used as fillers for construction materials. As a result, polymer materials provide superior compressive, tensile and flexural strength to the concrete compared to Portland cement. The study also revealed that polymers may provide good binding properties and good adhesion with aggregates due to its long chain chemical structure as well as resistance to physical damage such as abrasion, erosion, impact and chemical attack. The author also concludes that, Conventional concrete materials combined with polymers could yield composites with excellent mechanical and physical properties (Sivakurmar M., 2011).

Praveen et al. (2013), Studied that 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. (Elzafraneyet al., 2005), indicated that insulation materials such as polystyrene and polyethylene can be used in building construction for the purpose of saving energy. Polymer mortars and concretes have received wide acceptance as materials for many applications that 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 (Bignozziet al., 2000).

Types of Recycled Plastics

- Polyethylene terephthalate (PET)
- High density polyethylene (HDPE)
- Unplasticised polyvinyl chloride (UPVC)
- Low density polyethylene (LDPE)
- Polypropylene (PP)
- Polystyrene (PS)

HDPE is known for its high strength-to-density ratio. Although the density of HDPE is only marginally higher than that of low density polyethylene, HDPE has little branching, giving it stronger intermolecular forces and tensile strength than LDPE. The difference in strength exceeds the difference in density, giving HDPE a higher specific strength. ASTM classifies polyethylene by density as follows: high-density polyethylene (HDPE) (0.941g/cm^3 < density < 0.965 g/cm^3), low-density polyethylene (LDPE) (0.910 g/cm^3 < density < 0.925 g/cm^3), medium-density polyethylene (MDPE) (0.926 g/cm^3 < density <0.940 g/cm^3). Less commonly employed PE materials are homo polymers (density > 0.965 g/cm^3) and very low density polyethylene (VLDPE) (density < 0.910 g/cm^3).

Sources of Generation of Plastic Waste

Household, Carry Bags, Bottles, containers and trash bags, Hotel and Catering: Mineral water bottles, Glasses, Packaging items, Plastic plates, Hand gloves Health and Medicare, Disposable syringes, surgical gloves, glucose bottles, blood, Intravenous tubes, catheters.

2.4 Effect of Plastic waste Aggregate in Concrete.

The study was conducted to investigate the mechanical properties of concrete with a partial replacement of waste plastic as fine aggregates from 5% to 25% with 5% increment at the same time to reduce the wastage of plastic and improve the eco-friendly environment in concrete production. The study was an experimental type with M30 grade concrete at curing age of 7 days, 14 days and 28 days and its compressive strength, tensile strength, flexural strength results were compared with the conventional concrete. They found that compressive strength has increased for 5%, 10 %, 15 % and gradual decrement is obtained for 20% and 25% of partial replacement. The tensile strength and flexural strength has been increased for all percentage of waste plastic replacements. (T. Senthil Vadivel, et al., 2016).

Various methods have been followed for the disposal of plastic in an attempt to reduce the negative impact of the plastic on the environment. Recently, various types of plastic have been introduced in concrete to minimize the exposure of plastic to the environment. The properties of concrete containing polyethylene terephthalate (PET), and high density polyethylene (HDPE) plastic that were used as partial replacement of coarse aggregate (CA) was investigated. In the study, four compositions of stone aggregate(S): plastic waste ratios have been used by volume basis: 100% S: 0% Plastic (control concrete), 90% S: 10% PET, 90% S: 10% HDPE, and 90% S: 5% PET+5% HDPE. The effects of waste plastic addition on the mechanical properties of concrete was studied and presented. From the test result it was observed that reduction in compressive strength was 35% in case of 10% PET plastic replaced whereas split tensile strength increased by 21% for 10% PET replaced concrete when compared to control concrete specimen. Furthermore, fresh unit weight of concrete containing plastic waste has been decreased by 4% in comparison to control concrete mix. (Zasiah Tafheem et al, 2018).

The present study investigates the mechanical and chloride permeable properties of concrete with fine and coarse aggregates have been partially replaced with high density poly ethylene (HDPE) waste. Totally six different concrete mixes of M30 grade were designed with partial replacement of fine aggregate by 5%, 10%, 15% and coarse aggregate by 10%, 15%, 20% with HDPE waste. The strength and durability properties such as compressive strength, flexural strength, split tensile strength and rapid chloride ion penetration of concrete with HDPE specimens were conducted and the tests results were compared with the control concrete. The compressive and split tensile strength of the concrete mixes with varying replacement level of natural aggregates with HDPE waste shows a similar behaviour than that of the conventional cement concrete mix. Whereas the flexural strength properties of the mixes with the incorporation of HDPE waste, shows superior performance than conventional cement concrete mix. The rapid chloride permeability result infers that the chloride ion ingression reduces with the incorporation of HDPE waste and the mixes were categorized under moderate permeability compared to cement concrete of high permeability. The study shows that the waste plastic can be reused in concrete as an alternate for aggregates which will reduce considerably the disposal problems. The concrete produced using HDPE replacement can be found suitable in application of non-bearing concrete structures since the plastic has light weight. The partial replacement of aggregate with plastic can reduce the overall unit weight of the concrete substantially. The plastic do not corrode, it is lighter than steel fibers and better control of the plastic shrinkage cracking. (Shanmugapriya M. and Helen Santhi M., 2017).

Figure 2.1 HDPE Aggregate (Shanmugapriya M. and Helen Santhi M., 201 7)

An effort has been made to detail a systematic study of compressive strength of concrete with various proportions of E-waste as fine aggregate in concrete. One such type HDPE (High Density Polyethylene) was taken into consideration as it was easily available and had higher density than other types. HDPE plastics were collected, ground into smaller components, melted and pulverized in order to get granules of plastic of about 1mm size. The density of the Pulverized plastic was found to be 460 kg/m^3 and its specific gravity was 0.46. Sieve analyses were carried out and about 75% of the plastics were found to be in the range of 1 -1.7mm. 45 cubes of 15cm x15cm x15cm cement concrete with 1:1:2 (M 25) mix were casted for 0%, 25%, 50%, 75%, and 100% sand being replaced with Pulverized plastic material. As the density of plastic material was too low volumetric proportioning was used for mix design. Workability test, weight and compressive strength of the cubes were determined. From the test results the Authors reported that the yield as well as the ultimate strength of concrete at seventh day decreased by about 3 to 3.2 N/mm^2 for 25% replacement and 4 to 6.5 N/mm^2 for higher replacements of HDPE Plastic when compared to control concrete mix. The ultimate as well as the yield strength of concrete at 14th day and 28th day decreased by about 0.2 to 1 $N/mm^2$for 25% replacement and 9.1 to 14.6 N/mm^2 for higher replacements of Plastic when compared to control concrete mix. The water Cement ratio was also found to increase with the proportion of Plastics for a slump of 10 mm and density of the cube decreased with an increase in percentage replacement of Sand by Plastic Material. Thus it was inferred that Replacement of sand by plastic up to 25% can be adopted so that disposal of used plastic can be done as well the deficiency of Natural aggregates can be managed effectively. Usage of Cement Concrete in which less than 25% of the fine aggregate replaced with plastic material is very much recommended as there was not much difference in strength, (Suganthy P. et al, 2013).

The study was conducted (experimental type) to determine the physical properties of plastic aggregate such as density, specific gravity and aggregate crushing value. As it is not feasible to replace 100% natural coarse aggregate (NCA) with plastic coarse aggregate, partial replacement at various percentage were examined. The percentage substitution that gave maximum compressive strength was used for determining the other properties such as modulus of elasticity, split tensile strength and flexural strength. Maximum compressive strength was found with 20% NCA replaced concrete. (Praveen Mathew. et al, 2013).

The development of concrete with nonconventional aggregate, such as polystyrene foam wastes, HDPE, polyethylene terephthalate (PET), and other plastic materials has been investigated for use in concrete in order to improve the mechanical properties of the concrete and reduce cost. LDPE Recycled plastic was used in concrete as a partial replacement of Coarse aggregate in varying proportions (0%, 20%, 30%, and 40%) mixed with OPC, sand and tested for its physical properties and compressive strength. the size of plastic was 20µ with fineness modulus of 7.59 and specific gravity of waste plastic was found to be 1.1. The compressive strength for each variant was determined in laboratory and compared with control mix. It was found that the compressive strength up to 80% is achieved for a mix of waste plastic up to 30% (as a replacement for coarse aggregate) in concrete and it was recommended for light weight concrete structures. (Lakshmi and Nagan S., 2010).

Attempts were made in past to use E-waste and plastic waste in concrete by grinding them. The study deals with the grinding, rubbing and mixing technique to use e-waste and plastic waste in concrete. E-waste from electrical and electronic equipment, that were old and reached end of life as well as plastic waste from plastic mineral and cold drink bottles were collected and grinded to size of 2mm using pulverizing machine. The grinded pieces were rubbed against each other with friction roller machine designed and fabricated to develop roughness and make grinded pieces shape irregular so that they can bond well with cement when mixed with it. A concrete mix design was done for M20 grade of concrete by IS method. Ordinary Portland cement of 43 grade was selected. The Grinded E-waste and plastic waste was replaced by 0%, 2%, and 4% of the fine aggregates. Compressive and flexural strength were tested and compared with control concrete mix. Experiments done shows increase in compressive strength by 5% and reduce cost of concrete production by 7% at optimum percentage of grinded waste and Grinded waste greater than 2.75mm in certain proportion act as a good filler material in concrete and it was ensure better packing density and hence good strength obtained. (MS Shetty and Urmil V. Dave, 2013).

A study was done to determine the possibility of making plastic aggregate and using the aggregate made from plastic as a substitute for natural coarse aggregate in concrete. In the study Plastic aggregate is a lightweight material with specific gravity 0.94. The workability of concrete increased by 50% for a mix with 40% plastic aggregate. The Compressive strength and splitting tensile strength of concrete increased for 30% replacement of natural aggregate with plastic aggregate and on more replacement they tend to decrease but not below the target mean strength. The increase in Compressive strength was 9.4% and splitting tensile strength was 39% for a mix with 30 % replacement of natural aggregate by plastic aggregate when compared to conventional control concrete mix. Flexural strength of PCC beam and peak load of RCC beam increased up to 40% replacement. An improvement of 20% and 31% strength was observed respectively. The optimum percentage replacement of natural coarse aggregate using plastic aggregate was obtained as 30% After 90 days sulphuric acid curing (2% solution), the percentage decrease in weight of the mix with plastic aggregate was found to be 1.4% and that of control mix was 1%. Compressive strength increased by 11% for a mix with 30% replacement of natural aggregate by plastic aggregate when compared to control mix after sulphuric acid curing. After 90 days hydrochloric acid curing, the percentage decrease in weight of the control mix was 1.46% whereas that of the mix containing plastic aggregate was 0.5%. After hydrochloric acid curing, there was an increase in compressive strength by 3% for the mix with 30% plastic aggregate when compared to control concrete mix. After 90 days sodium sulphate curing (2% solution), the percentage decrease in the weight of the mix containing plastic aggregate was 1.35% and that of control mix was 1.53%. The Compressive strength enhanced by increasing up to 7% for the mix with 30% replacement of natural aggregate by plastic aggregate when compared to control mix; after sodium sulphate curing. Test Results showed that bonding stress was almost the same for both the mixes. The mix control mix had a bonding stress of 0.4 N/mm^2 whereas the mix containing plastic aggregate had a bonding stress of 0.44 N/mm^2. It was observed that plastic tends to reduce the unit weight of concrete. The weight was reduced by 12% for a mix with 40% replacement of plastic aggregate when compared to that of control mix (Anju Ramesan et al., 2015).

Chen et al. (2015) studied the effect of plastic waste as a partial and full replacement of fine aggregate on concrete mixes. Fine aggregate was replaced at a dosage of 0%, 10%, 20%, 30%, 50% and 100% by grinded plastic waste. They reported that, at 10% replacement level only 15% loss in strength was observed where as in other replacement level a notable reduction was observed as compared to that of control concrete mix. Where as in case of tensile test, the concrete mixes prepared with 10%, 20% and 30% replacement level showed significant increase in the tensile strength of concrete mixes as compared to that of control mix. This increase in tensile strength was attributed due to addition of High-density polyethylene (HDPE) plastic which causes fundamental changes in the concrete. Plastic is a byproduct of the shredding and pulverizing process which provides internal shear and tensile reinforcement. They also stated that, behavior of plastic is alike to that of the synthetic fiber which restricts the propagation of cracks and fractures in the concrete. They also concluded that, the heat absorption and heat transfer of concrete produced with 10%, 20% and 30% replacement showed a significant decrease in heat absorption, and a minor decrease in heat transfer through the test slab.

Harini and Ramana (2015) studied the influence of replacement of plastic waste and silica fume as fine aggregate and cement respectively in concrete mixes. The plastic waste was replaced in the percentage 5%, 6%, 8%, 10%, 15%, 20% by volume and silica fume 5%, 10%, 15% by weight in concrete. They reported that, the degree of workability was high in all the replacement levels. It was also stated that, in all the replacement levels of plastic waste as fine aggregate showed marginal reduction approximately 10% in compressive strength as compared to that of control mix. In case of silica fume replacement the compressive strength of concrete mixes increased by 13%, 20% and 23% at 5%, 10% and 15% respectively. Tensile strength of concrete reduced marginally at 8% to 20% replacement and increased marginally at 5% and 6% replacement levels as compared to that of control mix.

Guendouz et al., (2016) investigated the effect of waste plastic [(Polyethylene Terephthalate (PET) and Low Density Polyethylene (LDPE)] as a fibers and partial replacement of fine aggregates (powder) in concrete. The sand was replaced by plastic aggregates by volume fractions of sand (10%, 20%, 30% and 40%) and plastic fibers (0.5%, 1%, 1.5%, 2%) were introduced by volume in sand concrete mixes. It was reported that, the use of plastic waste as fine aggregate in concrete increases the workability by about 40%. This may be due to more free water exists in the mixes with plastic. On the other hand incorporation of plastic fibers in concrete reduces the workability. Also the reduction in bulk density and air content was reported. They also reported that, compressive and flexural strengths of concrete prepared with plastic waste as fine aggregate increased by approximately 30% with 20% replacement and in case of concrete with plastic fibers it increased by 25% at 1.5% content. They also come up with the final conclusion that, the optimum percentage for replacement was 20% and 1.5% for plastic powder (LDPP) and plastic fibers respectively.

Mahesh et al. (2016) studied the behavior of concrete with the utilization of plastic waste as replacement for fine aggregate in concrete with 2%, 4% and 6% pulverized/non pulverized polyethylene material. They reported that, at all replacement levels the concrete prepare with plastic waste as fine aggregate showed marginal reduction (less than 10%) in compressive and split tensile strength as compared to that of control concrete. Authors have concluded that, the use of plastic waste as a replacement for fine aggregate in concrete did not have any adverse impact on mechanical properties of concrete.

Jibrael and Peter (2016) studied the strength characteristics of concrete containing plastic waste as a partial replacement of fine aggregate 1%, 3% and 5% by weight. Two types of plastic waste were used, waste plastic bottle and bags for the production of fine aggregate. They observed that, the compressive strength, indirect tensile strength and modulus of rupture decreased when the replacement levels increased. The marginal reduction in all the values of strength was reported at a replacement level of 1% as compared to that of control mix. At 3% and 5% replacement level, the compressive strength, tensile strength and modulus of rupture of concrete containing plastic waste as fine aggregate indicated average reduction of 16%, 27% and 27% as compared to that of conventional concrete.

Gaur et al., (2017) studied the impact of plastic waste as a replacement for fine aggregate at 5%, 10%, 15%, 25% by weight in concrete with incorporation of steel fibers 1% by volume. Due to utilization of steel fibers the reduction in workability was observed. It was stated that, the use of plastic waste as fine aggregate results in reduction in compressive strength at all replacement levels as compared to control concrete mix. Finally they stated that at 5% replacement levels the compressive strength was nearly close to that of control mix and this proportion was suggested as an optimum proportion for the replacement in concrete mixes.

Strength characteristics of concrete was studied with plastic waste as a partial replacement of fine and coarse aggregate at 10%, 15%, 20% and 15%, 20%, 25% by Jaivignesh and Sofi (2017). In their study they reported that, the compressive strength of concrete was reduced by 9% at 10% replacement level where as at 15% and 20% replacement levels the compressive strength was reduced by 13 % and 17% respectively as compared to that of control concrete mix. A similar trend was observed in split tensile strength and flexural strength test. They concluded that, this reduction in strength is mainly due to poor bond strength between cement and plastic aggregate. This fact was also reported by various researchers in the past.

Ismail and AL-Hashmi (2008) used the plastic waste as partial replacement 10%, 15% and 20% for fine aggregate in concrete mixes and studied the mechanical properties of concrete. It was reported that, the slump values of concrete modified with plastic waste as fine aggregate were reduced by 68%, 88% and 95% at 10%, 15% and 20% replacement levels as compared to that of control mix. This reduction was due to irregular size and shape of aggregate which resulted in less fluidity. The fresh and dry density of concrete mixes prepared with plastic waste at above said replacement levels showed downward trend due to low density of plastic waste. The concrete prepared with plastic waste as replacement for fine aggregate showed reduction in compressive and flexural strength because of decrease in adhesive strength between the surface of the waste plastic and the cement paste. They also stated that, this reduction was due to hydrophobic property of plastic material which restricts the water required for the hydration during the curing period. From the load-deflection curves they reported that, the incorporation of plastic waste restrict the propagation of micro-cracks. They concluded that, all the values of concrete prepared with plastic waste as fine aggregate are higher that required for structural concrete B.S.1881, part 7.

Subramani and Pugal (2015) reported that, the use of plastic waste as a replacement for conventional coarse aggregate improves the physical and mechanical properties of concrete mixes. It was reported that, the compressive strength, flexural strength and split tensile strength of concrete was increased by 8%, 5% and 3% as compared to that of control concrete at 15% replacement level. As the percentage of replacement becomes greater than 15% all the properties of concrete become decreased. This was due to more available water in the cement paste because plastic waste has very low water absorption capacity than natural coarse aggregate.

Khilesh (2014) studied the impact of use of plastic waste and steel fiber addition on the properties of concrete. The fine aggregate was replaced by plastic waste at 0.2%, 0.4%, 0.6%, 0.8% and 1% by weight of cement and 0.1%, 0.2%, 0.3% 0.4% and 0.5% steel fibers were incorporated in concrete mixes. They observed that, replacement of fine aggregate by plastic waste in different percentages showed an increase in compressive strength whereas marginal reduction in slump as compared to that of control mix. On the other hand the mixture proportion of steel fiber and plastic waste also showed the same trend in compressive strength test. He summed up that, it was possible to use this plastic waste and steel fiber in concrete to produce a sustainable product.

Other study conducted by Mathew et al. (2013) reported the feasibility of utilization of plastic waste as a replacement for natural coarse aggregate in concrete mixes. The plastic coarse aggregate was obtained by crushing the boulder of plastic into the crusher. The concrete mix was prepared with 20% to 100% replacement level with an increment of 20%. They reported that, the replacement of natural coarse aggregate by plastic aggregate improves the compressive strength of concrete by 10% at a replacement of 20% as compared to that of control concrete. As the percentage of replacement increased the concrete mixes showed loss in compressive strength. The decrease in strength was due to less specific gravity and crushing value as compared to that of natural aggregates.

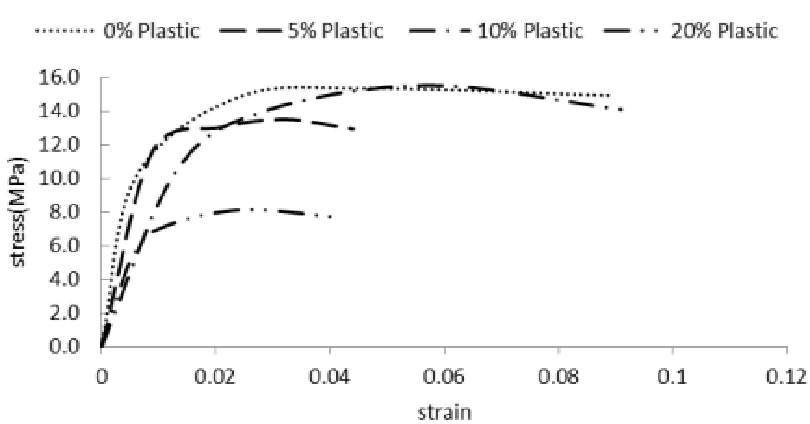
Ghernouti et al., (2009) conducted a study on concrete mixes with the utilization of plastic waste as replacement of fine aggregate in different percentages 10%, 20%, 30% and 40%. It was reported that, the workability of concrete increased with increase in replacement of plastic waste this was due to plastic waste does not absorb water and excess water is available for lubrication. Also, the bulk density decreases with increase of plastic bags waste. In case of flexural and compressive strength, appreciable reductions were observed. Plastic waste causes the increase in voids and low compactness of concrete. Strength reduction in concrete mix was prime concern and however they recommend 10% to 20% replacement of fine aggregate with plastic aggregate.

Recycling of plastic waste to produce new materials like concrete is one of the logical methods of disposing wastes, due to its economic and ecological advantages. Several works have been performed or are under way to evaluate the properties of concrete containing plastic waste. A study on the partial replacement of M sand with High Density Polyethylene is carried out to determine the Ultrasonic Pulse Velocity (UPV) test and durability properties of concrete. A comparison between conventional concrete and concrete with HDPE was carried out. In the study percentage replacement of M sand with HDPE was 5% to 20% with 5% increment. The velocity of cubes with HDPE powder is less than that of control specimen. But the obtained value of velocity of cubes with HDPE powder partially replaced by fine aggregate is within the excellent quality. HDPE powder is known for its large strength to density ratio. (Shyam S. and Drishya P., 2018).

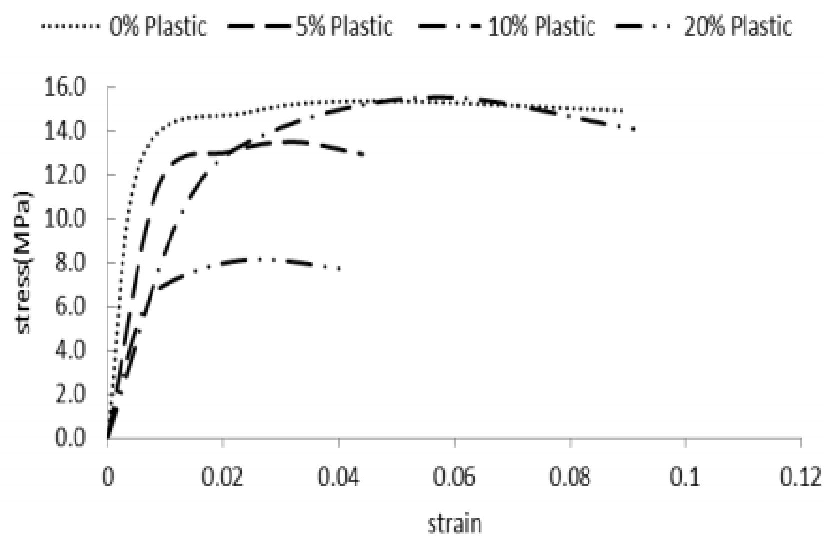
The study was conducted to investigate the properties of concrete such as workability, compressive strength, tensile strengths and thermal characteristics of the concrete in the partial replacement of aggregate. The results indicated that the use of plastic solid waste in the concrete results the formations of light weight concrete. The properties such as compressive as well as tensile strength are reduced with the addition of plastic in concrete. Further the thermal conductivity of concrete is also reduced, when it is mix with concrete and also lower the density. Reduction in thickness and resistance of high temperature achieved when plastic used in concrete pavement. The effect of water cement ratio on strength development is not predominant in case of plastic concrete. (M. Muzafar Ahmed and Dr. S. Siddi Raju,, 2015).

2.5 Stress - Strain Behaviour of Plastic Aggregate Concrete

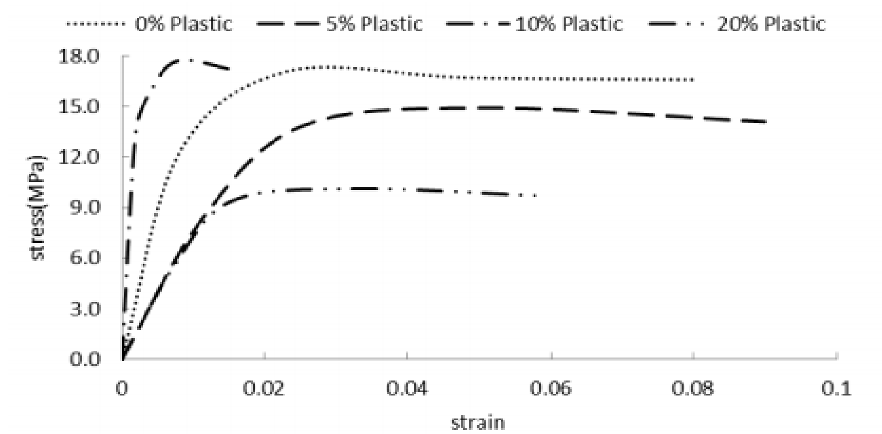
The stress-strain behavior of concrete specimen and other specimens containing 5%, 10%, 20% plastic was observed at 7, 21 and 28 days of curing. It was seen that the stress was decreasing as the increasing of strain. The stress of fresh concrete specimen was higher and the concrete specimen containing 10% plastic aggregate provided higher stress from other specimens containing various amount of plastic aggregate. The fresh concrete specimen was more brittle than others. The plastic aggregate produced softening behavior in other specimens resulting lower stress. The modulus of elasticity values specimen and other specimens containing 5%, 10% and 20% plastic aggregate were determined at 7, 21 and 28 days of curing. (MB Hossain, et al, 2016).



a. Stress-strain behavior of plastic containing concrete after 7 days



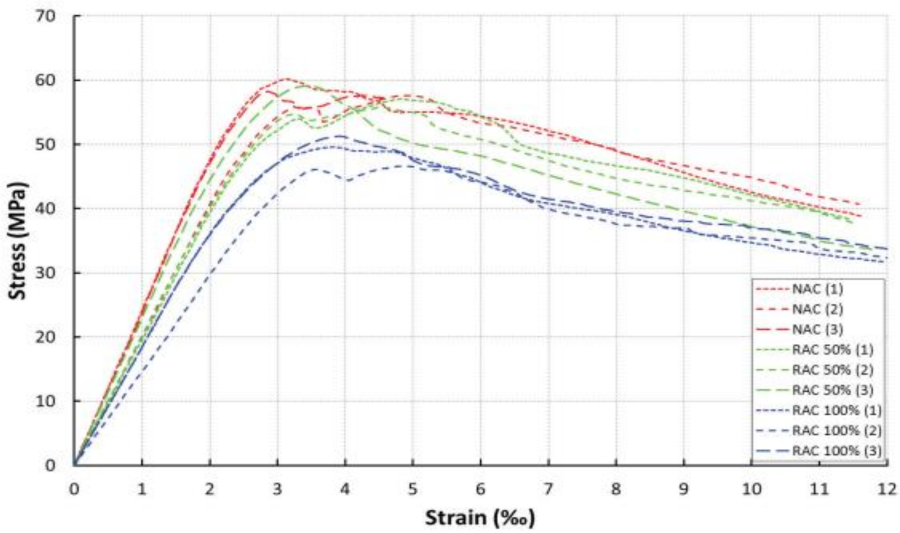
b. Stress-strain behavior of plastic containing concrete after 21 days



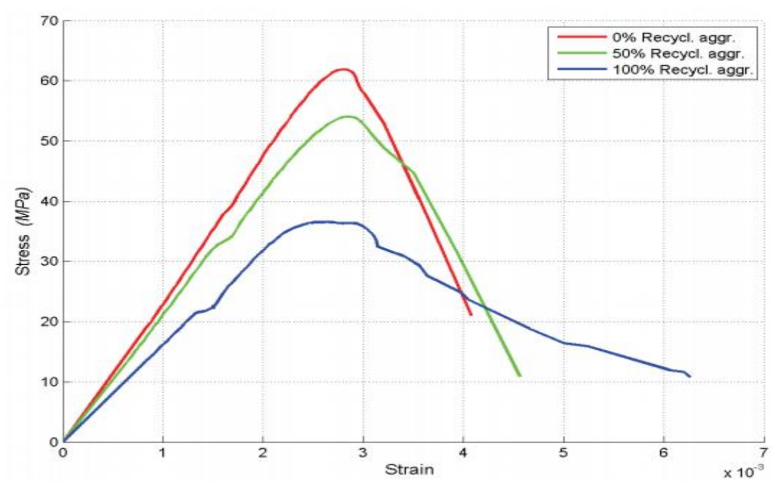
c. Stress-strain behavior of plastic containing concrete after 28 days

Figure 2.2 Stress-strain behavior of plastic containing concrete specimens. (MB Hossain, et al,2016).

