PERFORMANCE EVALUATION OF ENGINEERED CONCRETE WITH RECYCLED WASTE POLYPROPYLENE

NIAZ MD. ASHRAFUL HAQUE

(B.Sc Engg., AUST)

A THESIS SUBMITTED FOR THE DEGREE OF MASTER OF ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

MILITARY INSTITUTE OF SCIENCE AND TECHNOLOGY

2020

APPROVAL

The thesis titled "**Performance Evaluation of Engineered Concrete with Recycled Waste Polypropylene**" Submitted by Niaz Md. Ashraful Haque, Roll No: 1014110020, Session: October 2014, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Science in Civil Engineering (Structure) on 26th July 2020.

BOARD OF EXAMINERS

1. ________________________ Chairman
Lt Col Md Jahidul Islam, PhD (Supervisor)
Instructor Class A,
Department of Civil Engineering,
Military Institute of Science and Technology

2. ________________________ Member
Brig Gen Md Abul Kalam Azad, psc (Ex-officio)
Deand & Head
Department of Civil Engineering,
Military Institute of Science and Technology

3. ________________________ Member
Maj Md Soebur Rahman, PhD, PEng (Internal)
Instructor Class B
Department of Civil Engineering,
Military Institute of Science and Technology

4. ________________________ Member
Mohammad Al Amin Siddique, PhD (External)
Professor
Dept of Civil Engineering,
Bangladesh University of Engineering and Technology

DECLARATION

“Declaration I hereby declare that this thesis is my original work and it has been written by me in its entirety. I have duly acknowledged all the sources of information that have been used in the thesis. The thesis (fully or partially) has not been submitted for any degree or diploma in any university or institute previously.”

Niaz Md. Ashraful Haque

Student ID: 1014110020

AUGUST 2020

ACKNOWLEDGEMENTS

At first, I fervently express all of my admiration and devotion to the almighty ALLAH, the most beneficial who has enabled me to perform this research work and to submit this thesis. With much pleasure, I respectfully express my earnest gratitude to my honorable teacher and supervisor Lt Col Md Jahidul Islam, PhD, Department of Civil Engineering, Military Institute of Science and Technology (MIST) for his scholastic guidance, instructions, valuable advice, suggestions, relentless patience and continuous encouragement throughout my voyage of research. Words are always insufficient to express his working capacities and unending enthusiasm for scientific rigorousness for innovative investigations. This always becomes an everlasting source of inspiration for his students.

Next, I offer my gratefulness to Head, Department of Civil Engineering, MIST for the kind permission to perform this work. I am also grateful to MIST authority for providing the financial grant for this research.

I also pay the deepest homage to those who helped directly and indirectly in performing the work in connection with the thesis, especially the laboratory of MIST, Dhaka.

Finally, I would like to express my profound gratitude to my respected parents, especially my belated Father A.T.M Aminul Haque, with whom the last conversation was regarding my M.Sc thesis completion. I would mention special gratefulness for the moral support and sustaining inspiration provided by my family members. Their prayers and support helped me to complete my postgraduate degree in time. May Almighty help us always and enlighten us with knowledge.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Symbols	Description
ASASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
ASTM	American Society for Testing Materials
CDW	Constructed and Demolition Waste
DCC	Dhaka City Corporation
EPS	Expanded Polystyrene
EVA	Ethylene Vinyl Acetate
HDPE	High-Density Polyethylene
LWC	Light Weight Concrete
NCA	Natural Coarse Aggregate
OPC	Ordinary Portland Cement
PA	Plastic Aggregate
PET	Polyethylene Terephthalate
PP	Polypropylene
PS	Polystyrene
WPLA	Waste plastic light aggregate

ABSTRACT

Plastic waste generation is a major threat to the environment due to its non-biodegradable nature where polypropylene (PP) includes more than 35 percent of the total waste generation. These plastic wastes can be recycled and reused in concrete as an alternative to natural stones, thus preserve the environment. Therefore, this study aims to investigate the structural and durability performance of concrete partially mixed with recycled waste polypropylene (PP) plastic chips as coarse aggregate. To evaluate the performance of concrete, twelve different mixes were considered where crushed stones were replaced by PP at 10% and 20% (by volume replacement) with four different water-cement ratios (0.35, 0.40, 0.45, and 0.50) and compared with concrete with no polypropylene aggregate (control specimen). Water reducing admixture was used with samples of 0.35 and 0.4 water-cement ratios. The physical performance of concrete was evaluated in terms of strength parameters like compressive strength, tensile strength, flexural strength, stress-strain behavior, pull out strength, etc. Additionally, durability performance was evaluated through the shrinkage test, chloride ion penetration, and compressive strength at high-temperature exposure. It appears compressive strength and tensile strength reduction were 12% and 21% respectively for 10% of PP replacement. The results of pull-out strength indicate that PP can be used in structural concrete safely as these parameters were reduced up to 24% with 10% of PP replacement. The reduction rate for modulus of elasticity was 19%. However, the toughness index has shown improvement with an increment of up to 25%. In the case of durability, all the concrete samples have been fallen under a moderate category according to the test method for chloride ion penetration which indicates adequate durability of the concrete sample. Moreover, PP can also be used to produce lightweight concrete due to its lower unit weight, as the relative reduction was up to 10% in density for 20% of PP replacement than regular concrete. It also appears, at high-temperature exposure

(more than 200° C) for 1 hour, the compressive strength of concrete was still more than 20 MPa. Therefore, concrete with a low to moderate proportion of PP is safe and can generate strong structural elements is not only in the context of sustainability and environmental protection but also in engineering aspects.

CHAPTER 1 INTRODUCTION

1.1 General

Civilization has made waste disposal and waste management a major natural concern worldwide. Now a day, plastic products have become one of the most essential materials of our civilized lifestyle. Replacing or compensating for plastic and other material is a practice that has become widespread of late, given the increasing trend of plastic waste build-up. Among all of the waste materials, plastic-based waste materials are filling a significant portion of landfill spaces as they are not easily degraded or decomposed [1]. The existence of such waste results in a negative environmental impact. It hinders the drainage of water through the soil, which then pollutes the soil with diseases triggered by mosquitoes and diseases resulting from the flood water flow. The presence of plastic blocks seepage pipes in urban areas. Furthermore, such plastic blockages hinder or prolong the movement of plant roots. The blocks include certain toxic substances in their chemical compositions, thus exposing the future of the soil to risk factors that arise after decomposition occurs [2].

Concrete is the most widely used construction material all over the world. A major part of concrete is coarse aggregate, for which we mostly rely on natural resources as stones which are decreasing every day. Currently, the global concrete consumption is estimated at around 25 billion tons per year and annual coarse aggregate (stone) usage is more than 3.9 billion tones (2016) [3]. The construction industry is getting a quick expansion every day, so researchers are always working to develop cleaner, cheaper, and energy-efficient construction material to cope up with the development maintain State of Art technology.

The use of a waste product like plastics in concrete not only makes it economical but also helps in reducing disposal problems. The use of plastics due to its low unit weight reduces the unit weight of concrete which results in a reduction in a dead load of a structural concrete member of a building. Reduction in the self-weight of a building will help to reduce the seismic risk of the building since the earthquake forces linearly dependent on the dead-weight. Furthermore, it can also be concluded that the use of recycled polypropylene (PP) as a partial replacement of coarse aggregate in concrete provides some advantages, i.e., reduction in the use of natural resources, disposal of polymer wastes, low-cost alternative to regular aggregates, prevention of environmental pollution, and energy saving.

1.2 History and Use of Polypropylene

Concrete is the most widely used building material due to its diversity and availability. It is one of the most important construction materials in the world [4]. It is composed of cement (commonly Portland cement) along with other cementitious materials such as fly ash and slag, aggregate, water, and chemical admixtures. Sometimes modifying the concrete property, various types (such as plastic-like Polyethylene terephthalate, Polypropylene, Polystyrene, High-density polyethylene) of materials can be used in concrete partially as coarse or fine aggregates [5].

The history of man-made fibers began at the end of the 19th century with the first semi-synthetic or regenerated materials. Although completely synthetic polymers were developed in the early 20th century, many fibers that are now in common use were not fully exploited until the 1960s and 1970s. Polypropylene was first polymerized in 1951 by a pair of Phillips petroleum scientists named Paul Hogan and Robert Banks and later by Italian and German scientists Natta and Rehn [6]. It became prominent extremely fast, as commercial production began barely three years after Italian chemist, Professor Giulio Natta, first polymerized it. By 1957, its popularity had exploded and widespread commercial production began across Europe [7]. Today it is one of the most commonly produced plastics in the world.

Figure 1. 1: Processed Polypropylene (PP) aggregate

Polypropylene (PP) is a thermoplastic “addition polymer” made from the combination of propylene monomers. It is an important plastic product being used in many different forms and applications through a range of manufacturing processes. A large proportion of PP is used as fibers in constituents of fabrics, upholstery, and carpets. Many industrial uses involve ropes, woven and non-woven fabrics, and reinforcements. It is used in a variety of applications to include packaging for consumer products, plastic parts for various industries including the automotive industry, special devices like living hinges, and textiles. Since the 1980s the production, consumption, and applications of this polymer have increased through the application of even more efficient catalysts and property enhancements and today PP is the most common fiber used all over the world [8]. The usefulness of PP depends on the retention of its properties during prolonged service life. For instance, under mild conditions, PP will retain its properties for long periods. However, in most applications, exposure to heat and light will occur which accelerates oxidative degradation.

The properties that make PP widely used as a fiber do not prevent the fiber from the technological advancement around the world, disposal of wastes and waste management has gotten to be a major natural issue within the world. Among all these waste materials, plastic-based waste materials are worst as they don't effectively debase or decayed. Plastic is accessible nearly all over and its utilization around the world expanded from 5 million tons to almost 335 million tons amid the year 1950–2016 [9]. In America alone, around 31,750 thousand tons of plastic wastes was presented within the municipal solid waste in 2012. Amid the year 2010 – 2011, a few 750 thousand tons of reused plastic was produced and devoured in Bangladesh [10].

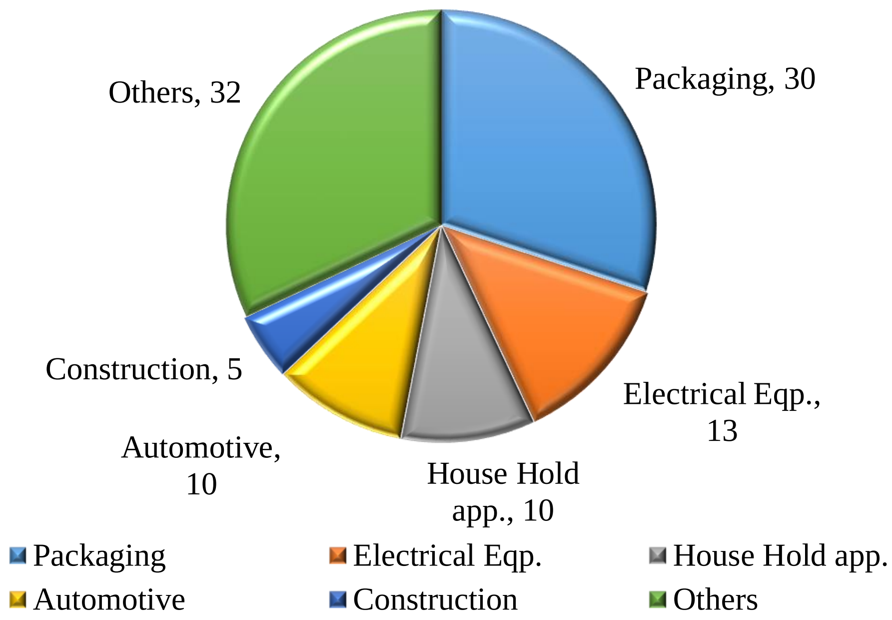


Figure 1. 2: Current application of Polypropylene

According to some reports, the current global demand for the material generates an annual market of about 45 million metric tons and it is estimated that the demand will rise to approximately 62 million metric tons by 2020 [11]. The major end-users of polypropylene are the packaging industry, which consumes about 30% of the total, followed by electrical and equipment manufacturing, which uses about 13% each. Household appliances and automotive industries both consume 10% each and construction materials follow with 5% of the market. Other applications together make up the rest of the global polypropylene consumption [12] .

Polypropylene is not particularly useful for structural applications like holding up a heavy door but is exceptionally useful for non-load bearing applications such as the lid on a bottle of ketchup or shampoo. Polypropylene is uniquely adept for living hinges because it does not break when repeatedly bent. Another advantage of Polypropylene is that it can be easily copolymerized (essentially combined into a composite plastic) with other polymers like polyethylene. Copolymerization changes the material properties significantly, allowing for more robust engineering applications than are possible with pure polypropylene (more of a commodity plastic on its own).

1.3 Plastic waste in Bangladesh

In Bangladesh, especially in Dhaka, plastic waste recycling is based on rudimentary technology and dominated by the informal sector. However, there is a dearth of information about the composition of plastic waste and the demand-supply scenario of recycled granules/ pellets. In DCC area 3315 tons of solid waste has been generated per day during 2005, of which 4.15% is composed of plastic materials [13]. As such, 50 with the growth of the economy of the country, the amount of plastic waste is also increasing. This trend in the growth of plastic waste is expected to continue in near future also.,214 tons of plastic waste is disposed of in the city at a rate of 137.57 tons/day. The per capita plastic consumption in Dhaka city is 9 kg/year while the national average stands at 3.6 kg/cap/year, which is lower than the global average of 20 kg/cap/year [10]. It has been found that 40.76 tons of unsoiled plastic are collected per day by feriwallas before it is disposed of, while 50.24 tons/day of soiled plastic is retrieved by various actors (van collectors, waste bin tokais, DCC collectors and dumpsite tokais) from the disposed waste of 137.57 tons/day. Thus the total amount of plastic waste recycled per day in DCC area stands at 91 tons/day. In a recent study, it was found that around 51% of the total plastic waste is recycled in Bangladesh and the rest are polluting the environment [14].

Figure 1. 3**:** Plastic Waste in Bangladesh [15]

Bangladesh has a few sources of natural stones to be used as coarse aggregate. So the construction industry of Bangladesh mostly depends upon imported aggregates. So, Using the recycled polypropylene in concrete would create an advantage of utilizing the waste as well as creating an alternative source of aggregates.

1.4 Usages of Concrete

Concrete is a versatile building material. It is easy to prepare in various shapes and forms. The mixture contains cement, water, and aggregates. Sometimes it also contains admixtures, fibers, and reinforcements. Depending on the strength requirements, the mixture is made in different proportions. One of the most significant benefits of using concrete is lower costs in comparison to the use of steel in commercial buildings. It is fire-resistant, sustainable, and can be made using locally available materials. This last feature means that it does not have to travel a long distance to be used on sites. It can be prepared on-site. With such advantages comes a wide range of applications. The traditional uses of concrete are very well-known to everyone. Few of the common uses as Buildings, Footings, Driveways, Patios, Dams, Parking lots, streets, roads, and highways Sidewalls.

Sustainable construction is now the main focus for the researchers. Concrete produced from the various replacement of aggregate e.g. Natural Coarse Aggregate (NCA) with PP leads towards green concrete or sustainable concrete. This resulting aggregate consumes and emit less energy and cost less than that of traditional concrete. Sustainable construction has a social, economic, and environmental impact in a long term perspective. Environmental benefits can be obtained by limiting the amount of industrial waste, by reducing the greenhouse gas emission for aggregate extraction and by reducing the demand for new natural aggregate and preserving ecosystems. The use of PP saves money associated with NCA that are obtained by blasting or stripping. The social benefits of using green concrete are many. The use of green concrete reduces construction waste. The use of recycled aggregate in green concrete reduces waste of broken structures. It helps to keep the society neat and clean. Replacing this recycled plastic as coarse aggregate is one of the methods for constructing sustainable material or green material.

Lightweight concrete (LWC) has become a prominent subject in modern concrete technology [16]. To produce concrete that is light in weight, lightweight aggregate is an essential ingredient. By using LWC the dimensions of the load-bearing members, such as beams, columns, foundations, of a structure can be reduced. It has a higher seismic resistance as concrete can absorb shock better in a lower density. It has a significantly low thermal conductivity and better sound absorption capacity. Because of these advantageous properties studies on finding suitable and cost-effective lightweight aggregate have grown considerably in recent years [10].

1.5 Types of Plastic and Plastic Wastes

The quantity of plastics consumed annually all over the world has been growing rapidly. Its exceptionally user-friendly characteristics/features, unique flexibility, fabricability, and processability coupled with immense cost-effectiveness and longevity are the main reasons for such astronomical growth. Besides its wide use in packaging, automotive, and industrial applications, plastics are also extensively used in medical delivery systems, artificial implants and other healthcare applications, water desalination and bacteria removal, preservation, and distribution of food, housing appliances, communication, and the electronics industry, etc. The name of the plastic is Polyethylene terephthalate (PET), High-density polyethylene (HDPE), Polystyrene (PS), Polypropylene (PP), etc. Here, some waste plastic like PET bottles has been recycled for use as an aggregate for concrete. Much of the research has been done by PET plastic as a fine aggregate.

Figure 1. 4: Various application of Polypropylene Plastics

In 1953, Karl Ziegler and Giulio Natta, working independently, prepared polypropylene from propylene monomers (CH2=CHCH3) and received the Nobel Prize in Chemistry in 1963 [7]. The various forms of polypropylene have different melting points and hardnesses. Polypropylene is an important plastic and is used in many different forms and applications through a range of manufacturing processes.

1.6 Research Significance

Polypropylene (PP) is a cheap and plentiful thermoplastic used in a wide variety of applications including food packaging, textiles, laboratory equipment, automotive components, and polymer banknotes [17]. It is slightly harder and more heat resistant, mechanically rugged material, and has a high chemical resistance. Production of polypropylene is increasing day by day in the world [18]. It is the second-most widely produced commodity plastic compared to the other plastic [19].

The global production of Polypropylene resin is 55.9 MMT in 2018 and is estimated to reach 83.17 MMT by 2025, at a CAGR of 5.84% for the forecasted period [20]. Every year plastic production has increased and simultaneously increased consumption of plastic materials. Due to the increasing growth of plastic, the most critical problem is municipal solid waste (MSW). The problem of solid waste creates its disposal problem. To overcome this problem, waste management is required. The use of waste production presents a way to reduce the difficulties related to solid waste management. Recycling of waste materials helps to mitigate disposal problem, save and sustain natural resources, and decreases environment contamination. PP aggregate concrete is a potential sustainable construction material [21].

Every year a large amount of natural aggregates is used for construction purpose and which can be the reason for the crisis of natural resources in the future. To overcome the crisis problem, many researchers investigated to use the PP in various forms. Many researchers have taken endeavor to achieve the desired performance of PP aggregate and many of those conducted mechanical properties of the specimen with different replacement levels of PP as fine aggregate or fiber. The combined mechanical properties and durability of concrete mixed PP are still not identified by the researchers.

The present research aims to provide experimental results regarding the information on the physical, mechanical properties and durability of PP reinforced aggregate concrete. It also discovers the path for utilizing the structural potentialities of waste construction materials for sustainable and eco-friendly construction in the near future. The concrete industry will be directly benefitted and practitioners will come to know for the correct proportion of PP replacement level. The results will encourage the application of it in other fields in different climates and situations. Moreover, this study will help the world to save a large number of natural resources by reusing plastic waste. In turn, it will save the significant cost of money to recycle the waste and disposal of polymer wastes, prevention of environmental pollution, and energy saving. As polypropylene is still not used as a replacement of natural aggregates, this type of research may help to make a scope for people to be acquainted with polypropylene mixed concrete and inspire them to get the benefits of polypropylene mixed concrete. Finally, it will open a new horizon of opportunities for sustainable construction by reusing/ recycling plastic waste in Bangladesh and all over the world.

1.7 Objective of the Study

The objectives of this study are:

a. To investigate the fresh (such as workability) and hardened (like density, compressive strength, tensile strength, flexural strength, pull out strength, Young's modulus, and stress-strain relationship) properties of concrete prepared with partial replacement of PP as coarse aggregate with four different water-cement ratios.
b. To study the performance of engineered concrete under various durability conditions including shrinkage, high-temperature exposure, and chloride ion penetration tests.

1.8 Scope of the Study

To fulfil the objectives, a number of experiments will be performed in the laboratories. The concrete samples will be prepared with 0%, 10% and 20% replacement of PP as coarse aggregate with four different w/c ratios (0.35, 0.40, 0.45 and 0.50). These samples will be tested for compressive strength, tensile strength, flexural strength, pull out strength, Young's modulus, shrinkage, compressive strength after exposed to high-temperature, and chloride ion penetration tests.