The stress-strain compressive behaviour with increasing strain of both normal and recycled aggregate concrete has been investigated by means of displacement-controlled tests. The complete stress-strain curves drawn for the normal specimen and the samples with 50% and 100% of recycled plastic aggregates. It is found that RAC showed significant ductility decrease in the post peak region of the stress-strain curves. As observed by this can probably be ascribed to the smaller confinement to which cylindrical samples are subjected that significantly reduces their ductility. The Authors also believe that the different speed of load application did not produce pronounced effects on the shape of the stress-strain curves. (Marco Breccolotti, et al, 2015).



a. Stress-strain curves for cubic specimens



b. Stress-strain curves for cylindrical specimens

Figure 2.3 Stress-strain curves for specimens with different percentages of recycled plastic aggregates content (Marco Breccolotti, et al, 2015).

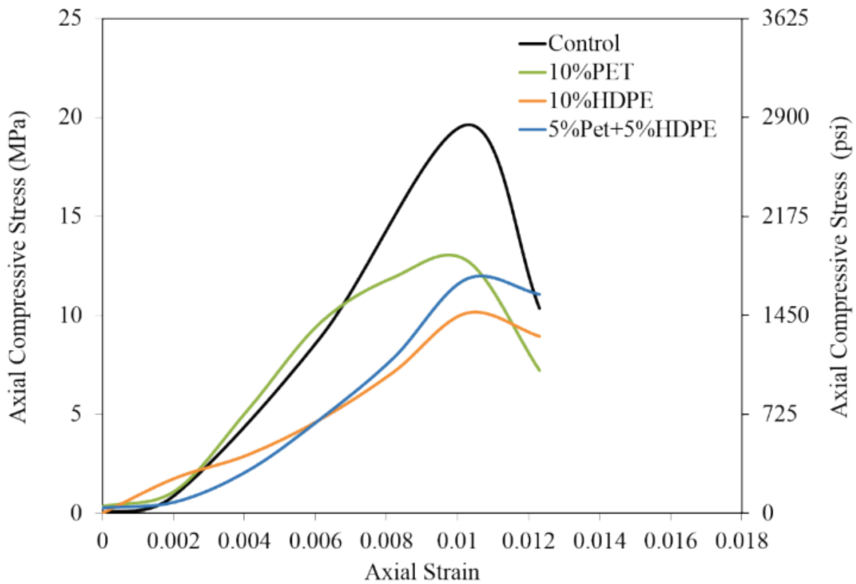


Figure 2.4 Axial stress - axial strain responses for different test specimens containing plastic aggregate. (ZasiahTafheem. Et al, 2018).

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Study Area

The study was conducted in Jimma Town, Oromia National Regional State South West Ethiopia which is located 346km from Addis Ababa. The geographical locations are 7° 13‟- 8° 56N latitude and 35°49‟-38°38‟E latitude and longitude respectively. The altitude is 1780m above sea level; the climate is (weynadega) and the estimated area of 19506.24km^2. The experimental test was conducted in Jimma University Civil Engineering Laboratory.

3.2 Research Design

This study was aimed to accomplish the proposed objectives related to the concept of mechanical strength of concrete with partial replacement of fine aggregate by using experimental method. The comparison of mechanical strength properties of concrete with partial replacement of fine aggregate by HDPE and without replacement of fine aggregate by HDPE was considered as control. A good theoretical background and analysis done by different researcher related to mechanical strength of concrete and the effect of partial replacement of fine aggregate with waste HDPE plastic in concrete mix was discussed in literature review.

In order to have a clear concept of the study on the effect of partially replacing fine aggregate with HDPE on concrete strength, laboratory test procedure was performed by considering different concrete mechanical properties like concrete compressive strength, split tensile strength, flexural strength, workability and from the result of compressive strength, comparison of stress and strain value of the concrete as well as from the result of flexural test crack pattern with partially replacing or not replacing fine aggregate by HDPE in concrete was observed.

3.3 Study Variables

Independent variables

- ✓ Performance of Concrete with Partial Replacement Fine Aggregate with HDPE.

Dependent Variables

- ✓ Concrete Compressive strength
- ✓ Concrete Split Tensile strength

- ✓ Concrete Flexural strength
- ✓ Crack length and pattern
- ✓ Concrete stress and strain diagram
- ✓ Percentage of HDPE fine aggregate

3.4 Data requirement

The available test machine for the experimental analysis of the cubes, beams and cylinders sample are cones and universal testing machine was used for finding the fresh and hardened concrete properties such as

i. Workability of fresh concrete

ii. Compressive strength

iii. Flexural strength

iv. Split tensile strength

3.5 Sources of Data

The data was collected from experiment done in laboratory test conducted on concrete ingredients. The qualities of data were assured through the replicate of sample by using standard operating procedures using three identical samples. The accuracy and validity of data was checked by instrument calibration and verification of machines.

3.6 Population and Sampling Method

The sampling size was done based on the replacing of fine aggregate with HDPE in concrete mix by volume, considering different percentage of replacing fine aggregate in the concrete mix. By considering the ingredients of concrete mix two samples were selected, one with the partial replacement of fine aggregate with HDPE and the other without partial replacement of fine aggregate with HDPE in the mix.

Hence, the total number of population was the number of cubes, cylinder and beams used as control and the numbers of cubes, cylinders and beams that was prepared from partial replacement of fine aggregate with HDPE at different percentages.

Sampling model was done by using representative sampling in which the samples were prepared in the laboratory by considering all the requirements of concrete properties in addition to this, the curing period and moisture contents of the concrete sample have been under consideration. For HDPE fine aggregate an additional safety was taken to prevent the materials from mix of dust and chemicals.

Table 3.1 total number of sample population

Replacement Of HDPE	samples								
	cubes			cylinders			beams		
	7 day	14 day	28 day	7 day	14 day	28 day	7 day	14 day	28 day
0%	3	3	3	3	3	3	3	3	3
3%	3	3	3	3	3	3	3	3	3
6%	3	3	3	3	3	3	3	3	3
9%	3	3	3	3	3	3	3	3	3
12%	3	3	3	3	3	3	3	3	3
total	45			45			45		

For this study, totally 45 samples of cubes, 45 samples of cylinders and 45 samples of beams were casted and their mechanical properties were tested. Hence, the total sample for the study was 135 samples.

3.7 Data collection process

For this research wasted High density Polyethylene (HDPE) plastics was used for the partial replacement of fine aggregate in concrete mix. The available waste HDPE plastic in jimma town was collected. Plastic recycling is a complex process compared to other recycling process because of the different types of plastic that exists. Mixed plastic cannot be used as it is poor in quality and different in properties. Therefore it is essential to sort out plastic materials. HDPE was thus sorted out.

The process of preparing HDPE powder for the use

- Collecting waste HDPE plastic from wasted environment
- The labels on the plastics was removed, cleaned, washed in clean water to remove dust and unnecessary impurities and then dried.

- The washed HDPE plastic cut into small size and shredded into flake size manually using table knife and scissors
- The dried and shredded HDPE plastics into smaller flake sizes were grinded using grinding machine that has set of blades and grind to powder such that the size is suitable for replacing natural sand in concrete.
- The grinded HDPE was then sieved by using sieve size of 4.75mm diameter to remove any grinded size of HDPE greater than 4.75mm.

Figure 3.1 Sorting and Cutting HDPE

Figure 3.2 Washing and sieving of HDPE plastic

3.8 Materials

Concrete is a building material composed of cement, fine aggregate, coarse aggregate and water. Grinded HDPE plastic was used to partially replace fine aggregate to produce concrete in addition to the usual concrete. To produce acceptable quality of concrete, it was important to test physical characteristic of material used for the investigation before any concrete experiment was carried out. In this study, materials used for this research and their physical properties test were conducted in the laboratory before using it to produce concrete. All the details of material test procedures and results were included in the appendix A.

Cement

Cement is a binding material in the concrete. The main functions of cement are:

- Binding the aggregate
- Fill up the void existing in concrete
- Coating the surface of concrete during fresh stage of concrete
- Provide the strength for concrete

There are wide varieties of cements available in market, ordinary Portland cement (OPC) of grade 42.5R CEMI was used in this experimental analysis. The cement was uniform grey colour and free from any hard lumps. Its specific gravity was 3.15.

Aggregates

Aggregates are material used as filler with cement paste in concrete. It is important to obtain right type and quality of aggregate to produce a good quality of concrete since the aggregates occupy more percentages in concrete production by volume.

Fine Aggregate

Fine aggregate serves for filling all the open space between coarse aggregate particles. Thus it reduces the porosity of final mass and considerably increases concrete strength. Fine aggregate can be naturally available or manufactured by crushing aggregate. In this investigation natural sand taken from river was used. The sand was free from clay material because, it causes expansion when wet and contraction when dries. The sand was washed first to remove unnecessary impurities (dust), dried and passed through 4.75mm sieve to remove any particles greater than 4.75mm. Sieve analysis was conducted to determine the particle size distribution using electric sieve shaker and series of sieve with different sizes in diameter as ASTM specification. The silt content, specific gravity, water absorption, Unit weight, moisture content and bulking of sand were also determined during laboratory test and outlined in appendix A.

Table 3.2 Standard test methods for fine aggregate

Property Tests	Standards
Sieve analysis of fine aggregate	ASTM C136
Unit weight of fine aggregate	ASTM C29
Silt content of fine aggregate	ASTM C117
Bulking of sand	IS2386
specific gravity and absorption of fine aggregate	ASTM C127
Moisture content of fine aggregate	ASTM C566

Course Aggregate

Crushed stone, gravel and broken brick are some of aggregate material which is available as a coarse aggregate in production of concrete. The aggregate used in this experimental investigation was crushed stone which was angular in shape and free from vegetable and dusts. The aggregate was washed to remove the dust.

Excess fines of coarse aggregate were removed through the use of sieving with 4.75mm sieve diameter to satisfy the requirement. Fines contain many impurities results in strength loss in the concrete and increase the surface area for water absorption increasing the characteristics of the mix (F. Gorden, 2003). Therefore, there is a need to sieve the aggregates to reduce the amount of fines. During experimental work the properties of coarse aggregate testes done were specific gravity, water absorption, sieve analysis, moisture content and unit weight. The test procedures and results were outlined in Appendix A.

Table 3.3 Standard test method for coarse aggregate

Property Tests	Standards
Sieve analysis of coarse aggregate	ASTM C136,C33
Unit weight coarse of aggregate	ASTM C29
specific gravity and absorption of coarse aggregate	ASTM C127
Moisture content of coarse aggregate	ASTM C566

Table 3.4 Specific gravity, absorption, moisture content and unit weight tests on aggregates

Aggregate	bulk specific gravity	Bulk specific gravity (SSD)	Apparent specific gravity	Absorption capacity (%)	Moisture content (%)	Unit weight (Kg/m^3)
Sand	2.61	2.64	2.69	1.11	0.705	1669
Gravel	2.87	2.91	2.97	1.06	0.985	1687

Water

Water is a very important component in the concrete production. The optimum content of water gives good concrete strength. Water is important since it hydrates the cement and makes concrete workable. Generally water that is satisfactory for drinking is also suitable for use in concrete. In this work portable water suitable for human consumption, fresh, clean, free from organic impurities and salt was employed in the experimental procedures.

Polymeric Material (HDPE plastic)

There are different types of plastic wastes available which are wastage on the earth from different plastic products and household uses. These are

HDPE: high density polyethylene

PET: polyethylene terephthalate

LDPE: low density polyethylene

PP: polypropylene

PS: polystyrene etc.

For this investigation high density polyethylene (HDPE) was collected which is highly available wastage on the land and used as partial replacement of fine aggregate for making concrete.

Some Mechanical properties of high density polyethylene (HDPE)

Table 3.5 Typical physical properties of HDPE plastics. (https:// www.bpf.co.uk/plastipedia/ polymers/ HDPE.aspx)

Properties	value
Density (Kg/m^3)	930-970
Surface Hardness	SD68
Tensile strength (Mpa)	32
Flexural modulus (Gpa)	1.25
Water absorption (%)	0.02
Specific gravity	0.95
Strain at yield (%)	15

Finely grinded HDPE plastic waste ranges in size from very fine powder to sand-sized particles were used as fine aggregate replacement. The particle size distribution of HDPE plastic aggregates was compared with conventional fine aggregate used. The HDPE plastic aggregates behaved quite similar to the conventional fine aggregate which is shown in Figure 3.3. The grinded HDPE plastic powder was sieved using sieve size of 4.75mm. The particle of grinded HDPE which pass 4.75mm diameter sieve was used for the partial replacement of sand.

The grinded HDPE material was mixed together with aggregate so as to achieve the maximum packing density. Equal volume of grinded HDPE plastic aggregate was replacing the volume of equivalent fine aggregate. The sieve analysis was done to determine the PSD and Fineness Modulus of grinded waste HDPE plastic. Fineness modulus of plastic is 2.99. The sieve analysis, procedures for HDPE and the result of particle size distribution for grinded HDPE used to replace fine aggregate is outlined in Appendix A.

Figure 3.3 Finely grinded HDPE plastics

3.9 Preparation of Samples

3.9.1 Mix proportion

Principally, Concrete is composed of cement, aggregate and water. To have a concrete with adequate and improved strength for desired use, the proportion of ingredient are very important in concrete mix. The selection of ingredient proportion in concrete mix involves a balance between reasonable economy and requirements for place ability, strength, durability, density and appearance. With regard to concrete strength, the mix design can be C-25, C-30, and C-40 for a desired cube with compressive strength of which carry a load that can cause stress of 25MPa, 30Mpa and 40Mpa respectively.

This study was done for C-25 grade concrete with mix design as per ACI procedures. The control mix has a mix ratio of 1:2.33:2.81 (cement: fine aggregate: coarse aggregate) which was adapted for this work with a constant water- cement ratio of 0.51. For making mixes containing HDPE plastics, the amount of plastic were calculated as 3%, 6%, 9% and 12% by volume proportion of fine aggregate in the concrete. The mix proportion for the control and the other mixes containing HDPE for the specimens are shown in Table 3.8.

Mix design procedures as per ACI

Collected data from Test results of aggregate for mix design.

Specific gravity for course and fine aggregate is 2.91 and 2.64 respectively

Specific gravity of ordinary Portland cement is 3.15

Unit weight of dry rodded course and fine aggregate is 1687Kg/m^3 and 1669Kg/m^3 respectively

Water absorption for course and fine aggregate is 1% and 1.11% respectively

Free surface Moisture content in course and fine aggregate 0.985% and 0.705% respectively

Fineness modulus of fine aggregate = 2.93

Step 1. Choice of the slump. The expected slump for workability is 25mm - 100mm.

Step 2. Choice of nominal maximum aggregate size. The coarse aggregate used for this study has nominal maximum size of 20mm and air content in volume of concrete is 2%.

Step 3. Estimation of mixing water and air content. The concrete is non-air entrained since the structure is not exposed to sever weathering as per ACI code for 20mm aggregate size the total density of water is 185 Kg/m^3

Step 4. Selection of water cement ratio (w/c). The water cement ratio was required for non-air entrained concrete of 25Mpa compressive strength.

- ✓ From strength point of view the estimated water-cement ratio is 0.62
- ✓ From the Exposure condition the estimated water to cement ratio is 0.5

Taking the minimum of the two values, the adopted water-cement ratio to be used for the mix design is 0.5.

Step 5. Calculation of cement content. The amount of cement per unit volume of concrete is fixed based on the determination made in step 3 and step 4. The required cement is equal to the estimated mixing water (in step 3) divided by water cement ratio (step 4).

$$\text{Cement} = \frac{185}{0.5} = 370\ Kg/m^3$$

Step 6. Estimation of coarse aggregate content. The quantity of coarse aggregate is estimated from bulk volume of dry rodded gravel. From ACI table 11.4 for maximum nominal size of gravel 20mm and fineness modulus of fine aggregate 2.93, the volume of dry rodded course aggregate is 0.61 per unit volume of concrete.

The quantity of coarse aggregate is

$$0.61*1687Kg/m^3 = 1029.07\ Kg/m^3$$

Step 7. Estimation of fine aggregate content. From ACI table 11.9 the first estimate density of fresh concrete for 20mm maximum size of aggregate and non-air entrained concrete is 2355 Kg/m^3

In Volume method, the absolute volume of mix ingredients per unit cubic meter volume of concrete on volume basis is

$$\text{Volume} = \frac{\text{weight}}{\text{specific gravity} * \text{unit weight of water}}$$

Table 3.6 Absolute volume of ingredients for mix design

Item No.	Ingredient	Weight (Kg/m^3)	Absolute volume (cm^3)
1	Cement	370	117460.3
2	Water	185	185000
3	Gravel	1029.07	353632.3
4	Air		20000

Therefore, Absolute volume of fine aggregate = 323907.4cm^3

Absolute weight of fine aggregate = 323907.4*2.64/1000= 855.116 Kg/m^3

Table 3.7 Adjustment for field condition of ingredients

Ingredients	Cement	Sand	Gravel	Water
Quantity (kg/m^3)	370	855.116	1029.07	185
Ratio	1	2.31	2.78	0.5
One bag cement, Kg	50	115.5	139	25

Step 8. Field Adjustment for moisture in the Aggregate. Since the aggregates will be neither Surface Saturated (SSD) nor Oven Dry (OD) in the field, it is necessary to adjust the aggregate weights for the amount of water contained in the aggregate. Since absorbed water does not become part of the mix water, only surface water needs to be considered.

Fine aggregate has absorption capacity of 1.11%.

Weight of fine aggregate = 864.608 kg/m^3

Coarse aggregate absorbs 1% of water.

Weight of course aggregate = 1039.361 kg/m^3

Adjust the amount of water based on moisture content

The required amount of mix water becomes

185 – 864.608 (0.00705-0.0111) – 1039.361(0.00985-0.01) = 188.658Kg/m^3

Table 3.8 Final design mix proportion of ingredients.

Ingredients	Cement	sand	gravel	water
Quantity (kg/m^3)	370	864.608	1039.361	188.658
Ratio	1	2.33	2.81	0.51
One bag cement (Kg)	50	116.5	140.5	25.5

The average unit weight of HDPE is taken to be 950Kg/m^3 and specific gravity is 0.95

Table 3.9 Amount of HDPE added for different percentage of mix design proportion

<table>
<tr><td>% Repl.</td><td>Cement (Kg)</td><td>Sand (Kg)</td><td>Gravel (Kg)</td><td>HDPE (Kg)</td><td>Water (Kg)</td></tr>
<tr><td>0%</td><td>52.560</td><td>122.456</td><td>147.694</td><td>-</td><td>26.806</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td rowspan="2">HDPE (Kg)</td><td>0%</td><td>3%</td><td>6%</td><td>9%</td><td>12%</td></tr>
<tr><td>-</td><td>2.423</td><td>4.845</td><td>7.258</td><td>9.690</td></tr>
</table>

3.9.2 Mixing, Casting and Curing of samples

The fine aggregate, coarse aggregate and plastic aggregates were measured first and mixed homogeneously for a moment in the concrete mixer. This was followed by the addition of cement and one third of total mixing water. After some minutes of mixing, remaining mixing water was added subsequently observing that the mix was undergo homogeneous. Mixing was ceased after all mixes when a homogenous mixture has been obtained.

Before casting, all the cubic moulds, cylinder moulds and beam moulds were cleaned and the internal parts 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 each layer with the tamping rod to compact. The specimens were left in the steel moulds for 24 hours. After 24 hours the specimens were remove from the moulds, and then kept in the curing tank containing clean water until the stipulated day of testing for mechanical strength properties.

Figure 3.4 Adding of replacement HDPE in concrete mix and compacting the mix in the mould

Figure 3.5 Homogeneously mixing of aggregates and surface finish of sample in moulds during casting.

3.10 Laboratory Test procedures

3.10.1 Tests on fresh concrete (Slump Test)

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 as the property determining the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity. The main characteristics of workability are consistency (or fluidity) and cohesiveness. Consistency measures the ease of flow of fresh concrete and cohesiveness describes 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 slump test is widely used test that measures the workability of fresh concrete. It measures the consistency of specifically prepared fresh concrete bach. The test was conducted according to ASTM C143 specification using slump cone. The interior of the slump cone was dampened and the cone was put on a steel flat level plate surface which was non absorbent. 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 layer for the purpose of removing excess air (compaction). After which the cone was lifted vertically upwards so as not disturb the fresh concrete and the slump was measured using a rod and a ruler. 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.

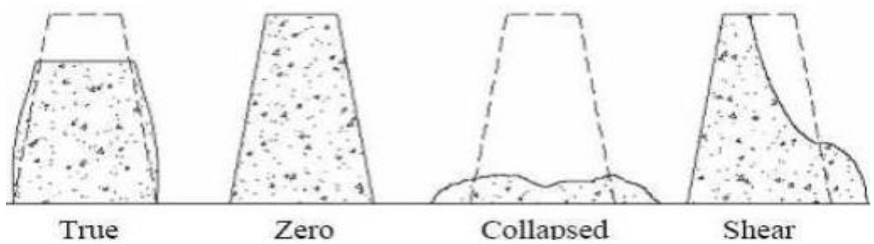


Figure 3.6 Types of slump failure

Figure 3.7 Measuring of slump height

3.10.2 Tests on Hardened Concrete

Compressive Strength

When load 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 the ability of the concrete to withstand load and quality of the hardened concrete.

Specimens for the testing compressive strength of concrete were prepared by filling 150mm×150mm×150mm dimension cubical steel moulds. The mix was containing partial replacement of sand with HDPE by percentage composition of 0%, 3%, 6%, 9%, and 12% by volume proportion. After 24 hours the specimens were removed from the moulds and placed in curing tanks containing clean water. Three identical samples were prepared from each percentage partial replacement of sand with HDPE plastic content and their compressive strength determined after 7, 14 and 28 days of curing by compression testing machine. The load was applied through the testing machine by gradually increasing rate of loading until failure occurs. The average compressive strength of three identical cubes by percentage of replacement was used to determine the compressive strength of each concrete mix. Based on the result of compressive strength test of the cube, Comparison was done for each cube specimen containing partial replacement of sand by HDPE with that of control specimen. The compressive strength results obtained for all the samples at each curing day for different mix percentages are listed in Appendix C.

The compressive strength was calculated from the formula;

$$\text{Compressive strength} = \frac{\text{Maximum Applied Load}}{\text{Crossectional Area of the cube Specimen}}$$

$$f_{tc} = \frac{P}{b*d}$$

Where, P = peak Load

f_{tc} = compressive strength

b = d = width of the cube specimen

Figure 3.8 Compressive strength test using compressive testing machine

The strain for corresponding point of compressive stress was determined by using displacement gauge which was attached on the compressive strength test machine before applying the load to the cube specimen as shown in Fig.3.9. During compression test the strain gauge was fitted to the compression testing machine so as to take the reading for strain stress diagram. The deformation (Δh) of specimens was recorded from the gauge with respect to each load increment and strain was calculated by dividing deformation to height of the cube specimen (h). The stress was caused due to applied compressive loading to the cube during the testing and it varies with respective gauge reading. The load which causes stress was taken with the respective gauge reading change in the compressive testing machine during the test. From the result of compressive strength test, the stress strain diagram was analyzed and comparison was done for each partial replacement of sand by HDPE with that of control specimen.

Figure 3.9 Strain gauge for cube compression test

Split Tensile Test

Concrete is not expected to resist the direct tension because of its low tensile strength and brittle nature. However the determination of tensile strength is necessary to determine the load at which the concrete members may crack. The cracking is a form of tensile failure.

Molding a simple cylindrical standard apparatus of height 200mm and diameter 100mm was used and filling by plain concrete which was mixed with HDPE powder by volume proportion. The percentage of the mix was done by replacing sand with HDPE by 0%, 3%, 6%, 9%, and 12% by volume proportion. After 24 hours the specimens were removed from the moulds and placed in curing tanks containing clean water. The split tensile strength determined at the age of 7, 14 and 28 days of curing in clean water.

The standard cylindrical concrete specimen was placed horizontally between the loading surfaces of the Compression Testing Machine as shown in Figure 3.10. The compression load was then applied uniformly along the length of the cylinder and the failure load recorded. A strip of poly wood was placed between the specimen and the loading surfaces to ensure uniform distribution of the applied load and preventing high magnitude of loads at the points of application. The failure of the cylinder was along the vertical diameter with respect to placed position during test. The average split tensile strength of three identical cylinders by percentage of replacement was used to determine the tensile strength of each concrete mix. Based on the result of Split Tensile strength test of the hardened cylindrical concrete specimen, comparison was done for each partial replacement of sand by HDPE with that of control specimen.

The splitting tensile strength of the specimen was calculated according to ASTM C496 as follows:

$$f_{ct} = \frac{2p}{\pi L d}$$

Where, f_{ct}= splitting tensile strength

L= length of the cylindrical specimen

d = diameter cylindrical specimen

P = maximum applied load by the testing machine

Figure 3.10 Split tensile strength testing

Flexural Strength Test

Flexural strength is the ability of a beam to resist failure in bending. It is measured by loading of concrete simple beam with third point loading and the flexural strength measured is expressed as modulus of rupture.

In the case of Flexural strength test beam with standard dimension of 100mm*100mm*500mm apparatus was used. The concrete mix contains partial replacement of sand with HDPE at 0%, 3%, 6%, 9% and 12% by volume proportion. Since no more mouls are available in the laboratory, wooden formwork was fixed with equal dimension of steel mould (100mm*100mm*500mm) and used for casting the beam. The moulds were filled by plain concrete considering 0% HDPE replacement as control specimen and the others for the same dimension of moulds were filled by concrete which was mixed with partial replacement of sand with HDPE at 3%, 6%, 9%, and 12% by volume proportion. After 24 hours the specimens were removed from the moulds and placed in curing tanks containing clean water. Then flexural strength test was done on 7, 14 and 28 days of curing the beam.

The beam was placed horizontally on the supports of flexural testing machine and load applied to the beam by gradually increasing rate until failure occurs. The average flexural strength of three identical beams by percentage of replacement HDPE was used to determine the Flexural strength of each concrete mix. Two point loading was used for the purpose of allowing the uniform distribution of bending moment between the two loading nodes. Comparison and conclusion were done based on the result of loading laboratory test recorded for the flexural strength of each partial replacement of HDPE with control beam. The flexural strength of the concrete was calculated as ASTM C78

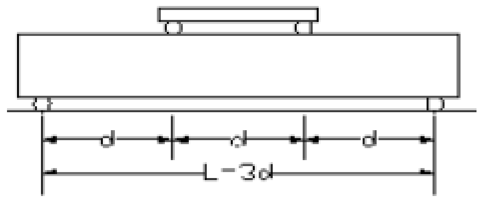


Figure 3.11 Two point loading of beam specimen

a) If failure with in the middle third of the span

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

Where:

R= modulus of rupture

P = maximum applied load indicated by the testing machine

L = span length

b = average width of specimen at the fracture

d = average depth of specimen at the fracture

b) If the failure occurs outside the middle third of the span length by not more than 5% of the span length

$$R = \frac{3Pa}{bd^2}$$

Where:

a = average distance between line of fracture and the nearest support measured on the tension surface of the beam

Figure 3.12 Flexural strength testing

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Sieve Analysis

Sieve analysis was done to determine the fineness modulus of aggregates and the relative amounts of particle sizes distribution of particle in the aggregate using sieve series of square or round openings starting with the large at the top. The sieve was arranged in descending order of size from top to bottom.

The course aggregate sieve analysis was done for course aggregates passing sieve size of 37.5mm and retained on sieve size of 4.75mm according to ASTM sieve size. Accordingly the upper and lower bound limit for the course aggregate shown in table 4.2.

Table 4.1 Sieve analysis for course aggregate

Sieve size (mm)	Mass of Samples			Avg. Mass retained (g)	% retained	Cumulative % retained	Cumulative % passing
	m_1 (g)	m_2 (g)	m_3 (g)				
37.5	0	0	0	0	0	0	100
28	847.5	849.2	857.8	851.5	8.515	8.515	91.485
19	4828	4831.6	4824.4	4828	48.28	56.795	43.205
12.5	2569.5	2562.8	2564.2	2565.5	25.655	82.45	17.55
9.5	1325.5	1323.8	1327.2	1325.5	13.255	95.705	4.295
4.75	427	429.6	424.4	427	4.27	99.975	0.025
pan	2.5	3	2	2.5	0.025	100	0

Table 4.2 ASTM upper and lower limit of PSD for course aggregate

Sieve sizes (mm)	Cumulative % passing		Cumulative % Retained	
	ASTM min	ASTM max	ASTM min	ASTM max
37.5	100	100	0	0
28	90	100	10	0
19	40	85	60	15
12.5	10	40	90	60
9.5	0	15	100	85
4.75	0	5	100	95
pan	0	0	100	100

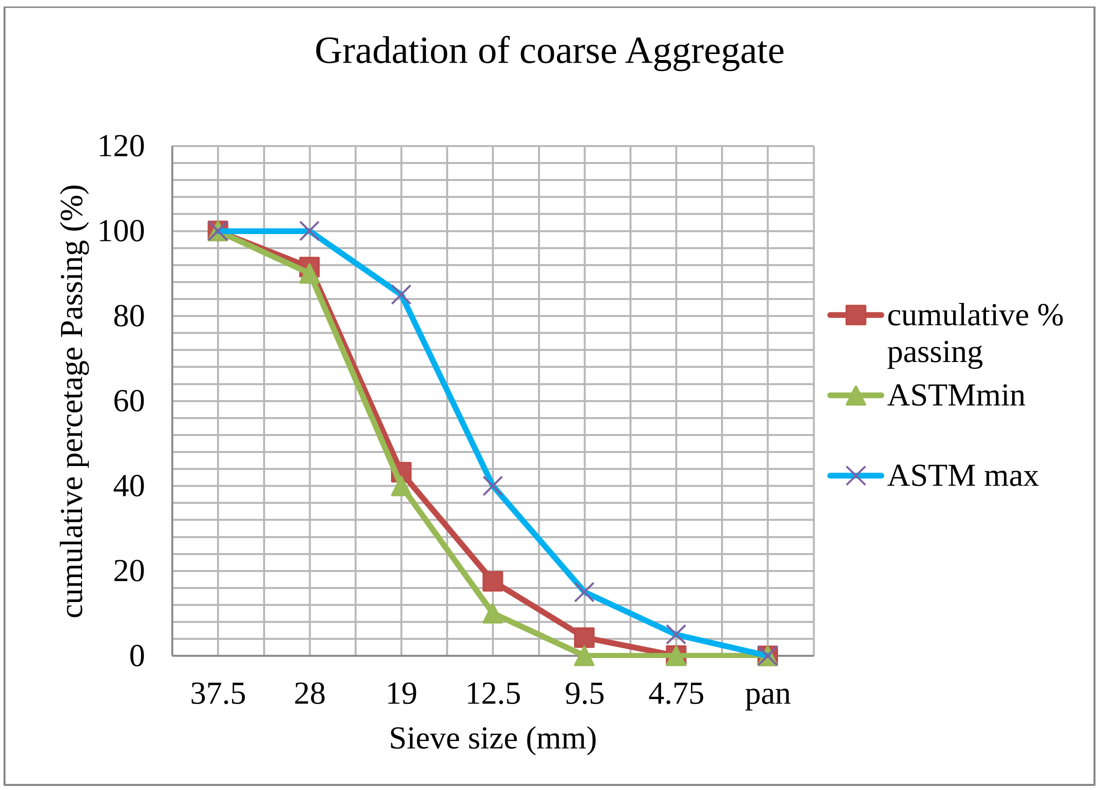


Figure 4.1 particle size distribution curve for course aggregate

For sieve analysis of fine aggregate, the fine aggregate used in this study passed the 9.5mm and almost passed 4.75mm sieve size which fulfills the standard requirement according to ASTM standard. The fineness module is between 2.3 and 3.1.According to ASTM C33 this means it was almost within the ASTM limit and the cumulative percentage passes and retains was within the intervals as shown in table 4.3.

Table 4.3 Sieve analysis for fine aggregate

Sieve size (mm)	sample			Avg. Mass retained (g)	% retained	Cumulative % retained	Cumul. %passing
	m1 (g)	m2 (g)	m3 (g)				
9.5	0	0	0	0	0	0	100
4.75	2	2.2	1.8	2	0.1	0.1	99.9
2.36	268.4	268	273.6	270	13.5	13.6	86.4
1.18	397.5	397.8	391.2	395.5	19.775	33.375	66.625
0.6	573.7	571.2	571.1	572	28.6	61.975	38.025
0.3	489.9	492.1	494	492	24.6	86.575	13.425
0.15	208	207.2	208.8	208	10.4	96.975	3.025
Pan	60.5	61.5	59.5	60.5	3.025	100	0

Table 4.4 ASTM upper and lower limit of PSD for fine aggregate

Sieve size (mm)	Cumulative % passing		Cumulative % Retained	
	ASTM min	ASTM max	ASTM min	ASTM max
9.5	100	100	0	0
4.75	95	100	5	0
2.36	80	100	20	0
1.18	50	85	50	15
0.6	25	60	75	40
0.3	5	30	95	70
0.15	0	10	100	90
pan	0	0.000	100	100

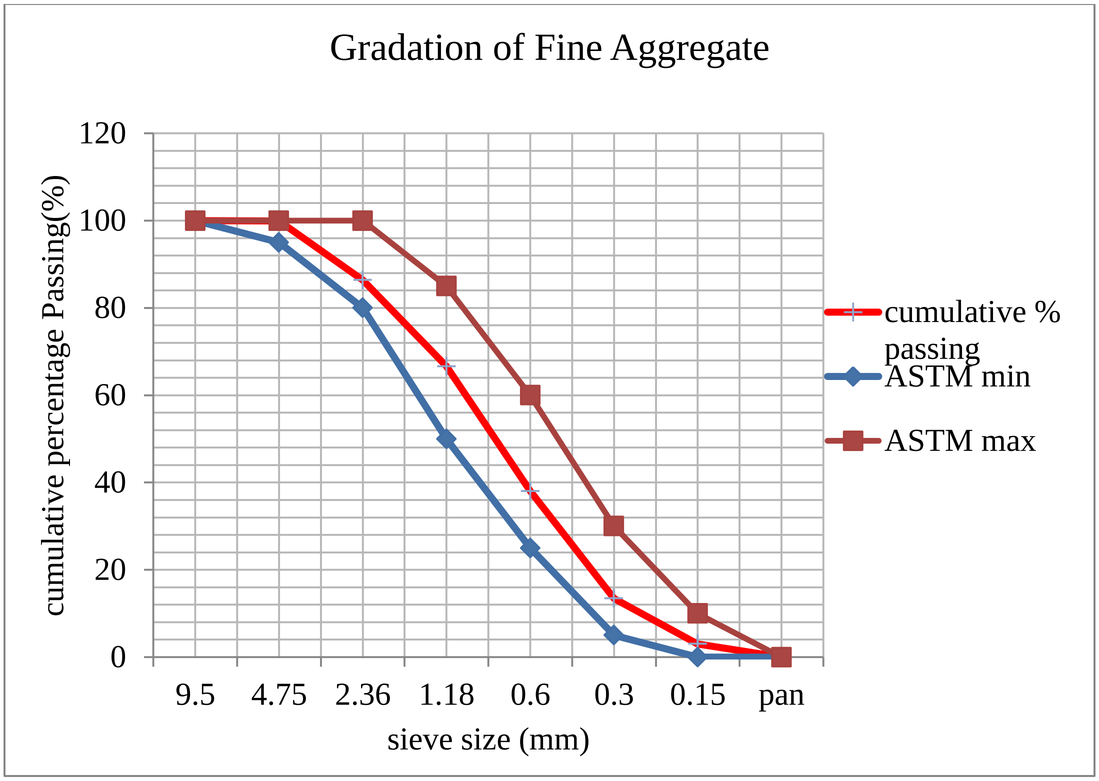


Figure 4.2 particle size distribution curve for fine aggregate

The sieve analysis was done for grinded HDPE which was used as partial replacement of fine aggregate. This was done to determine that the replacing material shows similar particle size distribution with that of natural fine aggregate used. From the test result of sieve analysis, the grinded HDPE plastic shows almost similar behavior to the natural fine aggregate and also confirms to ASTM limits of PSD recommendation as shown in table 4.5. The Fineness Modulus of grinded HDPE was found to be 2.99.

Table 4.5 sieve analysis for particle size distribution of HDPE

Sieve size (mm)	Mass of Sample (g)			Avg. mass (g)	%retained (%)	cum. % retained	cum.% passing
	M_1	M_2	M_3				
9.5	0	0	0	0	0	0	100
4.75	11.24	13.1	12.56	12.3	2.460	2.460	97.540
2.36	59.45	58.9	60.27	59.54	11.908	14.368	85.632

Continued…

1.18	104.2	99.75	103.55	102.5	20.5	34.868	65.132
0.6	160.56	161.91	152.82	158.43	31.686	66.554	33.446
0.3	97.5	93.7	96.2	95.8	19.16	85.714	14.286
0.15	46.25	48.6	49.54	48.13	9.626	95.340	4.660
Pan	20.8	24.04	25.06	23.3	4.66	100.000	0.000

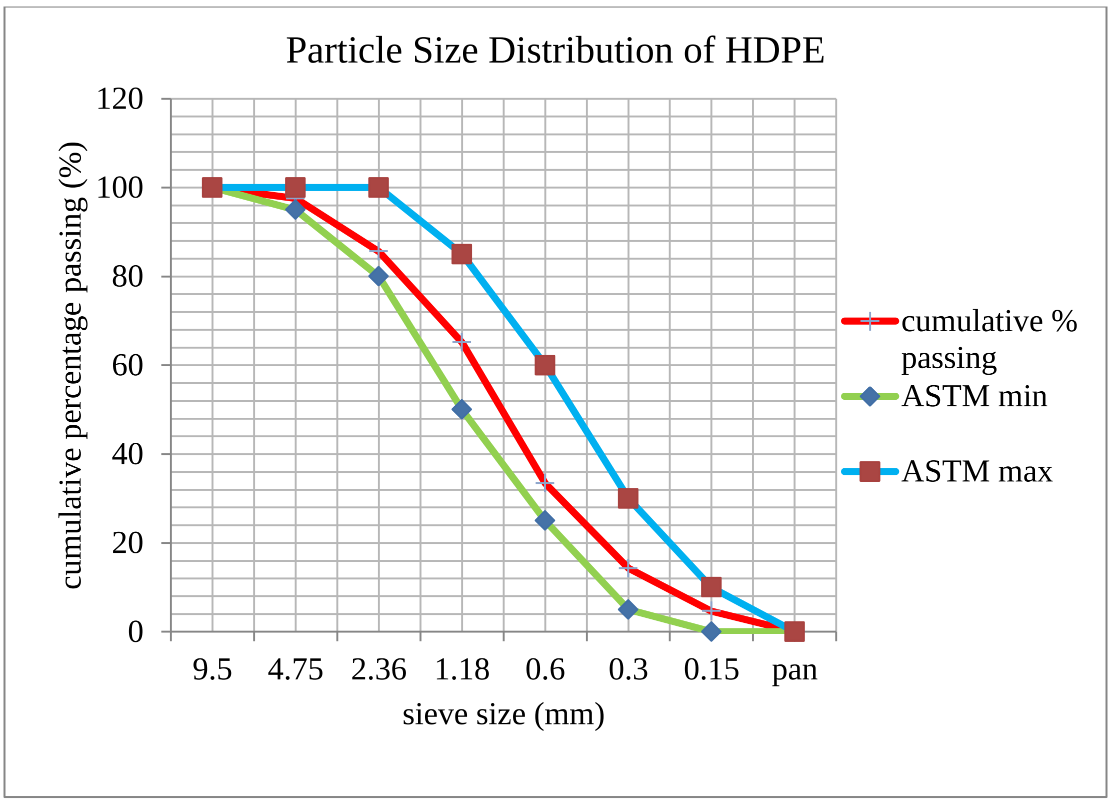


Figure 4.3 particle size distribution curves for HDPE Plastic

4.2 Effect of adding HDPE on fresh concrete

4.2.1 Workability test

The phenomena in which fresh concrete can be laid, compacted and enough workable for desire purpose is described by workability of fresh concrete. The workability of concrete is controlled by the amount of water in concrete. In this study slump test was conducted to determine the workability of fresh concrete and consistency of concrete in accordance with ASTM standard.

Table 4.6 limits of degree of workability and consistency

Degree of workability	Consistency	Slump (mm)
Extremely very low	Moist earth	0
Very low	Very dry	0-25
Low	Dry	25-50
Medium	Plastic	50-100
High	Semi – fluid	100-175

Table 4.7 slump test result on fresh concrete containing HDPE

HDPE percentage replacement	slump(mm)
0%	60
3%	66
6%	73
9%	78
12%	81

From test result it was observed that the replacing of more HDPE in concrete increases the value of workability of fresh concrete. From the result of slump test the maximum workability obtained at 12% HDPE replacement with fine aggregate by volume. The test result also indicated that for this particular study all mix are medium workable.

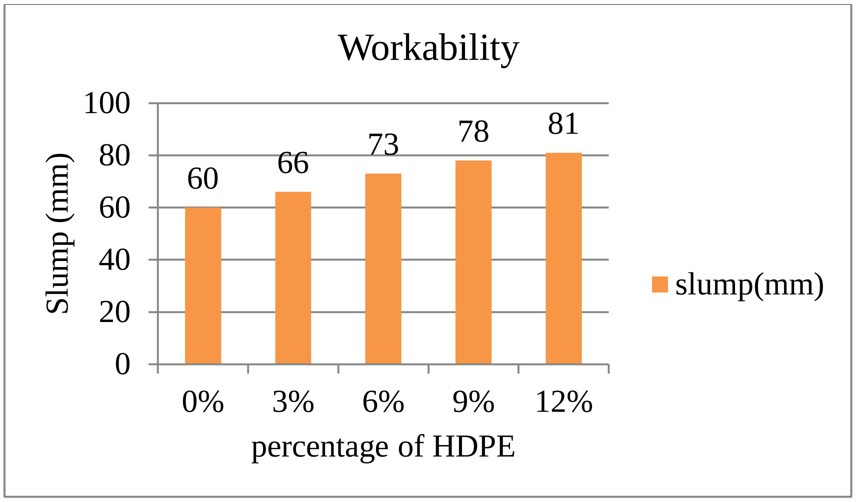


Figure 4.4 Slump for workability of fresh concrete with addition of HDPE.

From the test result, it was seen that the influence of HDPE plastic waste on the workability of concrete. The results of workability test on concrete with and without HDPE are presented in figure 4.4. It was observed that the more HDPE waste plastic content increases the more fluidity of concrete and improves that is favorable for concretes to be workable. This improvement can be attributed to the fact that plastic particle has a smoother surface than that of the sand. The plastic cannot absorb water, therefore excess water exist at the surface of HDPE plastic waste which improves the workability.

4.3 Effect HDPE on hardened concrete

4.3.1 Unit Weight

The variation on the density of concrete specimen studied related with the increase in percentage of HDPE replacement with fine aggregate at 0%, 3%, 6%, 9%and 12% dosage. The result shows that reduction in unit weight has been observed in case of cube test specimens containing HDPE plastic waste while compared to control concrete specimen. Mass of each individual samples measured and the calculated density of each cube sample is shown in Table 4.8.

Table 4.8 Variation in unit weight of cube with the addition of HDPE plastic as partial replacement of sand.

HDPE	mass of cube sample at 7 day (Kg)				Volume	Density	Reduction
	1	2	3	avg. mass	(m^3)	(Kg/m^3)	(%)
0%	8.692	8.632	8.541	8.622	0.00338	2554.568	-
3%	8.504	8.211	8.39	8.368	0.00338	2479.506	2.93
6%	8.251	8.457	8.192	8.3	0.00338	2459.259	3.73
9%	7.993	8.202	8.124	8.106	0.00338	2401.877	5.97
12%	7.983	8.102	8.025	8.037	0.00338	2381.235	6.78
HDPE	mass of cube sample at 14 day (Kg)				volume	Density	Reduction
	1	2	3	(%)	(m^3)	(Kg/m^3)	(%)
0%	8.317	8.485	8.341	8.381	0.00338	2483.259	-
3%	8.421	8.294	8.352	8.356	0.00338	2475.753	0.30
6%	8.215	8.272	8.182	8.223	0.00338	2436.444	1.89
9%	8.141	8.318	8.124	8.194	0.00338	2427.951	2.23
12%	7.983	8.102	8.075	8.053	0.00338	2386.173	3.91
HDPE	mass of cube sample at 28 day (Kg)				volume	Density	Reduction
	1	2	3	(%)	(m^3)	(Kg/m^3)	(%)
0%	8.428	8.495	8.452	8.458	0.00338	2506.173	-
3%	8.368	8.506	8.423	8.432	0.00338	2498.469	0.31
6%	8.367	8.223	8.314	8.301	0.00338	2459.654	1.86
9%	8.263	8.236	8.269	8.256	0.00338	2446.222	2.39
12%	8.207	8.128	8.095	8.143	0.00338	2412.840	3.72

The unit weight of cube specimens measured at the compressive strength test decrease with increasing HDPE content. The reduction in unit weight of concrete cube is resulted from the fact that waste HDPE plastic has lower density than natural sand aggregate since fine aggregate has been replaced by volume rather than weight. The main advantage of using plastic is that it will produce light weight concrete which will contribute to the reduction in self-weight of a structure. Hence, HDPE Plastic waste consumed in concrete as a partial replacement of fine aggregates can be used in non-structural concrete found in various components like sidewalk, handicap ramp, stair, interior partition wall, low rise concrete wall building, cladding, since the self-weight of concrete having plastic is less. All the details of unit weight for cylinder and beam are also calculated and the result is outlined in appendix B.

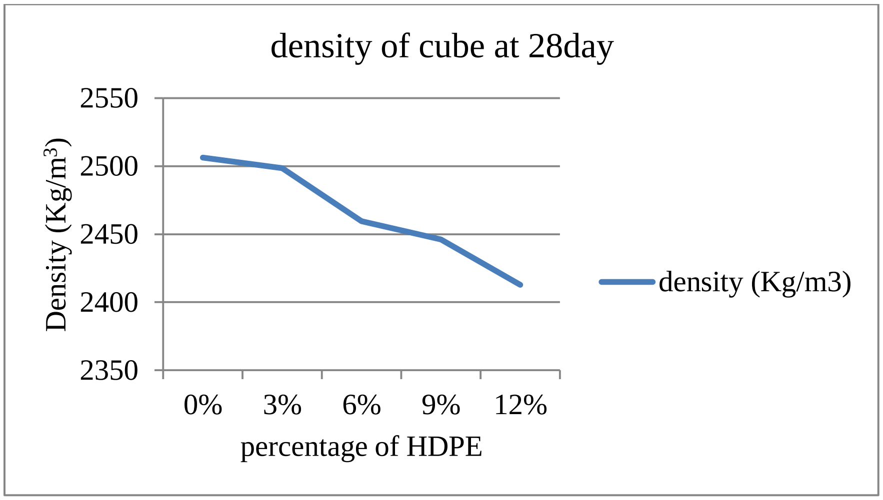


Figure 4.5 Reduction in density of cube containing HDPE

4.3.2 Compressive strength test

Compressive strength of concrete plays an important role in controlling and conforming the quality of cement concrete work. The main factor in favour of the use of concrete in structures is its compressive strength. One of the important properties of the hardened concrete is its strength which represents its ability to resist compression loads. The compressive strength of the concrete is considered to be the most important and is often taken as an index of the overall quality of concrete. The compressive strength of concrete is the compression load which causes the failure of specimen per unit cross section area of the specimen over which the load is applied.

In this study the effect of partial replacement of HDPE plastic with fine aggregate on concrete compressive strength characteristics studied and compared with control specimen. The replacement percentage was 3%, 6%, 9% and 12% by volume of fine aggregate to compare the compressive strength of partially replaced concrete with the control concrete of C-25 grade concrete. Three identical percentage replacement of HDPE cube concrete mix was used at each curing day to determine the compressive strength. The average of three loads used to calculate the average strength of the cube. All the cubes specimens were done with the dimension of 150mm x 150mm x 150mm. The result of compressive strength of the cubes tested at the age of 7 day, 14 day and 28 day in compressive testing machine is shown in the table 4.9.

Table 4.9 Compressive load and the corresponding compressive strength of cube containing HDPE

7th day cube strength result

% of HDPE	Load(KN) Sample1	Load(KN) Sample 2	Load(KN) Sample 3	Avg. Peak Load (KN)	Compressive strength (Mpa)	Variation from control (%)
0%	437.58	474.14	420.12	443.95	19.73	-
3%	446.61	492.98	497.32	478.97	21.29	7.89
6%	431.42	519.75	538.2	496.46	22.07	11.83
9%	456.75	416.73	424.26	432.58	19.23	-2.56
12%	436.5	374.63	448.05	419.73	18.66	-5.46
14th day cube strength result						
% of HDPE	Load(KN) Sample 1	Load(K) Sample 2	Load(KN) Sample 3	Avg. Peak Load (KN)	Compressive strength (Mpa)	Variation from control (%)
0%	582.02	603.93	560.12	582.02	25.87	-
3%	640.95	598.97	638.2	626.04	27.82	7.56
6%	651.36	630.62	647.65	643.21	28.59	10.51
9%	562.98	550.37	571.3	561.55	24.96	-3.52
12%	541.32	510.21	557.47	536.33	23.84	-7.85
28th day cube strength result						
% of HDPE	Load(KN) Sample 1	Load(K) Sample 2	Load(KN) Sample 3	Avg. Peak Load (KN)	Compressive strength (Mpa)	Variation from control (%)
0%	743.14	718.99	720.54	727.56	32.34	-
3%	748.14	794.05	776.2	772.80	34.35	6.22

Continued…

6%	772.21	809.56	823.15	801.64	35.63	10.18
9%	713.38	688.94	672.34	691.55	30.74	-4.95
12%	652.1	606.28	675.24	644.54	28.65	-11.41

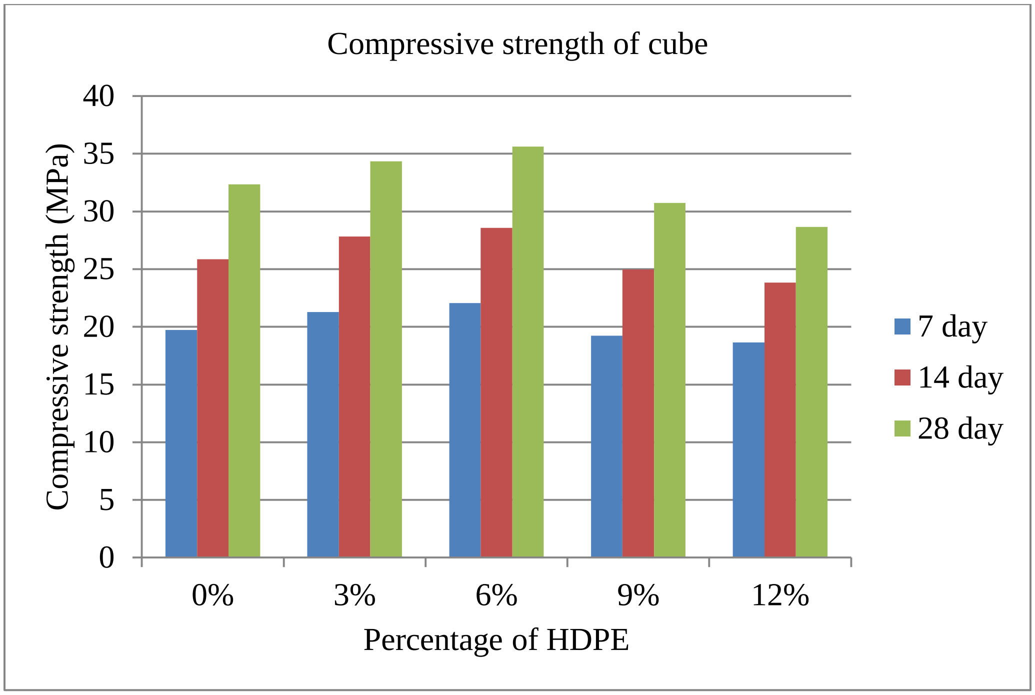


Figure 4.6 Comparison of compressive strength for different percentage of HDPE replacement.