1.9 Methodology

The concrete cylinder samples, 100 mm x 200 mm, will be prepared as per the requirement of the test methods following ASTM C 192 [21] . After 24 hours of humidity curing the samples will be water cured for 28 days, except for 7 days test. To achieve the fresh, hardened and durability properties of concrete following tests will be conducted:

a. Workability at 0 and 15 minutes after mixing of concrete ingredients.
b. Dry density of concrete.
c. Compressive strength test following ASTM C39 at 7, 28 and 90 days and tensile strength test following ASTM C496 at 28 and 90 days.
d. Pull out strength determination at 28 days.
e. Shrinkage test between 7 to 35 days after casting.
f. Chloride ion penetration test by surface resistivity meter following AASHTO TP 95 at 28 days.
g. Compressive strength test after high-temperature exposure (100ºC and 200°C for 1 hour) after 28 days.

All the obtained results will be analysed and represented in graphical forms for comparison and discussed the nature of the physical and durability properties of the PP concrete.

1.10 Organization of the Thesis

Chapter 1 presents the background of the research. It also highlights the uses of concrete and types of plastic and plastic wastes as well as the significance and objective of the research.

Chapter 2 discusses a detailed literature review on concrete mixed with plastic-based on previous studies and publications. This chapter provides general ideas and guidance on the physical, mechanical, and durability of all types of plastic concrete.

Chapter 3 describes the properties of the material used and the research methodology that was used in the experiment.

Chapter 4 discusses the experimental results of the test in tabular and graphical forms and analysis of the results based on compressive strength, splitting tensile strength, flexural strength, pull out strength, shrinkage, chloride penetration.

Chapter 5 presents a summary of the whole research work, conclusion, and recommendation for future work.

CHAPTER 2 LITERATURE REVIEW

2.1 General

In this chapter, a review of literature related to the behavior of conventional concrete has been carried out. A brief review of the published work on material and structural characteristics of concrete with plastic aggregates is presented and finally the need if the present investigation is identified.

2.2 Plastic Concrete

There are many forms of waste plastic utilization to produce lightweight concrete. Polyethylene Terephthalate (PET) slices shredded by the machine can be used. Several studies were also conducted using handheld devices to cut plastic and used a grinding machine which produced fiber in irregular forms. Some researchers used the PET as a single additive material in concrete. In PET, the effect of fine and coarse aggregates was investigated. The test result showed a good relationship between concrete and polyethylene terephthalate (PET) – aggregate and also showed better performance of durability of concrete with the plastic waste of different sizes and shapes.

Generally, two forms of plastics, namely, Plastic Aggregate (PA) and Plastic Fibers (PF), are used in concrete. Recycled PAs are extracted from different types of plastic waste. Tables 2.1 lists the types and properties of PA used in concrete as reported in the literature. The tables also summarize the recycling methods for plastic aggregates (PA); these methods typically involve direct mechanical recycling or melting. The former is an efficient and economical way to obtain recycled PA, while the latter yields materials with more uniform size and properties.

Table 2. 1: Recycling method and Properties of Plastic Concrete Aggregate (PA)

No	References	Type of plastic	Origin of plastic waste	Recycle/treating procedure	Particle size (mm)/shape
1.	Ravindrarajah and Tuck [23]	EPS	Virgin	NA	≤4.75/beads
2.	Lai et al. [24]	EPS	Virgin	NA	2.6 average/beads
3.	Naik et al. [25]	HDPE	HDPE waste	Shredding	Small particles
4.	Sabaa and Ravindrarajah [26]	EPS	Waste EPS	Crushing	≤3.7/angular
5.	Babu and Babu [27]	EPS	Virgin	NA	Type A: ≤.3 mostly/beads, Type B: 4.75 mostly/beads
6.	Chen and Liu [28]	EPS	Virgin	NA	Type A: 3 mostly/beads, Type B: 8 mostly/beads
7.	Elzafraney et al. [29]	Mix plastic of HDPE, PVC and PP	Waste HDPE, PVE and PP	Grinding	≤10/irregular shape
8.	Choi et al. [30]	PET	PET bottles	Melted PET mix with GBFS	Round and smooth
9.	Babu et al. [31]	EPS	Virgin	NA	Type A: ≤.3 mostly/beads, Type B: 4.75 mostly/beads
10.	Haghi et al. [32]	EPS	Virgin	NA	Type A: 8/beads, Type B: 6/beads
11.	Babu et al. [33]	EPS and UEPS	Virgin	NA	≤8/spherical
12.	Batayneh et al. [34]	Not mentioned	Waste plastic	Grinding to small sized particles	≤9.5/small particles

No	References	Type of plastic	Origin of plastic waste	Recycle/ treating procedure	Particle size (mm)/shape
13.	Ismail and AL-Hashmi [35]	Mix plastic of 80% PET and 20% PS	Plastic containers	Crushing	Irregular shape with length of 0.15–12mm
14.	Tang et al. [36]	EPS	Waste EPS	Thermal treatment	4 average/beads
15.	Choi et al. [37]	PET	PET bottles	Melted PET mix with river sand	64.74/smooth and rounded
16.	Kou et al. [38]	PVC	PVC pipes	Grinding	≤5/irregular shape
17.	Akçaözogˇ lu et al. [39]	PET	PET bottles	Shredding after washing	≤4/granular
18.	Lima et al. [40]	Ethylene vinyl acetate (EVA)	Waste EVA from footwear industry	Cutting	≤9.5/small particles
19.	Frigione [41]	PET	PET bottles	Grinding	≤2.36/small
20.	Rai et al. [42]	PP	Waste Plastic	-	3 mostly/beads
21.	Silva et al. [43]	PET	PET bottles	Pc and Pf: shredding; Pp: thermal treatment	Pc: ≤11.2; Pf, Pp: ≤4
22.	Herki et al.[44]	EPS	Waste EPS	Mixed cement with waste EPS	≤8 mm
23.	Akçaözogˇlu and Ulu [45]	PET washing	PET Bottoles	Crushing after washing	≤4/granules
24.	Islam et al. [10], [46]	PET	PET Bottles	Crushing	≤9.5/small particles

As we can see, there was significant research conducted on concrete with plastics but almost nothing as Polypropylene plastic aggregates. There are some studies related to PP used as fibers in concrete, but there is little information about how it performs as a form of chips or coarse aggregates. So, this research emphasis on evaluating the performance of concrete with PP aggregates as a partial replacement to the stones.

2.3 Material Properties of Plastics Used in Concrete

The Plastic aggregates as used in previous studies were coarse aggregates (CA) and fine aggregates (FA). It is no surprise that the bulk density of Plastic aggregate (PA) is much lower than that of typical natural aggregates; hence, PA is suitable for manufacturing lightweight concrete. The specific gravity of all types of PA is 0.9– 1.4, which is much lower than that of natural aggregates commonly used in concrete. Moreover, the bulk density of PA is much lower than its specific gravity due to the hollow sections between PA particles. The bulk density of PA differs based on the recycling method. Typically, the direct mechanical recycling method leads to a relatively low bulk density, whereas the melting process leads to a higher bulk density of PA, such as the case in waste expanded polystyrene (EPS). To avoid segregation in the concrete matrix, the EPS aggregates were coated with a hydrophilic chemical. The bulk density of recycled EPS aggregates prepared by this method ranges from 24 to 27 kg/m^3.

In comparison with natural aggregates, PAs generally have lower bulk density, lower water absorption, and higher ultimate tensile strength, but much lower melting points. Some of the studies suggested a new type of aggregates that could be obtained by mixing melted plastic with natural aggregates to realize better aggregate properties than that achieved by the normal recycling method. These types of Waste plastic light aggregate (WPLA) had smooth surfaces and rounded shape, with a bulk density of 844 kg/m^3 and 0% water absorption, and were used as fine aggregates in concrete. In contrast, PET aggregates manufactured by direct mechanical recycling had a bulk density of 200–500 kg/m^3, and 0.11–0.75% water absorption. The physical and mechanical properties of concrete containing WPLA were better than those of concrete containing directly recycled PET FA, as discussed in further detail in Section 2.4.

2.4 Fresh Properties of Concrete Containing Plastic Aggregates

2.4.1 Effect of PA on Slump Value

The slump of PA concrete is affected by several factors such as water-cement ratio (w/c), substitution level of plastic aggregates (R_{PA}), and the shape of the waste plastic. Figure. 2.1 shows the representative results obtained from the existing studies on the effect of RPA on the slump [30], [34]–[38].

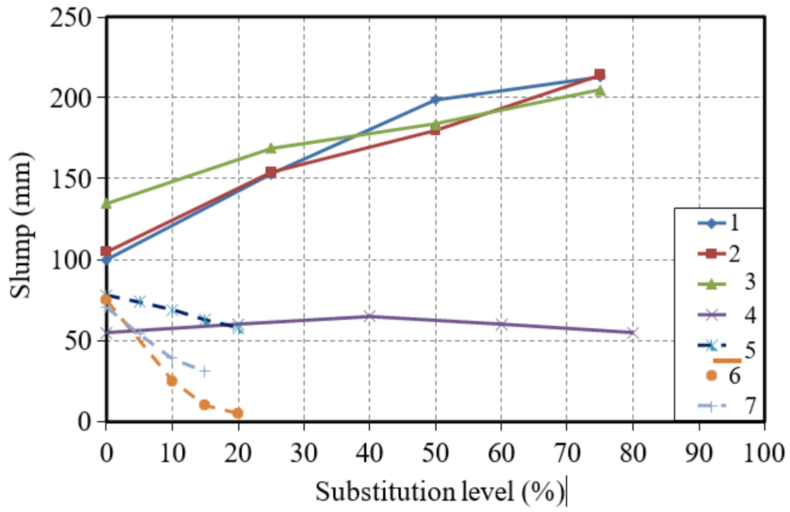


Figure 2. 1 **:** Variation of the slump of concrete with different substitution level of plastic aggregates

Note: (1), (2), (3): fine aggregates [30]; (4): coarse aggregates [36]; (5): fine aggregates [34]; (6): fine aggregates [35]; and (7): fine aggregates [47] [solid lines: uniformly shaped aggregates; dotted lines: non-uniformly shaped aggregates].

In some studies, the slump of fresh concrete was greatly influenced by the increase in R_{PA}, and the slump showed a tendency to decrease. This is attributed to the non-uniform shapes of PAs, which results in low fluidity. Ismail and Al-Hashmi [35] observed that the slump reduced up to 95% the value for natural aggregate concrete at 20% substitution of FA. However, in some circumstances, R_{PA} has no significant influence on the slump value [36], [38]. Tang et al. [36] reported that the slump value of fresh lightweight concrete containing 20–80% PS CA was generally similar to that of the corresponding normal weight concrete.

The authors attributed this to the fact the PS CA concrete had a closed cellular structure with negligible water absorption capacity. Moreover, Choi et al. [30], [37] reported an increase in the slump value of concrete with increasing substitution levels of two types of WPLA (FA). According to Choi et al. [30], this may be attributed to not only the spherical shape with a smooth surface but also the absorption capacity (almost zero) of WPLA. Additionally, the problem of segregation may occur when dealing with concrete components characterized by aggregates with different specific weights, especially light aggregates such as PA [27]. To prevent such segregation in the concrete mixes, PA treated with hydrophilic type chemical coating was widely used in the previous studies [23], [24], [32], [36], [48].

2.4.2 Unit Weight and Density

Figure 2.2 shows the results of the existing studies [26], [36], [40], [49] and geopolymer concrete [45] on the effect of RPA on the density; the subcategories of concrete containing plastic CA are also shown.

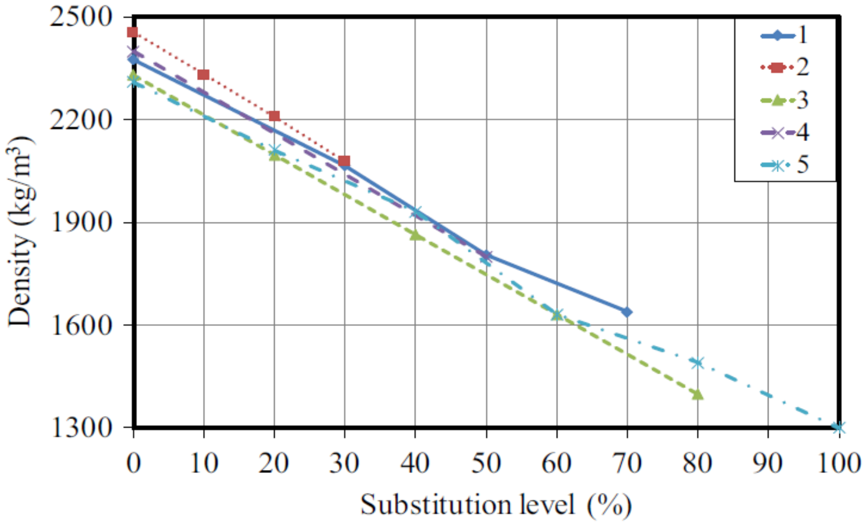


Figure 2. 2 : Variation of the density of concrete with different substitution level of plastic coarse aggregates

(1): [26]; (2): [49]; (3): [36]; (4): [40]; and (5): geopolymer concrete [45]

The figures show that the density of PA concrete decreases with increasing substitution. Sabaa and Ravindrarajah [26] reported that the increase in the substitution level of waste EPS CA caused almost a linear reduction in the unit weight of concrete. For 70% substitution level of waste EPS, the unit weight reduced by up to 31%.

Lima et al. [40] reported that at 50% substitution level of waste ethylene vinyl acetate (EVA) CA, the fresh wet, air-dried, oven-dried, and hardened densities of concrete all reduced by approximately 26% of the value for the conventional concrete. So, for all the cases it was determined that with increasing substitution level of plastic the density of concrete decreases.

2.5 Mechanical Properties of Concrete Containing Plastic Aggregates

2.5.1 Compressive Strength of Concrete

Many researcher worked on plastics in concrete [10], [28], [38], [43], [46], [48], [50]–[53] investigating the compressive strength. Silva et al. [43] investigated on concrete mixed with polyethylene terephthalate (PET) aggregate, where 0%, 7.5% and 15% of natural aggregates were replaced by PET aggregate. In this study, plastic was used both as fine and coarse aggregates. It had been observed that the compressive strength decreased with the increasing level of Plastic Aggregate (PA) content which reduced up to 42.1% than that of RC for a 7.5% replacement level of plastic coarse aggregates. This strength reduction was due to the low bonding strength between the PET aggregates and the cement paste as the PA has impermeable nature.

Figure 2.3 shows the results of some existing studies on the effect of plastic aggregates on compressive strength of concrete.

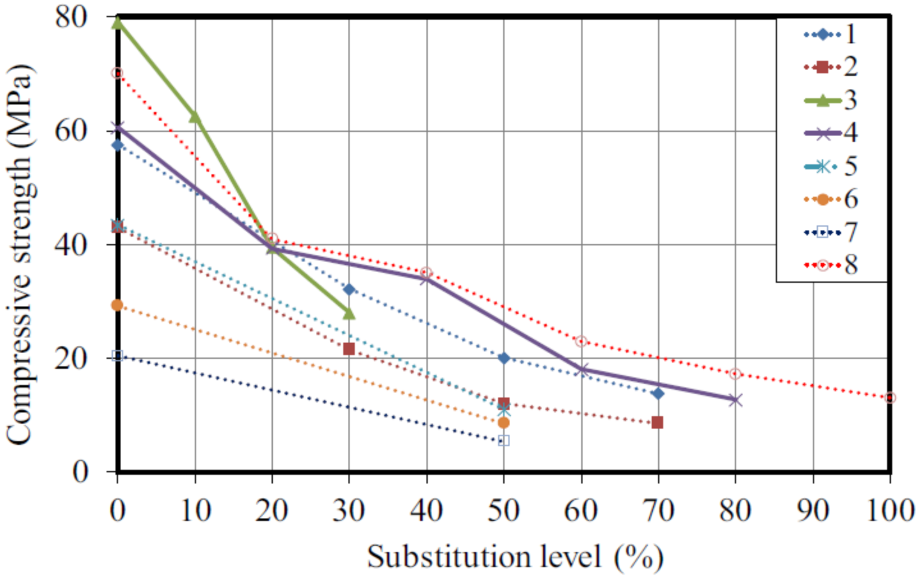


Figure 2. 3: Variation of 28-day compressive strength of concrete with substitution level of plastic coarse aggregates

Note: (1), (2): EPS [26]; (3): [49]; (4): EPS [36]; (5), (6), (7): EVA [40]; and (8): PET [45]; [solid lines: uniformly shaped aggregates; dotted lines: non-uniformly shaped aggregates].

Saikia et al. [54] investigated polyethylene terephthalate (PET) aggregate was replaced by 5%,10%, and 15% in the volume of natural aggregate. The compressive strength of concrete deteriorates due to the incorporation of PET aggregate and the deterioration of these properties intensifies with increasing content of this aggregate. The compressive strength decreased with an increasing amount of PET aggregate. Unlike natural aggregate, PET aggregate cannot interact with cement paste and therefore the interfacial transition zone (ITZ) in concrete containing PET aggregate is weaker than that in the reference concrete, which lowers the resulting compressive strength. The 28-day compressive strength of concrete containing 5% of fine PET aggregate was more than 75% of the compressive strength of reference concrete. Concrete mixed with fine PET with 10% and 15% were respectively 71% and 59%, and for concrete mixed with course PET with 5%, 10%, and 15% were respectively 73%, 52%, and 35% of the compressive strength of reference concrete. This is due to the differences in the shape of these two types of PET aggregate.

Naik et al. [25] studied the use of post-consumer waste HDPE plastic in concrete as a soft filler. In this study, a high-density plastic was shredded into small particles for using it in concrete. These particles were subjected to chemical treatments like water, bleach, bleach + NaOH to improve their bonding with the cementitious matrix. The concrete mixed with plastic particles in the range of 0-5% of the total mixture by weight. The effect of soft plastic as "aggregates" on all concrete mixed with 4.5% of HDPE showed lower compressive strength than the reference mixture without plastic. This was attributed to the lower compressive strength of the plastic particles compared to the natural fine and coarse aggregates.

Babu et al. [27] investigated on expanded polystyrene (EPS) beads as lightweight aggregate with silica fume in concretes. The concrete was mixed with EPS with varying percentages of silica at 3%, 5%, and 9% respectively. The compressive strength of concrete was observed at 7days, 28days, and 90days. It is observed that the compressive strength of concrete decreased at age increased and increased with the amount of silica fume. The compressive strength of concrete mixed with 3% silica fume at 7days was almost 75% of its 28-day strength and silica fume with 5% and 9% were almost 85% and 95% of its 28-day strength respectively. There was no significant change in strength at 28 days and 90days. The strength of concrete mixed with EPS increased with the amount of silica fume.

Saikia et al. [54] researched the strength behavior of concrete containing three types of recycled polyethylene terephthalate (PET) aggregate. The concrete mixed with three different sizes and shapes of recycled PET aggregate to understand how its size and shape influence the strength of the concrete compared to the conventional concrete. The coarse flakes (PC), the fine fraction (PF), and the plastic pellets were used with the concrete. The researcher observed the effect on flexural strength, splitting tensile strength and compressive strength, and the relationships between compressive strength and other strength. The ratio between the tensile and compressive strength gave information on the toughness behavior of concrete specimens. The concrete with high values of ratio showed higher toughness. The tensile/compressive strength and flexural/compressive strength ratios. The ratios of tensile and compressive strengths of concrete with PET aggregate showed higher than the conventional concrete and observed that the value of the ratio increased with an increasing amount of PET. For a particular amount of PET aggregate, it was observed that the large-flake PET-aggregates showed more toughness behavior than the other two fractions. It showed that the concrete mixed with PET which is coarser and flakier than the other two PET-aggregates represent more toughness and the results suggested that the toughness of the concrete mixed PET dependent on the size and shape of the PET-aggregate.

Ferreira et al. [55] studied the mechanical performance of concrete mixed with plastic aggregate. The concrete mixes were prepared with three types of plastic aggregates with 0%, 7.5%, and 15%. Three types of plastic aggregate were used as Pc and Pf, the former bigger than the latter but both lamellar and irregular, and Plastic pallets consisting of a regular cylindrical granulate. It observed that the concrete with an increased percentage of plastic and its size led to a fall in compressive strength. The compressive strength of concrete was observed at 7, 28, and 56 days respectively for all mixes and curing conditions. The results showed that the compression strength of concrete decreased with an increasing amount of plastic aggregate. Plastic waste aggregate is rough and has little affinity with water they repel it, thus limiting the cement hydration in the plastic waste aggregate/cementitious matrix interface and conditioning this bond.

Islam et al. [10], [46] worked with waste PET in concrete and concluded that high strength concrete is achievable with the PCA (PET coarse Aggregate), especially for concrete with low w/c ratio and a small amount of PCA replacement. With 20% PCA replaced concrete at w/c ratio of 0.42, 30.3 MPa compressive strength was achieved. Since PAC (PET Aggregate Concrete) has high workability incorporating a low w/c ratio in concrete mix design is not a big issue, and thus, PAC can be adopted for structural concrete with confidence.