It has been observed form the test result that the cube specimen tested for 7, 14 and 28days with different percentage of HDPE plastic shows a variation in compressive strength when compared with the control specimen. At early age of concrete test, the increaments of compressive strength are 7.89% and 11.83% for 3% and 6% replacement respectively. The reduction in compressive strength of 2.56% and 5.46% observed for 9% and 12% replacement respectively. It has been also observed from the test results that, at early age of compressive strength test the 7day strength are satisfactory for C-25 compressive strength as it is greater than 65% of 25MPa strength for all mix. At age of 14day concrete test the increment of compressive strength are 7.56% and 10.51% for 3% and 6% replacement respectively. The reduction in compressive strength of 3.52% and 7.85% observed for 9% and 12% replacement respectively. Similarly At age of 28day concrete test, the improvement in compressive strength are 6.22% and 10.18% for 3% and 6% replacement respectively, while the reduction in compressive strength of 4.95% and 11.41% observed for 9% and 12% replacement respectively.

For the mix with 9% and 12% HDPE partially replaced sand the compressive strength goes on decreasing. The reason for the reduction in the compressive strength with the increase in the HDPE waste may be attributed due to low bonding of plastic in the matrix, (Saikia N. de Brito J.,2012), as well as the hydrophobic nature of the plastic, where the hydration of cement can be inhibited by restricting the movement of water (Foti D., 2011).

The 28 days compressive strength of the concrete mixes with 6% replacement of sand shows higher compressive strength than other percentage replacement.

4.3.3 Strain stress relation of cubes containing HDPE.

In this study the strain stress for cube specimen was analyzed for 0%, 3%, 6%, 9% and 12% partial replacement of fine aggregate with HDPE plastic by volume as concrete mechanical strength improvement for C-25 grade concrete. The strain at peak point of compressive stress was determined by using displacement gauge which was attached on the compressive strength test machine before applying the load to the cube specimen. The deformation (Δh) of specimens was recorded from the gauge with respect to each load increment and strain was calculated by dividing deformation to height of the cube specimen (h).

The stress was calculated using the load which was taken with the respective gauge reading change in the compressive testing machine during the test under go. The uniaxial stress is given by

$$\sigma = \frac{P}{A}$$

Where; σ = Stress with respective load

P = Applied load

A= Area of cube

The strain was also calculated for the change in height of cube obtained from the gauge reading during the load was applied to the cube divided by the original length of the sample.

$$\varepsilon = \frac{\Delta h}{h}$$

Where; ε = Strain for each change in length

Δh = Change in height of cube and

h= original height of cube

The area of the cube specimen varies as load applied to the specimen in slowly increasing rate on compression. Therefore, the area is a function of the applied load i.e. A = f (P).

$$A_c = \frac{A}{1-\varepsilon_c}$$

A= original area of the cube

A_c = area with respect to each increasing loading
ε_c = strain with respective to each recorded length change.

In this study an attempt was done to draw the stress strain curves from the experimental result of cube test. Indeed, stress is calculated for each respective change in area of cube and respective varying load during the test of compressive strength and strain stress diagram was drawn using the values obtained from the result of computed values for each HDPE replacement at each curing age of 7day, 14day and 28day. The nature of the stress-strain diagram was studied based on peak stress and strain at peak stress. The details of all results and values computed for strain stress relation is tabulated in Appendix D.

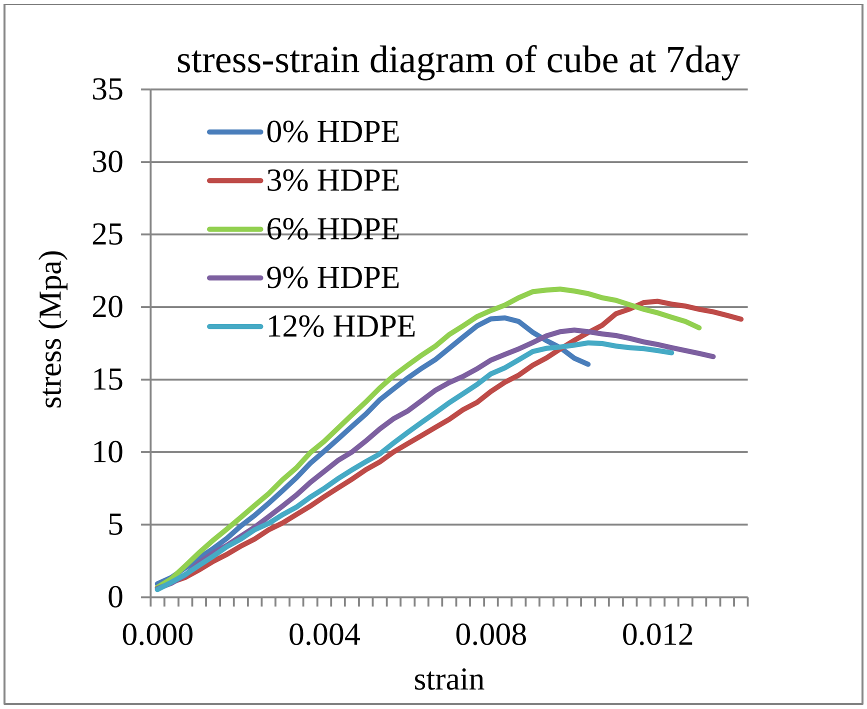


Figure 4.7 The stress - strain responses of concrete cubes made with and without HDPE plastic waste at age of 7days

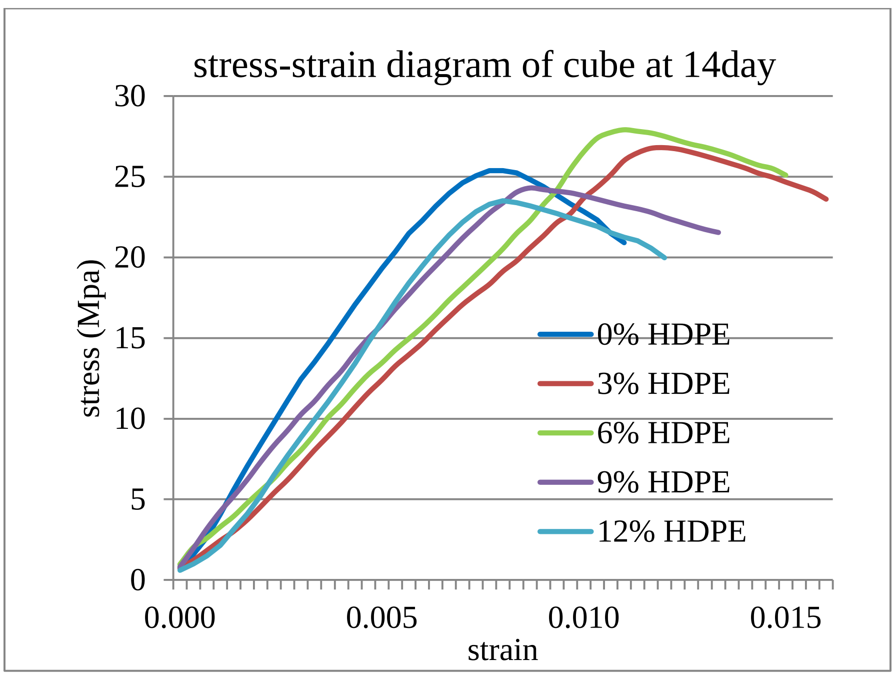


Figure 4.8 The stress - strain responses of concrete cubes made with and without plastic HDPE waste at age of 14days

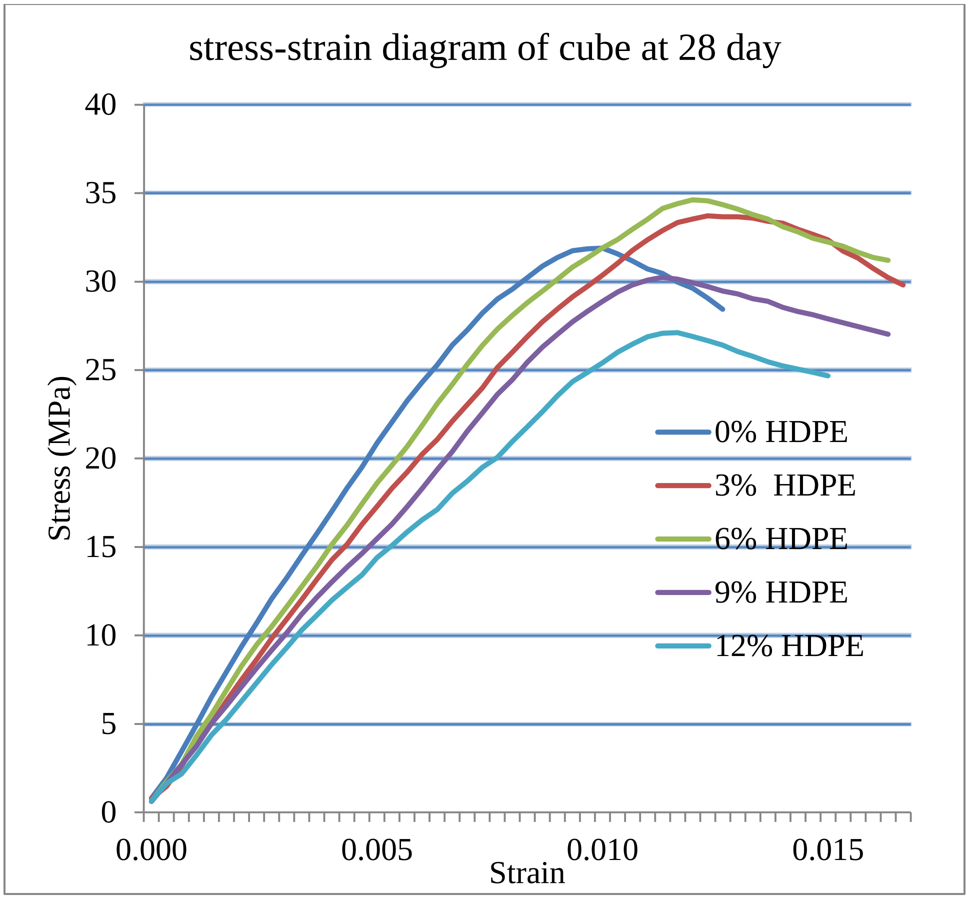


Figure 4.9 The stress - strain responses of concrete cubes made with and without HDPE plastic waste at age of 28 days

From the stress-strain diagram it has been observed that concrete specimens with 9% and 12% HDPE waste plastic have comparatively lower compressive strength than that of control concrete. As the stress increases the peak value of the strain decreased. This can be attributed to the decrease in adhesive strength between the surface of the waste plastic and the cement paste. Additionally, plastic is considered to be a hydrophobic material, so this property may restrict the water necessary for cement hydration during the curing period. It is clearly observed that for concrete mix with HDPE at 3% and 6% shows superior performance than the control. For specimens containing HDPE after the peak stress the stress decrease at slower rate than the control specimen. This shows the ductile property of HDPE plastic in preventing more crack than natural sand.

4.3.4 Split tensile strength test

Concrete is not expected to resist the direct tension because of its low tensile strength and brittle nature. Tensile strength is property of concrete which describe tensile crack of concrete due to tensile applied loading. Split Tensile strength of concrete is lower when compared to its compressive strength. Due to difficulty in applying uniaxial tension to a concrete specimen, the tensile strength of concrete can be determined by indirect test method called Split tensile test and it was used in this study for determining tensile properties of concrete specimens.

In this study, the effect of partial replacement of HDPE plastic with fine aggregate at percentage of 3%, 6%, 9% and 12% on concrete split Tensile strength studied and compared with control concrete mix. The split tensile strength test result of cylinders at 7days, 14days and 28days are shown in Table 4.10.

Table 4.10 Split Tensile load and the corresponding tensile strength of cylinder containing HDPE

7 day split tensile strength

% of HDPE	Load(KN) Sample1	Load(KN) Sample 2	Load(KN) Sample 3	Avg. Peak Load (KN)	Split tensile strength(Mpa)	Variation from control (%)
0%	78.91	92.49	86.52	85.97	2.74	-
3%	95.33	84.73	100.94	93.67	2.98	8.95
6%	86.5	91.8	129.6	102.63	3.27	19.38
9%	97.58	89.2	81.47	89.42	2.85	4.01
12%	75.65	74.09	98.2	82.65	2.63	-3.87
14th day split tensile strength						
% of HDPE	Load(KN) Sample1	Load(KN) Sample 2	Load(KN) Sample 3	Avg. Peak Load (KN)	Split tensile strength(Mpa)	Variation from control (%)
0%	102.4	109.04	91.32	100.92	3.21	-
3%	102.38	118.22	107.21	109.27	3.48	8.27
6%	131.13	106.93	121.58	119.88	3.82	18.79

Continued…						
9%	99.84	118.35	96.29	104.83	3.34	3.87
12%	103.24	96.35	88.61	96.07	3.06	-4.81
28th day split tensile strength						
% of HDPE	Load(KN) Sample1	Load(KN) Sample 2	Load(KN) Sample 3	Avg. Peak Load (KN)	Split tensile strength(Mpa)	Variation from control (%)
0%	122.1	131.64	98.65	117.46	3.74	-
3%	128.11	131.57	121.2	126.96	4.04	8.09
6%	146.52	143.4	126.87	138.93	4.43	18.28
9%	138.4	118.54	108.65	121.86	3.88	3.75
12%	106.54	102.34	124.67	111.18	3.54	-5.35

The relative comparison of split tensile strength test values between the control specimen and concrete with different percentage of HDPE plastic is presented in Figure 4.10.

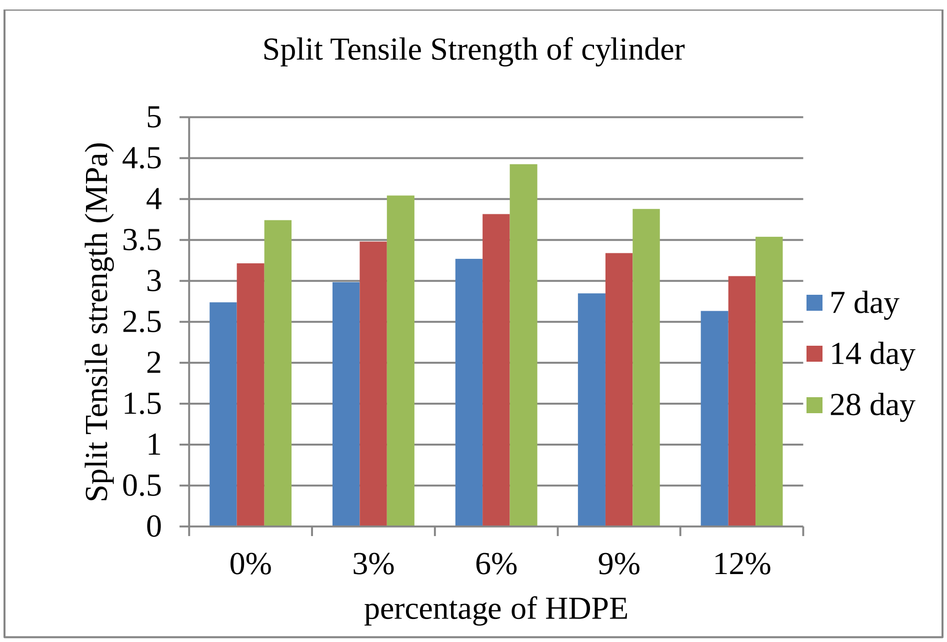


Figure 4.10 Comparison of split tensile strength for different percentage of HDPE replacement

From the observed result, it is evident that at the 7day curing age splitting tensile strength values for 3%, 6%, and 9% HDPE replaced concrete specimens were increased by 8.95%, 19.38%, and 4.01% respectively with respect to control specimen. However, for 12%HDPE replacement the result indicates a decrease of 3.87% with respect to control concrete mix. At the 14day curing age splitting tensile strength values for 3%, 6% and 9% HDPE replaced concrete specimens were increased by 8.27%, 18.79% and 3.87% respectively with respect to control specimen. However, for 12%HDPE replacement the result indicates a decrease of 4.81% with respect to control concrete. Similarly, at the 28day curing age splitting tensile strength values for 3% HDPE, 6%HDPE and 9% HDPE replaced concrete specimens were increased by 8.09%, 18.28% and 3.75% respectively with respect to control specimen. However, for 12%HDPE replacement the result indicates a decrease of 5.35% with respect to control concrete.

Thus, the split tensile strength of the concrete mixes affected in terms of tensile strength with the addition of HDPE plastic as partial replacement of fine aggregate in concrete production at 7, 14 and 28days of curing ages.

The improved performance may be associated with the ductile property of the HDPE waste. The maximum tensile strength of the concrete specimens with HDPE aggregates was inferred due to plastic which trap the cracks and shows better results than control concrete at optimum replacement, (Foti D., 2011). On the other hand, the reduction in the split tensile strength of the concrete mixes with increasing volume of HDPE waste beyond the optimum replacement is mainly due to the weaker bond between the smooth surface of the plastic and cement paste due to the free water available at the surface of the plastic.

4.3.5 Flexural strength test

Flexural strength of a concrete is the ability of concrete to with stand without failure of bending stress arise due to applied load on the beam specimen. The results of flexural test on concrete expressed as a modulus of rupture. The test was done to observe the effect of partially replacing fine aggregate with HDPE at 0%, 3%, 6%, 9% and 12% on flexural strength of concrete at 7, 14 and 28days of curing age. The flexural test on concrete conducted using the two points loading and test results on beam specimen at 7day, 14day and 28day are shown in Table 4.11.

Table 4.11 Flexural load and the corresponding flexural strength of beam

		7th day flexural test result				
% of HDPE	Load(KN) Sample 1	Load(KN) Sample 2	Load(KN) Sample 3	Avg. Peak Load (KN)	Flexural strength(Mpa)	Variation from control (%)
0%	17.04	16.75	17.43	17.07	5.12	-
3%	19.15	18.74	19.03	18.97	5.69	11.13
6%	21.65	21.24	21.34	21.40	6.42	25.38
9%	20.28	19.29	20.68	20.08	6.02	17.63
12%	17.62	17.34	17.76	17.57	5.27	2.92
		14th day flexural strength				
% of HDPE	Load(KN) Sample 1	Load(KN) Sample 2	Load(KN) Sample 3	Avg. Peak Load (KN)	Flexural strength(Mpa)	Variation from control (%)
0%	19.49	17.44	18.93	18.62	5.59	-
3%	21.2	19.68	21.14	20.67	6.20	11.03
6%	23.55	22.83	23.2	23.19	6.96	24.57
9%	21.45	20.78	20.63	20.95	6.29	12.53
12%	19.13	19.01	19.26	19.13	5.74	2.77
			28th day flexural strength			
% of HDPE	Load(KN) Sample 1	Load(KN) Sample 2	Load(KN) Sample 3	Avg. Peak Load (KN)	Flexural strength(Mpa)	Variation from control (%)
0%	21.19	20.7	19.92	20.60	6.18	-
3%	22.59	22.39	23.41	22.80	6.84	10.66
6%	25.44	26.14	25.06	25.55	7.66	24.01
9%	23.04	21.58	22.41	22.34	6.70	8.46
12%	20.81	20.86	21.06	20.91	6.27	1.51

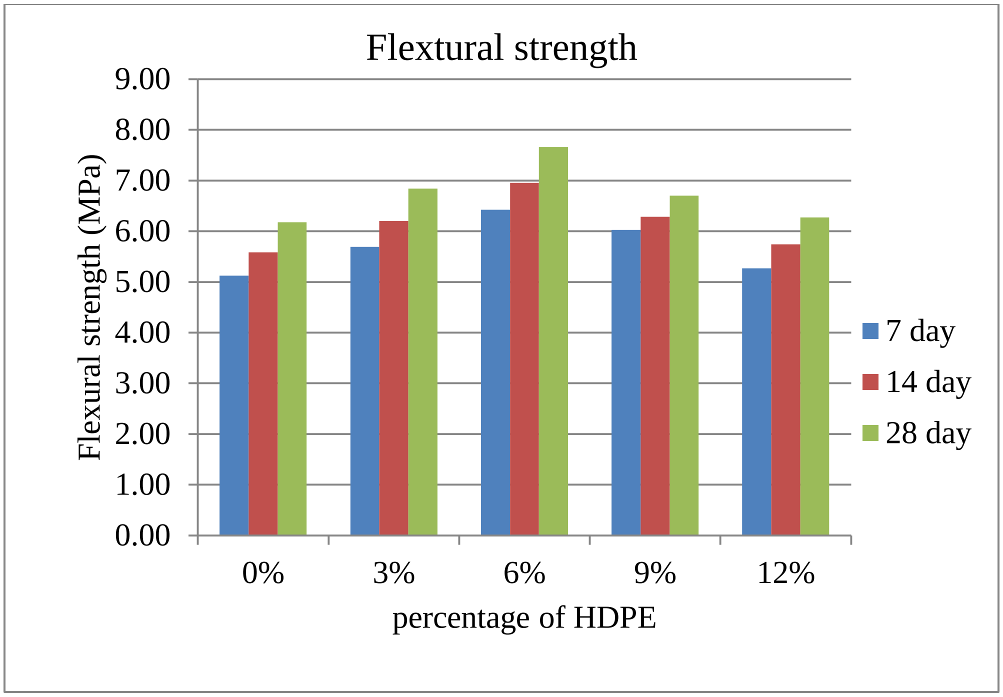


Figure 4.11 The variation in the flexural strength of the concrete mix with HDPE

The test result reveals that the performance of beam tested with HDPE as partial replacement of fine aggregate in concrete shows good performance with respect to control concrete mix. The flexural strength of concrete mix increased by 11.13%, 25.38%, 17.63% and 2.92% for 7day with the partial replacement of HDPE at 3%, 6%, 9% and 12% dosage by volume respectively. At the dosage of 3%, 6%, 9% and 12% HDPE by volume, the flexural strength increased by 11.03%, 24.57%, 12.53% and 2.77% at 14days of curing age and 10.66%, 24.01%, 8.46% and 1.51% increase in flexural strength observed at 28days of curing age respectively.

Flexural strength of concrete influenced with the addition of plastic content in concrete. Replacement of natural fine aggregate with HDPE plastic tends to make concrete ductile and hence increases the ability of concrete to significantly deform before failure. The 28 days flexural strength was found to be maximum for the mixes with 6% replacement of sand (7.66 MPa).

It has been observed from the test results that the mixes with partial replacement of fine aggregates with HDPE waste shows superior performance in the flexural strength compared to the control cement concrete mix. With the increasing of HDPE in concrete mix beyond 6% the flexural strength of concrete decreases for 9% and 12% replacement but it is greater than the control specimen strength.

4.3.6 Crack patterns and types

For this study the effect of waste HDPE plastic was considered for the strength performance of concrete. During the test in laboratory for cubes, cylinders and beams composed of concrete with partial replacement of fine aggregate with HDPE different types of crack patterns observed for each type of specimens.

1. **Cubes**

a. Cube crack

It is clearly evident that under compressive load, the failed control specimen shows more rupture tendency than concrete samples with HDPE plastic.

2. **Cylinders**

b. Cylinder crack

It has been noticed that under splitting tension load, the control test specimen was divided completely into two pieces. Little gap was observed at the vicinity of cracked line for concrete sample containing HDPE plastic at optimum percentage. A little more gap space was found as more HDPE replace sand beyond optimum replacement percentage sample and the highest gap in case of 12% HDPE concrete sample. This clearly indicates that HDPE plastic has capable of crack arresting capacity at optimum dosage of HDPE plastic in concrete.

3. **Beams**

c. Beam crack

Figure 4.12 Patterns and types of crack observed for tested samples.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

A study was conducted to investigate the possibility of partially replacing naturally available fine aggregate with grinded HDPE plastic waste in concrete. The study is aimed at studying the strength characteristics and workability of concrete with partial replacement of natural fine aggregate by HDPE plastic aggregate. Based on the result observed from experiment done on concrete strength with partial replacement of sand with HDPE, the following conclusion was drawn.

1. It is identified that waste HDPE plastic can be used as partial replacement of fine aggregate for concrete production in construction industries.
2. The density of concrete decreases with the increases of HDPE plastic in concrete.
3. The property of fresh concrete is affected by the addition of HDPE plastic. With the increase of HDPE in concrete production the workability of fresh concrete goes on increasing.
4. The mechanical properties of hardened concrete are affected in the partial replacement of fine aggregate with HDPE in concrete. Strength characteristics of concrete decreases with increasing of waste HDPE plastic.
5. The optimum partial replacement of fine aggregate with HDPE in concrete production in terms of workability and strength is found to be 6%.
6. Compressive strength of the concrete increases up to 10.18% for 6% replacement of fine aggregate with HDPE.
7. Split Tensile strength of concrete increases up to 18.28% for 6% replacement of fine aggregate with HDPE
8. Flexural strength of concrete increases up to 24.01% for 6% replacement of fine aggregate with HDPE plastic powder.

5.2 Recommendation

The effect of waste HDPE plastic on concrete mechanical characteristics with partial replacement of fine aggregate at various percentages (0%, 3%, 6%, 9% and 12%) with HDPE plastics in concrete mix was observed in the study.

The present study can be extended for further study to;

1. The test can be carried out to investigate the effect of grades of concrete on mechanical properties of concrete with HDPE in concrete mix.
2. The use of admixtures in the test can be performed to get improved strength.
3. Experimental study can be conducted for other varieties of plastics like PET, PP, and PVC and others.
4. The study can be extended for shear strength characteristics of concrete with partial replacement of fine aggregate by HDPE in concrete.
5. The durability and shrinkage of concrete with plastics has to be tested for beams and columns with varying proportions of waste plastic at different ages.
6. Future study can be carried out for better understanding of the effect of plastic waste on different Properties of concrete mix like, thermal conductivity, specific heat capacity, impact resistance and permeability of plastic waste concrete can be determined through laboratory tests to get a broad idea of various characteristics of concrete having plastic.

REFERENCES

American Concrete Institute (2010). Guide for Specifying, Proportioning, and Production of Fiber-Reinforced Concrete. Farmington Hills, MI.

American Society for Testing and Materials, Annual Book OF ASTM Standards: Section 04.02 – Concrete and Aggregates, Printed IN Baltimore, MD, 2002.