Also, Saikia and de Brito [54] confirmed that different shape and size distribution of waste PET aggregates resulted in different compressive strengths of concrete with the same substitution levels of PAs. It was also reported that the compressive strength of concrete with 100% polyurethane (PUR) foam CA. PUR foam CA used in some of the concrete samples were immersed in water for 24 h before mixing. Reductions of 78% and 57% were observed in the compressive strength with and without the immersing procedure, respectively.

2.5.2 Stress-Strain of Concrete

Babu et al. [31] investigated the mechanical properties of expanded polystyrene (EPS) concretes containing fly ash compared to conventional concrete. Expanded polystyrene is a stable low-density foam to produce lightweight concrete. Concrete with partial replacement of EPS of the total aggregate was ranging from 0 to 90%. It was seen that when the concrete mixed with a high percentage of EPS, the stress-strain curve was lower. It was also observed that concrete failed at lower values of strain with increasing the values of strength. It was also observed that with the decreasing amount of EPS in concrete the length of propagation of cracks increases.

Frigione [41] investigated on recycled PET bottles as a fine aggregate in concrete. Concrete mixed with PET aggregate of 5% by weight of natural fine aggregate with a w/c ratio of 0.45. It was observed that the reference concrete and concrete mixed with PET plastic showed very similar compressive strength curves. The maximum strain of reference concrete was 0.0018 where the maximum strains of concrete mixed with PET were 0.0020 for WPET/concrete at 70 MPa compressive stress. It indicated that the concrete mixed with PET is more ductile than the reference concrete. When PET is used as a partial replacement of fine aggregate in a reference concrete, it increases the ductility and toughness of the concrete.

2.5.3 Split Tensile Strength

Ferreira et al. [55] studied the mechanical performance of concrete mixed with plastic aggregate. The research was investigated on the concrete which is mixed with waste plastic aggregate. Plastic wastes were replaced with 0%, 7.5% and 15% of natural aggregate. Three types of plastic waste were used depending on the size as Pc and Pf, the former bigger than the latter but both lamellar and irregular, and Plastic pallets consisting of a regular cylindrical granulate. The results showed that split tensile strength is low in Pc and high in Pf and Pp. With an increasing amount of plastic, the tensile strength of concrete decreased. The tensile strength of concrete mixed with 7.5% plastic was higher than 15% plastic aggregate compared to conventional concrete.

Saikia et al. [54] investigated the strength behavior of concrete which is mixed with three types of recycled polyethylene terephthalate (PET) aggregate. The concrete mixed with three different sizes and shapes recycled PET aggregate to understand how its size and shape influence the strength of the concrete compared to the conventional concrete. The coarse flakes (PC), the fine fraction (PF), and the plastic pellets were used with the concrete.

PET plastic was mixed in concrete with 5%, 10%, and 15% of total natural aggregate by volumes of each type of PET aggregate. From the test, the reference concrete and 5%, 10%, and 15% PP mixture concrete were separated into two pieces and 5% PF concrete showed large crack after the tensile test. But all mixture of PC concrete and 10% and 15% PF concrete was able to prevent them from separating into two pieces. Thus, concrete mixed with PET aggregate can carry additional loading after the crack. Concrete mixed with flaky PET aggregates is better to transfer loading than concrete mixed with pellet PET aggregate. From that observed concrete pellets, the matrix is too short to transfer the applied load whereas flaky are longer and better to transfer the applied load.

Lima et al. [40] studied two types of recycled aggregate. One type of waste was ethylene vinyl acetate (EVA) from cutting off the EVA expanded sheets used to produce insoles in the footwear industry and another is constructed and demolition waste (CDW). Concrete mixed with the recycled aggregate with three w/c ratios: 0.49, 0.63, and 0.83. Tests were conducted on fifteen mixtures which are produced from substituting different rates of aggregate as 0%, 50% EVA, 50% CDW, 25% CDW–25% EVA, and 50% CDW–50% EVA by volume. From the results observed that the tensile strength of concrete was decreased with an increasing amount of concrete. For 50% CDW concrete, the ratio of the flexural and the splitting strengths for the compressive strength is in the range of 11.6–17.6% and 8.9–11.4%, respectively. The tensile strength was higher for the concrete which was mixed with EVA aggregate than natural or CDW mixed concrete. From the test values, concrete mixed with EVA aggregates showed ductile behavior where natural aggregate and CDW mixed concrete showed brittle behavior.

Irwan et al. [56] investigated the relationship between splitting tensile strength and flexural strength with the compressive strength of concrete mixed with waste PET as fine aggregates replacement. Concrete mixed with plastic PET by 25%, 50%, and 75% in volume of natural aggregate. Tests were conducted at the age of 28days. The tensile strength of concrete decreased with an increasing amount of plastic PET. The tensile strength of conventional concrete was 3.52MPa and the tensile strength of 25% PET mixed concrete reduced 15% in strength compared to conventional concrete. The other two combinations of PET also reduced the strength and it was 50% PET mixed concrete reduced 32% in strength and 75% mixed concrete reduced 42% in strength.

2.5.4 Flexural Strength

Saikia et al. [54] investigated the strength behavior of concrete which is mixed with three types of recycled polyethylene terephthalate (PET) aggregate. The concrete mixed with three different sizes and shapes recycled PET aggregate to understand how its size and shape influence the strength of the concrete compared to the conventional concrete. The coarse flakes, the fine fraction, and the plastic pellets were used with the concrete. PET plastic was mixed in concrete with 5%, 10%, and 15% of total natural aggregate by volumes of each type of PET aggregate. The research was investigated the percentage of reduction of compressive strength was also compared with the percentage reductions of flexural strength with respect to the reference concrete. The reduction in compressive strength of PET concrete was greater observed in the flexural strength. The difference of reduction in strength is more in coarse and flaky PET mixed concrete than the other two PET aggregates. Concrete mixed with plastic pellets showed less strength reduction. From the results observed the flexural strength of PET mixed concrete is dependent on the size and shape of the PET aggregate.

Irwan et al. [56] investigated the relationship between splitting tensile strength and flexural strength with the compressive strength of concrete mixed with waste PET as fine aggregates replacement. Concrete mixed with plastic PET by 25%, 50%, and 75% in volume of natural aggregate. The flexural strength of conventional concrete was 4.99MPa and the percentage reduction of flexural strength of concrete containing 25%, 50%, and 75% PET was 5%, 24%, and 48% respectively.

2.6 Durability of Concrete

Concrete is a composite material where the main components are aggregate and cement paste. The properties of the concrete can be controlled by varying the grading of the aggregates, the composition of the cement paste, and the casting and curing procedure.
A common design parameter is the compressive strength Requirements on strength are usually fulfilled by specifying an appropriate w/c-ratio. However, high strength is not the same as high durability.

2.6.1 Shrinkage

Drying shrinkage is another important property of concrete containing Plastic Aggregates. In most of the studies, concrete containing waste plastic as a substitution of natural aggregates has higher drying shrinkage than conventional concrete. This is because of the low stiffness of the plastic aggregates as a result of which, it provides very low resistance to the shrinkage of cement paste.
Sabaa and Ravindrarajah [26] also reported that the drying shrinkage of concrete containing crushed EPS waste CA increased as the substitution level increased; 40% of the increase was observed for a substitution level of 70% at 240 days. Chen and Liu [28] reported the drying shrinkage of concrete containing 0, 25%, 40%, and 55% EPS CA and FA. At 90 days, for the EPS concrete with a 55% substitution level, the drying shrinkage was almost twice that of conventional concrete.

However, Silva et al. [43] reported that the drying shrinkage of concrete containing waste PET CA and FA was lower than that of the conventional concrete; this observation was attributed to the fact that the amount of water absorbed by the aggregates was less because of the impervious nature of the plastic aggregates; as a result, more free water was available to hydrate the cement, leading to lower shrinkage values. The tendency of drying shrinkage to decrease when the substitution level of PVC FA in specific lightweight expanded clay aggregate concrete was increased was also investigated by Kou et al [38]. .According to the authors, PVC granules can be assumed to be impervious, and they did not absorb water. Therefore, the PVC granules did not shrink; hence, the overall shrinkage of concrete was reduced.

2.6.2 Chloride Ion Penetration

Silva et al. [43] studied the durability in terms of chloride penetration. Concrete mixed with plastic waste aggregate polyethylene terephthalate (PET) with 0%, 7.5%, 15%. It was observed that the chloride permeability of concrete mixed with plastic PET was higher than the conventional concrete. The chloride migration coefficients were higher for coarse plastic PET than the conventional concrete but lower carbonation depths in concrete containing only fine PET aggregates compared with conventional concrete and concrete with coarse plastic PET aggregates. The total charges passed in coulomb were reduced by 11.9%, 19.0% for concrete mixed with PET plastic with 7.5%, 15% than conventional concrete.

Fraj et al. [57] investigated on mechanical properties and the durability of rigid polyurethane (PUR) foam waste as coarse aggregates. Two types of concrete were made: lightweight aggregate concretes (LWAC) using lightweight aggregate and normal weight concrete (NWC) using normal aggregate. The value of the effective chloride coefficient for NWC was 1.87x10-12m^2/s and for LWAC was 1.62x10-12m^2/s. The chloride diffusion coefficient of LWAC decreased by 13% of NWC. From the result, NWC and LWAC showed relatively close values of the chloride diffusion coefficient. For the same W/C ratios, lightweight concrete and normal weight concrete showed similar values of chloride penetration rate.

2.6.3 High Temperature Exposure

The temperature of fire for the building around 800°C-1000°C and for that some researchers conducted the temperature test on plastic concrete. Serrano investigated on the decrease in concrete resistance and the expansion generated in reinforced concrete structures by direct exposure to fire at 400°C maximum temperature [58]. Compression tests of concrete at room temperature were conducted in the specimens without PP and with different percentages of PP. Concrete mixed with Polypropylene fiber with 1% and 2% showed a better behavior. Specimens tested with highest temperatures within the first 45 min of the fire started, reaching peaks of 413°C in concretes mixed with metallic fiber, 337°C, and 380°C in specimens without and with mixed with polypropylene fibers respectively. The concrete mixed with metallic fiber had suffered the fire action more intensely than the concrete mixed without or with polypropylene fibers. These researchers found that concrete subjected to high temperatures, the addition of steel fibers increased concrete porosity but to a lesser extent than in the case of the addition of polypropylene fibers, reducing the pressure in the pores in the deeper concrete areas. Concrete mixed with polypropylene fibers, when the melting point was reached (170°C), it released pore pressure, but gradually reducing the temperature, decreased the cracks in the cooling phase. Concrete mixed with polypropylene fibers reached lower temperatures due to increasing the porosity. In the fire test, concrete mixed with Polypropylene fiber with 1% has a better performance than the concrete mixed with 2%. The concrete mixed with Polypropylene 1% fibers in concrete increased the temperature more rapidly than in any of the other cases.

Albano worked on polyethylene terephthalate (PET). Concrete mixed with polyethylene terephthalate (PET) with varying the water/cement ratio (0.50 and 0.60) and PET content (10 and 20 vol%) and different PET particle sizes at different temperatures (200, 400, 600°C) [57]. The morphological changes obtained were similar for concrete mixed with 10% and 20% of PET. At 200°C, there were no significant changes on the surface of the concrete. At high temperature 400°C, there was a significant change of color of the surface from gray to brown. At temperature 600°C, the difference between the values of thermal dilation of the concrete and of the PET 8.5×10-6 m/m °C and 7.0×10-6 m/m °C, respectively which indicate that concrete dilates a broader ratio than PET.

2.7 Summary

Different types of plastic were used in concrete which influenced the physical and durability properties of the concrete. Based on the above-mentioned literature review the output is summarized in this section.

Concrete with an increasing percentage of Plastic replacement has almost no effect on slump changes but the density decreases with the increment of the percentage of plastic replacement. With the increasing amount of plastic in concrete, the compressive and tensile strength of plastic mixed concrete decreased.

From the stress vs. strain plots, it was found that plastic concrete has better ductility and toughness than conventional concrete. The reduction of the flexure strength of plastic concrete was considered high.

Under the effect of higher temperature, the compressive strength of plastic concrete decreased. The shrinkage of plastic concrete is higher than conventional concrete. Chloride ion penetration of plastic concrete is almost similar to the regular concrete.

CHAPTER 3 EXPERIMENTAL PROCEDURE

3.1 General

The present study approaches the initial preparation for investigating the properties of polypropylene (PP) concrete. To investigate the applicability of the concrete, it was tested thoroughly in terms of fresh, hardened, and durability properties. To achieve good quality concrete, it is necessary to adopt quality ingredients. Therefore, materials for concrete, such as cement, crushed stone, sand, admixture, and PP were collected from the best possible local sources. Furthermore, all the materials were extensively tested according to the respective ASTM standards. Based on the properties of the material, concrete mix proportions were prepared and concrete samples were prepared for testing. This chapter elaborates on study planning, materials properties, mix designs, sample preparation, and casting procedures.

3.2 Study Plan

The study plan for completing the present work is illustrated in Figure 3.1. According to the study plan, after completing the background study and test method selection, the acquisition of materials (PP, cement, stones, and sand) was done. After that testing of materials was done and different properties of PP, cement, stone, and sand were calculated and analyzed for the next phase of the study. The next step was the concrete mix design and trial test of concrete. The casting of concrete samples (cylinder, beam) was done according to the ASTM specifications. During the casting process slump tests were performed on fresh concrete.

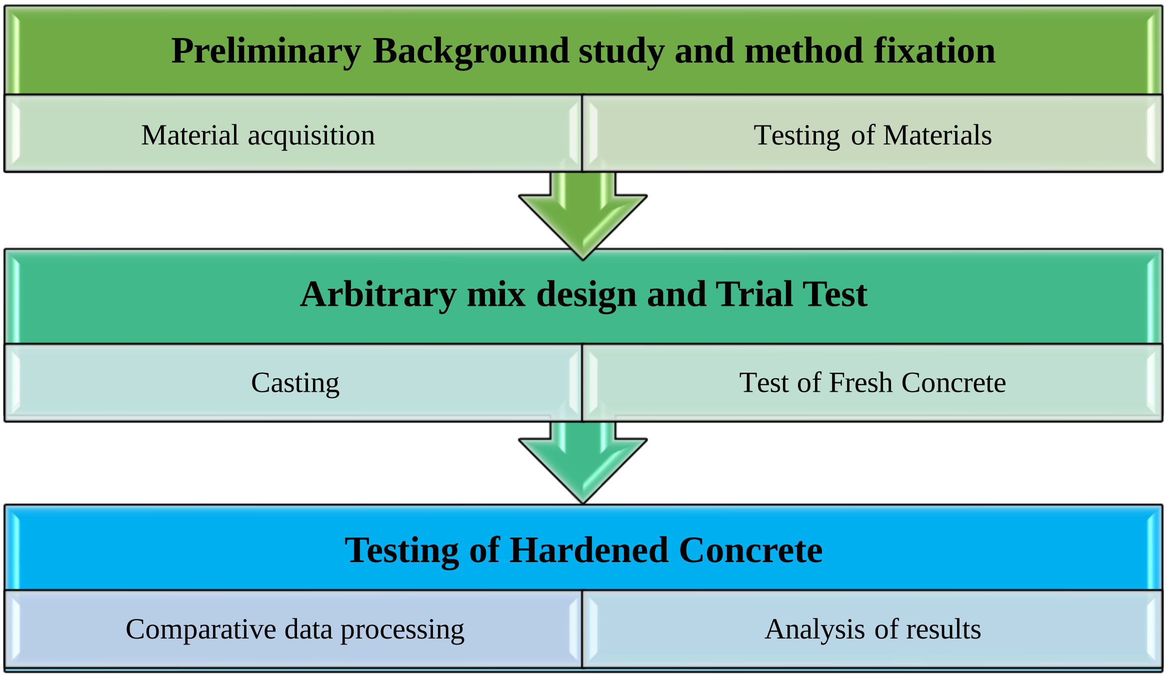


Figure 3. 1: Process diagram of the research work

Concrete cylinders and beams were prepared for several tests. To determine the physical and mechanical properties of the concrete number of tests were performed, such as density, compressive strength, tensile strength, flexural strength, Young's modulus, stress-strain behavior, pull out strength of concrete. To determine the durability performance of concrete few tests were also conducted, such as shrinkage test, chloride ion penetration test by surface resistivity meter, and compressive strength at elevated temperature. After performing all the tests, the results were interpreted and co-related to the standards; and finally presented in a graphical or tabular form. Table 3.1 shows the performed tests on samples.

Table 3. 1: Performed test on the sample with standards and duration

SL	Name of Test	Code/ Standard	Test conducted on (Days)
1	Slump Test	ASTM C143 [59]	0
2	Compressive Strength of concrete	ASTM C39 [58]	7, 28, 90
3	Tensile strength test of concrete	ASTM C496 [59]	28, 90
4	Flexural strength of concrete	ASTM C78 [60]	28
5	Pull out Strength	ASTM C900 [63]	28
6	Shrinkage test of concrete	ASTM C157 [62]	7, 35
7	Determination of Elastic Moduli by digital compressometer	ASTM C469 [63]	28
8	Chloride Penetration test by Surface resistivity tester	AASHTO TP 95 [66]	28
9	Effect of High temperature on compressive strength	ASTM C39 [58]	28

3.3 Material Preparation and Properties

Ordinary Portland cement (OPC) has been used as binding material for the present study. Sylhet sand has been collected and used as fine aggregates. For the experimental work, stone chips and recycled wastes polypropylene were used as coarse aggregates. Stone chips were purchased from the local market according to desired quantities. Shredded polypropylene (PP) was used as a partial replacement of coarse aggregate. Polypropylene was prepared through a process of scraping, then collection and washing. After that, it had been melted and cooled into a certain shape. Those cooled plastic molds were shredded into specific sizes. Figure 3.2 and 3.3 represents the process of preparing polypropylene aggregates.