Anju Ramesan, Shemy S. Babu, Aswathy Lal., (*October 2015*). Experimental Investigation on the Performanceof Plastic Aggregate Concrete.International Journal for Research in Applied Science & EngineeringTechnology (IJRASET).*Volume 3 Issue X, ISSN: 2321-9653*

Bandodkar L., Gaonkar D., Gaonkar A., and Gauns Y., (2011).Pulverized PET bottles as partial replacement for sand.*International Journal of Earth Sciences and Engineering*, Vol. 4, p. 1010-1012.

Batayneh M., Marie I., and Ibrahim A., (2007).Use of selected waste materials in concrete mixes, *Waste Management 27*, p. 1873-1875.

Bhikshma V., Jagannadha K., Balaji B., (2010).An experimental study on behavior of polymer cement concrete.*Asian Journal of Civil Engineering (Building and Housing)*, Vol. 11,No. 5,p. 563-573.

Bignozzi M.,Saccani A.,Sandrolini F.,(2000). New polymer mortars containing polymeric waste.Part 1: microstructure and mechanical properties, *Composites: Part A 31*,p. 97-98.

Chen, C.C., Jaffe, N., Koppitz, M., Weimer, W., Polocoser A., (2015).Concrete mixture with plastic as fine aggregate.*International Journal of Advances in Mechanical and Civil Engineering*, 2(4), 49–53.

E. Hınıslıoğlu and E. Ağar, (2004). Use of waste high density polyethylene as bitumen modifier in asphalt concrete mix.*Materials Letters*, vol. 58, no. 3-4, pp. 267–271.

Elzafraney M., Soroushian P., Deru M., (2005). Development of energy efficient concrete buildings using recycled plastic aggregates. *Journal of Architectural Engineering*, p.122- 129

F.Gorden (2003), Resistant changes during compression of carbon fibre cement composite, *Journal of Materials in Civil Engineering*, ASCE, vol.15, no.5, pp. 476 – 483.

Foti D. (2011), Preliminary analysis of concrete reinforced with waste bottles PET fibers. *Construction Build Mater*, 25: p. 1906-1915.

Gaur, K., Arya, Jyotsana, A.K. & Singh, N.K. (2017).Use of Plastic as Partial Replacement of Fine Aggregate in Fibre Reinforced Concrete.*IOSR Journal of Mechanical and Civil Engineering*, 14(3), 71–74.

Ghernouti, Y., Rabehi, B., Safi, B. &Chaid, R. (2009). Use of recycled plastic bag waste in the concrete *Journal of International Scientific Publications: Materials, Methods and Technologies*, 8, 480–487.

Guendouz, M., Debieb, F., Boukendakdji, O., Kadri, E. H., Bentchikou, M., &Soualhi, H. (2016).Use of plastic waste in sand concrete.*J. Mater. Environ. Sci*, *7*(2), 382-389.

Harini, B. &Ramana, K. V. (2015).Use of Recycled Plastic Waste as Partial Replacement for Fine Aggregate in Concrete.*International Journal of Innovative Research in Science, Engineering and Technology*, 4(9), 8596–8603.

https:// www.bpf.co.uk/plastipedia/ polymers/ HDPE.aspx

Ismail, Z.Z. & AL-Hashmi, E.A. (2008).Use of waste plastic in concrete mixture as aggregate replacement.*Waste Management*, 28(11), 2041–2047.

Jaivignesh, B. and Sofi, A., (2017). Study on Mechanical Properties of Concrete Using Plastic Waste as an Aggregate. In *IOP Conference Series: Earth and Environmental Science* ,Vol. 80, No. 1, p. 012016. IOP Publishing.

Janković K., Nicolic D., Bogovic D., L omcar L., Ramacov Z.,(2011). The estimation of compression strength of normal and recycled aggregates concrete, *Architecture and CivilEngineering*, Vol. 9,No 3,p. 419-331

Jibrael, M.A. & Peter, F. (2016). Strength and Behavior of Concrete Contains Waste Plastic. *Journal ofEcosystem &Ecography*, 6(2), 2–5.

Khilesh S. (2014). Study of Strength Property of Concrete Using Waste Plastics and Steel Fiber. The *International Journal of Engineering And Science*, 3(5), 9–11.

Lakshmi R, Nagan S. (2010). Recycled plastics used as coarse aggregate for constructional concrete. *International Journal Of Environmental Sciences;* 1:270.

M.C.Guru Prasad, K.Tanuja, N.Vasu Deva Naidu. (Sep- 2016). Experimental study and strength of concrete by using steel and glass fiber. International Journal of Research in Engineering & Technology Vol. 3, Issue 9, p.233-240.

M.Muzafar Ahmed, Dr. S. SiddiRaju. (May 2015). Properties of Concrete by the Addition of Plastic Solid Waste.*International Journal of Science and Research (IJSR)* Volume 4 Issue 5.

Mahesh, M., Rao, B.V.N. & Sri, C.H.S. (2016). Re-Use of Polyethylene Plastic Waste In Concrete. *International Journal of Engineering Development and Research*, 4(4), 693–702.

Marco Breccolotti, Antonella D'Alessandro, Francesca Roscini, Massimo Federico Bonfigli (2015). Investigation Of Stress - Strain BehaviourOf Recycled Aggregate Concrete Under Cyclic Loads. *Environmental Engineering and Management Journal*, Vol.14, No. 7, p. 1543-1552

Mathew, P., Varghese, S., Paul, T., & Varghese, E. (2013).Recycled plastics as coarse aggregate for structural concrete.*International Journal of Innovative Research in Science, Engineering andTechnology*, *2*(3), 687-690.

MB Hossain, P Bhowmik, KM Shaad (2016). Use of waste plastic aggregation in concrete as a constituent material.*Journal of Progressive Agriculture* 27 (3): 383-391.

MS Shetty,Urmil V. Dave (2013). Utilization of e-waste and plastic bottle waste in concrete.*A review.Environmental protection Mater*. Vol.4. 156-159.

Nibudey R., Nagarnaik P., Parbat K., Pande A., (2013). Strength prediction of plastic fibre reinforced concrete (M30), *Engineering Research and Applications*, Vol. 3, Issue 1, p. 1818-1819.

Praveen M., Varghese S., Paul T., Eldo V.,(2013). Recycled plastics as coarse aggregate for structural concrete, *International Journal of Innovative Research in Science, Engineeringand Technology*, Vol.2, Issue 3, p. 687-690.

R. Vasudevan, S. K. Nigam, R. Velkennedy, A. R. C. Sekar, and B. Sundarakannan, (2009). Utilization of waste polymers for flexible pavement and easy disposal of waste polymers, *InternationalConference on Sustainable Solid Waste Management*, Chennai, India, pp. 105-111.

Saikia N, de Brito J.,(2012).Use of plastic waste as aggregate in cement mortar and concrete preparation: *A review. Constru Build Mater*.;34:385.

Shanmugapriya M and Helen Santhi M. (2017).Strength and Chloride Permeable Properties of Concrete with High DensityPolyethylene Waste.*International Journal Of Chemical Science.*Vol. 15.ISS I.

Shyam S, Drishya P. (2018).Reuse of Plastic Waste as Replacement of M Sand in Concrete.*IOSR Journal of Engineering (IOSRJEN).*Vol. 08, Issue 6, PP 41 -47.

Sivakurmar M.,(2011) Effect of polymer modification on mechanical and structural properties of concrete-an experimental investigation. *International Journal of Civil and StructuralEngineering*, Vol. 1,No 4,p. 733-734.

Subramani, T., &Pugal, V. K. (2015). Experimental Study On Plastic Waste As A Coarse Aggregate For Structural Concrete. *International Journal of Application or Innovation in Engineering &Management (IJAIEM)*, *4*(5), 144-152.

Sudharsan.A and Balamurugan.G,.(2017). Experimental Investigation on Recycle Plasticin Concrete.*International Journal of Innovative Research in Science,Engineering and Technology*, (Vol. 6, Issue 5, p. 8311 – 8315.)

Suganthy P, Chandrasekhar D, Sathish Kumar PK.(2013). Utilization of pulverized plastic in cement concrete as fine aggregate. *International Journal of Research in Engineering and Technology*,Volume: 02 Issue: 06, p. 1015-1019.

T. SenthilVadivel, M. Doddurani and K.S. Shobana.*(*2016*)*. An Experimental Study on Waste Plastic Aggregate BasedConcrete - An Initiative Towards Cleaner Environment. *Middle-East Journal of Scientific Research* 24 (3): 552-556.

ZasiahTafheem, Rakibul Islam Rakib, M.D. Esharuhullah , S.M. ReduanulAlam, Md. MashfiqulIslam (2018*)*. Experimental investigation on the properties of concrete containing post-consumer plastic waste as coarse aggregate replacement.*Journal of materials and engineering structures* (5); 23–31.

APPENDIX

A- Tests on Aggregate

A-1 Tests on Fine Aggregate

Sand sieve analysis

There are different types of sand, so we will have to judge which type of sand is the best for use. The sand is differentiated on the basis of its gradation. The sand will be called graded if it consists of particles having a variety of dimensions. For this reason sieve analysis is conducted to determine the particle size distribution in a sample of aggregate.

Apparatus: Sieve Apparatus or sieve set. The apparatus consists of eight different types of sieves i.e. 9.5mm, 4.75mm, 2.36mm, 1.18mm, 0.6mm, 0.3mm, 0.15mm and pan sieve for fine aggregate, electric shaker, weighing balance.

Procedures

1. The sample was washed and brought to an air-dried condition before weighing and sieving.
2. 2000g of the sand was measured from the sample which was proposed to use for the study.
3. The sieves were arranged in descending order of size from the top.
4. The measured sample of sand was put on the top most sieve and shake for 10 minutes. During the shake material was not forced to pass through the sieve by hand pressure.
5. After 10 minutes the shaker was stopped. Then with the help of balance the weight of retained sample of sand particles on each sieve measured and noted in the table.
6. The percentage of weight retained on each sieve and cumulative percentage retained was calculated.
7. The percentage weight which has passed through each sieve was calculated.
8. Finally the fineness modulus calculated.

Table A-1. Particle size distribution and fineness modules of the sand

Sieve size (mm)	sample			Avg. Mass retained (g)	% retained	Cumulative % retained	Cumul. %passing
	m1 (g)	m2 (g)	m3 (g)				
9.5	0	0	0	0	0	0	100
4.75	2	2.2	1.8	2	0.1	0.1	99.9
2.36	268.4	268	273.6	270	13.5	13.6	86.4
1.18	397.5	397.8	391.2	395.5	19.775	33.375	66.625
0.6	573.7	571.2	571.1	572	28.6	61.975	38.025
0.3	489.9	492.1	494	492	24.6	86.575	13.425
0.15	208	207.2	208.8	208	10.4	96.975	3.025
Pan	60.5	61.5	59.5	60.5	3.025	100	0

Fineness modulus is defined as sum of the cumulative percentage of sand retained in the designated sieves divided by 100.

$$\mathrm{F.M} = \frac{\Sigma \mathrm{Cummulative\ Coarser}(\%)}{100}$$

$$= \frac{292.6}{100}$$

$$= 2.93$$

Moisture content of sand

Its objective was to determine moisture content of sand.

The procedure for the determination of moisture content in sand was;

1. 500g of sand was measured (A),
2. The measured sample of sand allowed to dry in oven for 24hrs.
3. After 24hrs, the sample removed from the oven and its weight measured and noted as dry weight (B).
4. Finally calculations of moisture content in sand have done based on the following calculation.

% Moisture content = $\frac{(A-B)}{B}$*100%

Where: A= weight of original sample (g)

B = weight of oven dry sample (g)

Table A-2. Percentage moisture content of sand

sample	A (g)	B (g)	Moisture content (%)
1	500	496.5	0.705
2	500	495.8	0.847
3	500	497.2	0.563
Average			0.705

Average percentage of moisture content in sand = 0.705%

Specific gravity and water Absorption of sands

Specific gravity is the ratio of the weight in air of a given volume of a material to the weight in air of an equal volume of distilled water. Absorption is a measure of the amount of water that an aggregate can absorb into its pore structure. Pores that absorb water are also referred to as water permeable voids. This test was done to investigate bulk and apparent specific gravity of sand and absorption of sand.

Apparatus: 500g of sample sand, water, pycnometer bottle and weighing balance

Procedure

1. 500g sand was put in pycnometer and filled with water to the calibration capacity.
2. Rolling and agitating the pycnometer to eliminate air bubbles have processed.
3. The total weight of the pycnometer, sample, and water together measured (C).

   C = 0.9976Va+500+W

   Where:

   C = Weight of pycnometer filled with sample and water

   Va = Volume of water added to pycnometer empty

   W = Weight of the pycnometer empty

4. The fine aggregate was removed from the pycnometer, allowed to dry at a temperature of $105 \pm 5^{\circ} c$ in oven for 24hrs and after removal of fine aggregates from the oven cooled in air at room temperature and measurement have done (A).
5. The empty pycnometer was cleaned thoroughly and filled with water to full level of pycnometer capacity.
6. The weight of pycnometer filled to its calibration capacity with water was determined (B).

   B = 0.9976V+W

   Where:

   B = Weight of flask filled with water

   V = Volume of flask

   W = Weight of the flask empty

Bulk specific gravity

$$\text{Bulk Sp gr} = \frac{A}{B+500-C}$$

Bulk specific gravity (Saturated Surface Dry Basis)

$$\text{Bulk Sp gr (SSD)} = \frac{500}{B+500-C}$$

Apparent Specific gravity:

$$\text{Apparent Sp. gr} = \frac{A}{B+A-C}$$

Absorption:

$$\text{Absorption (\%)} = \frac{(500-A)*100}{A}$$

Where

A=weight of oven dry sample in air

B=Weight of pycnometer filled with water

C= Weight of pycnometer with sample and water to calibration mark

Table A-3.Specific gravity and water absorption of sand

sample	C (g)	B (g)	A (g)	Bulk Spec. gravity	Bulk Specific Gravity (SSD)	Apparent sp. gravity	Absorption (%)
1	1870	1560	495.2	2.61	2.63	2.67	0.97
2	1867	1555	493.9	2.63	2.66	2.72	1.24
3	1865	1556	494.5	2.59	2.62	2.67	1.11
Average				2.61	2.64	2.69	1.11

Unit weight of sand

Unit weight is the ratio of weight to volume of a given graded aggregate. Laboratory procedures have done to determine unit weight of fine aggregate used for this study in laboratory. The overall procedure includes filling 1/3, 2/3 and full level of cylindrical metal and 25 times random compaction for each layer have done. The cylindrical metal used has constant volume. Finally, the net weights of sand measurement have recorded.

Unit weight = $\frac{M}{V}$

Where:

M = mass of sand

V = volume of cylindrical metal

Table A-4.Unitweight data for sand

sample	Mass of cylinder and sample (Kg)	Mass of cylinder (Kg)	Mass of sample (Kg)	Volume of cylinder (m^3)	Unit weight (Kg/m^3)
1	9.414	1.06	8.354	0.005	1670.8
2	9.398	1.06	8.338	0.005	1667.6
3	9.409	1.06	8.349	0.005	1669.8

Average unit weight = 1669 Kg/m^3

Silt content of sand

Determination of sand silt content by laboratory and field settling test method was done as per Ethiopian standard. It is recommended to remove the sand if the percentage of silts in sand is greater than 6%, because as the percent of silt in sand increase it affects quality of concrete strength. In this study Field method and Laboratory test method were used to determine the silt content of sand.

Field settling test method: Under this method after preparing the required testing apparatus like glass jar, small size spoon, sample sand and clean water, selected sand sample were pour in a glass jar up to 50mm height, next to this 75% of the jar filled with water then finally the jar shacked for about a minute then the jar were placed for about three hours finally the amount of silt in the sample has calculated.

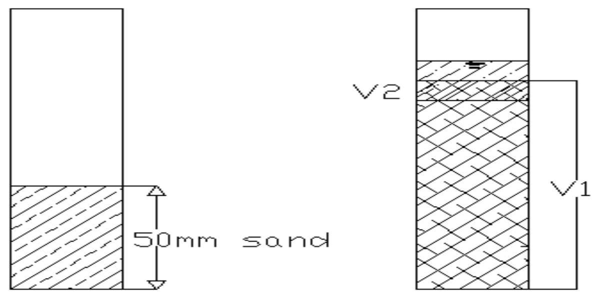


Figure A-1 Water and sand contents in jar

Silt content (%) $=\frac{V2}{V1} * 100$

Where:

V1= volume of sample (sand and water)

V2= volume of silt

Therefore the final calculation of silt content for three samples were listed in table A-5

Table A-5 Field method of silt content test in sand

Description	Samples		
	1	2	3
Volume of sample (sand + water) in mm	50	50	50
Volume of silt after 3hrs (mm)	1.2	1.8	1.5
Percentage of silt content by volume	2.4	3.6	3
Average silt content (%)	3		

Average value of percentage silt content is less than 6%

Laboratory method silt content determination: Laboratory experimental determination of silt contents in sand has done to compare the results with that of field method. The general procedure includes, measuring 1Kg sand from the sample and then washing the sand was done up to clean water has observed, this was done to remove silts finer than sieve size 0.075mm then the sample was put in oven for 24hrs. After a 24 hours the value of silts in the sand were calculated.

Silt content (%) = $\frac{(M1-M2)}{M1} * 100$

Where; M1 = original dry mass

M2 = dry mass after washing

TableA-6 Laboratory method of silt content in sand.

Description	Samples		
	1	2	3
Original dry mass (Kg)	1	1	1
Dry mass after washing (Kg)	0.972	0.967	0.97
Percentage of silt content (%)	2.8	3.3	3
Average silt content (%)	3.03		

Average value of silt content in sand is less than 6%.

Table A-7. Summary of physical properties of fine aggregate used

Tests	Laboratory Result
Type of sand used	Naturally available sand
Moisture content (%)	0.705
Specific gravity (SSD)	2.64
Fineness modules	2.93
Water absorption (%)	1.11
Unit weight (Kg/m^3)	1669

Bulking of sand

The main objective of this test includes determining the percentage bulk of moist sand. It was done to determine how finer materials are more easily pushed apart by moisture than coarser ones by surface moisture. Thus, the existence of moistures in the sand increases the total volume of sands.

The general procedure contains, filling 75% of cylinder with the moist sand then the height of the sample (V1) was measured. On the other side another empty cylinder filled to the same level with water and pure the sand slowly in to water have done, removing all bubbles by stirring with a rod, measuring the height of fully saturated (submerged) sand V2, finally calculating the bulking volume have done step by step procedure.

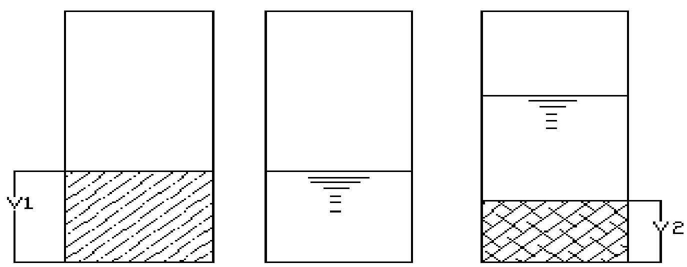


Figure A-2 Damp sand, water and sand& water respectively

Percentage of bulking of sand = $\frac{(V1-V2)*100}{V2}$

Buckling factor = $\frac{V1}{V2}$

Where:

V1=volume of moist sand

V2=volume of fully saturated sand

Table A-8 Percentage of bulking

Description	Samples		
	1	2	3
Volume of moist sand (mm)	375	375	375
Volume of fully saturated sand (mm)	270	260	280
Percentage of bulking (%)	38.89	44.23	33.93
Bulking factor	1.39	1.44	1.34
Average bulking (%)	39.02		

A-2.Test on course aggregate

Specific gravity and absorption test

Specific gravity of an aggregate is a measure of strength or quality of the material. The specific gravity of a substance is the ratio between the weight of the substance and that of the same volume of water. Stones having low specific gravity are generally weaker than those with higher specific gravity. Water absorption indicates strength of rocks. Stones having more water absorption are more porous in nature and are unsuitable unless they are found to be acceptable based on strength, impact and hardness tests.

Its objective was to determine specific gravity and water absorption capacity of coarse aggregate.

Apparatus: Beaker, Hot air oven, weighing balance, tray, sample containers, a wire basket suitable apparatus for suspending the sample container in water from the center of the scale pan or balance.

Procedure

1. A sample (2Kg) of Coarse aggregate were used and washed with pure water to remove any dust or fine particles
2. Placing in a wire basket and immersing the basket with the sample in distilled water have done. The basket with sample was completely immersed for a period of 24hrs. The basket placed at 5cm above water top of basket. The basket lifted 25 mm above the base of tank and allowed to drop 25 times at the rate of more than one drop per second.

3. After 24hrs weighing the basket with sample in water (Wa) and drying for a few minutes have done and weight recorded.
4. Then returning the basket in the water and weighing in water, (Wb) and Weighing the aggregate which is surface dried with close,(MSSD) have done.
5. Then placing the aggregate in an oven at a temperature of 100°c to 110°c for about 24hrs then after 24hrs, the sample removed from the oven, cooled in the air tight container and weighed and, (MD).

Calculation:

W_b= weight of basket

M_w = weight of the saturated aggregate in water (w_a- w_b)

MSSD = mass of saturated surface dry

MD = mass of oven dry sample

Average Apparent specific gravity = $\frac{MD}{MD-MW}$

Average Bulk specific gravity (oven dry basis) = $\frac{MD}{MSSD-MW}$

Bulk specific gravity (saturated surface dry basis) = $\frac{MSSD}{MSSD-MW}$

% Water Absorption = $\frac{(MSSD-MD)}{MD}$ *100

Table A-9.Experimental observation and record Result of Coarse aggregate Test

sample	M_W (g)	M_{SSD} (g)	M_D (g)	Apparent Sp. Gravity (Oven dry)	Bulk Specific Gravity (SSD basin)	Bulk spec. Gravity (oven dry)	Absorption (%)
1	1319.6	2008.5	1985.5	2.98	2.93	2.88	1.16
2	1313.0	2006.2	1986.0	2.95	2.88	2.86	1.02
3	1315.8	2005.0	1985.0	2.97	2.91	2.88	1.01
Average				2.97	2.91	2.87	1.06

Sieve analysis test

This section discuss about the gradation or relative particle size distribution of coarse aggregate by series of square or round opening sieve and also to determine the fineness modulus of course aggregate. Based on the result of sieve analysis particle size distribution can be categorized under well graded, Gap graded and poor graded coarse aggregate.

Procedure

1. A sample of 10Kg coarse aggregate was measured from the sample which was washed and brought to an air-dried condition before weighing and sieving.
2. The sieves were arranged in descending order of size from the top.
3. The measured sample of coarse aggregate was put on the top most sieve and shake for 10 minutes. During the shake material was not forced to pass through the sieve by hand pressure.
4. After 10 minutes the shaker was stopped. Then with the help of balance the weight of retained sample of gravel particles on each sieve measured and noted in the table.
5. The percentage of weight retained on each sieve and cumulative percentage retained was calculated.
6. The percentage weight which has passed through each sieve was calculated.
7. Finally the fineness modulus of coarse aggregate calculated.

Table A-10.Particle size distributions and Fineness module of course aggregate

Sieve size (mm)	Mass of Samples			Avg. Mass retained (g)	% retained	Cumulative % retained	Cumulative % passing
	m_1 (g)	m_2 (g)	m_3 (g)				
37.5	0	0	0	0	0	0	100
28	847.5	849.2	857.8	851.5	8.515	8.515	91.485
19	4828	4831.6	4824.4	4828	48.28	56.795	43.205
12.5	2569.5	2562.8	2564.2	2565.5	25.655	82.45	17.55

9.5	1325.5	1323.8	1327.2	1325.5	13.255	95.705	4.295
4.75	427	429.6	424.4	427	4.27	99.975	0.025
pan	2.5	3	2	2.5	0.025	100	0

$$\mathrm{F.M} = \frac{\Sigma \text{Cummulative Coarser}(\%)}{100}$$

$$\mathrm{F.M} = \frac{343.44}{100} = 3.43$$

Moisture content of coarse aggregate

Under this investigation determination of moisture content of coarse aggregate have done. The procedure for the determination of moisture content in coarse aggregate includes

1. weighing 2000g of coarse aggregate (A),
2. oven dry for 24hrs, after removal of the sample after a day weighing the sample (B) and
3. Finally calculation of moisture in coarse aggregate has determined.

Observation and calculation

%Moisture content = $\frac{(A-B)*100}{B}$

Where; A = weight of original sample (g)

B = weight of oven dry (g)

Table A-11. Percentage moisture content of coarse aggregate

sample	A (g)	B (g)	Moisture content (%)
1	2000	1980.5	0.985
2	2000	1981.6	0.929
3	2000	1979.4	1.041
Average			0.985

Average percentage of moisture content of coarse aggregate = 0.985

Unit weight of coarse aggregate

Unit weight is the ratio of sample weight to its volume occupied by the sample. In this study, three samples have taken for the determination of unit weight of coarse aggregate and the compact weight determination was used to determine compact unit weight of aggregate. The unit weight is simply measured by filling a container of known volume and weighing it.

Apparatus

Balance, a cylindrical metal measure and tamping tool

Procedure was:

1. The aggregate was filled on three layers (one third, two third and full level) and each level randomly compacted with steel rod 25 times.
2. The surface of aggregate was leveled with straight edge such way that any slight projection of the larger pieces of coarse aggregate balances the void surfaces below the top of the measure.
3. Weigh the measure and finally dividing this weight by the volume of the measure have processed.

Calculation.

Unit weight = $\frac{M}{V}$

Where:

M = mass of Aggregate

V = volume of cylindrical metal

Mass of sample = (mass of sample + mass of cylinder) - Mass of cylinder

Table A-12. Unit weight of coarse aggregate determination

sample	Mass of cylinder and sample (Kg)	Mass of cylinder (Kg)	Mass of sample (Kg)	Volume of cylinder (m^3)	Unit weight (Kg/m^3)
1	18.552	1.682	16.870	0.01	1687.0
2	18.549	1.682	16.867	0.01	1686.7
3	18.543	1.682	16.861	0.01	1686.1
Average					1686.6

Avg. unit weight = 1687 Kg/m^3

Summary of coarse aggregate physical properties

Table A-13. Summary of physical properties of coarse aggregate used

Tests	Laboratory result
Moisture content (%)	0.985
Specific gravity(SSD)	2.91
Water absorption (%)	1.06
Unit weight ($\frac{Kg}{m^3}$)	1687

A-3.Sieve analysis of HDPE

Particle Size Distribution (PSD) of HDPE

The grinded HDPE powder of 500g was weighed and then placed on the first sieve of the arranged series of sieves in descending order on the electric shaker and the machine was turned on. After the sieve shaker shaked the plastic aggregates, some aggregates passing through each sieves and others retained on each sieve series. After 10 minutes the sieve shaker automatically stopped and the plastic aggregates retained in the respective sieves were weighed for their masses. The same process was repeated three times with 500g of HDPE powder so that the average of the retained mass on each respective sieve was used for PSD determination.

Table A-14.Particle size distributions and Fineness module of HDPE

Sieve size (mm)	Mass of Sample (g)			Avg. mass (g)	%retained (%)	cum. % retained	cum.% passing
	M_1	M_2	M_3				
9.5	0	0	0	0	0	0	100
4.75	11.24	13.1	12.56	12.3	2.460	2.460	97.540
2.36	59.45	58.9	60.27	59.54	11.908	14.368	85.632
1.18	104.2	99.75	103.55	102.5	20.5	34.868	65.132
0.6	160.56	161.91	152.82	158.43	31.686	66.554	33.446
0.3	97.5	93.7	96.2	95.8	19.16	85.714	14.286
0.15	46.25	48.6	49.54	48.13	9.626	95.340	4.660
Pan	20.8	24.04	25.06	23.3	4.66	100.000	0.000

FM = 2.99

B- Density of test specimen

Table B-1.Density of cubes specimens

HDPE	mass of cube sample at 7 day (Kg)				volume (m^3)	density (Kg/m^3)
	1	2	3	avg. mass		
0%	8.692	8.632	8.541	8.622	0.00338	2554.568
3%	8.504	8.211	8.39	8.368	0.00338	2479.506
6%	8.251	8.457	8.192	8.3	0.00338	2459.259
9%	7.993	8.202	8.124	8.106	0.00338	2401.877
12%	7.983	8.102	8.025	8.037	0.00338	2381.235

HDPE	mass of cube sample at 14 day (Kg)				volume (m^3)	density (Kg/m^3)
	1	2	3	avg. mass		
0%	8.317	8.485	8.341	8.381	0.00338	2483.259
3%	8.421	8.294	8.352	8.356	0.00338	2475.753
6%	8.215	8.272	8.182	8.223	0.00338	2436.444
9%	8.141	8.318	8.124	8.194	0.00338	2427.951
12%	7.983	8.102	8.075	8.053	0.00338	2386.173

HDPE	mass of cube sample at 28 day (Kg)				Volume(m^3)	density (Kg/m^3)
	1	2	3	avg. mass		
0%	8.428	8.495	8.452	8.458	0.00338	2506.173
3%	8.368	8.506	8.423	8.432	0.00338	2498.469
6%	8.367	8.223	8.314	8.301	0.00338	2459.654
9%	8.263	8.236	8.269	8.256	0.00338	2446.222
12%	8.207	8.128	8.095	8.143	0.00338	2412.840

Table B-2.Density of split tensile specimens

HDPE	mass of cylinder sample at 7 day (Kg)				Volume (m^3)	density (Kg/m^3)
	1	2	3	avg. mass		
0%	3.512	3.895	3.826	3.744	0.00157	2384.926
3%	3.781	3.727	3.694	3.734	0.00157	2378.344
6%	3.658	3.715	3.64	3.671	0.00157	2338.217
9%	3.732	3.634	3.564	3.643	0.00157	2320.594
12%	3.658	3.644	3.602	3.635	0.00157	2315.074
HDPE	mass of cylinder sample at 14 day (Kg)				volume (m^3)	density (Kg/m^3)
	1	2	3	avg. mass		
0%	3.772	3.761	3.821	3.785	0.00157	2410.616
3%	3.734	3.849	3.704	3.762	0.00157	2396.391
6%	3.677	3.849	3.754	3.76	0.00157	2394.904
9%	3.766	3.72	3.723	3.736	0.00157	2379.830
12%	3.668	3.707	3.652	3.676	0.00157	2341.189
HDPE	mass of cylinder sample at 28 day (Kg)				volume (m^3)	density (Kg/m^3)
	1	2	3	avg. mass		
0%	3.893	3.684	3.739	3.772	0.00157	2402.548
3%	3.669	3.793	3.612	3.691	0.00157	2351.168
6%	3.68	3.689	3.696	3.688	0.00157	2349.257
9%	3.725	3.698	3.624	3.682	0.00157	2345.435
12%	3.612	3.678	3.602	3.631	0.00157	2312.527

Table B-3.Density of beam specimens

HDPE	mass of beam sample at 7 day (Kg)				volume (m^3)	density (Kg/m^3)
	1	2	3	avg. mass		
0%	12.73	12.283	12.454	12.489	0.005	2497.800
3%	12.106	12.244	12.825	12.392	0.005	2478.333
6%	12.413	12.4	12.302	12.372	0.005	2474.333
9%	12.122	12.827	12.012	12.320	0.005	2464.067
12%	11.654	12.048	12.167	11.956	0.005	2391.267
HDPE	mass of beam sample at 14 day (Kg)				volume (m^3)	density (Kg/m^3)
	1	2	3	avg. mass		
0%	12.414	12.263	12.336	12.338	0.005	2467.533
3%	12.747	11.979	12.012	12.246	0.005	2449.200
6%	12.142	12.053	12.427	12.207	0.005	2441.467
9%	11.945	12.478	11.835	12.086	0.005	2417.200
12%	12.021	11.897	12.157	12.025	0.005	2405.000
HDPE	mass of beam sample at 28 day (Kg)				volume (m^3)	density (Kg/m^3)
	1	2	3	avg. mass		
0%	12.191	12.253	12.201	12.215	0.005	2443.000
3%	12.252	12.076	12.131	12.153	0.005	2430.600
6%	12.25	11.972	12.156	12.126	0.005	2425.200
9%	12.056	12.181	12.104	12.114	0.005	2422.733
12%	11.968	12.045	12.065	12.026	0.005	2405.200

C- Test result of the specimen

Table C-1. Cube Test Result

7th day cube strength result						
HDPE	Cubes Load (KN)			Aveg. Load (KN)	Strength (MPa)	Variation from control
	1	2	3			
0%	437.58	474.14	420.12	443.95	19.73	-
3%	446.61	492.98	497.32	478.97	21.29	7.89
6%	431.42	519.75	538.2	496.46	22.07	11.83
9%	456.75	416.73	424.26	432.58	19.23	-2.56
12%	436.5	374.63	448.05	419.73	18.66	-5.46
14th day cube strength result						
HDPE	Cubes Load (KN)			Avg. Load (KN)	strength (MPa)	Variation from control
	1	2	3			
0%	582.02	603.93	560.12	582.02	25.87	-
3%	640.95	598.97	638.2	626.04	27.82	7.56
6%	651.36	630.62	647.65	643.21	28.59	10.51
9%	562.98	550.37	571.3	561.55	24.96	-3.52
12%	541.32	510.21	557.47	536.33	23.84	-7.85
28th day cube strength result						
HDPE	Cubes Load (KN)			Avg. Load (KN)	strength (MPa)	Variation from Control
	1	2	3			
0%	743.14	718.99	720.54	727.56	32.33	-
3%	748.14	794.05	776.2	772.80	34.35	6.22
6%	772.21	809.56	823.15	801.64	35.63	10.18
9%	713.38	688.94	672.34	691.55	30.74	-4.95
12%	652.1	606.28	675.24	644.54	28.65	-11.41

Table C-2. Cylinder Test Result

7 day cylinder strength						
HDPE	Cylinders Load (KN)			Avg. Load (KN)	Strength (MPa)	Variation from control
	1	2	3			
0%	78.91	92.49	86.52	85.97	2.74	-
3%	95.33	84.73	100.94	93.67	2.98	8.95
6%	86.5	91.8	129.6	102.63	3.27	19.38
9%	97.58	89.2	81.47	89.42	2.85	4.01
12%	75.65	74.09	98.2	82.65	2.63	-3.87
14 day cylinder strength						
HDPE	Cylinders Load (KN)			Avg. Load (KN)	Strength (MPa)	Variation from control
	1	2	3			
0%	102.4	109.04	91.32	100.92	3.21	-
3%	102.38	118.22	107.21	109.27	3.48	8.27
6%	131.13	106.93	121.58	119.88	3.82	18.79
9%	99.84	118.35	96.29	104.83	3.34	3.87
12%	103.24	96.35	88.61	96.07	3.06	-4.81
28day cylinder strength						
HDPE	Cylinders Load (KN)			Avg. Load (KN)	Strength (Mpa)	Variation from control
	1	2	3			
0%	122.1	131.64	98.65	117.46	3.74	-
3%	128.11	131.57	121.2	126.96	4.04	8.09
6%	146.52	143.4	126.87	138.93	4.43	18.28
9%	138.4	118.54	108.65	121.86	3.88	3.75
12%	106.54	102.34	124.67	111.18	3.54	-5.35

Table C-3. Beam Test Result.

7th day flexural test result						
HDPE	Beam load (KN)			Avg. Load (KN)	Strength (Mpa)	Variation from control
	1	2	3			
0%	17.04	16.75	17.43	17.07	5.12	-
3%	19.15	18.74	19.03	18.97	5.69	11.13
6%	21.65	21.24	21.34	21.41	6.42	25.38
9%	20.28	19.29	20.68	20.08	6.02	17.63
12%	17.62	17.34	17.76	17.57	5.27	2.92
14th day flexural strength						
HDPE	Beam load (KN)			Avg. Load (KN)	Strength (Mpa)	Variation from control
	1	2	3			
0%	19.49	17.44	18.93	18.62	5.59	-
3%	21.2	19.68	21.14	20.67	6.20	11.03
6%	23.55	22.83	23.2	23.19	6.96	24.57
9%	21.45	20.78	20.63	20.95	6.29	12.53
12%	19.13	19.01	19.26	19.13	5.74	2.77
28th day flexural strength						
HDPE	Beam load (KN)			Avg. Load (KN)	strength (MPa)	Variation from control
	1	2	3			
0%	21.19	20.7	19.92	20.60	6.18	-
3%	22.59	22.39	23.41	22.80	6.84	10.66
6%	25.44	26.14	25.06	25.55	7.66	24.01
9%	23.04	21.58	22.41	22.34	6.70	8.46
12%	20.81	20.86	21.06	20.91	6.27	1.51

D- Stress - strain diagram for cube test

Table D-1. Stress - Strain Diagram for Cube at Age of 7day

Cube with 0% HDPE at 7day									
ΔH (mm)	strain	Load (KN)			Area (mm^2)	Stress (MPa)			
		1	2	3		1	2	3	Avg.
0	0.0000	21.0	19.0	22.0	22500	0.933	0.844	0.978	0.919
0.05	0.0003	32.5	28.5	31.0	22507.5	1.444	1.266	1.377	1.363
0.1	0.0007	52.0	45.9	38.0	22515	2.310	2.039	1.688	2.012
0.15	0.0010	59.0	62.2	62.1	22522.5	2.620	2.762	2.757	2.713
0.2	0.0013	68.0	85.0	73.3	22530	3.018	3.773	3.253	3.348
0.25	0.0017	97.0	92.0	84.8	22537.6	4.304	4.082	3.763	4.050
0.3	0.0020	120.0	108.4	103.7	22545.1	5.323	4.808	4.600	4.910
0.35	0.0023	136.1	119.8	125.0	22552.6	6.035	5.312	5.543	5.630
0.4	0.0027	151.2	134.0	153.0	22560.2	6.702	5.940	6.782	6.475
0.45	0.0030	169.7	146.7	179.8	22567.7	7.520	6.500	7.967	7.329
0.5	0.0033	170.0	185.6	202.5	22575.3	7.530	8.221	8.970	8.241
0.55	0.0037	201.0	196.0	228.0	22582.8	8.901	8.679	10.096	9.225
0.6	0.0040	226.8	219.5	235.2	22590.4	10.040	9.717	10.412	10.056
0.65	0.0043	252.7	239.3	247.9	22597.9	11.182	10.589	10.970	10.914
0.7	0.0047	283.5	261.8	252.6	22605.5	12.541	11.581	11.174	11.766
0.75	0.0050	304.5	278.9	274.2	22613.1	13.466	12.334	12.126	12.642
0.8	0.0053	323.8	298.1	301.3	22620.6	14.314	13.178	13.320	13.604
0.85	0.0057	331.8	319.5	323.4	22628.2	14.663	14.120	14.292	14.358
0.9	0.0060	344.4	334.7	346.9	22635.8	15.215	14.786	15.325	15.109
0.95	0.0063	352.8	345.2	373.6	22643.4	15.581	15.245	16.499	15.775
1	0.0067	365.1	356.9	391.8	22651	16.118	15.756	17.297	16.391
1.05	0.0070	380.3	370.6	414.7	22658.6	16.784	16.356	18.302	17.147
1.1	0.0073	393.4	407.1	418.7	22666.2	17.356	17.961	18.472	17.930
1.15	0.0077	424.5	426.6	420.1	22673.8	18.722	18.815	18.528	18.688
1.2	0.0080	437.5	449.3	418.4	22681.5	19.289	19.809	18.447	19.182
1.25	0.0083	427.5	467.8	415.5	22689.1	18.842	20.618	18.313	19.257
1.3	0.0087	414.0	474.1	406.0	22696.7	18.241	20.888	17.888	19.006
1.35	0.0090	407.5	444.1	392.7	22704.3	17.948	19.560	17.296	18.268
1.4	0.0093	395.0	436.5	372.8	22712	17.392	19.219	16.414	17.675
1.45	0.0097	385.6	426.4	360.3	22719.6	16.972	18.768	15.859	17.200
1.5	0.0100	360.2	414.1	349.4	22727.3	15.849	18.220	15.374	16.481
1.55	0.0103	355.0	396.9	342.3	22734.9	15.615	17.458	15.056	16.043
1.6	0.0107				22742.6	0.000	0.000	0.000	0.000
1.65	0.0110				22750.3	0.000	0.000	0.000	0.000

Cube with 3% HDPE at 7day									
ΔH (mm)	strain	Load (KN)			Area (mm^2)	Stress(MPa)			
		1	2	3		1	2	3	Avg.
0	0.00000	17.0	16.0	13.0	22500	0.756	0.711	0.578	0.681
0.05	0.00033	21.3	26.0	22.8	22507.5	0.946	1.155	1.013	1.038
0.1	0.00067	35.2	31.7	25.0	22515	1.563	1.408	1.110	1.361
0.15	0.00100	40.0	39.7	48.1	22522.5	1.776	1.763	2.136	1.891
0.2	0.00133	46.0	52.4	67.8	22530	2.042	2.326	3.009	2.459
0.25	0.00167	53.7	70.0	75.0	22537.6	2.383	3.106	3.328	2.939
0.3	0.00200	60.5	85.1	93.0	22545.1	2.684	3.775	4.125	3.528
0.35	0.00233	72.6	91.5	107.2	22552.6	3.219	4.057	4.753	4.010
0.4	0.00267	83.4	103.0	128.7	22560.2	3.697	4.566	5.705	4.656
0.45	0.00300	96.7	110.5	139.0	22567.7	4.285	4.896	6.159	5.114
0.5	0.00333	108.2	121.6	156.4	22575.3	4.793	5.386	6.928	5.702
0.55	0.00367	118.6	142.3	164.7	22582.8	5.252	6.301	7.293	6.282
0.6	0.00400	134.0	160.0	175.0	22590.4	5.932	7.083	7.747	6.920
0.65	0.00433	146.2	177.3	187.4	22597.9	6.470	7.846	8.293	7.536
0.7	0.00467	153.5	194.7	204.0	22605.5	6.790	8.613	9.024	8.143
0.75	0.00500	184.0	204.0	208.0	22613.1	8.137	9.021	9.198	8.785
0.8	0.00533	193.0	224.6	214.8	22620.6	8.532	9.929	9.496	9.319
0.85	0.00567	208.3	243.0	228.1	22628.2	9.205	10.739	10.080	10.008
0.9	0.00600	214.0	268.4	236.0	22635.8	9.454	11.857	10.426	10.579
0.95	0.00633	235.2	273.0	247.3	22643.4	10.387	12.056	10.922	11.122
1	0.00667	246.7	293.0	255.7	22651	10.891	12.935	11.289	11.705
1.05	0.00700	254.0	306.4	273.0	22658.6	11.210	13.522	12.048	12.260
1.1	0.00733	278.0	319.0	281.7	22666.2	12.265	14.074	12.428	12.922
1.15	0.00767	285.3	333.7	294.9	22673.8	12.583	14.717	13.006	13.435
1.2	0.00800	306.1	347.0	312.0	22681.5	13.496	15.299	13.756	14.183
1.25	0.00833	328.7	355.0	325.2	22689.1	14.487	15.646	14.333	14.822
1.3	0.00867	337.6	361.9	342.5	22696.7	14.874	15.945	15.090	15.303
1.35	0.00900	347.4	376.8	364.0	22704.3	15.301	16.596	16.032	15.976
1.4	0.00933	361.5	388.4	373.2	22712	15.917	17.101	16.432	16.483
1.45	0.00967	384.1	402.9	379.4	22719.6	16.906	17.734	16.699	17.113
1.5	0.01000	399.4	412.0	396.2	22727.3	17.574	18.128	17.433	17.711
1.55	0.01033	411.2	429.8	402.4	22734.9	18.087	18.905	17.700	18.230
1.6	0.01067	420.3	442.3	416.3	22742.6	18.481	19.448	18.305	18.745
1.65	0.01100	422.6	461.2	449.2	22750.3	18.576	20.272	19.745	19.531
1.7	0.01133	426.6	469.8	460.4	22757.9	18.745	20.643	20.230	19.873

1.75	0.01167	424.3	472.9	489.6	22765.6	18.638	20.773	21.506	20.305
1.8	0.01200	425.8	470.0	497.3	22773.3	18.697	20.638	21.837	20.391
1.85	0.01233	423.4	465.9	491.3	22781	18.586	20.451	21.566	20.201
1.9	0.01267	420.1	462.8	488.4	22788.7	18.435	20.308	21.432	20.058
1.95	0.01300	412.3	458.1	487.3	22796.4	18.086	20.095	21.376	19.853
2	0.01333	406.6	452.3	486.9	22804.1	17.830	19.834	21.351	19.672
2.05	0.01367	404.1	443.8	481.3	22811.8	17.715	19.455	21.099	19.423
2.1	0.01400	390.3	442.9	478.2	22819.5	17.104	19.409	20.956	19.156
2.15	0.01433				22827.2	0.000	0.000	0.000	0.000
2.2	0.01467				22834.9	0.000	0.000	0.000	0.000
2.25	0.01500				22842.6	0.000	0.000	0.000	0.000

Cube with 6% HDPE at 7day									
ΔH (mm)	strain	Load(KN)			Area (mm^2)	Stress (MPa)			
		1	2	3		1	2	3	Avg.
0	0.00000	15.0	18.0	12.0	22500	0.667	0.800	0.533	0.667
0.05	0.00033	23.4	26.7	35.8	22507.5	1.040	1.186	1.591	1.272
0.1	0.00067	52.6	51.0	42.0	22515	2.336	2.265	1.865	2.156
0.15	0.00100	61.0	70.9	76.8	22522.5	2.708	3.148	3.410	3.089
0.2	0.00133	73.3	84.5	107.0	22530	3.253	3.751	4.749	3.918
0.25	0.00167	92.0	97.0	127.7	22537.6	4.082	4.304	5.666	4.684
0.3	0.00200	118.6	108.0	146.4	22545.1	5.261	4.790	6.494	5.515
0.35	0.00233	125.0	131.3	171.0	22552.6	5.543	5.822	7.582	6.316
0.4	0.00267	143.4	144.9	194.3	22560.2	6.356	6.423	8.613	7.131
0.45	0.00300	156.4	155.4	236.0	22567.7	6.930	6.886	10.457	8.091
0.5	0.00333	167.7	178.9	257.3	22575.3	7.428	7.925	11.397	8.917
0.55	0.00367	199.6	196.5	279.0	22582.8	8.839	8.701	12.355	9.965
0.6	0.00400	205.0	224.0	298.4	22590.4	9.075	9.916	13.209	10.733
0.65	0.00433	241.6	237.2	311.6	22597.9	10.691	10.497	13.789	11.659
0.7	0.00467	246.7	272.4	333.8	22605.5	10.913	12.050	14.766	12.577
0.75	0.00500	279.1	292.1	341.9	22613.1	12.342	12.917	15.120	13.460
0.8	0.00533	306.5	317.6	354.3	22620.6	13.550	14.040	15.663	14.418
0.85	0.00567	328.1	339.0	368.6	22628.2	14.500	14.981	16.289	15.257
0.9	0.00600	339.6	361.2	384.3	22635.8	15.003	15.957	16.978	15.979
0.95	0.00633	354.9	388.9	388.6	22643.4	15.673	17.175	17.162	16.670
1	0.00667	376.3	391.1	408.6	22651	16.613	17.266	18.039	17.306
1.05	0.00700	394.8	409.2	427.3	22658.6	17.424	18.059	18.858	18.114
1.1	0.00733	415.4	412.8	443.1	22666.2	18.327	18.212	19.549	18.696
1.15	0.00767	422.2	438.1	455.0	22673.8	18.621	19.322	20.067	19.337

1.2	0.00800	431.4	445.7	467.7	22681.5	19.020	19.650	20.620	19.764
1.25	0.00833	428.4	453.9	487.9	22689.1	18.881	20.005	21.504	20.130
1.3	0.00867	421.8	485.9	498.2	22696.7	18.584	21.408	21.950	20.648
1.35	0.00900	413.1	497.6	523.8	22704.3	18.195	21.917	23.070	21.061
1.4	0.00933	401.5	502.4	538.2	22712	17.678	22.120	23.697	21.165
1.45	0.00967	394.4	517.7	535.4	22719.6	17.359	22.786	23.566	21.237
1.5	0.01000	388.7	519.5	531.1	22727.3	17.103	22.858	23.368	21.110
1.55	0.01033	383.8	515.1	528.2	22734.9	16.882	22.657	23.233	20.924
1.6	0.01067	376.4	507.9	523.2	22742.6	16.550	22.333	23.005	20.629
1.65	0.01100	372.8	502.7	520.6	22750.3	16.387	22.096	22.883	20.455
1.7	0.01133	361.2	496.7	518.7	22757.9	15.871	21.825	22.792	20.163
1.75	0.01167	355.5	489.7	510.9	22765.6	15.616	21.511	22.442	19.856
1.8	0.01200	348.4	485.8	504.4	22773.3	15.299	21.332	22.149	19.593
1.85	0.01233	345.1	480.2	492.9	22781	15.149	21.079	21.636	19.288
1.9	0.01267	333.1	478.4	488.2	22788.7	14.617	20.993	21.423	19.011
1.95	0.01300	328.1	466.4	475.3	22796.4	14.393	20.459	20.850	18.567
2	0.01333				22804.1	0.000	0.000	0.000	0.000
2.05	0.01367				22811.8	0.000	20.972	0.000	6.991
2.1	0.01400				22819.5	0.000	0.000	0.000	0.000

Cube with 9% HDPE at 7day									
ΔH (mm)	strain	Load (KN)			Area (mm^2)	Stress (MPa)			
		1	2	3		1	2	3	Avg.
0	0.00000	11.0	17.0	12.0	22500	0.489	0.756	0.533	0.593
0.05	0.00033	24.6	28.4	12.4	22507.5	1.093	1.262	0.551	0.969
0.1	0.00067	31.3	39.8	31.2	22515	1.390	1.768	1.386	1.515
0.15	0.00100	60.1	57.8	43.3	22522.5	2.668	2.566	1.923	2.386
0.2	0.00133	77.3	63.8	64.0	22530	3.431	2.832	2.841	3.034
0.25	0.00167	82.0	74.6	84.7	22537.6	3.638	3.310	3.758	3.569
0.3	0.00200	97.3	88.9	98.0	22545.1	4.316	3.943	4.347	4.202
0.35	0.00233	109.5	100.0	117.4	22552.6	4.855	4.434	5.206	4.832
0.4	0.00267	130.0	121.3	124.9	22560.2	5.762	5.377	5.536	5.558
0.45	0.00300	150.0	141.5	134.0	22567.7	6.647	6.270	5.938	6.285
0.5	0.00333	168.1	156.4	153.7	22575.3	7.446	6.928	6.808	7.061
0.55	0.00367	194.5	166.7	174.6	22582.8	8.613	7.382	7.732	7.909
0.6	0.00400	210.0	190.0	187.4	22590.4	9.296	8.411	8.296	8.667
0.65	0.00433	227.4	207.4	205.0	22597.9	10.063	9.178	9.072	9.437
0.7	0.00467	236.7	218.3	223.4	22605.5	10.471	9.657	9.883	10.003
0.75	0.00500	261.1	234.1	236.2	22613.1	11.546	10.352	10.445	10.781

0.8	0.00533	280.1	254.3	251.9	22620.6	12.382	11.242	11.136	11.587
0.85	0.00567	288.6	284.8	261.6	22628.2	12.754	12.586	11.561	12.300
0.9	0.00600	301.3	301.2	268.1	22635.8	13.311	13.306	11.844	12.820
0.95	0.00633	321.7	308.6	289.5	22643.4	14.207	13.629	12.785	13.540
1	0.00667	327.5	329.7	312.3	22651	14.459	14.556	13.787	14.267
1.05	0.00700	336.8	340.0	328.7	22658.6	14.864	15.005	14.507	14.792
1.1	0.00733	341.1	352.3	341.6	22666.2	15.049	15.543	15.071	15.221
1.15	0.00767	348.0	366.6	356.4	22673.8	15.348	16.168	15.719	15.745
1.2	0.00800	352.4	399.4	359.4	22681.5	15.537	17.609	15.846	16.331
1.25	0.00833	360.6	412.1	365.7	22689.1	15.893	18.163	16.118	16.725
1.3	0.00867	381.9	414.8	369.0	22696.7	16.826	18.276	16.258	17.120
1.35	0.00900	397.8	416.7	381.4	22704.3	17.521	18.353	16.799	17.558
1.4	0.00933	411.6	413.4	402.1	22712	18.123	18.202	17.704	18.010
1.45	0.00967	423.9	408.3	414.8	22719.6	18.658	17.971	18.257	18.295
1.5	0.01000	425.1	405.9	424.2	22727.3	18.704	17.860	18.665	18.410
1.55	0.01033	445.6	401.4	401.9	22734.9	19.600	17.656	17.678	18.311
1.6	0.01067	446.7	390.1	400.8	22742.6	19.642	17.153	17.623	18.139
1.65	0.01100	450.8	383.1	397.3	22750.3	19.815	16.839	17.464	18.039
1.7	0.01133	456.7	365.3	395.6	22757.9	20.068	16.052	17.383	17.834
1.75	0.01167	448.9	360.7	392.6	22765.6	19.718	15.844	17.245	17.603
1.8	0.01200	444.6	355.3	390.3	22773.3	19.523	15.602	17.139	17.421
1.85	0.01233	433.8	354.1	388.1	22781	19.042	15.544	17.036	17.207
1.9	0.01267	426.4	348.9	386.4	22788.7	18.711	15.310	16.956	16.992
1.95	0.01300	420.1	340.4	388.5	22796.4	18.428	14.932	17.042	16.801
2	0.01333	418.5	331.5	384.2	22804.1	18.352	14.537	16.848	16.579
2.05	0.01367				22811.8	0.000	0.000	0.000	0.000
2.1	0.01400				22819.5	0.000	0.000	0.000	0.000
2.15	0.01433				22827.2	0.000	0.000	0.000	0.000
2.2	0.01467				22834.9	0.000	0.000	0.000	0.000
2.25	0.01500				22842.6	0.000	0.000	0.000	0.000