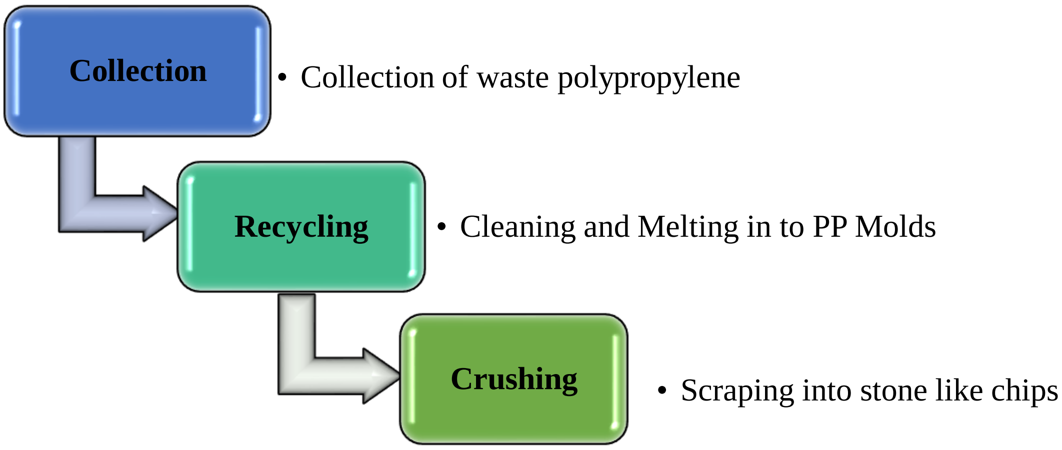


Figure 3. 2: Processing the Polypropylene

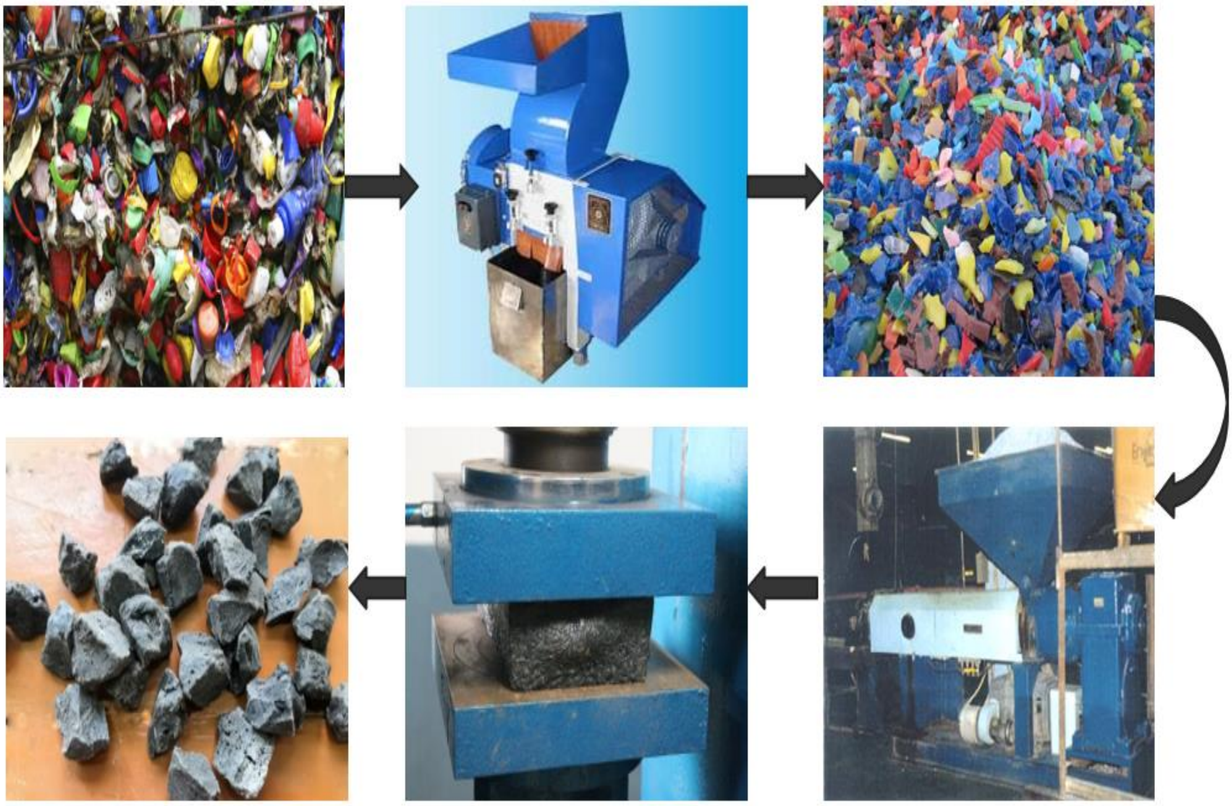


Figure 3. 3: Preparation of Polypropylene Aggregates

Figure 3. 4: PP aggregates

Figure 3. 5: Stone aggregates

Figure 3. 6: Fine Aggregates

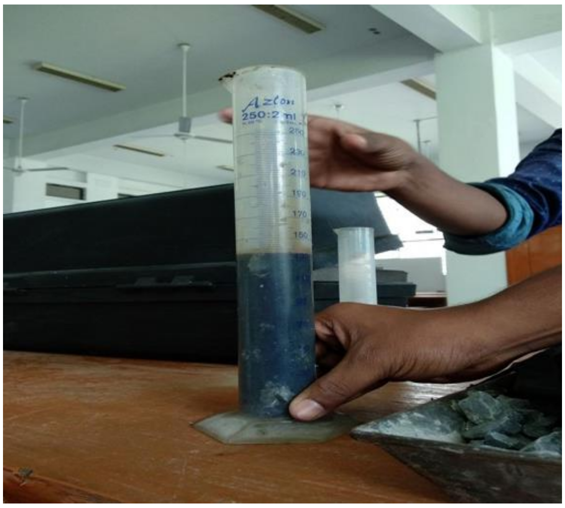


Figure 3. 7: Admixture

The Materials properties have been determined by performing specific tests in the laboratory according to the ASTM standards. Properties of the aggregates are summarized in Table 3.2 and the properties of cement are summarized in Table 3.3. According to the ASTM C33 [65], the gradation of the coarse aggregates was performed. Figure 3.8 and 3.9 represents the gradation of Coarse and Fine Aggregates. All the coarse and fine aggregates were in saturated surface dry (SSD) condition.

Table 3. 2: Properties of fine and coarse aggregates

Description	**Sand**	**Stone Chips**	**Polypropylene**
Maximum Size (mm)	4.75	19	12
Specific gravity	2.58	2.59	0.81
Apparent Specific Gravity	2.70	2.61	0.82
Water Absorption Capacity (%)	2.80	0.36	0.30
Fineness Modulus (F.M.)	2.46	8.12	6.77
Unit Weight (loose) (kg/m^3)	1516	1423	573
Unit Weight (Compacted) (kg/m^3)	1604	1560	622
Aggregate impact Value (AIV)	-	22	4
Aggregate crushing Value (ACV)	-	20	1

Table 3. 3: Properties of cement

Description	**OPC Cement**
Consistency (%)	27.9
Initial Setting Time (min)	84
Final Setting Time (min)	168.8
Specific Gravity	3.15
Fineness value (m^2/kg)	304
Strength at 28 days (MPa)	54

From the properties of coarse aggregate, we can see that the maximum size of stone used was 19mm with a specific gravity of 2.59 whereas the polypropylene aggregate had a maximum size of 12mm with a specific gravity of 0.81.

The unit weight of PP is almost one-third of the stone that clearly shows that PP is way much lighter than the stone that helps to produce concrete with less density property. The water absorption capacity of both of the coarse aggregate is similar. The ACV and AIV values of PP aggregates are very low compared to natural stone aggregates.

Master Rheobuild-1100 admixture was used for mix design. It is a high range water reducer admixture. The surface of cement grain absorbs the negative charge of the admixture. Electrostatic repulsion occurs to mix the concrete mix flowable. MasterRheobuild-1100 is used to increase workability and compressive strength. MasterRheobuild-1100 enables water reductions to produce a dense concrete mixture with reduced water penetration. The admixture used is Naphthalene Sulphonate Based and with dark brown appearance. The specific gravity of the admixture was 1.210 at 25°C having a pH value between 5 to 7. It satisfies the standard of EN 934-2 ASTM C-494 Types A and F BS 5075 Part 1 and 3 (superseded by EN 934-2).

The water used for the research has an ideal PH level of 6 to 7 which was free from alkalis, acids, oils, salt, sugar, organic materials. The temperature of 25°C was monitored during the application of water. In Figures 3.8 and 3.9 its represented that, both of the coarse and fine aggregates are in between the ASTM upper and lower limits. Figure 3.8 represents that, the gradation of coarse aggregate at 10% and 20% replacement of stone by PP is also within the upper and lower limits of ASTM.

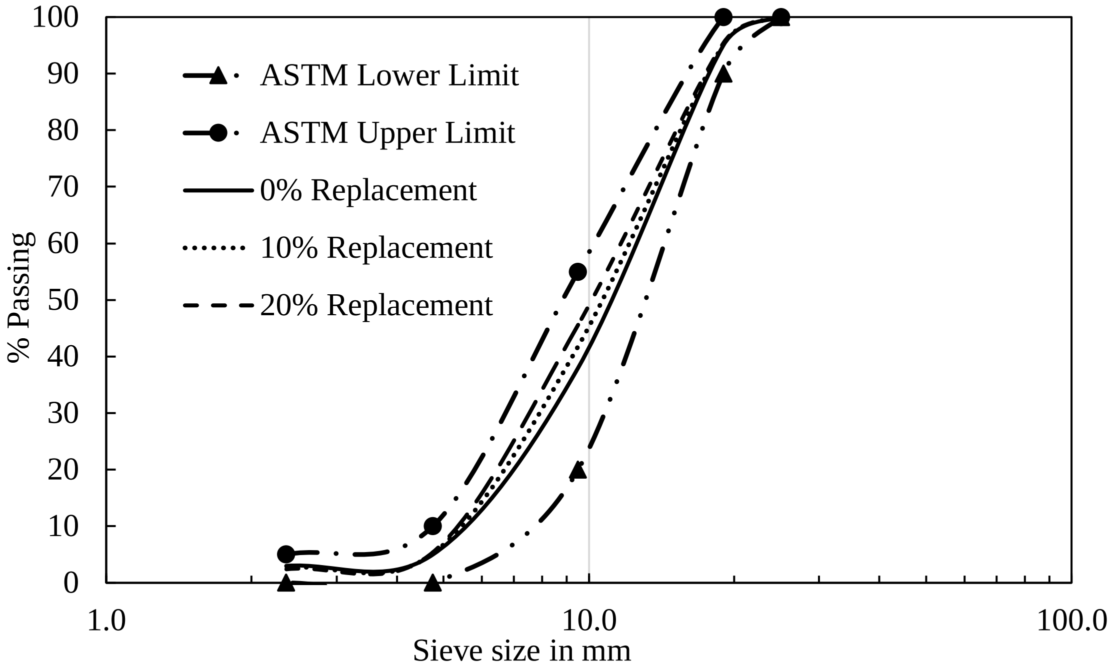


Figure 3. 8**:** Gradation of Coarse aggregate

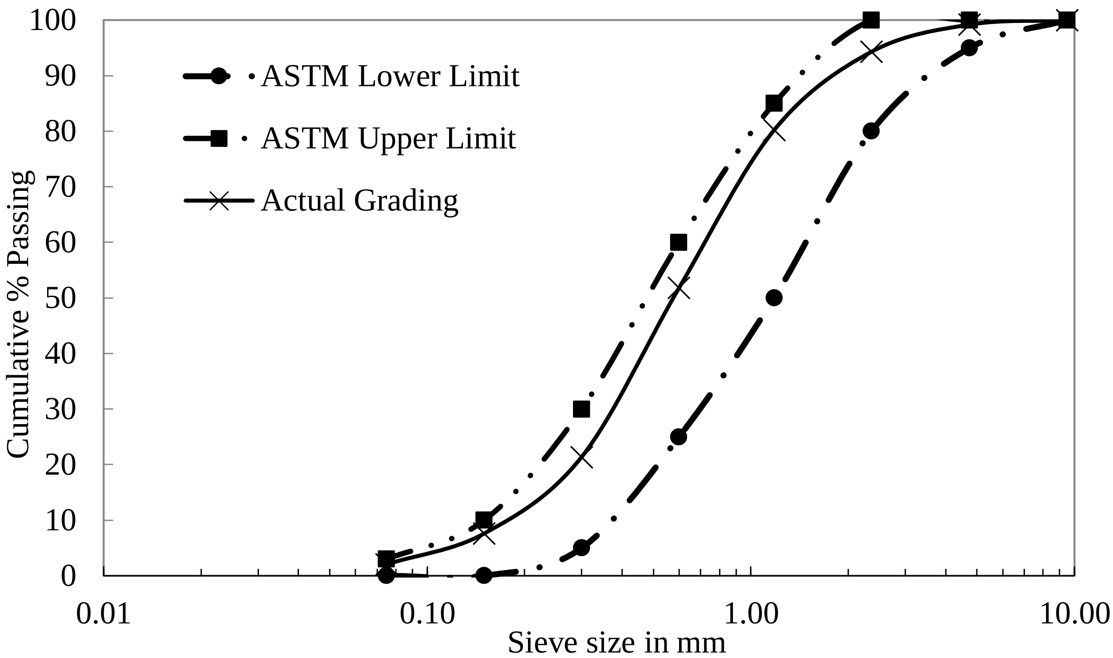


Figure 3. 9: Gradation of Fine aggregates

3.4 Mix Design

Concrete mix design is a process for deciding the proportion of the ingredients of the concrete mixture. For designing a concrete mixture, the desired strength, durability, and workability of the concrete were considered. Workability is measured in terms of slump flow. The coarse aggregate size is also an important parameter. Increasing the maximum aggregate size makes the mix design economical by reducing the amount of cement in the concrete mix volume while keeping the same workability. Air content in the concrete mixture is another significant parameter. The durability of concrete increasing with the increasing amount of air content as the air content gives the space for water expanding when it freezes. Concrete strength and water-cement ratio are the most important consideration for the mix design. It governs the strength, durability, and workability of the concrete mixture. Finesse modulus, unit weight, and water absorption capacity of coarse and fine aggregates are also playing a key role in the mix design [68]. The amount of water in concrete mix design depends on the admixture type and admixture amount. Therefore, the admixture selection for mix design helps to keep the fixed water-cement ratio without compromising strength and durability.

In the present study, mix design for the concrete specimens was proposed considering crushed stone with three different partial replacement of PP (0%, 10%, and 20%) along with four different water-cement ratios (0.35, 0.40, 0.45 and 0.50). The admixture was only used for two w/c ratios, such as 0.35 and 0.40. Table 5 shows the mix design proportion for 1 cum of concrete.

Table 3. 4: Mix design for 1 m^3 of concrete

Designation	**W/C Ratio**	**PP %**	**Water (kg)**	**Cement (kg)**	**CA (kg)**	**PP (kg)**	**FA (kg)**	**Admixture (ml)**	**Total**
WC35P0	0.35	0	206	589	977	0	487	1854	4112
WC40P0	0.40		206	514	975	0	552	1233	3480
WC45P0	0.45		205	456	972	0	605	0	2238
WC50P0	0.50		205	410	972	0	643	0	2230
WC35P10	0.35	10	206	589	879	39	474	1854	4041
WC40P10	0.40		206	514	877	39	539	1233	3409
WC45P10	0.45		205	456	875	39	592	0	2161
WC50P10	0.50		205	410	875	39	630	0	2159
WC35P20	0.35	20	206	589	781	78	461	1854	3969
WC40P20	0.40		206	514	780	78	526	1233	3337
WC45P20	0.45		205	456	778	77	579	0	2096
WC50P20	0.50		205	410	778	77	617	0	2087

Note: WCXPY: WCX = % of water-cement ratio (0.35, 0.40, 0.45 and 0.50) and PY = % of PP replacement.

3.5 Sample Preparation

Sample preparation is the most important stage of research work. The accuracy of the result directly depends on the sample material processing. The measure of materials for the sample preparation was done carefully. Stone chips, sand, cement, and PP were measured separately for each mix design. The weight of the stone, sand, cement, and PP were taken by the digital weight measuring meter as shown in Figure 3.10 (a and b). To maintain the workability at lower w/c ratios, a superplasticizer admixture was used. The admixture measured by the volumetric meter as shown in Figure 3.7. The admixture was used when the mixing process done in the mixing machine. Figure 3.11 represents the sample preparation.

(a) (b)

Figure 3. 10: Weight measuring of stone chips and water with digital weight meter

(a) (b)

Figure 3. 11: Sample preparation

3.6 Casting and Sampling

Concrete materials mixing for the different water-cement ratio was very challenging. Using a concrete mixing machine, the materials for concrete mixers were mixed for 12 combinations of concrete, as illustrated in Fig 3.12(a). After mixing the fresh concrete was poured in a dry surface Figure 3.12(b). It was strictly preventing the additional water mixing or touch with fresh concrete. Within a very short time, the freshly mixed concrete was tested for slump value and recorded (Figure 3.13). Then the concrete was cast in a cylindrical shape and beam shape. An internal vibrator was used for better compaction of the concrete samples (Figure 3.14). In total, 312 cylinders (100 mm x 200 mm) samples and 36 beams (100 mm x 100 mm x 500 mm) samples were prepared and stored for testing.

(a) (b)

Figure 3. 12: Concrete mixed with concrete mixer machine

(a) (b)

Figure 3. 13: Slump test of fresh concrete and casting

(a) (b)

Figure 3. 14: Concrete casting process

3.7 Testing and Data Acquisition

3.7.1 Compressive Strength Test of Concrete

The compressive strength of hardened concrete is the most important parameter and representative of almost the overall quality of concrete. It mainly depends on the water-cement ratio of the mixture, curing process, and time after it is cast. It also depends on the size and shape of the specimen, batching, mixing procedures, sampling, mold fabrication, temperature, and moisture conditions during curing. After the preparation of the samples, they were stored in moist air for 24 hours and then removed from the molds and kept submerged. After hardening the specimen had been taken for testing at various stages such as7 days, 28 days, and 90 days. Cylinder and block specimens are tested in the compression testing machine up to failure loading. Vertical displacements and axial loads are recorded. The axial stress-strain curves are also plotted using these data. Determination of modulus of elasticity, the toughness of concrete and stress-strain behavior was calculated from the stress-strain curves. The test method complies with the ASTM C 39 [45].

(a) (b)

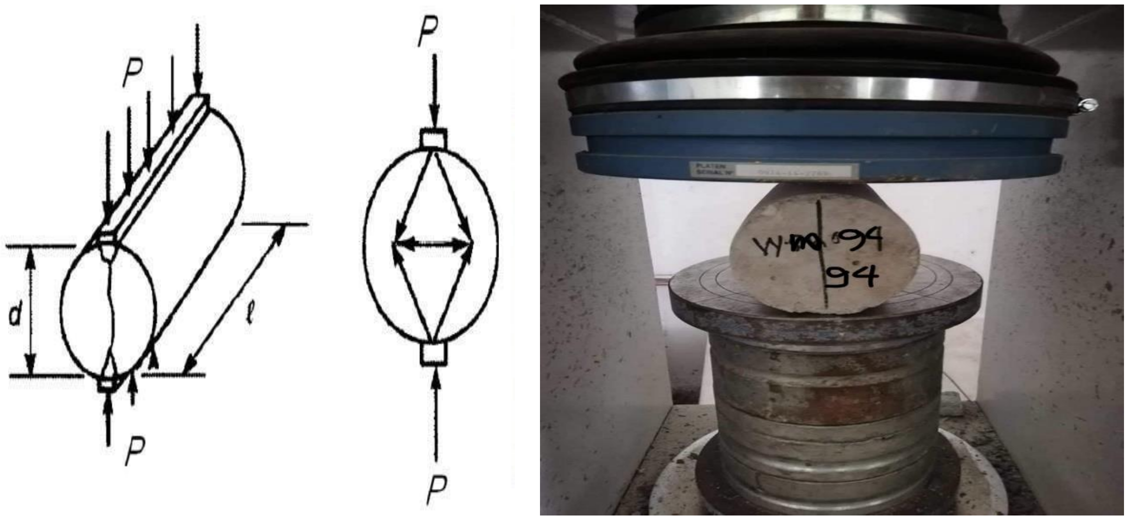
Figure 3. 15: Compressive strength test of concrete

3.7.2 Tensile Strength Test of Concrete

Tensile strength is very important for concrete structure because concrete structure is very vulnerable for tensile force as the cracking of concrete is occurs easily due to tensile force. However, concrete tensile strength capacity is very less than the compressive strength. As it is very difficult to determine the tensile strength directly, tensile strength is determined by two indirect methods. (1) Split Cylinder test and (2) Flexure Test**.** But these two methods give a higher value than the uniaxial tensile strength. Here both tests were done.

3.7.2.1. Split Cylinder Test

It is an indirect standard test for concrete tensile test. The test method complies with the ASTM C496 [61]. A standard sample (100mm x 200mm) was used horizontally between the loading sections of the compressive testing machine. Figure 3.16 represents the standard laboratory setup for split tensile test of concrete.

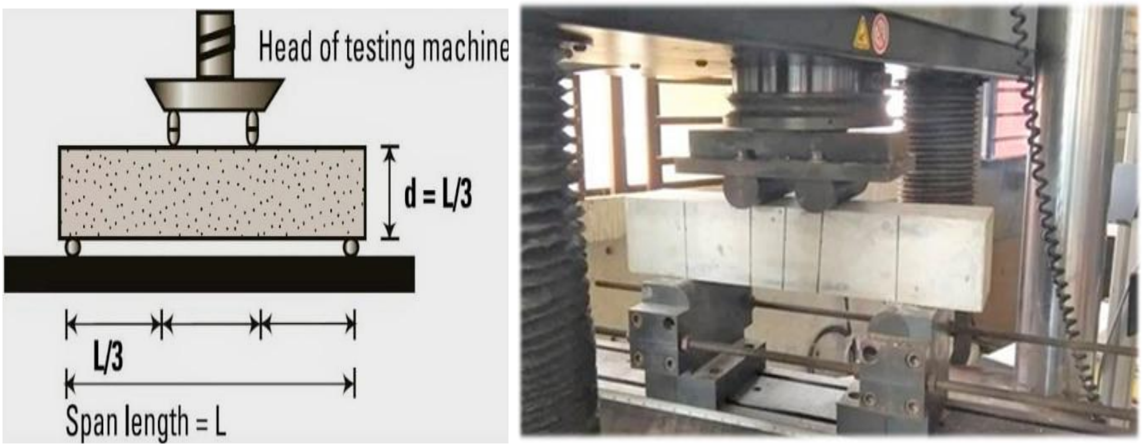


(a) (b)

Figure 3. 16: Tensile split test of concrete

3.7.2.2. Flexure Test

Another common test is the flexure test for tensile strength. In this test simple plain beam loaded at one third span plan. The test method complies with the ASTM C78 [47]. Here size of the beam was 150mm*150mm*500mm. The typical arrangement of the flexure test shown in the figure 3.17. Equal loads are applied from the same distance. The load on beam increase in such a way that the stress increase range was 0.01 MPa to 0.02 MPa. The loading condition shows the pure bending of the beam.

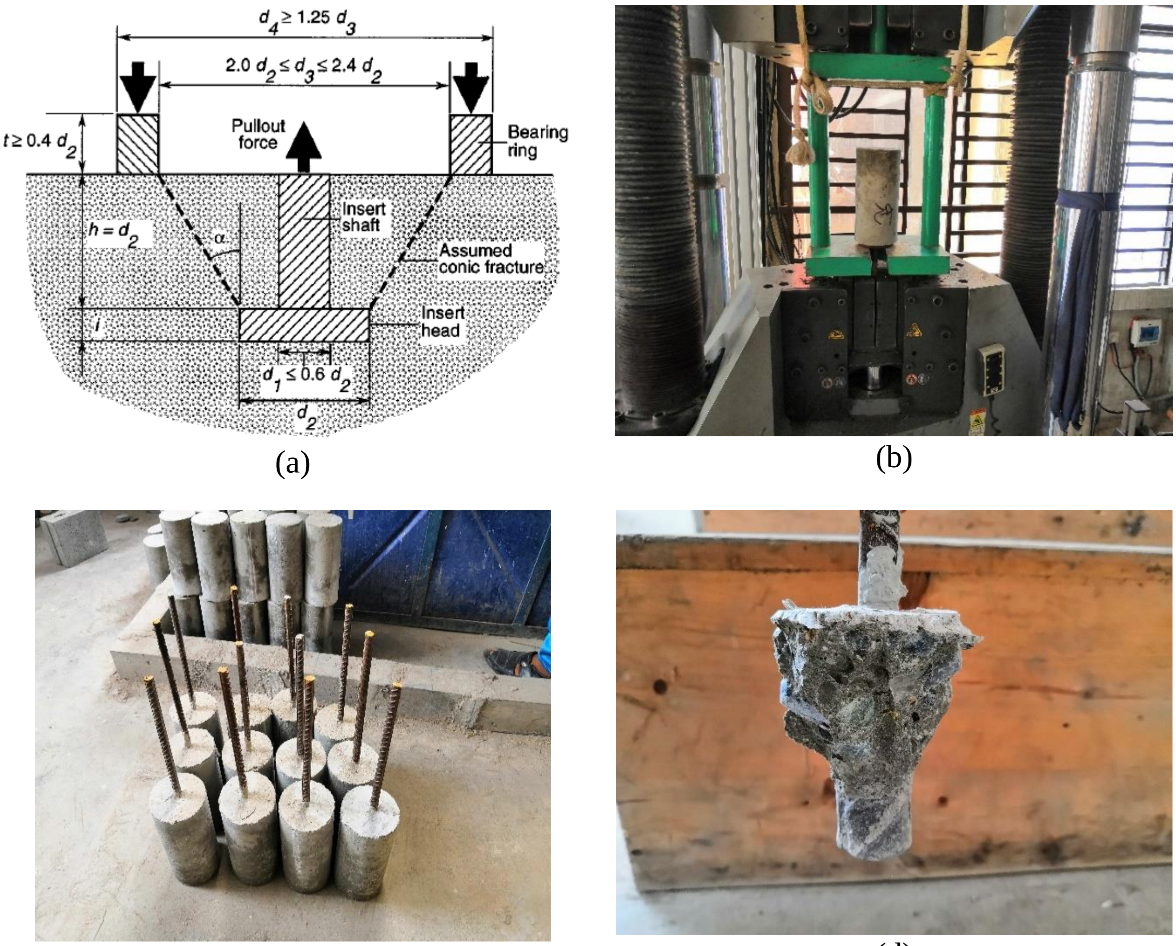


(a) (b)

Figure 3. 17: Flexure test of concrete

3.7.3 Pull Out Test of Concrete

The pullout test was performed to determine the pull-out strength of hardened concrete by measuring the force required to pull out an embedded metal inside and the attached concrete fragment from a concrete test specimen of structure. The insert was cast into fresh concrete and after 28 days it was pulled using a jack reacting against a bearing ring. The pullout strength is determined by measuring the maximum force required to pull the insert from the concrete mass. Figure 3.18 represents the test setup and samples of the pull-out test.



(a) (b)

(c) (d)

Figure 3. 18: Pull out test setup and samples

3.7.4 Shrinkage Test of Concrete

The shrinkage of concrete is a disadvantage of concrete design. As the concrete naturally shrieked after casting, the design shrink value is important for safe structural design. Here for the measuring shrinkage value of concrete 150mm*150mm*500mm beam samples were used. The lateral shrink value was taken. The procedure for this test was very easy. The beam length deference for 28days was measured with the digital shrinkage testing machine. After casting the sample beam was submerged 7 days in the lime water. Then the initial value was taken. After that, the sample beam was in the dry condition for 28days. Then the final value was taken. The difference in the length of the beam shows the lateral shrinkage. Beam setup was shown below in Figure 3.19.

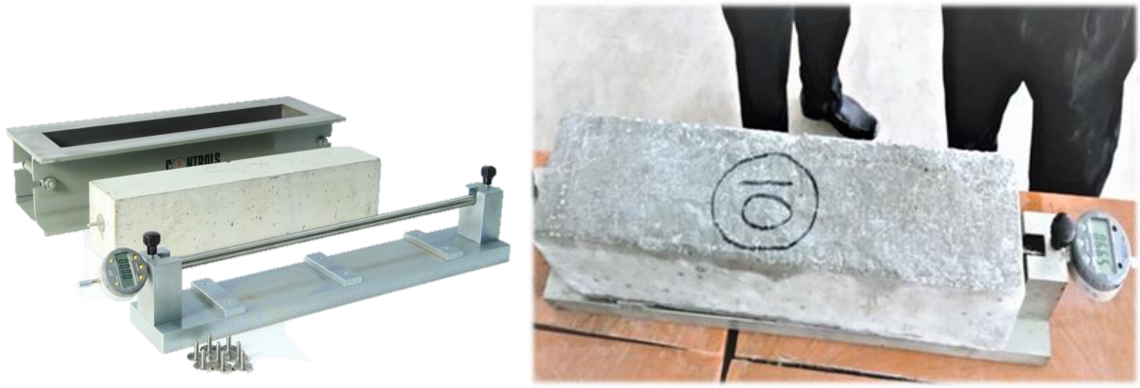


Figure 3. 19: Shrinkage test of Concrete beam

3.7.5 Chloride Penetration Test by Surface Resistivity Meter

Chloride penetration is very important as it indicates the durability of the concrete. It can be determined indirectly by the surface resistivity value. Here using the surface resistivity meter, the value of surface resistance was determined. Then the value was linked with the chloride ion penetration test with the help of the AASHTO TP95 [66] code. For this test concrete cylinder sample was used. The cylinder was cleaned up very carefully. Then the help of surface resistivity meter the value was taken in right-angle around the cylinder. Then the average value shows the value of resistivity of concrete surface. The setup of the testing machine was given in figure 3.20.

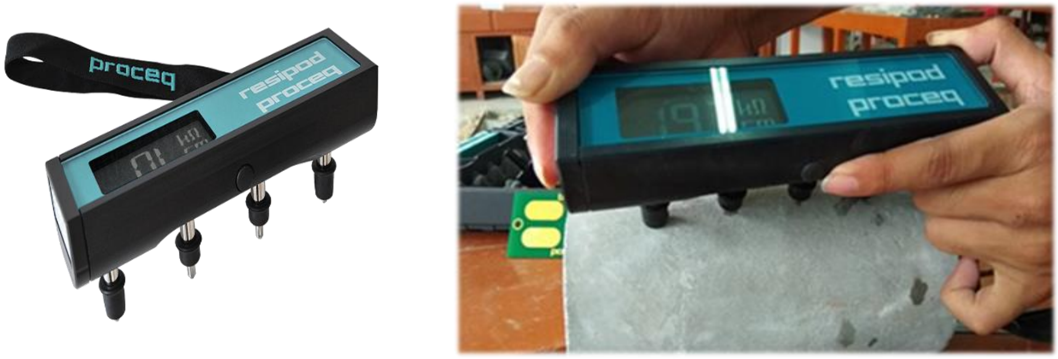


Figure 3. 20: Surface Resistivity Test of Concrete for Chloride ion penetration

3.7.6 Effect of Temperature on Compressive Strength Test

Concrete is good for fire. But as we used the Polypropylene in the concrete, we need to check the durability of such concrete at different weather conditions. As the temperature of the geographic condition is different so it was made artificial high-temperature conditions for determining the compressive strength change due to temperature increase. After 90days the concrete cylinder sample was burned with the help of an automatic burning machine at 100°C and 200°C. After burning in high temperature 15 minutes the sample was kept in a dry condition for cooling itself. Then the sample was tested for compressive strength by the compressive strength machine. The setup for a concrete cylinder in an electric burning machine is given below at figure 3.21.

(a) (b)

Figure 3. 21: Temperature effect test of concrete

3.8 Summary

Planning and data acquisition is an important part of thesis work. The methods selected for a test, properties of materials, mix design, sample preparation, and testing process were included in this part. Cement, sand, stone chips, and polypropylene were the main materials for the concrete mixture where polypropylene used as a partial replacement of stone chips. PP aggregate has lower ACV and AIV value compared to stone aggregate. PP aggregate has a lower specific gravity and unit weight compared to regular stone aggregate. The absorption capacity of PP aggregate is less than stone but nearly the same.

Based on the properties of the materials, the mix design was done for the 12 combinations of the concrete mixture. Then the casting process was done very carefully. The test process was done for compressive strength, spilt tensile strength, flexural strength, pull out strength, chloride penetration, and for the shrinkage value. The effect of high temperature in the compressive strength also determined for the polypropylene replacement. By using digital compressometer data were collected for stress vs strain diagram.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 General

Based on various physical, mechanical, and durability test results, the performance of PP concrete was evaluated compared to regular concrete. For the fresh concrete test, a slump test has been done. For the evaluation of hardened concrete, compressive strength test, determination of modulus of elasticity, toughness of concrete, density, tensile strength test of the concrete cylinder, and flexure strength test of concrete beam and pull out strength test were performed. On the other hand, evaluating the durability performances of PP concrete chloride ion penetration test, the effect on compressive strength of concrete after exposure to high temperature and shrinkage effect on concrete beam was also conducted.

4.2 Workability of Concrete

Though there are many tests for the workability of fresh concrete, the slump test is the most popular and thus has been used to measure the workability performance of concrete in the present study. The test has been done according to ASTM C143 [59]. In the present study, an approach has been taken where the degree of workability is quantified based on the slump value, and the correlation between the workability and slump value is shown in Table 4.1.

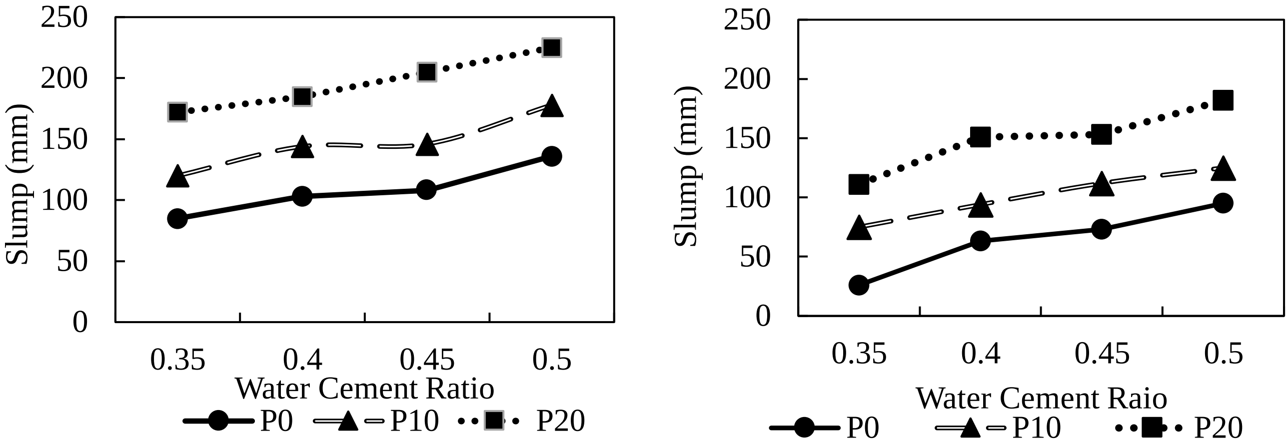
Table 4. 1: Degree of workability based on slump value [69]

Degree of Workability	**Slump Value (mm)**
Very Low	0-25
Low	25-50
Medium	50-100
High	100-200
Very High	>200

For the water-cement ratio 0.35 with admixture, slump value for 0% PP replaced concrete lies between 50-100 mm at the time after mixing which indicates medium workability performance for concrete. But after 15 minutes of mixing slump value lies between 25-50 mm range which indicates low workability performance. With the increase of PP percentage, slump value has been also increased by 10% and 20% PP replaced concrete but the value is in between the range of 100-200 mm. Therefore, the workability of concrete has been increased. But after 15 minutes of mixing, slump value also lies between 100-200 mm ranges but which indicates high workability performance. Therefore, it is evident from the test results that the PP replaced concrete shown better workability for a longer period. The results for all combinations are summarized in Table 4.2.

Table 4. 2**:** Slump values of concrete at different water-cement ratios

Title	**Water Cement Ratio**	**Admixtures**	**Slump Value (0 min), mm**	**Degree of Workability**	**Slump Value (15 min), mm**
WC35P0	0.35	Yes	85	High	26
WC35P10			120	High	75
WC35P20			172	High	111
WC40P0	0.40	Yes	103	High	63
WC40P10			144	High	94
WC40P20			185	Very High	151
WC45P0	0.45	No	108	High	73
WC45P10			146	High	112
WC45P20			205	Very High	153
WC50P0	0.50	No	136	High	95
WC50P10			178	High	125
WC50P20			225	Very High	182



(a) (b)

Figure 4. 1**:** (a) Slump values at 0 min and (b) Slump value After 15 min

It appears from the figure 4.1 (a) and (b) that the slump values were increased for higher water-cement ratio. Also, it concludes that the slump values get slightly lower after 15 minutes. As water reducing superplasticizer admixture was used to maintain similar workability of all water-cement ratio, most of the combination of the sample were under medium to high workability category.

4.3 Density of Concrete

The density of the concrete sample was measured by the ratio of mass and volume of the concrete sample. Based on the test data it can be said that concrete with PP will produce lighter concrete compare to the regular concrete with no PP content. All the calculated data are summarized in Figure 4.2.

With the increase of PP percentage, the density of the concrete decreases due to the lower unit weight of PP. At different water-cement ratios, with or without admixture in mix design, the density of concrete decreases linearly with the increase of PP content. For the water-cement ratio 0.35 with admixtures, density reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 4% and 8% respectively.

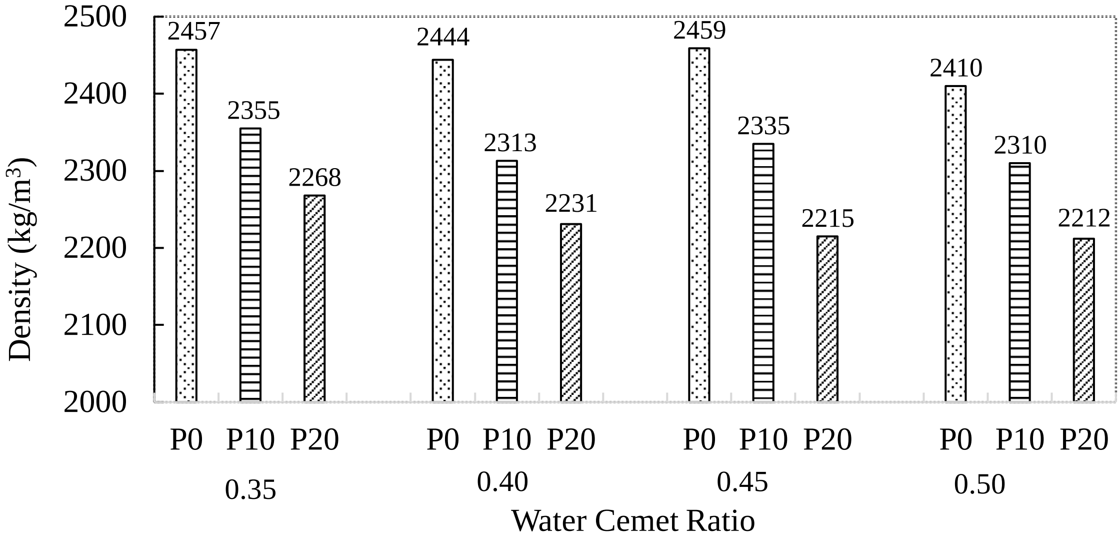


Figure 4. 2: Effect of density on various PP replaced concrete.

For the water-cement ratio 0.40 with admixtures, density reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 5% and 9% respectively. For the water-cement ratio 0.45 without admixtures, density reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 5% and 10% respectively. For the water-cement ratio 0.50 with admixtures, density reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 4% and 8% respectively. Figure 4.3 represents the relative density reduction compared to the control sample of 0% PP replaced concrete.

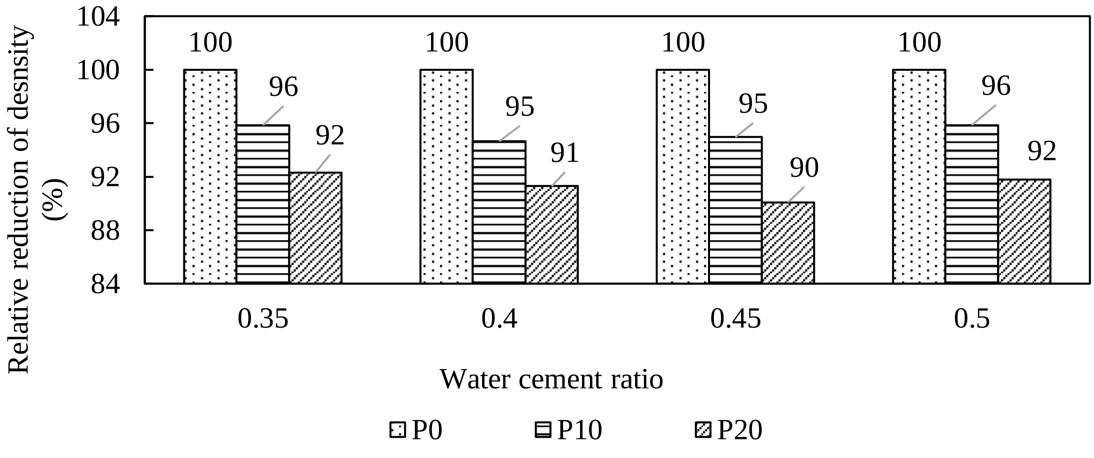


Figure 4. 3: Relative Density Reduction

4.4 Compressive Strength of Concrete

Compressive strengths at 7 days, 28 days, and 90 days after casting were measured according to ASTM C39 [58] for all types of concretes. Based on the test data it can be said that concrete with PP will produce lower strength compared to the regular concrete with no PP content. This is expected as synthetic PP does not bond well with the binding material used in the content. However, the reduction of compressive strength is not that significant nor is linearly variable with PP content.

For the water-cement ratio of 0.35, concrete compressive strength at 7 days, reductions for 10%, and 20% PP replaced concrete compare to 0% PP replaced concrete is only 30% and 20%. At 28 days, compressive strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 21% and 20%. At 90 days, compressive strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 16% and 25%. Increasing with PP percentage, the compressive strength of concrete has been reduced but the compressive strength of 10% and 20% PP concrete are nearly the same. But the increase of strength with time (7 to 90 days) for 10% and 20% PP replaced concrete is 56% and 37% which is 25% and 6% greater respectively than 0% PP replaced concrete. All the results have been shown respectively in Figures 4.4 and 4.5.

For the water-cement ratio of 0.40, concrete compressive strength at 7 days, reductions for 10%, and 20% PP replaced concrete compare to 0% PP replaced concrete is only 13% and 18%. At 28 days, compressive strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 20% and 13%.

At 90 days, compressive strength reductions for 20% PP replaced concrete compare to 0% PP replaced concrete is only 14% but for 10% PP replaced concrete, the compressive strength increases 1% instead of reductions.