Cube with 12% HDPE at 7day									
ΔH (mm)	strain	Load (KN)			Area (mm2)	Stress (MPa)			
		1	2	3		1	2	3	Avg.
0	0.00000	13	12.0	10.0	22500	0.578	0.533	0.444	0.519
0.05	0.00033	25.0	24.0	20.0	22507.5	1.111	1.066	0.889	1.022
0.1	0.00067	35.9	35.7	33.1	22515	1.594	1.586	1.470	1.550
0.15	0.00100	51.0	50.2	48.0	22522.5	2.264	2.229	2.131	2.208
0.2	0.00133	63.5	64.0	62.5	22530	2.818	2.841	2.774	2.811

0.25	0.00167	80.0	77.4	77.6	22537.6	3.550	3.434	3.443	3.476
0.3	0.00200	91.6	90.0	89.3	22545.1	4.063	3.992	3.961	4.005
0.35	0.00233	96.9	108.3	109.6	22552.6	4.297	4.802	4.860	4.653
0.4	0.00267	110.0	118.9	116.1	22560.2	4.876	5.270	5.146	5.097
0.45	0.00300	121.0	134.1	130.0	22567.7	5.362	5.942	5.760	5.688
0.5	0.00333	135.2	145.0	140.3	22575.3	5.989	6.423	6.215	6.209
0.55	0.00367	152.8	159.6	154.3	22582.8	6.766	7.067	6.833	6.889
0.6	0.00400	166.3	175.5	166.0	22590.4	7.362	7.769	7.348	7.493
0.65	0.00433	183.4	191.0	179.8	22597.9	8.116	8.452	7.956	8.175
0.7	0.00467	198.6	198.9	197.0	22605.5	8.785	8.799	8.715	8.766
0.75	0.00500	209.0	212.0	213.6	22613.1	9.242	9.375	9.446	9.354
0.8	0.00533	222.3	223.1	225.0	22620.6	9.827	9.863	9.947	9.879
0.85	0.00567	244.4	234.8	241.8	22628.2	10.801	10.376	10.686	10.621
0.9	0.00600	263.0	251.0	257.0	22635.8	11.619	11.089	11.354	11.354
0.95	0.00633	279.0	275.0	263.0	22643.4	12.321	12.145	11.615	12.027
1	0.00667	295.0	292.0	277.0	22651	13.024	12.891	12.229	12.715
1.05	0.00700	320.0	304.0	286.9	22658.6	14.123	13.417	12.662	13.400
1.1	0.00733	335.2	322.0	297.0	22666.2	14.789	14.206	13.103	14.033
1.15	0.00767	352.0	334.0	312.0	22673.8	15.525	14.731	13.760	14.672
1.2	0.00800	366.3	350.0	330.5	22681.5	16.150	15.431	14.571	15.384
1.25	0.00833	376.0	357.5	342.0	22689.1	16.572	15.756	15.073	15.801
1.3	0.00867	386.0	364.3	364.4	22696.7	17.007	16.051	16.055	16.371
1.35	0.00900	391.5	374.6	387.6	22704.3	17.243	16.499	17.072	16.938
1.4	0.00933	404.6	354.3	409.3	22712	17.814	15.600	18.021	17.145
1.45	0.00967	417.4	337.1	421.3	22719.6	18.372	14.837	18.543	17.251
1.5	0.01000	429.2	320.3	434.7	22727.3	18.885	14.093	19.127	17.368
1.55	0.01033	436.5	312.7	446.9	22734.9	19.200	13.754	19.657	17.537
1.6	0.01067	433.4	311.3	448.0	22742.6	19.057	13.688	19.699	17.481
1.65	0.01100	429.1	305.1	447.2	22750.3	18.861	13.411	19.657	17.310
1.7	0.01133	427.4	304.3	443.2	22757.9	18.780	13.371	19.475	17.209
1.75	0.01167	425.9	302.4	441.3	22765.6	18.708	13.283	19.385	17.125
1.8	0.01200	422.7	299.2	438.9	22773.3	18.561	13.138	19.273	16.991
1.85	0.01233	420.6	291.8	438.4	22781	18.463	12.809	19.244	16.839
1.9	0.01267				22788.7	0.000	0.000	0.000	0.000
1.95	0.01300				22796.4	0.000	0.000	0.000	0.000
2	0.01333				22804.1	0.000	0.000	0.000	0.000

Table D-2. Stress - Strain Diagram for Cube at Age of 14day

Cube with 0% HDPE at 14day									
ΔH (mm)	strain	Load (KN)			Area (mm^2)	Stress (MPa)			
		1	2	3		1	2	3	Avg.
0	0.0000	14.0	15.3	17.0	22500	0.622	0.680	0.756	0.686
0.05	0.0003	39.5	40.0	27.6	22507.5	1.755	1.777	1.226	1.586
0.1	0.0007	57.8	67.5	53.5	22515	2.567	2.998	2.376	2.647
0.15	0.0010	95.7	93.6	85.6	22522.5	4.249	4.156	3.801	4.069
0.2	0.0013	136.0	134.0	108.9	22530	6.036	5.948	4.834	5.606
0.25	0.0017	172.0	159.0	146.4	22537.6	7.632	7.055	6.496	7.061
0.3	0.0020	218.6	181.2	170.0	22545.1	9.696	8.037	7.540	8.425
0.35	0.0023	241.0	224.3	195.7	22552.6	10.686	9.946	8.677	9.770
0.4	0.0027	274.3	236.0	243.1	22560.2	12.159	10.461	10.776	11.132
0.45	0.0030	301.0	267.0	274.6	22567.7	13.338	11.831	12.168	12.446
0.5	0.0033	328.5	280.0	306.7	22575.3	14.551	12.403	13.586	13.513
0.55	0.0037	350.4	305.1	335.7	22582.8	15.516	13.510	14.865	14.631
0.6	0.0040	376.8	327.4	371.0	22590.4	16.680	14.493	16.423	15.865
0.65	0.0043	401.2	352.0	405.0	22597.9	17.754	15.577	17.922	17.084
0.7	0.0047	435.0	371.2	427.1	22605.5	19.243	16.421	18.894	18.186
0.75	0.0050	462.3	394.6	454.1	22613.1	20.444	17.450	20.081	19.325
0.8	0.0053	493.7	423.5	463.8	22620.6	21.825	18.722	20.503	20.350
0.85	0.0057	516.7	454.1	487.4	22628.2	22.834	20.068	21.539	21.481
0.9	0.0060	534.8	472.6	505.1	22635.8	23.626	20.878	22.314	22.273
0.95	0.0063	550.4	507.4	516.8	22643.4	24.307	22.408	22.823	23.180
1	0.0067	569.7	518.0	541.0	22651	25.151	22.869	23.884	23.968
1.05	0.0070	578.3	544.2	551.8	22658.6	25.522	24.017	24.353	24.631
1.1	0.0073	574.4	571.4	558.4	22666.2	25.342	25.209	24.636	25.062
1.15	0.0077	582.0	584.1	560.1	22673.8	25.668	25.761	24.702	25.377
1.2	0.0080	575.3	598.8	552.6	22681.5	25.364	26.400	24.364	25.376
1.25	0.0083	567.0	603.9	546.4	22689.1	24.990	26.616	24.082	25.229
1.3	0.0087	555.0	594.7	540.1	22696.7	24.453	26.202	23.796	24.817
1.35	0.0090	544.7	579.2	537.2	22704.3	23.991	25.511	23.661	24.387
1.4	0.0093	539.5	561.6	523.5	22712	23.754	24.727	23.050	23.844
1.45	0.0097	523.1	545.4	520.7	22719.6	23.024	24.006	22.919	23.316
1.5	0.0100	512.8	529.3	514.8	22727.3	22.563	23.289	22.651	22.835
1.55	0.0103	507.6	508.9	505.2	22734.9	22.327	22.384	22.221	22.311
1.6	0.0107	484.1	492.6	489.4	22742.6	21.286	21.660	21.519	21.488
1.65	0.0110	471.8	483.2	472.1	22750.3	20.738	21.239	20.751	20.910
1.7	0.0113				22757.9	0.000	0.000	0.000	0.000

1.75	0.0117				22765.6	0.000	0.000	0.000	0.000
1.8	0.0120				22773.3	0.000	0.000	0.000	0.000
1.85	0.0123				22781	0.000	0.000	0.000	0.000
1.9	0.0127				22788.7	0.000	0.000	0.000	0.000
1.95	0.0130				22796.4	0.000	0.000	0.000	0.000
2	0.0133				22804.1	0.000	0.000	0.000	0.000

Cube with 3% HDPE at 14day									
ΔH (mm)	strain	Load (KN)			Area (mm^2)	Stress (MPa)			
		1	2	3		1	2	3	Avg.
0	0.00000	15.0	18.0	17.0	22500	0.667	0.800	0.756	0.741
0.05	0.00033	26.4	22.6	33.9	22507.5	1.173	1.004	1.506	1.228
0.1	0.00067	32.6	38.0	52.6	22515	1.448	1.688	2.336	1.824
0.15	0.00100	41.0	50.0	74.2	22522.5	1.820	2.220	3.294	2.445
0.2	0.00133	58.0	53.8	92.0	22530	2.574	2.388	4.083	3.015
0.25	0.00167	76.1	74.0	101.8	22537.6	3.377	3.283	4.517	3.726
0.3	0.00200	85.7	89.5	132.6	22545.1	3.801	3.970	5.882	4.551
0.35	0.00233	109.3	103.0	153.7	22552.6	4.846	4.567	6.815	5.410
0.4	0.00267	126.1	115.0	179.2	22560.2	5.589	5.097	7.943	6.210
0.45	0.00300	144.0	133.9	204.0	22567.7	6.381	5.933	9.039	7.118
0.5	0.00333	160.0	158.0	227.3	22575.3	7.087	6.999	10.069	8.052
0.55	0.00367	176.2	178.4	248.6	22582.8	7.802	7.900	11.008	8.904
0.6	0.00400	196.4	191.6	274.1	22590.4	8.694	8.481	12.133	9.770
0.65	0.00433	221.2	213.5	291.0	22597.9	9.789	9.448	12.877	10.705
0.7	0.00467	253.1	230.0	303.9	22605.5	11.196	10.175	13.444	11.605
0.75	0.00500	276.0	250.0	315.2	22613.1	12.205	11.056	13.939	12.400
0.8	0.00533	290.0	270.0	340.0	22620.6	12.820	11.936	15.031	13.262
0.85	0.00567	304.0	283.8	360.0	22628.2	13.435	12.542	15.909	13.962
0.9	0.00600	313.1	301.0	382.9	22635.8	13.832	13.298	16.916	14.682
0.95	0.00633	326.4	312.4	415.1	22643.4	14.415	13.797	18.332	15.514
1	0.00667	342.3	332.5	433.1	22651	15.112	14.679	19.121	16.304
1.05	0.00700	361.0	349.8	450.0	22658.6	15.932	15.438	19.860	17.077
1.1	0.00733	374.6	366.2	464.5	22666.2	16.527	16.156	20.493	17.725
1.15	0.00767	388.7	374.6	484.1	22673.8	17.143	16.521	21.351	18.338
1.2	0.00800	414.6	389.0	498.7	22681.5	18.279	17.151	21.987	19.139
1.25	0.00833	430.0	402.0	514.0	22689.1	18.952	17.718	22.654	19.775
1.3	0.00867	447.6	423.6	530.0	22696.7	19.721	18.664	23.351	20.579
1.35	0.00900	458.0	445.0	550.0	22704.3	20.172	19.600	24.224	21.332
1.4	0.00933	474.0	456.4	579.1	22712	20.870	20.095	25.498	22.154

1.45	0.00967	482.7	473.1	592.4	22719.6	21.246	20.823	26.074	22.715
1.5	0.01000	500.0	495.2	619.1	22727.3	22.000	21.789	27.240	23.676
1.55	0.01033	526.2	508.1	626.7	22734.9	23.145	22.349	27.566	24.353
1.6	0.01067	549.3	526.0	638.2	22742.6	24.153	23.128	28.062	25.114
1.65	0.01100	582.6	555.7	636.6	22750.3	25.609	24.426	27.982	26.006
1.7	0.01133	598.9	581.3	627.8	22757.9	26.316	25.543	27.586	26.482
1.75	0.01167	611.3	598.9	617.6	22765.6	26.852	26.307	27.129	26.763
1.8	0.01200	636.1	584.3	610.5	22773.3	27.932	25.657	26.808	26.799
1.85	0.01233	640.9	581.4	602.9	22781	28.133	25.521	26.465	26.707
1.9	0.01267	631.0	583.8	597.8	22788.7	27.689	25.618	26.232	26.513
1.95	0.01300	623.4	578.9	595.5	22796.4	27.346	25.394	26.123	26.288
2	0.01333	618.6	573.3	589.9	22804.1	27.127	25.140	25.868	26.045
2.05	0.01367	612.4	567.2	585.5	22811.8	26.846	24.864	25.667	25.792
2.1	0.01400	604.9	565.8	577.1	22819.5	26.508	24.795	25.290	25.531
2.15	0.01433	598.2	558.3	569.8	22827.2	26.206	24.458	24.961	25.208
2.2	0.01467	590.2	553.7	567.0	22834.9	25.846	24.248	24.830	24.975
2.25	0.01500	580.9	548.2	561.2	22842.6	25.431	23.999	24.568	24.666
2.3	0.01533	571.8	544.1	555.3	22850.4	25.024	23.811	24.302	24.379
2.35	0.01567	563.2	536.2	551.7	22858.1	24.639	23.458	24.136	24.078
2.4	0.01600	556.0	529.8	533.8	22865.9	24.316	23.170	23.345	23.610
2.45	0.01633				22873.6	0.000	0.000	0.000	0.000
2.5	0.01667				22881.4	0.000	0.000	0.000	0.000

Cube with 6% HDPE at 14day									
ΔH (mm^2)	Strain	Load (KN)			Area (mm^2)	Stress (MPa)			
		1	2	3		1	2	3	Avg.
0	0.00000	19.0	21.3	25.0	22500	0.844	0.947	1.111	0.967
0.05	0.00033	39.5	50.1	47.4	22507.5	1.755	2.226	2.106	2.029
0.1	0.00067	57.0	62.4	55.7	22515	2.532	2.771	2.474	2.592
0.15	0.00100	70.3	85.0	67.5	22522.5	3.121	3.774	2.997	3.297
0.2	0.00133	92.6	99.7	75.2	22530	4.110	4.425	3.338	3.958
0.25	0.00167	121.0	122.4	79.0	22537.6	5.369	5.431	3.505	4.768
0.3	0.00200	145.6	134.8	94.0	22545.1	6.458	5.979	4.169	5.536
0.35	0.00233	161.2	158.0	107.4	22552.6	7.148	7.006	4.762	6.305
0.4	0.00267	175.3	185.4	129.1	22560.2	7.770	8.218	5.722	7.237
0.45	0.00300	201.0	211.8	132.7	22567.7	8.907	9.385	5.880	8.057
0.5	0.00333	230.6	237.4	143.4	22575.3	10.215	10.516	6.352	9.028
0.55	0.00367	285.7	252.6	144.0	22582.8	12.651	11.186	6.377	10.071
0.6	0.00400	295.0	260.3	183.8	22590.4	13.059	11.523	8.136	10.906

0.65	0.00433	310.4	270.2	224.0	22597.9	13.736	11.957	9.912	11.868
0.7	0.00467	335.8	290.7	238.0	22605.5	14.855	12.860	10.528	12.748
0.75	0.00500	339.4	325.4	248.0	22613.1	15.009	14.390	10.967	13.455
0.8	0.00533	350.7	339.0	278.0	22620.6	15.504	14.986	12.290	14.260
0.85	0.00567	377.0	342.4	296.0	22628.2	16.661	15.132	13.081	14.958
0.9	0.00600	395.3	358.0	310.7	22635.8	17.463	15.816	13.726	15.668
0.95	0.00633	401.8	379.5	338.0	22643.4	17.745	16.760	14.927	16.477
1	0.00667	430.5	381.1	367.8	22651	19.006	16.825	16.238	17.356
1.05	0.00700	440.5	394.5	397.8	22658.6	19.441	17.411	17.556	18.136
1.1	0.00733	462.4	402.8	421.3	22666.2	20.400	17.771	18.587	18.919
1.15	0.00767	478.0	415.6	447.3	22673.8	21.082	18.329	19.728	19.713
1.2	0.00800	500.0	437.2	460.1	22681.5	22.044	19.276	20.285	20.535
1.25	0.00833	525.5	470.0	466.5	22689.1	23.161	20.715	20.561	21.479
1.3	0.00867	539.7	498.5	477.8	22696.7	23.779	21.964	21.052	22.265
1.35	0.00900	584.0	492.9	508.7	22704.3	25.722	21.710	22.405	23.279
1.4	0.00933	593.5	531.5	522.8	22712	26.132	23.402	23.019	24.184
1.45	0.00967	615.8	582.3	537.2	22719.6	27.104	25.630	23.645	25.460
1.5	0.01000	637.3	603.8	569.1	22727.3	28.041	26.567	25.040	26.550
1.55	0.01033	639.0	614.7	614.6	22734.9	28.107	27.038	27.033	27.393
1.6	0.01067	646.8	628.4	617.3	22742.6	28.440	27.631	27.143	27.738
1.65	0.01100	651.3	630.6	622.9	22750.3	28.628	27.718	27.380	27.909
1.7	0.01133	645.0	622.6	631.5	22757.9	28.342	27.358	27.749	27.816
1.75	0.01167	639.5	615.2	637.6	22765.6	28.091	27.023	28.007	27.707
1.8	0.01200	622.2	609.1	647.6	22773.3	27.321	26.746	28.437	27.502
1.85	0.01233	618.0	607.9	635.9	22781	27.128	26.685	27.914	27.242
1.9	0.01267	612.9	600.6	632.9	22788.7	26.895	26.355	27.773	27.008
1.95	0.01300	609.8	597.4	627.6	22796.4	26.750	26.206	27.531	26.829
2	0.01333	602.4	592.5	624.7	22804.1	26.416	25.982	27.394	26.598
2.05	0.01367	598.0	589.3	614.9	22811.8	26.215	25.833	26.955	26.334
2.1	0.01400	593.2	578.4	608.6	22819.5	25.995	25.347	26.670	26.004
2.15	0.01433	587.1	569.1	604.3	22827.2	25.719	24.931	26.473	25.708
2.2	0.01467	583.9	566.8	596.7	22834.9	25.570	24.822	26.131	25.508
2.25	0.01500	574.2	557.6	588.1	22842.6	25.137	24.410	25.746	25.098
2.3	0.01533				22850.4	0.000	0.000	0.000	0.000
2.35	0.01567				22858.1	0.000	0.000	0.000	0.000
2.4	0.01600				22865.9	0.000	0.000	0.000	0.000
2.45	0.01633				22873.6	0.000	0.000	0.000	0.000
2.5	0.01667				22881.4	0.000	0.000	0.000	0.000

Cube with 9% HDPE at 14day									
ΔH (mm)	Strain	Load (KN)			Area (mm^2)	Stress (MPa)			
		1	2	3		1	2	3	Avg.
0	0.00000	17.2	21.5	16.0	22500	0.764	0.956	0.711	0.810
0.05	0.00033	34.0	45.8	52.3	22507.5	1.511	2.035	2.324	1.956
0.1	0.00067	86.3	63.1	64.7	22515	3.833	2.803	2.874	3.170
0.15	0.00100	108.0	82.0	97.4	22522.5	4.795	3.641	4.325	4.254
0.2	0.00133	124.3	113.2	114.3	22530	5.517	5.024	5.073	5.205
0.25	0.00167	143.6	136.4	140.0	22537.6	6.372	6.052	6.212	6.212
0.3	0.00200	178.1	165.0	152.0	22545.1	7.900	7.319	6.742	7.320
0.35	0.00233	192.4	186.7	186.2	22552.6	8.531	8.278	8.256	8.355
0.4	0.00267	213.6	214.0	200.0	22560.2	9.468	9.486	8.865	9.273
0.45	0.00300	236.1	234.3	224.8	22567.7	10.462	10.382	9.961	10.268
0.5	0.00333	251.0	251.8	247.5	22575.3	11.118	11.154	10.963	11.079
0.55	0.00367	274.3	267.5	276.0	22582.8	12.146	11.845	12.222	12.071
0.6	0.00400	300.0	284.6	294.0	22590.4	13.280	12.598	13.014	12.964
0.65	0.00433	333.0	302.6	316.2	22597.9	14.736	13.391	13.992	14.040
0.7	0.00467	351.2	327.2	338.4	22605.5	15.536	14.474	14.970	14.993
0.75	0.00500	375.4	343.0	354.6	22613.1	16.601	15.168	15.681	15.817
0.8	0.00533	393.8	369.3	376.3	22620.6	17.409	16.326	16.635	16.790
0.85	0.00567	426.0	380.0	395.0	22628.2	18.826	16.793	17.456	17.692
0.9	0.00600	449.2	400.0	414.7	22635.8	19.845	17.671	18.321	18.612
0.95	0.00633	474.2	413.9	434.5	22643.4	20.942	18.279	19.189	19.470
1	0.00667	490.0	434.1	457.2	22651	21.633	19.165	20.185	20.327
1.05	0.00700	514.2	453.0	474.1	22658.6	22.693	19.992	20.924	21.203
1.1	0.00733	525.6	464.9	504.2	22666.2	23.189	20.511	22.245	21.981
1.15	0.00767	541.7	489.6	516.3	22673.8	23.891	21.593	22.771	22.752
1.2	0.00800	559.0	500.0	532.1	22681.5	24.646	22.044	23.460	23.383
1.25	0.00833	562.9	529.0	544.0	22689.1	24.809	23.315	23.976	24.034
1.3	0.00867	556.7	537.8	560.2	22696.7	24.528	23.695	24.682	24.302
1.35	0.00900	544.3	540.3	563.7	22704.3	23.973	23.797	24.828	24.199
1.4	0.00933	526.4	550.3	565.3	22712	23.177	24.230	24.890	24.099
1.45	0.00967	523.2	541.4	571.3	22719.6	23.029	23.830	25.146	24.001
1.5	0.01000	521.1	535.7	567.0	22727.3	22.928	23.571	24.948	23.816
1.55	0.01033	516.9	532.3	560.7	22734.9	22.736	23.413	24.662	23.604
1.6	0.01067	512.7	529.6	553.4	22742.6	22.544	23.287	24.333	23.388
1.65	0.01100	507.5	527.1	547.5	22750.3	22.307	23.169	24.066	23.181
1.7	0.01133	504.2	524.0	542.7	22757.9	22.155	23.025	23.847	23.009
1.75	0.01167	500.5	519.8	536.2	22765.6	21.985	22.833	23.553	22.790

1.8	0.01200	497.8	513.4	525.2	22773.3	21.859	22.544	23.062	22.488
1.85	0.01233	491.7	503.6	524.0	22781	21.584	22.106	23.002	22.231
1.9	0.01267	488.3	501.3	512.7	22788.7	21.427	21.998	22.498	21.974
1.95	0.01300	485.5	494.7	506.1	22796.4	21.297	21.701	22.201	21.733
2	0.01333	482.0	490.0	501.8	22804.1	21.137	21.487	22.005	21.543
2.05	0.01367				22811.8	0.000	0.000	0.000	0.000
2.1	0.01400				22819.5	0.000	0.000	0.000	0.000
2.15	0.01433				22827.2	0.000	0.000	0.000	0.000
2.2	0.01467				22834.9	0.000	0.000	0.000	0.000

Cube with 12% HDPE at 14day									
ΔH (mm)	Strain	Load (KN)			Area (mm^2)	Stress (MPa)			
		1	2	3		1	2	3	Avg.
0	0.00000	12.0	14.0	15.0	22500	0.533	0.622	0.667	0.607
0.05	0.00033	29.5	16.4	21.0	22507.5	1.311	0.729	0.933	0.991
0.1	0.00067	40.2	24.8	35.7	22515	1.785	1.101	1.586	1.491
0.15	0.00100	59.7	37.5	48.0	22522.5	2.651	1.665	2.131	2.149
0.2	0.00133	84.6	54.9	72.4	22530	3.755	2.437	3.213	3.135
0.25	0.00167	97.0	84.2	95.1	22537.6	4.304	3.736	4.220	4.087
0.3	0.00200	125.8	107.0	121.0	22545.1	5.580	4.746	5.367	5.231
0.35	0.00233	141.4	129.5	170.6	22552.6	6.270	5.742	7.565	6.525
0.4	0.00267	171.6	159.8	190.4	22560.2	7.606	7.083	8.440	7.710
0.45	0.00300	199.1	171.3	227.6	22567.7	8.822	7.590	10.085	8.833
0.5	0.00333	219.6	209.8	243.1	22575.3	9.727	9.293	10.768	9.930
0.55	0.00367	246.2	232.7	267.5	22582.8	10.902	10.304	11.845	11.017
0.6	0.00400	252.7	285.4	289.6	22590.4	11.186	12.634	12.820	12.213
0.65	0.00433	283.0	310.2	316.5	22597.9	12.523	13.727	14.006	13.419
0.7	0.00467	321.9	321.6	357.4	22605.5	14.240	14.227	15.810	14.759
0.75	0.00500	344.2	358.4	382.3	22613.1	15.221	15.849	16.906	15.992
0.8	0.00533	372.1	395.9	402.0	22620.6	16.450	17.502	17.771	17.241
0.85	0.00567	394.7	412.4	443.2	22628.2	17.443	18.225	19.586	18.418
0.9	0.00600	410.3	432.5	478.4	22635.8	18.126	19.107	21.135	19.456
0.95	0.00633	437.7	453.1	499.8	22643.4	19.330	20.010	22.073	20.471
1	0.00667	460.7	478.2	514.0	22651	20.339	21.112	22.692	21.381
1.05	0.00700	471.3	497.2	539.6	22658.6	20.800	21.943	23.814	22.186
1.1	0.00733	498.8	510.2	543.3	22666.2	22.006	22.509	23.970	22.828
1.15	0.00767	523.0	503.4	557.4	22673.8	23.066	22.202	24.583	23.284
1.2	0.00800	541.3	502.0	556.8	22681.5	23.865	22.133	24.549	23.516
1.25	0.00833	538.9	501.0	552.3	22689.1	23.752	22.081	24.342	23.392