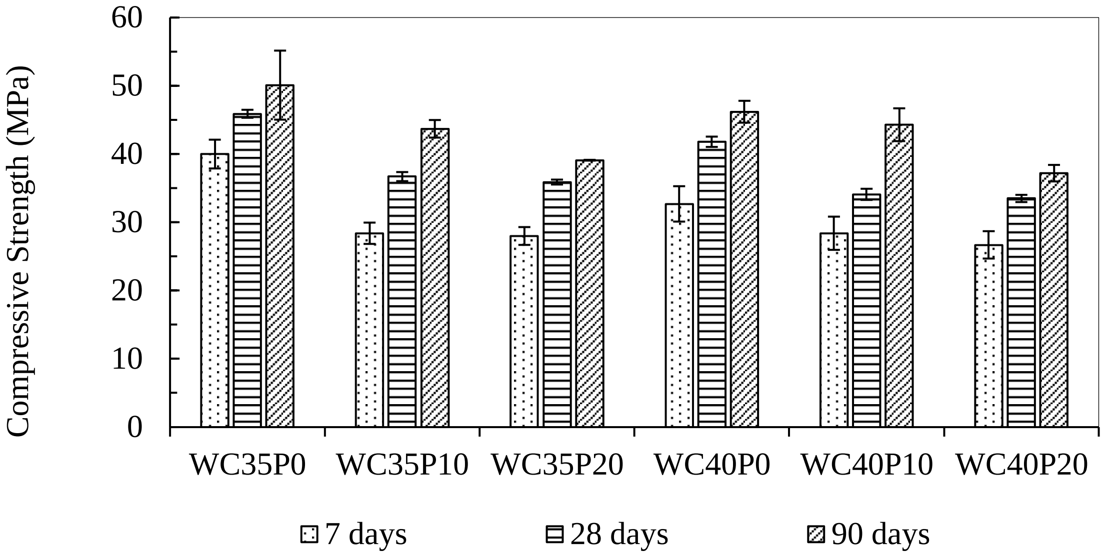


Figure 4. 4: Compressive strength comparison of concrete samples with admixture and w/c ratio of 0.35 and 0.40

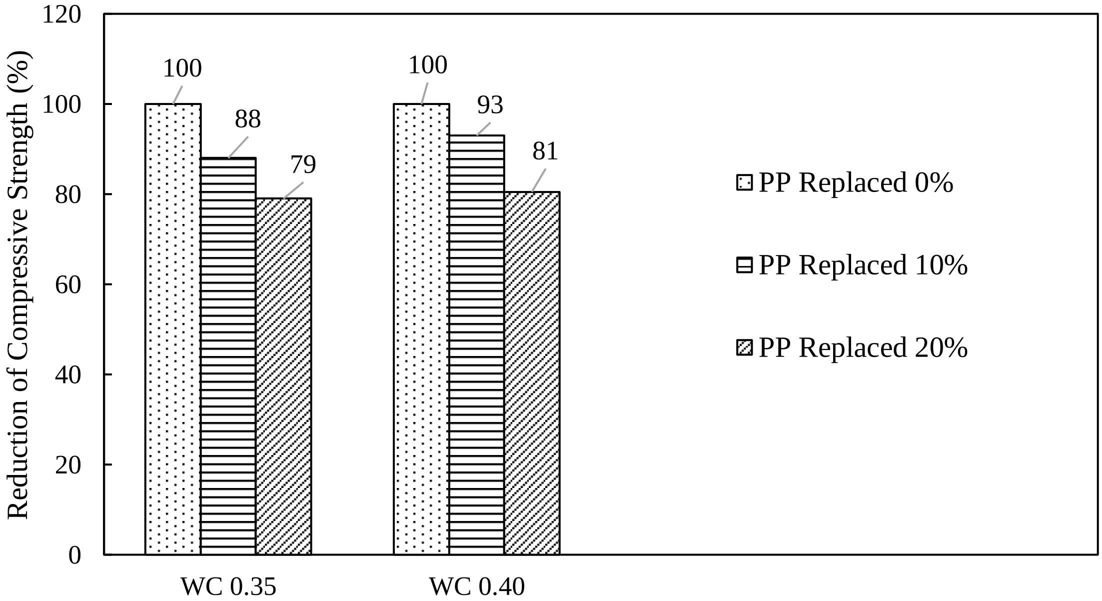


Figure 4. 5: Relative Comparison of Compressive Strength with Admixtures at 28 Days

Increasing with PP percentage, the compressive strength of concrete has been reduced but the compressive strength of 10% and 20% PP concrete are nearly the same. Besides, the increase of strength with time (7 to 90 days) for 10% and 20% PP replaced concrete is 56%

and 39% which is 23% and 6% greater respectively than 0% PP replaced concrete. All the results have been shown respectively in Figures 4.4 and 4.5.

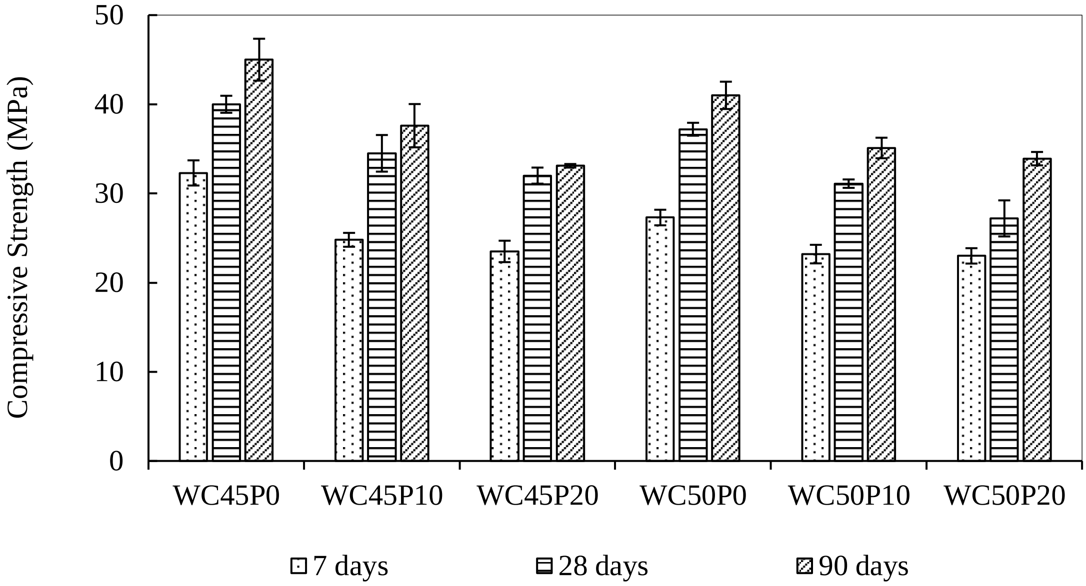


Figure 4. 6: Compressive strength comparison of concrete samples without admixture and w/c ratio of 0.45 and 0.50

For the water-cement ratio of 0.45, concrete compressive strength at 7 days, reductions for 10%, and 20% PP replaced concrete compare to 0% PP replaced concrete is only 23% and 27%. At 28 days, compressive strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 13% and 20%. At 90 days, compressive strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 23% and 27%. Increasing with PP percentage, compressive strength of concrete has been reduced but the compressive strength of 10% and 20% PP concrete are nearly same.

Besides, the increase of strength with time (7 to 90 days) for 10% and 20% PP replaced concrete is 52% and 41% which is 13% and 2% greater respectively than 0% PP replaced concrete. All the results have been shown respectively in Figures 4.6 and 4.7.

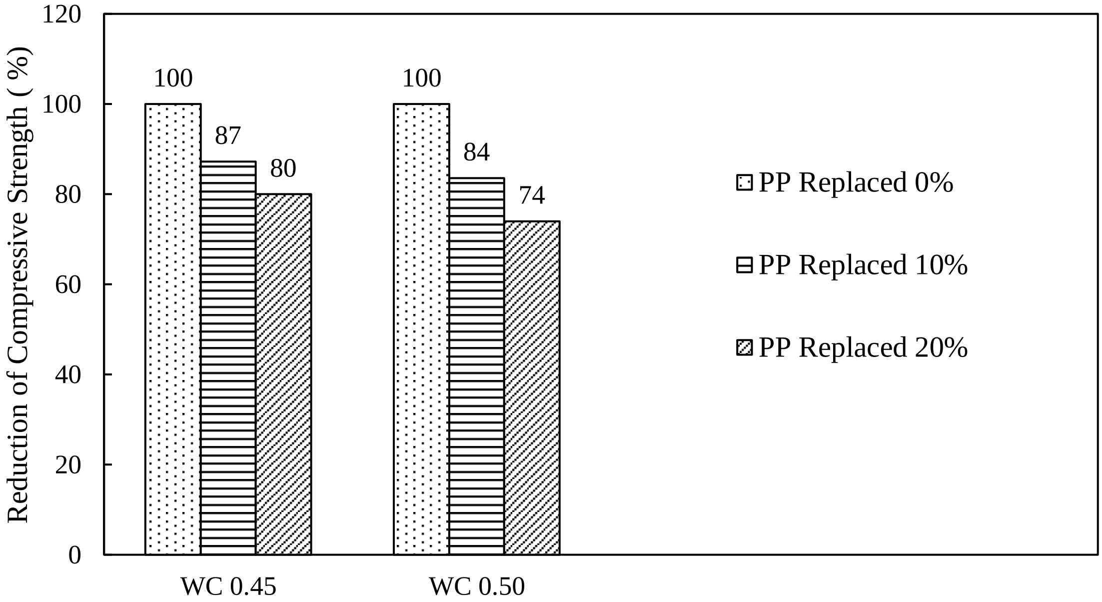


Figure 4. 7: Relative Comparison of Compressive Strength without Admixtures at 28 Days

For the water-cement ratio of 0.50, concrete compressive strength at 7 days, reductions for 10%, and 20% PP replaced concrete compare to 0% PP replaced concrete is only 15% and 16%. At 28 days, compressive strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 27% and 16%. At 90 days, compressive strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 26% and 17%. Increasing with PP percentage, the compressive strength of concrete has been reduced but the compressive strength of 10% and 20% PP concrete are nearly the same. Besides, the increase of strength with time (7 to 90 days) for 10% and 20% PP replaced concrete is 32% and 46% which is 18% and 4% lesser respectively than 0% PP replaced concrete. All the results have been shown respectively in Figures 4.6 and 4.7.

(a) (b)

(b) (d)

Figure 4. 8: Failure of concrete cylinder under compressive force.

Figure 4.8 represents some of the failed concrete cylinders under the compressive force. In most cases, failure was limited to cone and shear failure. Figure 4.8 (a) also indicates the good distribution of PP aggregates in the concrete.

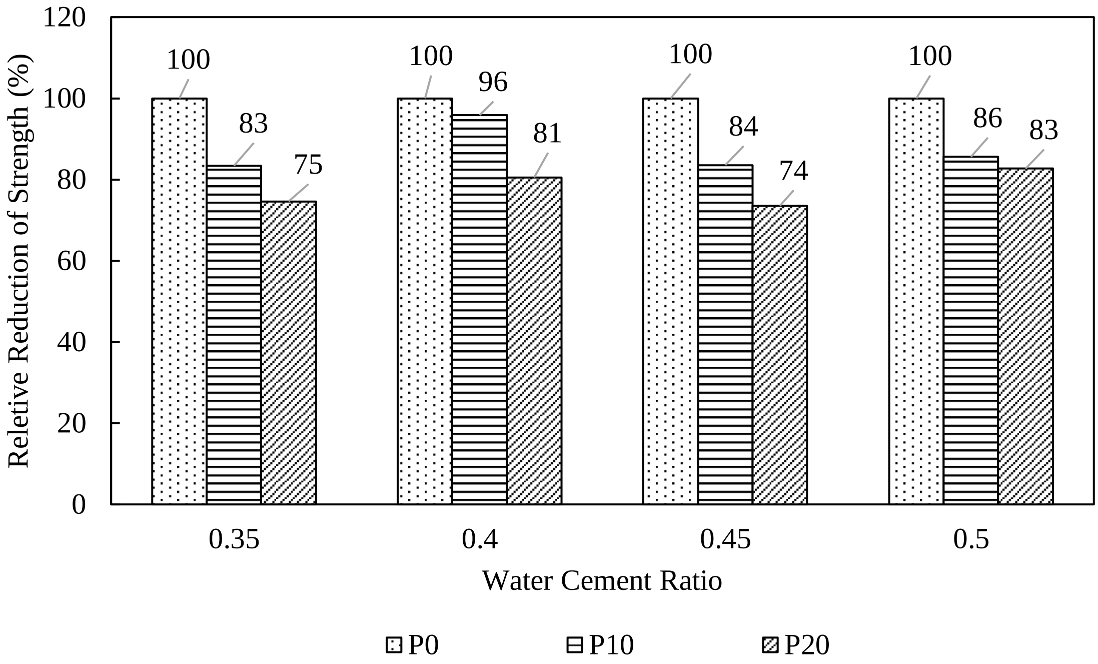


Figure 4. 9: Relative Change of Compressive Strengths at 90 days

The relative change of compressive strengths at 90 days for all types of combinations are represented in Figure 4.9. It clearly shows that, at 90 days, for 10% and 20% PP replacement, the relative reduction for water-cement ratio 0.35 was 17% and 25% respectively. Also, for water-cement ratio 0.45 reduction was 4% and 19%; for water-cement ratio 0.50 reduction was 16% and 26% and lastly for water-cement ratio 0.50 reduction was 14% and 17%.

4.5 Stress-Strain Behaviour of Concrete

Stress-strain behavior of concrete has been measured by using a digital compressometer and the data were collected from through a data logger under compressive stress. The test was performed according to ASTM C469 [54] for all types of concrete samples. Based on the test data stress vs strain graphs were plotted and demonstrated in Figure 4.10 and 4.11.

Based on the graphs it can be said that concrete with PP will produce more ductile concrete compare to the regular concrete with no PP content.

For the water-cement ratio 0.35 and 0.40 with admixtures, increasing with PP percentage ductility behavior also increases. But ductility behavior is nearly the same for 10% and 20% PP replaced concrete. Stress-strain behavior is most ductile for 20% PP replaced concrete compared to regular concrete for this water-cement ratio when admixture is mixed. Stress-strain behavior has been shown respectively in Figures 4.10(a) and 4.10(b).

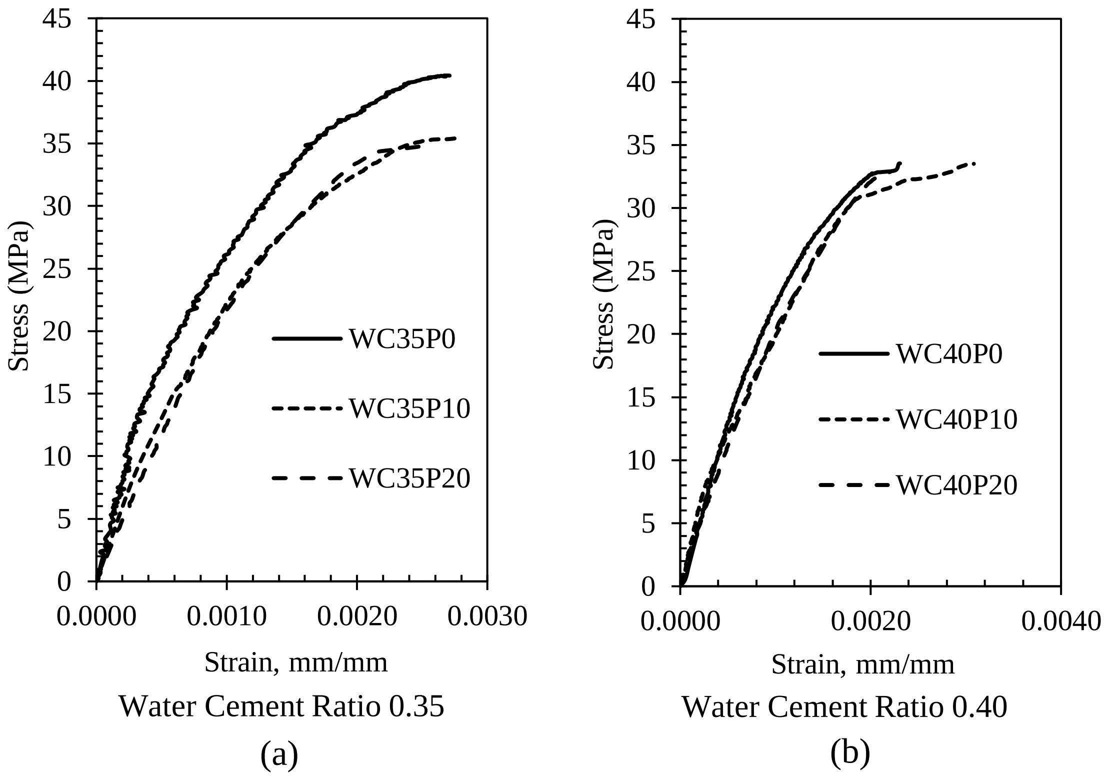


Figure 4. 10: Comparison of Stress vs Strain behaviors (with admixture); (a), (b)

For the water-cement ratio 0.45 and 0.50 without admixtures, increasing with PP percentage ductility behavior also increases. But ductility behavior of 10% PP replaced concrete is better than 20% PP replaced concrete for these combinations.

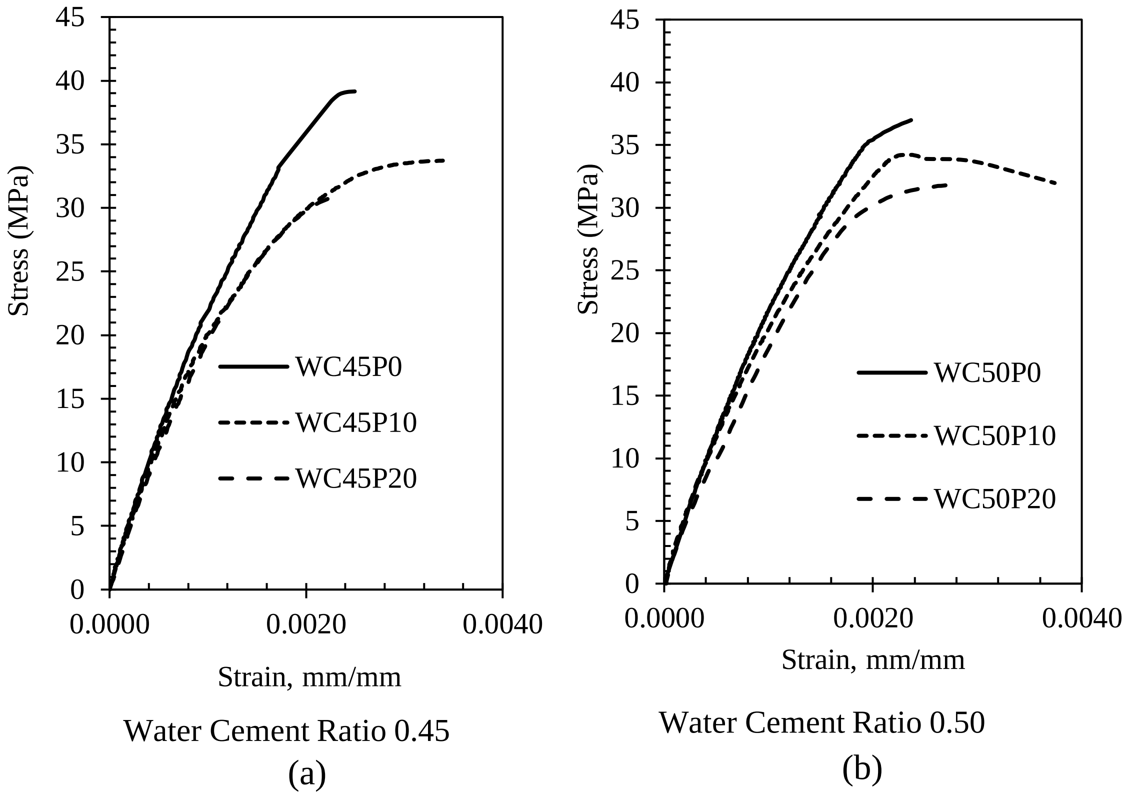


Figure 4. 11: Comparison of Stress vs Strain behaviors (without admixture); (a), (b)

Stress-strain behavior is most ductile for 10% PP replaced concrete compared to regular concrete for these water-cement ratios when no admixture is mixed. The stress-strain behaviour of the concrete sample has been shown respectively in Figure 4.11(a) and 4.11(b).

4.5.1 Determination of Toughness Index of Concrete

The toughness of the concrete measured from the strain vs stress graph of concrete. The area under the strain vs stress graph indicates the toughness of concrete. Based on the calculated results, it can be said that concrete with PP will produce higher toughness value compare to the regular concrete with no PP content. The determined toughness values are summarized in table 4.3.

For the water-cement ratio 0.35, toughness value of 10% and 20% PP replaced concrete increases by 36% and 55% respectively compared to regular concrete. For the water cement ratio 0.40, toughness value of 10% and 20% PP replaced concrete increases 30% and 43% respectively compared to regular concrete.

Table 4. 3: Toughness of concrete at different water-cement ratios

Designation	**W/C Ratios**	**Admixtures**	**PP Percentage (%)**	**Toughness Index (J/m^3)**
WC35P0	0.35	Yes	0	76477
WC35P10			10	77350
WC35P20			20	58006
WC40P0	0.40	Yes	0	55941
WC40P10			10	74484
WC40P20			20	44185
WC45P0	0.45	No	0	60237
WC45P10			10	84007
WC45P20			20	45745
WC50P0	0.50	No	0	54155
WC50P10			10	96234
WC50P20			20	60235

For these two water-cement ratios with admixtures, toughness value increases from 0% PP replaced concrete to 20% PP replaced concrete proportionally. For the water-cement ratio 0.45, toughness value of 10%, and 20%, PP replaced concrete increases by 35% and 40% respectively compared to regular concrete. For the water-cement ratios 0.50, toughness value of 10% and 20% PP replaced concrete increases by 22% and 45% respectively compared to regular concrete. For these water-cement ratios without admixtures toughness value increment percentage of concrete is highest for 20% PP replaced concrete and lowest for 0% PP replaced concrete. Toughness value for 10% PP replaced concrete is in between them. Figure 4.12 represents the comparison.

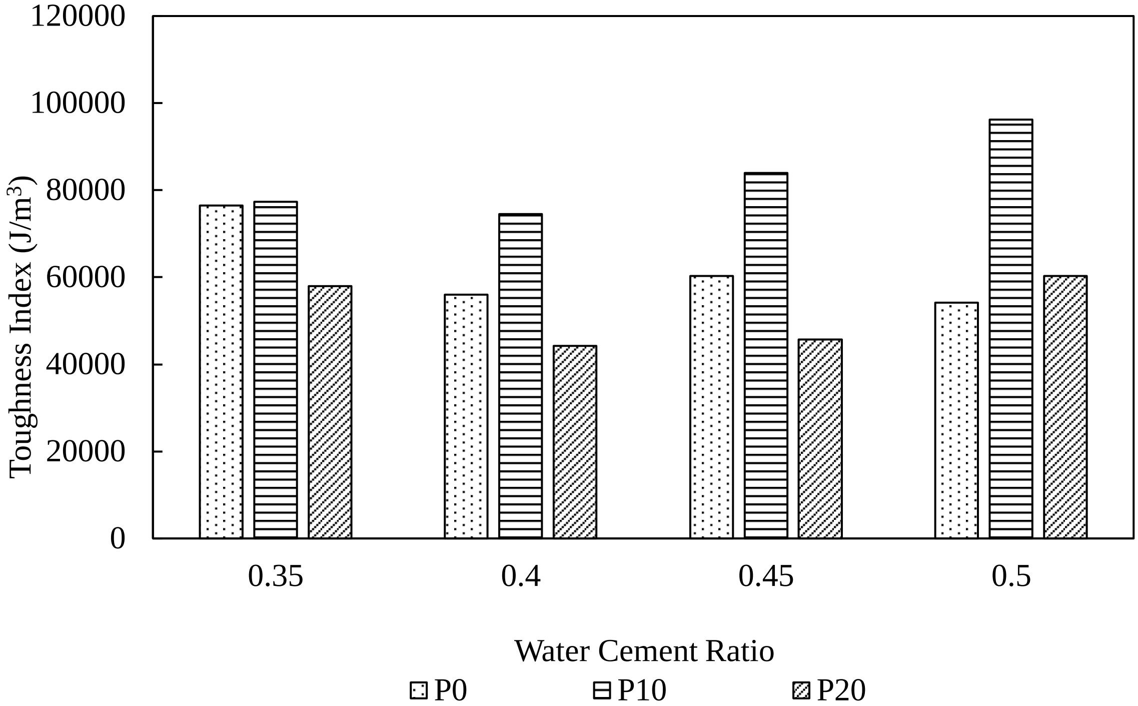


Figure 4. 12: Comparison of Toughness Index

4.5.2 Determination of Modulus of Elasticity of Concrete

Modulus of Elasticity of concrete is also measured from the stress vs strain curve of concrete. Tangent of stress vs strain curve of concrete indicates the modulus of elasticity of concrete. It is also described as Young's Modulus of Concrete. Based on the calculation it can be said that concrete with PP will produce lower modulus of elasticity compared to the regular concrete with no PP content. This is expected as synthetic PP does not bond well with the binding material used in the content. However, the reduction of modulus of elasticity of concrete is not that significant nor is linearly variable with PP content. All the calculated results and the formed equation has been summarized in Table 4.4.

For the water-cement ratio 0.35, modulus of elasticity of 10% and 20% PP replaced concrete decreases by 20% and 25% respectively compared to regular concrete. For the water-cement ratios, 0.40, toughness value of 10% and 20% PP replaced concrete decreases

8% and 11% respectively compared to regular concrete. For these two water-cement ratios without admixtures modulus elasticity of concrete value decreases from 0% PP replaced concrete to 20% PP replaced concrete proportionally. Modulus of elasticity of 10% PP replaced concrete is in between them.

Table 4. 4: Modulus of elasticity of concrete at different water-cement ratios

Designation	Water Cement Ratio	Admixtures	PP Percentage (%)	Modulus of Elasticity-MOE, (MPa)
WC35P0	0.35	Yes	0	30600
WC35P10			10	24100
WC35P20			20	22800
WC40P0	0.40	Yes	0	23800
WC40P10			10	21200
WC40P20			20	21100
WC45P0	0.45	No	0	23300
WC45P10			10	22300
WC45P20			20	21200
WC50P0	0.50	No	0	22700
WC50P10			10	22000
WC50P20			20	19700

For the water-cement ratio 0.45, modulus of elasticity of 10% and 20% PP replaced concrete decreases 8% and 9% respectively compared to regular concrete. For the water-cement ratios 0.50, modulus of elasticity of 10% PP replaced concrete decreases 4% and 20% PP replaced concrete decreases 13% compared to regular concrete. For 0.45 water-cement ratio without admixtures modulus elasticity of concrete value decreases from 0% PP replaced concrete to 20% PP replaced concrete proportionally. Modulus of elasticity of 10% PP replaced concrete is in between them. But for 0.50 water-cement ratio without admixtures, modulus of elasticity of concrete is highest for 10% PP replaced concrete and lowest for 0% PP replaced concrete. Modulus of elasticity for 20% PP replaced concrete is in between them. Figure 4.13 illustrates the comparison.

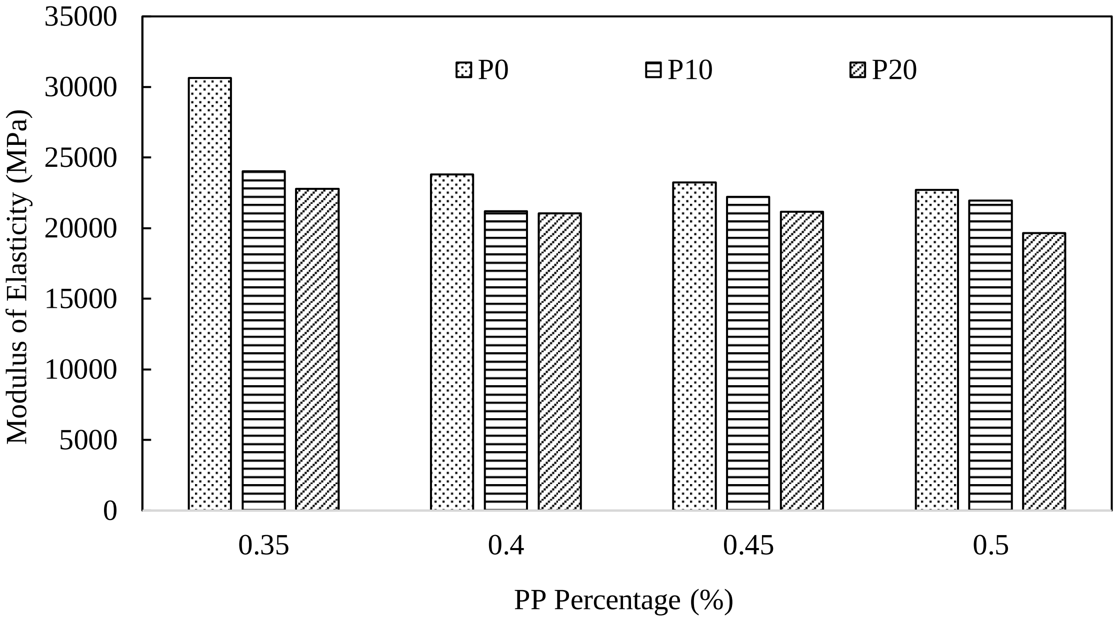


Figure 4. 13: Comparison of modulus of elasticity of concrete

4.6 Tensile Strength Test

The tensile strengths at 7 days, 28 days, and 90 days after casting were measured according to ASTM C496 [61] for all types of concretes. Based on the test data it can be said that concrete with PP will produce nearly the same tensile strength compared to the regular concrete with no PP content. For the water-cement ratio of 0.35, at 28 days, tensile strength reductions for 20% PP replaced concrete compare to 0% PP replaced concrete is only 10% but for 10% PP replaced concrete, tensile strength increases 1.5% instead of reduction.

(a) (b)

Figure 4. 14: Failure of cylinders under split tensile force

At 90 days, tensile strength reductions for 20% PP replaced concrete compare to 0% PP replaced concrete is only 14% but for 10% PP replaced concrete, tensile strength increases 5% instead of reduction.

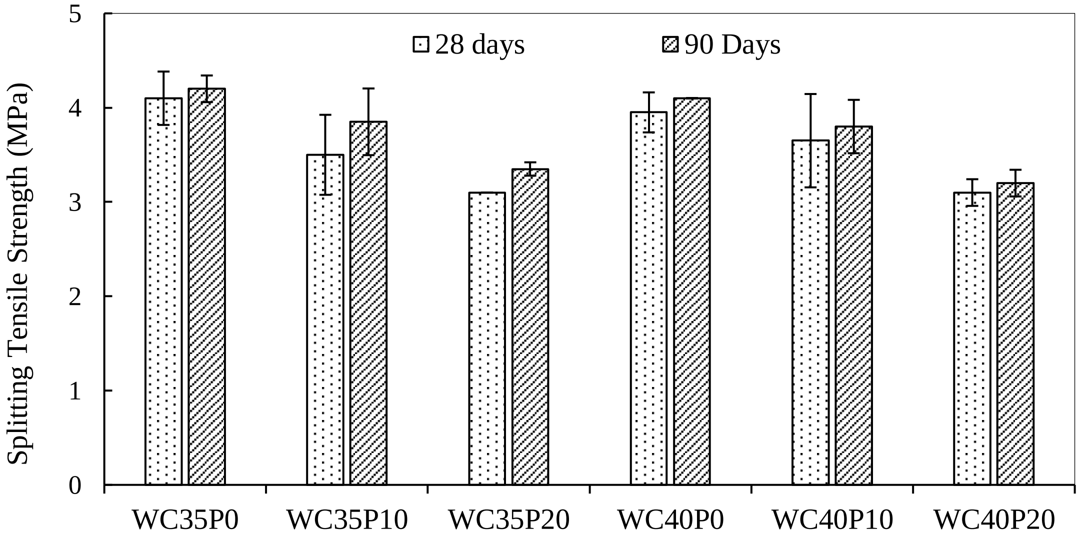


Figure 4. 15: Comparison of Tensile Strengths with admixtures for w/c 0.35 and 0.40

For the water-cement ratio of 0.40, at 28 days, tensile strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 7% and 21%. At 90 days, tensile strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 7% and 21%. For the water-cement ratio of 0.45, at 28 days, tensile strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 2% and 19%. At 90 days, tensile strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 9% and 27%.

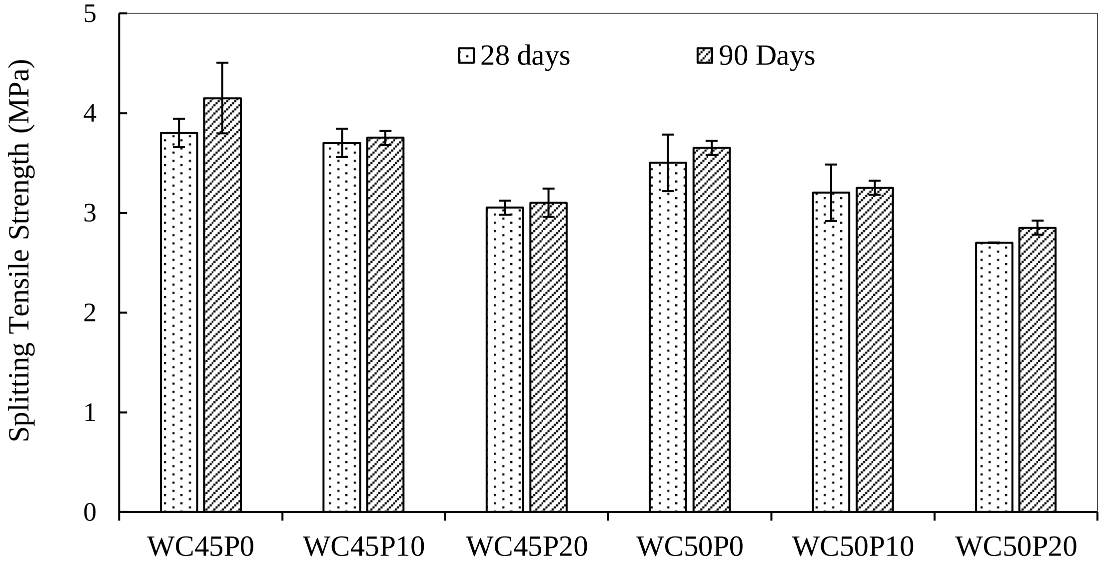


Figure 4. 16: Comparison of Tensile Strengths without admixtures for w/c 0.45 and 0.50

For the water-cement ratio of 0.50, at 28 days, tensile strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 8% and 22%. At 90 days, tensile strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 11% and 22%. Figure 4.15 and 4.16 represents all the data.

4.7 Relationship Between Compressive and Tensile Strength

The relationship between the compressive and tensile strength for 0, 10 and 20% PP replaced concrete, as shown in Figure 4.19, indicates that tensile strength is related to compressive strength and increases with increasing compressive strength. An equation is proposed for tensile strength with a moderate correlation ($R^2 = 0.775$).

Table 4. 5: Proposed equation for split tensile strength

Designation	**Equation**	**Aggregate type**
Proposed Eqn.	$f_t = 0.212 f'^{0.78}_c$	PP+NA
Babu et. al [31]	$f_t = 0.242 f'^{0.79}_c$	EPS
ACI 318 [68]	$f_t = 0.556 f'^{0.5}_c$	NA

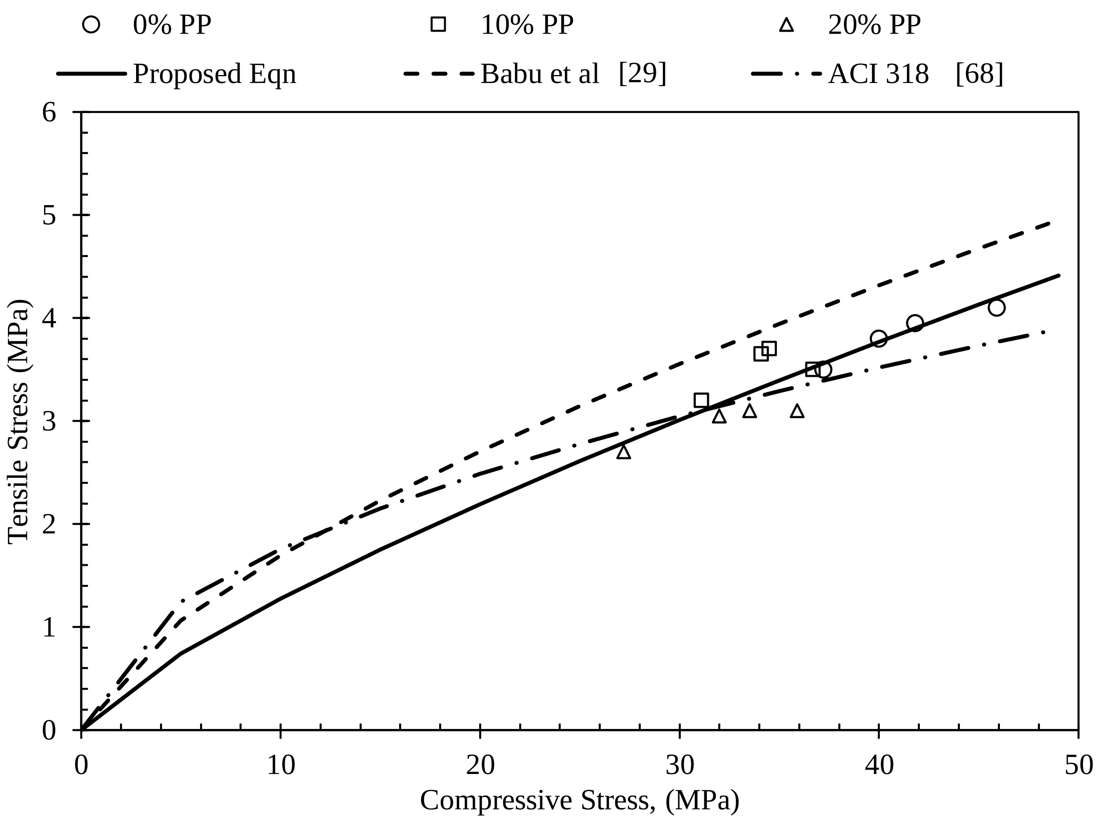


Figure 4. 17: Relationship Between Compressive and Tensile Strength

Babu et al. [31] used expanded polystyrene (EPS) in concrete and proposed an expression for splitting tensile strength. ACI 318 [70] also provides a guideline for calculating splitting tensile strength from the compressive strength. Both these equations along with the proposed equation are illustrated in Table 4.5 and Figure 4.17. As observed from Figure 4.17, the equation proposed by Babu et al. overestimates the tensile strength. ACI 318 equation gives better prediction for 10% and 20% PP replaced concrete.

4.8 Pull Out Strength

The pull out strength test was conducted according to ASTM C900 [61]. In this test method, the strength was determined by pulling a cast in place insert rebar using a jack reacting against a bearing ring. The pull out strength was determined by measuring the maximum force to pull the inserted rebar from the concrete mass. All the measured forces and corresponding pull out strengths for various combinations are demonstrated in Table 4.6.

Table 4. 6: Pull out strength of concrete specimens

SL	Designation	Pull out Force, (KN)	Pull Out Stress (MPa)
1.	WC35P0	43.7	5.95
2.	WC35P10	37.8	5.31
3.	WC35P20	26.3	3.70
4.	WC40P0	42.3	5.34
5.	WC40P10	35	6.14
6.	WC40P20	22.9	3.22
7.	WC45P0	34.7	4.36
8.	WC45P10	30	5.08
9.	WC45P20	22.5	3.16
10.	WC50P0	33.5	3.48
11.	WC50P10	28.8	4.04
12.	WC50P20	22.5	3.14

From the pull-out force data, it can be observed that, for all four types of water-cement ratios, with the increment of PP percentage, the bonding strength between the concrete and rebar decreases.

Figure 4. 18: Concrete conic frustum after cast in pull out test of rebar.

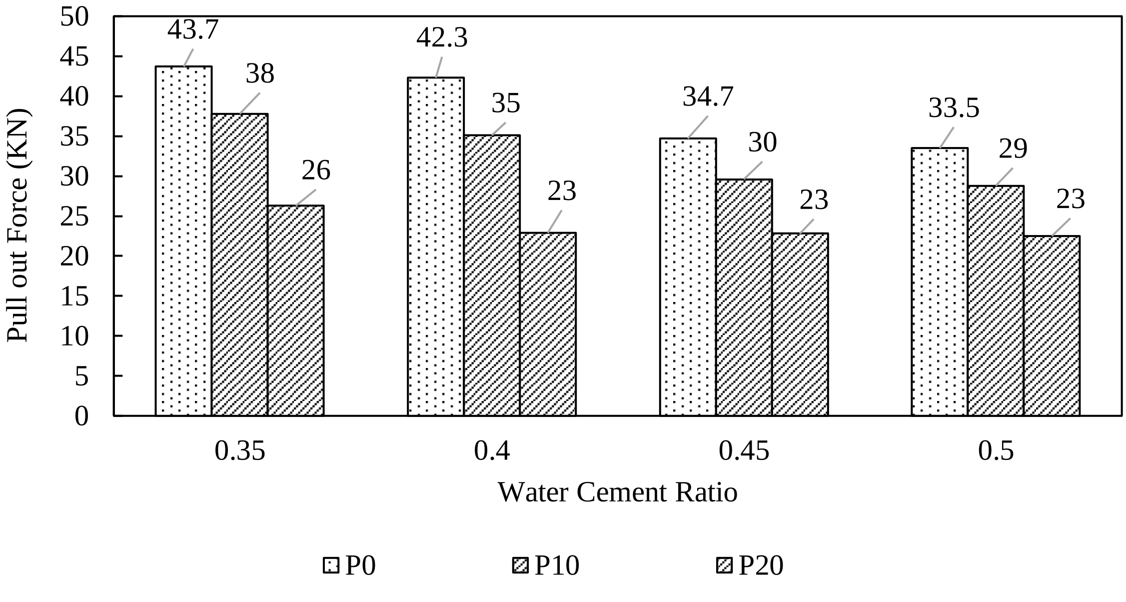


Figure 4. 19: Pull out strength Comparison

However, except for concrete with w/c ratio of 0.35, the 10% PP replaced concrete showed 14 – 17% higher bonding strength than the control sample with no PP concrete. Higher pull out strength indicates good bonding behaviour between the rebar and concrete with 10% PP replacement.