1.3	0.00867	532.7	497.2	549.1	22696.7	23.470	21.906	24.193	23.190
1.35	0.00900	526.0	492.1	544.8	22704.3	23.167	21.674	23.995	22.946
1.4	0.00933	525.3	483.5	538.9	22712	23.129	21.288	23.728	22.715
1.45	0.00967	522.1	474.1	533.5	22719.6	22.980	20.867	23.482	22.443
1.5	0.01000	516.2	468.5	527.7	22727.3	22.713	20.614	23.219	22.182
1.55	0.01033	511.3	459.0	524.6	22734.9	22.490	20.189	23.075	21.918
1.6	0.01067	512.4	446.3	510.0	22742.6	22.530	19.624	22.425	21.526
1.65	0.01100	509.5	435.0	505.1	22750.3	22.395	19.121	22.202	21.239
1.7	0.01133	500.6	433.5	501.2	22757.9	21.997	19.048	22.023	21.023
1.75	0.01167	485.2	425.9	494.0	22765.6	21.313	18.708	21.699	20.573
1.8	0.01200	465.7	419.4	480.2	22773.3	20.449	18.416	21.086	19.984
1.85	0.01233				22781	0.000	0.000	0.000	0.000
1.9	0.01267				22788.7	0.000	0.000	0.000	0.000
1.95	0.01300				22796.4	0.000	0.000	0.000	0.000
2	0.01333				22804.1	0.000	0.000	0.000	0.000

Table D-3. Stress - Strain Diagram for Cube at Age of 28day

Cube with 0% HDPE at 28day									
ΔH (mm)	Strain	Load (KN)			Area (mm^2)	Stress (MPa)			
		1	2	3		1	2	3	Avg.
0	0.00000	18.0	15.0	21.0	22500	0.800	0.667	0.933	0.800
0.05	0.00033	50.5	34.7	45.8	22507.5	2.244	1.542	2.035	1.940
0.1	0.00067	92.3	66.5	73.7	22515	4.099	2.954	3.273	3.442
0.15	0.00100	123.1	108.0	103.5	22522.5	5.466	4.795	4.595	4.952
0.2	0.00133	158.6	132.5	150.0	22530	7.039	5.881	6.658	6.526
0.25	0.00167	190.0	177.0	171.0	22537.6	8.430	7.854	7.587	7.957
0.3	0.00200	224.0	212.0	199.0	22545.1	9.936	9.403	8.827	9.389
0.35	0.00233	250.1	232.0	242.0	22552.6	11.090	10.287	10.730	10.702
0.4	0.00267	280.0	275.0	263.4	22560.2	12.411	12.190	11.675	12.092
0.45	0.00300	310.8	302.1	284.9	22567.7	13.772	13.386	12.624	13.261
0.5	0.00333	332.0	326.5	325.3	22575.3	14.706	14.463	14.410	14.526
0.55	0.00367	363.2	362.0	342.0	22582.8	16.083	16.030	15.144	15.752
0.6	0.00400	384.7	393.4	375.7	22590.4	17.029	17.415	16.631	17.025
0.65	0.00433	415.1	424.9	402.0	22597.9	18.369	18.803	17.789	18.320
0.7	0.00467	436.5	463.6	423.1	22605.5	19.309	20.508	18.717	19.511
0.75	0.00500	462.3	499.2	454.1	22613.1	20.444	22.076	20.081	20.867
0.8	0.00533	488.0	532.0	478.0	22620.6	21.573	23.518	21.131	22.074
0.85	0.00567	506.9	564.2	507.6	22628.2	22.401	24.933	22.432	23.256

0.9	0.00600	538.0	591.0	522.0	22635.8	23.768	26.109	23.061	24.313
0.95	0.00633	560.0	612.5	545.6	22643.4	24.731	27.050	24.095	25.292
1	0.00667	580.4	633.0	581.3	22651	25.624	27.946	25.663	26.411
1.05	0.00700	612.3	636.4	603.9	22658.6	27.023	28.086	26.652	27.254
1.1	0.00733	636.0	658.6	624.1	22666.2	28.059	29.056	27.534	28.217
1.15	0.00767	649.4	684.0	640.5	22673.8	28.641	30.167	28.248	29.019
1.2	0.00800	651.8	691.5	668.7	22681.5	28.737	30.487	29.482	29.569
1.25	0.00833	670.4	702.3	684.6	22689.1	29.547	30.953	30.173	30.225
1.3	0.00867	695.7	709.4	697.5	22696.7	30.652	31.256	30.731	30.880
1.35	0.00900	708.5	718.9	709.6	22704.3	31.205	31.664	31.254	31.374
1.4	0.00933	725.6	717.4	720.5	22712	31.948	31.587	31.723	31.753
1.45	0.00967	737.4	715.0	718.6	22719.6	32.457	31.471	31.629	31.852
1.5	0.01000	743.1	713.4	718.3	22727.3	32.696	31.390	31.605	31.897
1.55	0.01033	732.1	708.5	712.7	22734.9	32.202	31.164	31.348	31.571
1.6	0.01067	721.3	700.9	704.1	22742.6	31.716	30.819	30.960	31.165
1.65	0.01100	716.6	688.4	691.9	22750.3	31.499	30.259	30.413	30.723
1.7	0.01133	705.8	683.7	689.7	22757.9	31.013	30.042	30.306	30.454
1.75	0.01167	686.8	677.4	682.3	22765.6	30.168	29.755	29.971	29.965
1.8	0.01200	681.9	663.6	679.1	22773.3	29.943	29.139	29.820	29.634
1.85	0.01233	665.3	659.2	662.1	22781	29.204	28.936	29.064	29.068
1.9	0.01267	649.2	656.3	638.9	22788.7	28.488	28.799	28.036	28.441
1.95	0.01300				22796.4	0.000	0.000	0.000	0.000
2	0.01333				22804.1	0.000	0.000	0.000	0.000
2.05	0.01367				22811.8	0.000	0.000	0.000	0.000
2.1	0.01400				22819.5	0.000	0.000	0.000	0.000

Cube with 3% HDPE at 28day									
ΔH (mm)	Strain	Load (KN)			Area (mm^2)	Stress (MPa)			
		1	2	3		1	2	3	Avg.
0	0.00000	18.0	15.0	20.0	22500	0.800	0.667	0.889	0.785
0.05	0.00033	31.6	24.9	42.1	22507.5	1.404	1.106	1.870	1.460
0.1	0.00067	54.0	53.2	70.0	22515	2.398	2.363	3.109	2.623
0.15	0.00100	84.8	85.9	97.0	22522.5	3.765	3.814	4.307	3.962
0.2	0.00133	114.3	101.0	125.0	22530	5.073	4.483	5.548	5.035
0.25	0.00167	138.0	135.0	154.2	22537.6	6.123	5.990	6.842	6.318
0.3	0.00200	171.0	163.2	174.0	22545.1	7.585	7.239	7.718	7.514
0.35	0.00233	193.4	187.8	204.0	22552.6	8.575	8.327	9.046	8.649
0.4	0.00267	220.0	212.1	234.1	22560.2	9.752	9.402	10.377	9.843
0.45	0.00300	250.4	235.3	254.6	22567.7	11.096	10.426	11.282	10.935

0.5	0.00333	287.8	254.1	273.0	22575.3	12.748	11.256	12.093	12.032
0.55	0.00367	316.2	289.0	287.0	22582.8	14.002	12.797	12.709	13.169
0.6	0.00400	346.8	296.4	324.1	22590.4	15.352	13.121	14.347	14.273
0.65	0.00433	364.7	311.4	351.0	22597.9	16.139	13.780	15.532	15.150
0.7	0.00467	380.0	343.6	381.0	22605.5	16.810	15.200	16.854	16.288
0.75	0.00500	400.0	365.1	408.0	22613.1	17.689	16.146	18.043	17.292
0.8	0.00533	422.0	404.2	417.8	22620.6	18.656	17.869	18.470	18.331
0.85	0.00567	441.5	427.3	436.1	22628.2	19.511	18.883	19.272	19.222
0.9	0.00600	463.1	451.3	460.0	22635.8	20.459	19.937	20.322	20.239
0.95	0.00633	474.5	472.0	485.3	22643.4	20.955	20.845	21.432	21.078
1	0.00667	507.8	495.2	499.0	22651	22.418	21.862	22.030	22.104
1.05	0.00700	534.8	514.2	517.3	22658.6	23.603	22.693	22.830	23.042
1.1	0.00733	554.0	537.4	540.0	22666.2	24.442	23.709	23.824	23.992
1.15	0.00767	580.0	556.7	573.1	22673.8	25.580	24.553	25.276	25.136
1.2	0.00800	601.1	568.4	600.0	22681.5	26.502	25.060	26.453	26.005
1.25	0.00833	615.5	591.4	624.4	22689.1	27.128	26.065	27.520	26.904
1.3	0.00867	625.0	623.9	639.7	22696.7	27.537	27.489	28.185	27.737
1.35	0.00900	647.4	640.0	651.0	22704.3	28.514	28.188	28.673	28.459
1.4	0.00933	663.8	657.1	664.8	22712	29.227	28.932	29.271	29.143
1.45	0.00967	679.0	674.5	673.2	22719.6	29.886	29.688	29.631	29.735
1.5	0.01000	690.0	682.7	698.0	22727.3	30.360	30.039	30.712	30.370
1.55	0.01033	694.5	704.1	718.6	22734.9	30.548	30.970	31.608	31.042
1.6	0.01067	712.4	726.0	729.3	22742.6	31.324	31.922	32.068	31.772
1.65	0.01100	720.0	747.8	741.0	22750.3	31.648	32.870	32.571	32.363
1.7	0.01133	724.8	755.1	764.8	22757.9	31.848	33.180	33.606	32.878
1.75	0.01167	736.0	784.1	756.5	22765.6	32.329	34.442	33.230	33.334
1.8	0.01200	740.0	781.0	770.0	22773.3	32.494	34.295	33.812	33.533
1.85	0.01233	743.2	784.7	776.2	22781	32.624	34.445	34.072	33.714
1.9	0.01267	746.0	787.4	767.4	22788.7	32.736	34.552	33.675	33.654
1.95	0.01300	748.1	788.9	765.0	22796.4	32.817	34.606	33.558	33.660
2	0.01333	747.9	789.6	760.5	22804.1	32.797	34.625	33.349	33.591
2.05	0.01367	746.5	791.0	749.1	22811.8	32.724	34.675	32.838	33.413
2.1	0.01400	745.1	791.9	742.3	22819.5	32.652	34.703	32.529	33.295
2.15	0.01433	724.3	793.1	739.5	22827.2	31.730	34.744	32.396	32.956
2.2	0.01467	712.7	794.0	731.8	22834.9	31.211	34.771	32.047	32.677
2.25	0.01500	700.9	788.8	728.1	22842.6	30.684	34.532	31.875	32.363
2.3	0.01533	687.9	762.7	723.9	22850.4	30.105	33.378	31.680	31.721
2.35	0.01567	681.8	751.4	715.0	22858.1	29.827	32.872	31.280	31.327
2.4	0.01600	655.6	745.0	709.2	22865.9	28.672	32.581	31.016	30.756

2.45	0.01633	632.8	739.7	702.1	22873.6	27.665	32.339	30.695	30.233
2.5	0.01667	621.7	726.3	698.8	22881.4	27.171	31.742	30.540	29.818
2.55	0.01700				22889.1	0.000	0.000	0.000	0.000
2.6	0.01733				22896.9	0.000	0.000	0.000	0.000

Cube with 6% HDPE at 28day									
ΔH (mm)	Strain	Load (KN)			Area (mm^2)	Stress (MPa)			
		1	2	3		1	2	3	Avg.
0	0.00000	16.0	13.0	14.0	22500	0.711	0.578	0.622	0.637
0.05	0.00033	40.0	45.0	32.0	22507.5	1.777	1.999	1.422	1.733
0.1	0.00067	60.0	65.0	57.6	22515	2.665	2.887	2.558	2.703
0.15	0.00100	118.6	99.7	73.0	22522.5	5.266	4.427	3.241	4.311
0.2	0.00133	156.4	123.0	94.8	22530	6.942	5.459	4.208	5.536
0.25	0.00167	184.6	146.0	137.6	22537.6	8.191	6.478	6.105	6.925
0.3	0.00200	226.3	168.5	165.4	22545.1	10.038	7.474	7.336	8.283
0.35	0.00233	259.0	189.0	193.7	22552.6	11.484	8.380	8.589	9.484
0.4	0.00267	274.8	211.9	224.3	22560.2	12.181	9.393	9.942	10.505
0.45	0.00300	286.0	247.7	254.0	22567.7	12.673	10.976	11.255	11.635
0.5	0.00333	321.8	269.4	273.5	22575.3	14.255	11.933	12.115	12.768
0.55	0.00367	352.6	294.0	296.5	22582.8	15.614	13.019	13.129	13.921
0.6	0.00400	374.3	327.4	324.9	22590.4	16.569	14.493	14.382	15.148
0.65	0.00433	395.7	362.7	341.8	22597.9	17.510	16.050	15.125	16.229
0.7	0.00467	417.8	385.0	379.6	22605.5	18.482	17.031	16.792	17.435
0.75	0.00500	455.0	405.0	402.4	22613.1	20.121	17.910	17.795	18.609
0.8	0.00533	464.6	441.0	426.0	22620.6	20.539	19.495	18.832	19.622
0.85	0.00567	491.4	466.7	445.1	22628.2	21.716	20.625	19.670	20.670
0.9	0.00600	525.0	496.3	463.6	22635.8	23.193	21.925	20.481	21.867
0.95	0.00633	563.8	514.0	491.5	22643.4	24.899	22.700	21.706	23.102
1	0.00667	586.4	541.2	515.4	22651	25.888	23.893	22.754	24.178
1.05	0.00700	622.0	563.4	536.4	22658.6	27.451	24.865	23.673	25.330
1.1	0.00733	653.1	593.0	549.1	22666.2	28.814	26.162	24.225	26.401
1.15	0.00767	678.4	616.4	563.5	22673.8	29.920	27.186	24.852	27.319
1.2	0.00800	701.4	621.3	589.4	22681.5	30.924	27.392	25.986	28.101
1.25	0.00833	711.3	641.5	609.1	22689.1	31.350	28.274	26.846	28.823
1.3	0.00867	736.3	659.7	610.8	22696.7	32.441	29.066	26.911	29.473
1.35	0.00900	740.4	673.3	639.3	22704.3	32.611	29.655	28.158	30.141
1.4	0.00933	755.6	689.1	655.4	22712	33.269	30.341	28.857	30.822
1.45	0.00967	748.4	707.6	680.7	22719.6	32.941	31.145	29.961	31.349
1.5	0.01000	751.0	718.7	705.4	22727.3	33.044	31.623	31.038	31.901

1.55	0.01033	753.7	733.4	720.7	22734.9	33.152	32.259	31.700	32.370
1.6	0.01067	765.9	752.1	730.4	22742.6	33.677	33.070	32.116	32.954
1.65	0.01100	767.1	763.6	756.9	22750.3	33.718	33.564	33.270	33.518
1.7	0.01133	772.2	779.4	778.7	22757.9	33.931	34.247	34.217	34.132
1.75	0.01167	770.1	792.2	787.3	22765.6	33.827	34.798	34.583	34.403
1.8	0.01200	762.2	800.0	802.6	22773.3	33.469	35.129	35.243	34.614
1.85	0.01233	741.3	809.5	811.5	22781	32.540	35.534	35.622	34.565
1.9	0.01267	728.6	800.2	819.6	22788.7	31.972	35.114	35.965	34.350
1.95	0.01300	724.9	783.5	823.1	22796.4	31.799	34.370	36.107	34.092
2	0.01333	713.0	779.1	819.8	22804.1	31.266	34.165	35.950	33.794
2.05	0.01367	712.2	771.9	811.1	22811.8	31.221	33.838	35.556	33.538
2.1	0.01400	701.5	759.5	804.9	22819.5	30.741	33.283	35.273	33.099
2.15	0.01433	690.6	754.8	801.3	22827.2	30.253	33.066	35.103	32.807
2.2	0.01467	682.9	747.2	793.1	22834.9	29.906	32.722	34.732	32.453
2.25	0.01500	677.1	740.9	791.1	22842.6	29.642	32.435	34.633	32.236
2.3	0.01533	670.1	734.2	788.9	22850.4	29.326	32.131	34.525	31.994
2.35	0.01567	661.9	727.7	781.4	22858.1	28.957	31.836	34.185	31.659
2.4	0.01600	656.3	721.4	774.1	22865.9	28.702	31.549	33.854	31.368
2.45	0.01633	653.4	716.3	771.8	22873.6	28.566	31.316	33.742	31.208
2.5	0.01667				22881.4	0.000	0.000	0.000	0.000
2.55	0.01700				22889.1	0.000	0.000	0.000	0.000
2.6	0.01733				22896.9	0.000	0.000	0.000	0.000

Cube with 9% HDPE at 28day									
ΔH (mm)	Strain	Load (KN)			Area (mm^2)	Stress (MPa)			
		1	2	3		1	2	3	Avg.
0	0.00000	15.0	13.0	14.0	22500	0.667	0.578	0.622	0.622
0.05	0.00033	34.6	45.2	30.0	22507.5	1.537	2.008	1.333	1.626
0.1	0.00067	53.0	74.0	54.9	22515	2.354	3.287	2.438	2.693
0.15	0.00100	73.2	93.0	87.0	22522.5	3.250	4.129	3.863	3.747
0.2	0.00133	108.0	127.4	104.3	22530	4.794	5.655	4.629	5.026
0.25	0.00167	125.7	142.5	140.0	22537.6	5.577	6.323	6.212	6.037
0.3	0.00200	166.4	161.5	153.5	22545.1	7.381	7.163	6.809	7.118
0.35	0.00233	190.0	194.3	167.4	22552.6	8.425	8.615	7.423	8.154
0.4	0.00267	215.6	218.0	186.7	22560.2	9.557	9.663	8.276	9.165
0.45	0.00300	236.0	234.4	216.3	22567.7	10.457	10.387	9.584	10.143
0.5	0.00333	264.3	261.8	234.0	22575.3	11.708	11.597	10.365	11.223
0.55	0.00367	278.9	285.0	260.3	22582.8	12.350	12.620	11.526	12.166
0.6	0.00400	291.7	304.5	286.0	22590.4	12.913	13.479	12.660	13.017

0.65	0.00433	316.5	330.0	293.4	22597.9	14.006	14.603	12.983	13.864
0.7	0.00467	349.8	346.3	296.0	22605.5	15.474	15.319	13.094	14.629
0.75	0.00500	362.4	375.1	312.0	22613.1	16.026	16.588	13.797	15.470
0.8	0.00533	380.0	400.0	326.5	22620.6	16.799	17.683	14.434	16.305
0.85	0.00567	393.4	428.0	351.2	22628.2	17.385	18.914	15.520	17.273
0.9	0.00600	416.5	440.0	386.4	22635.8	18.400	19.438	17.070	18.303
0.95	0.00633	450.0	465.0	401.0	22643.4	19.873	20.536	17.709	19.373
1	0.00667	484.1	480.2	421.3	22651	21.372	21.200	18.600	20.391
1.05	0.00700	501.2	510.6	452.6	22658.6	22.120	22.534	19.975	21.543
1.1	0.00733	523.4	538.0	473.7	22666.2	23.092	23.736	20.899	22.575
1.15	0.00767	541.8	557.0	508.0	22673.8	23.895	24.566	22.405	23.622
1.2	0.00800	570.7	571.6	522.0	22681.5	25.162	25.201	23.014	24.459
1.25	0.00833	584.6	594.1	553.4	22689.1	25.766	26.184	24.391	25.447
1.3	0.00867	593.8	617.8	579.5	22696.7	26.162	27.220	25.532	26.305
1.35	0.00900	615.0	621.2	604.0	22704.3	27.087	27.360	26.603	27.017
1.4	0.00933	621.5	645.3	622.4	22712	27.364	28.412	27.404	27.727
1.45	0.00967	637.0	647.0	647.2	22719.6	28.037	28.478	28.486	28.334
1.5	0.01000	654.6	654.0	661.3	22727.3	28.802	28.776	29.097	28.892
1.55	0.01033	664.3	663.5	677.8	22734.9	29.219	29.184	29.813	29.406
1.6	0.01067	670.8	671.4	691.2	22742.6	29.495	29.522	30.392	29.803
1.65	0.01100	672.3	679.4	701.0	22750.3	29.551	29.863	30.813	30.076
1.7	0.01133	670.1	681.4	713.3	22757.9	29.445	29.941	31.343	30.243
1.75	0.01167	664.7	685.1	708.2	22765.6	29.198	30.094	31.108	30.133
1.8	0.01200	660.1	688.9	696.4	22773.3	28.986	30.250	30.580	29.939
1.85	0.01233	654.9	685.9	690.3	22781	28.748	30.108	30.302	29.719
1.9	0.01267	650.4	680.7	684.0	22788.7	28.541	29.870	30.015	29.475
1.95	0.01300	657.9	677.2	668.4	22796.4	28.860	29.707	29.320	29.296
2	0.01333	655.7	670.9	660.1	22804.1	28.754	29.420	28.947	29.040
2.05	0.01367	649.9	668.9	657.9	22811.8	28.490	29.323	28.840	28.884
2.1	0.01400	647.6	657.9	648.8	22819.5	28.379	28.831	28.432	28.547
2.15	0.01433	643.2	655.5	640.1	22827.2	28.177	28.716	28.041	28.311
2.2	0.01467	640.8	649.1	637.4	22834.9	28.062	28.426	27.913	28.134
2.25	0.01500	638.3	640.0	632.8	22842.6	27.943	28.018	27.703	27.888
2.3	0.01533	636.4	636.8	624.0	22850.4	27.851	27.868	27.308	27.676
2.35	0.01567	632.5	631.1	619.7	22858.1	27.671	27.609	27.111	27.464
2.4	0.01600	630.1	623.3	615.6	22865.9	27.556	27.259	26.922	27.246
2.45	0.01633	626.2	620.7	607.2	22873.6	27.377	27.136	26.546	27.020
2.5	0.01667				22881.4	0.000	0.000	0.000	0.000
2.55	0.01700				22889.1	0.000	0.000	0.000	0.000

2.6	0.01733				22896.9	0.000	0.000	0.000	0.000

Cube with 12% HDPE at 28day									
ΔH (mm)	Strain	Load (KN)			Area (mm^2)	Stress (MPa)			
		1	2	3		1	2	3	Avg.
0	0.00000	15.0	14.0	15.2	22500	0.667	0.622	0.676	0.655
0.05	0.00033	40.0	42.0	28.5	22507.5	1.777	1.866	1.266	1.636
0.1	0.00067	63.4	52.7	31.0	22515	2.816	2.341	1.377	2.178
0.15	0.00100	93.6	87.2	38.4	22522.5	4.156	3.872	1.705	3.244
0.2	0.00133	137.9	109.5	48.9	22530	6.121	4.860	2.170	4.384
0.25	0.00167	168.0	127.0	61.5	22537.6	7.454	5.635	2.729	5.273
0.3	0.00200	194.7	156.0	75.0	22545.1	8.636	6.919	3.327	6.294
0.35	0.00233	224.0	179.4	93.0	22552.6	9.932	7.955	4.124	7.337
0.4	0.00267	254.0	205.8	106.5	22560.2	11.259	9.122	4.721	8.367
0.45	0.00300	267.4	233.4	130.5	22567.7	11.849	10.342	5.783	9.325
0.5	0.00333	316.2	248.0	134.8	22575.3	14.006	10.985	5.971	10.321
0.55	0.00367	344.4	267.3	143.0	22582.8	15.251	11.836	6.332	11.140
0.6	0.00400	368.1	284.3	160.0	22590.4	16.295	12.585	7.083	11.987
0.65	0.00433	383.0	308.9	170.5	22597.9	16.948	13.669	7.545	12.721
0.7	0.00467	416.3	314.0	180.4	22605.5	18.416	13.890	7.980	13.429
0.75	0.00500	443.2	341.0	192.7	22613.1	19.599	15.080	8.522	14.400
0.8	0.00533	451.8	356.1	216.0	22620.6	19.973	15.742	9.549	15.088
0.85	0.00567	476.2	374.5	224.7	22628.2	21.045	16.550	9.930	15.842
0.9	0.00600	500.0	382.8	239.6	22635.8	22.089	16.911	10.585	16.528
0.95	0.00633	516.4	393.5	252.3	22643.4	22.806	17.378	11.142	17.109
1	0.00667	538.2	415.3	271.6	22651	23.761	18.335	11.991	18.029
1.05	0.00700	547.2	432.0	293.7	22658.6	24.150	19.066	12.962	18.726
1.1	0.00733	560.0	466.7	299.6	22666.2	24.706	20.590	13.218	19.505
1.15	0.00767	580.0	480.0	305.0	22673.8	25.580	21.170	13.452	20.067
1.2	0.00800	616.4	490.0	320.0	22681.5	27.176	21.604	14.108	20.963
1.25	0.00833	645.2	500.0	338.0	22689.1	28.437	22.037	14.897	21.790
1.3	0.00867	622.3	564.3	356.1	22696.7	27.418	24.863	15.690	22.657
1.35	0.00900	632.9	583.4	387.9	22704.3	27.876	25.696	17.085	23.552
1.4	0.00933	635.0	593.6	430.8	22712	27.959	26.136	18.968	24.354
1.45	0.00967	645.3	606.2	443.7	22719.6	28.403	26.682	19.529	24.871
1.5	0.01000	651.9	602.7	478.1	22727.3	28.684	26.519	21.036	25.413
1.55	0.01033	652.1	592.1	530.4	22734.9	28.683	26.044	23.330	26.019
1.6	0.01067	650.2	582.3	573.2	22742.6	28.590	25.604	25.204	26.466
1.65	0.01100	647.5	571.3	615.4	22750.3	28.461	25.112	27.050	26.874

1.7	0.01133	643.1	566.2	639.8	22757.9	28.258	24.879	28.113	27.084
1.75	0.01167	641.8	561.6	648.7	22765.6	28.192	24.669	28.495	27.118
1.8	0.01200	636.4	550.4	651.5	22773.3	27.945	24.169	28.608	26.907
1.85	0.01233	620.1	532.5	670.2	22781	27.220	23.375	29.419	26.671
1.9	0.01267	617.9	512.3	675.2	22788.7	27.114	22.480	29.629	26.408
1.95	0.01300	609.3	501.9	670.4	22796.4	26.728	22.017	29.408	26.051
2	0.01333	602.0	496.5	665.3	22804.1	26.399	21.772	29.175	25.782
2.05	0.01367	599.5	488.1	655.8	22811.8	26.280	21.397	28.748	25.475
2.1	0.01400	593.4	484.0	650.0	22819.5	26.004	21.210	28.484	25.233
2.15	0.01433	590.0	478.8	647.3	22827.2	25.846	20.975	28.357	25.059
2.2	0.01467	586.3	475.7	641.4	22834.9	25.676	20.832	28.089	24.865
2.25	0.01500	582.2	471.3	636.8	22842.6	25.487	20.632	27.878	24.666
2.3	0.01533				22850.4	0.000	0.000	0.000	0.000
2.35	0.01567				22858.1	0.000	0.000	0.000	0.000
2.4	0.01600				22865.9	0.000	0.000	0.000	0.000

E- Sample photo captured during laboratory experiment.