4.9 Flexure Strength

The flexure strengths of the beam at 28 days after casting were measured according to ASTM C78 [58] for all types of concretes. Based on the test data it can be said that concrete with PP will produce lower flexural strength but nearly the same compare to the regular concrete with no PP content. This is expected as synthetic PP does not bond well with the binding material used in the content. But content with PP content has shown allowable strength. Besides, with the increase of PP percentage ductility of concrete beam shows better behaviour.

Table 4. 7: Flexure strength of concrete at different water-cement ratios

SL	Designation	Water Cement Ratio	Admixtures	PP Percentage, (%)	Flexural Strength, (MPa)
1.	WC35P0	0.35	Yes	0	6.60
2.	WC35P10			10	5.57
3.	WC35P20			20	4.05
4.	WC40P0	0.40	Yes	0	6.29
5.	WC40P10			10	5.09
6.	WC40P20			20	3.99
7.	WC45P0	0.45	No	0	5.93
8.	WC45P10			10	4.64
9.	WC45P20			20	3.53
10.	WC50P0	0.50	No	0	4.53
11.	WC50P10			10	4.03
12.	WC50P20			20	3.43

For the water-cement ratio of 0.35, at 28 days, flexure strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 15% % and 35%. But the results are still allowable range.

For the water-cement ratio of 0.40, at 28 days, flexure strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 19% and 36%. But the results are still allowable range.

For the water-cement ratio of 0.45, at 28 days, flexure strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 5% and 2%. But the results are still allowable range.

For the water-cement ratio of 0.50, at 28 days, flexure strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 21% and 40%. But the results are still allowable range.

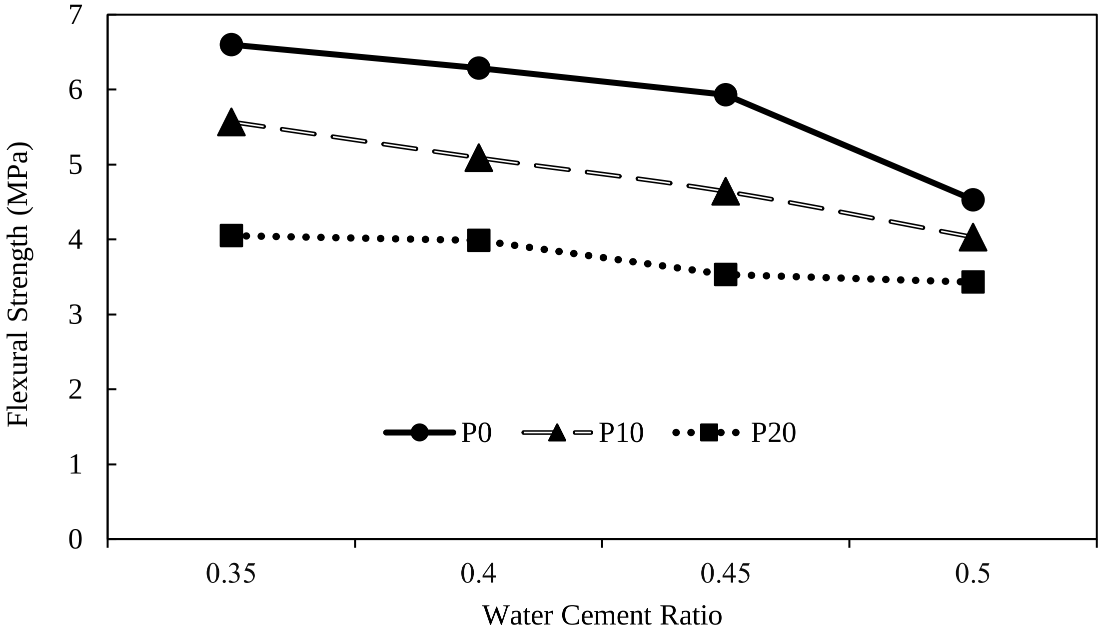


Figure 4. 20: Comparison of Flexural Strength of Concrete

From this graphical representation of flexure strength in Figure 4.20, of PP replaced concrete at different water-cement ratios, it has been observed that for 0.50 water-cement ratio, fluctuation of flexure strength is minimal. So, in this case, the 0.40 water-cement ratio should be proposed for better flexural behaviour.

4.10 Shrinkage Test

The shrinkage test of the beam was performed according to ASTM C157 [64]. In this test method, the initial shrinkage and final shrinkage value of the concrete beam have been recorded and the shrinkage percentage has been calculated. For all the PP percentages, shrinkage of the concrete beam has done in a minor percentage.

For the water cement ratio of 0.35, shrinkage percentage increases for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete. For 10% and 20% PP replaced concrete shrinkage percentage is 0.0378% and 0.0528% respectively where for 0% PP replaced concrete is 0.0304%.

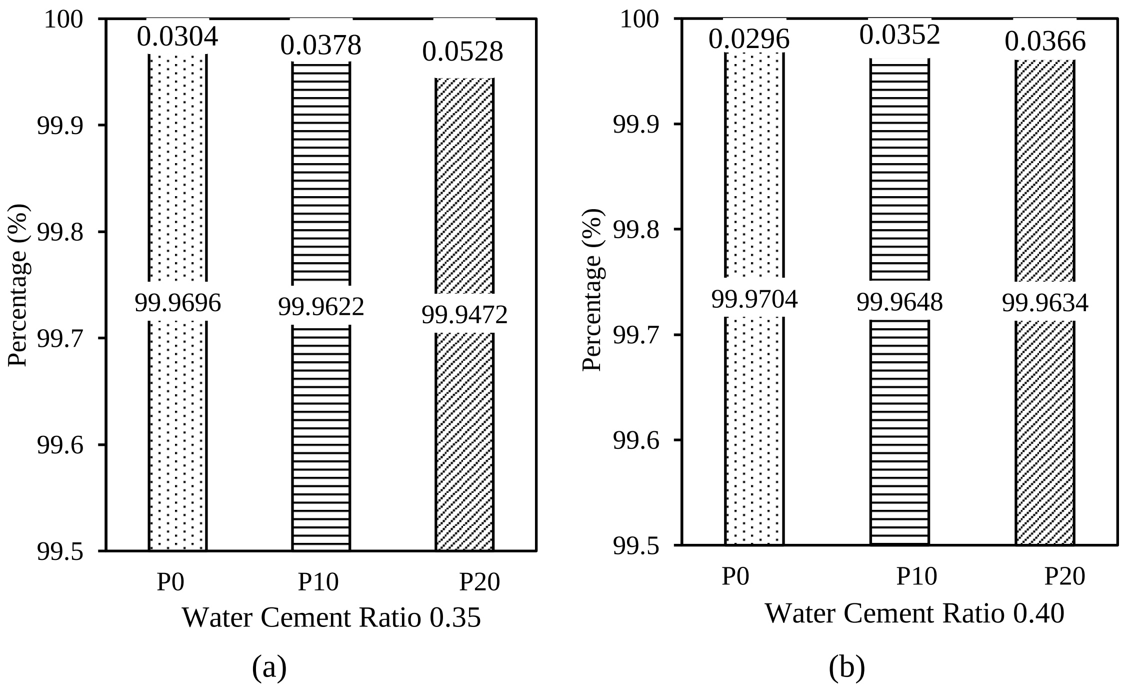
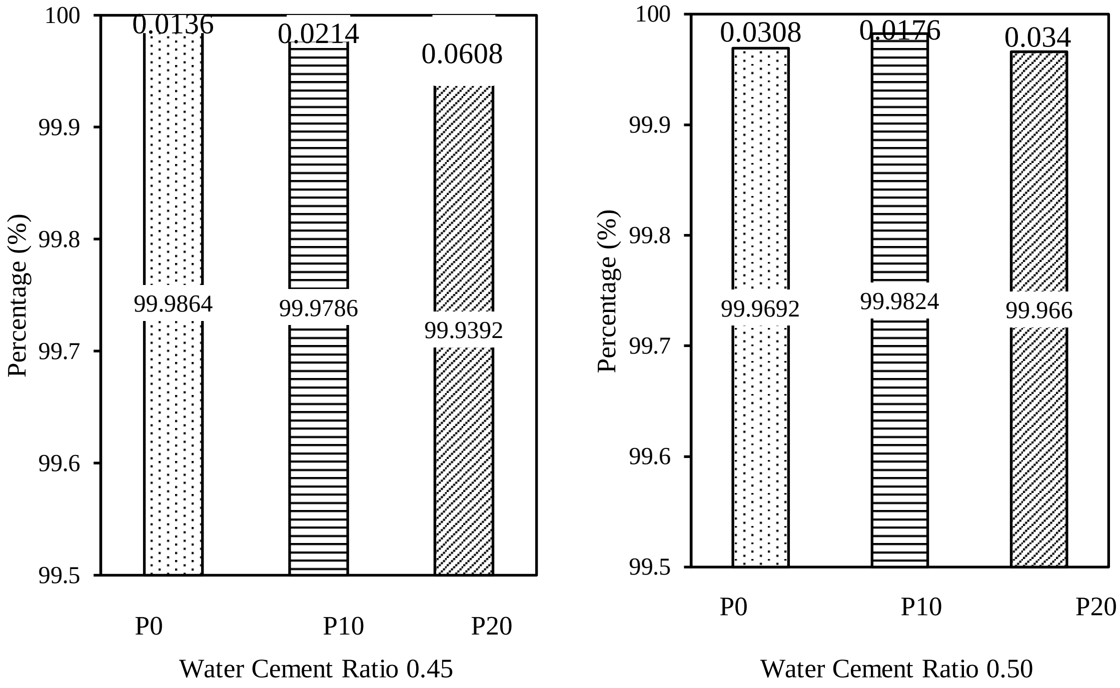


Figure 4. 21: Comparison of shrinkage percentage (with admixture)

For the water cement ratio of 0.40, shrinkage percentage increases for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete. For 10% and 20% PP replaced concrete shrinkage percentage is 0.0352% and 0.0366% respectively where for 0% PP replaced concrete is 0.0296%. For the water cement ratio of 0.45, shrinkage percentage increases for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete. For 10% and 20% PP replaced concrete shrinkage percentage is 0.0214% and 0.0608% respectively where for 0% PP replaced concrete is 0.0136%.



(a) (b)

Figure 4. 22: Comparison of shrinkage percentage (without admixture)

For the water cement ratio of 0.35, shrinkage percentage increases for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete. For 10% and 20% PP replaced concrete shrinkage percentage is 0.0176% and 0.034% respectively where for 0% PP replaced concrete is 0.0308%.

4.11 Chloride Ion Penetration Test

The surface resistivity test was done according to AASHTO TP 95 [55]. In this test method, the surface resistivity of concrete was measured by surface resistivity meter and the data was correlated to the chloride penetrability classification of the concrete (Table 4.8). Figure

4.23 and 4.24 shows the specific resistance in kOhm-cm for four different water-cement ratios and three different PP replacement percentages. For some cases, chloride ion penetrability of concrete falls under moderate category and other cases, it falls under low category.

Table 4. 8: Chloride penetrability classification with respect to AASHTO TP 95

Chloride Ion Penetrability	**Specific Resistance R (kOhm-cm)**
High	<12
Moderate	12-21
Low	21-37
Very Low	37-254
Negligible	>254

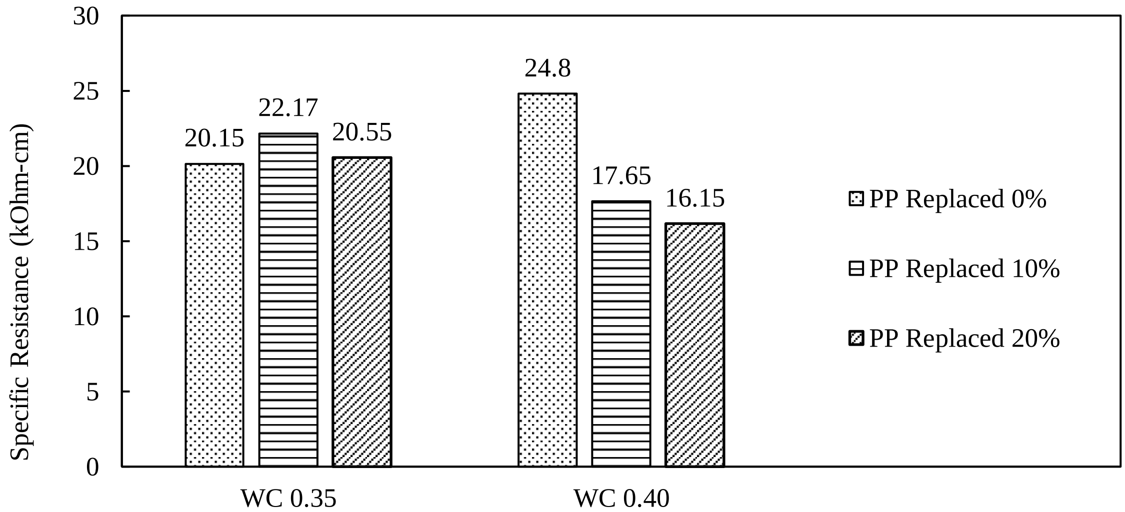


Figure 4. 23: Effect of Chloride Ion penetration with admixture (w/c 0.35 and 0.40)

For the water-cement ratio of 0.40, specific resistance reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 28% and 34%. For the 10% and 20% PP percentage, chloride ion penetrability of concrete falls under the moderate category. But for 0% PP percentage, chloride ion penetrability of concrete falls under the low category.

For the water-cement ratio of 0.45, specific resistance reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 13% and 21%. For all the PP percentage, chloride ion penetrability of concrete falls under the moderate category.

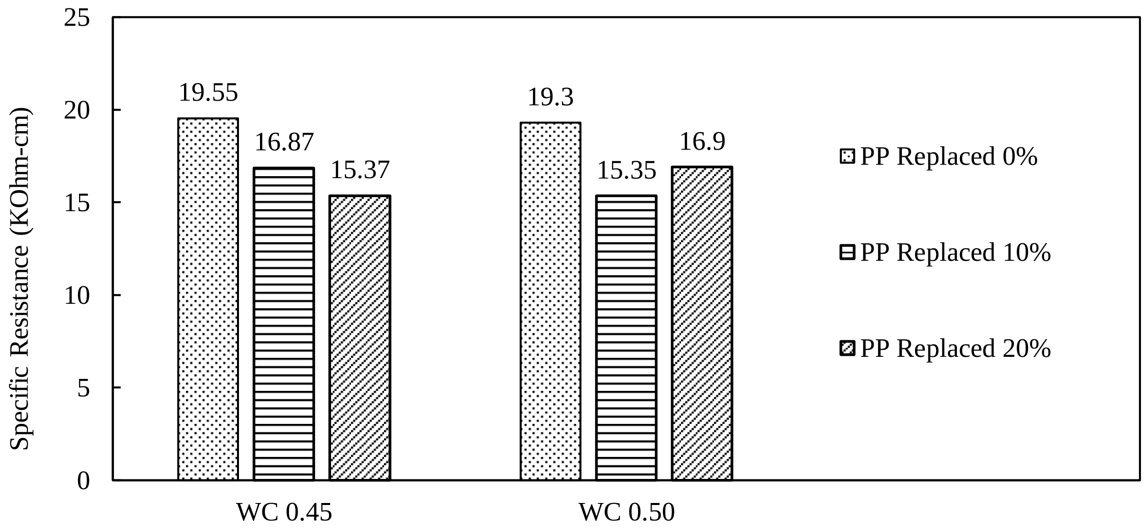


Figure 4. 24: Effect of Chloride Ion penetration without admixture (w/c 0.45 and 0.50)

For the water-cement ratio of 0.50, specific resistance reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 20% and 12%. For all the PP percentage, chloride ion penetrability of concrete falls under the moderate category.

4.12 Effect on High Temperature Exposure

For high-temperature exposure, the concrete cylinders were heated evenly in an enclosed furnace chamber at the age of 90 days. The temperature loading curve shown in Figure 4.25 indicates that the concrete cylinders were exposed to 200°C for over an hour. After the application of temperature, the samples were cooled down to room temperature at the laboratory. Samples were then tested for compressive strength. Compressive strength results, as presented in Figure 4.26 and 4.27, are compared with for all three PP replaced concrete (0, 10 and 20%) for different w/c ratios.

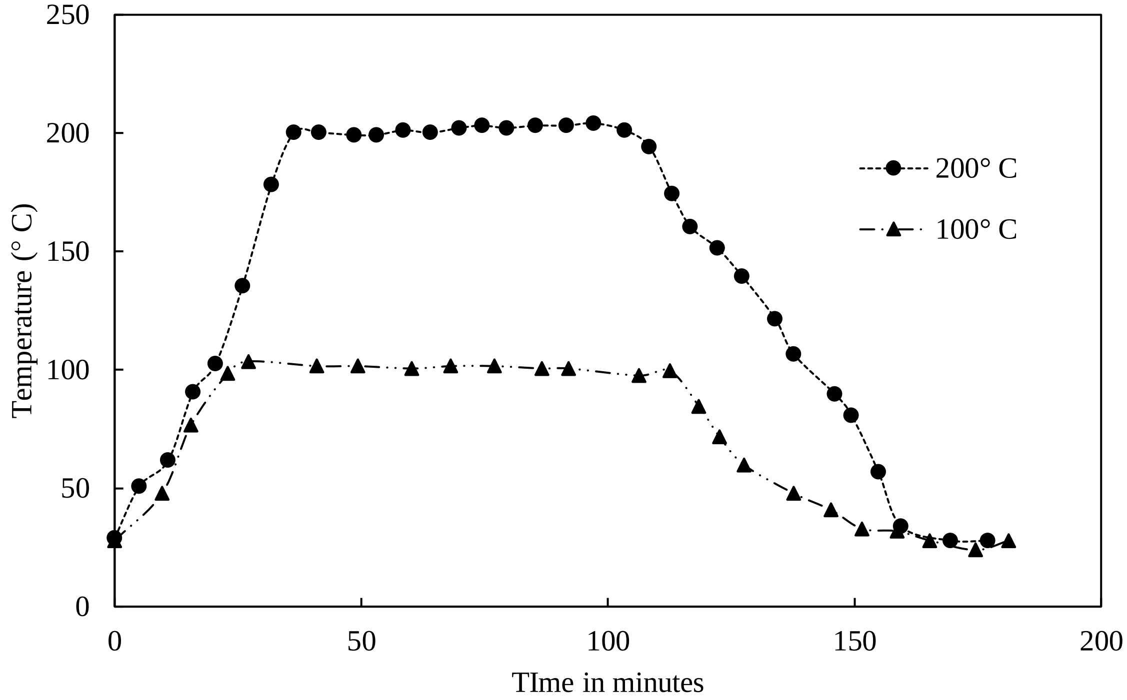
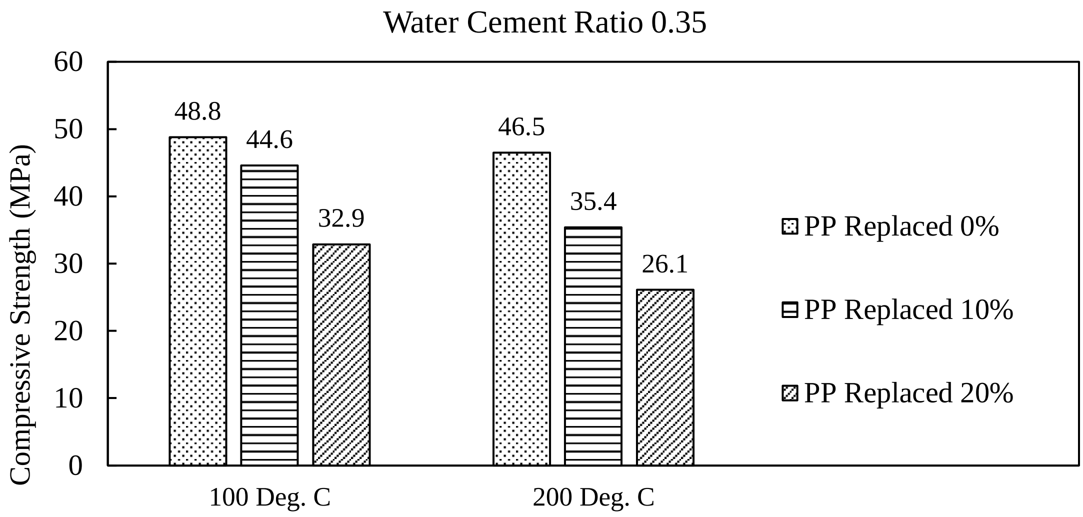
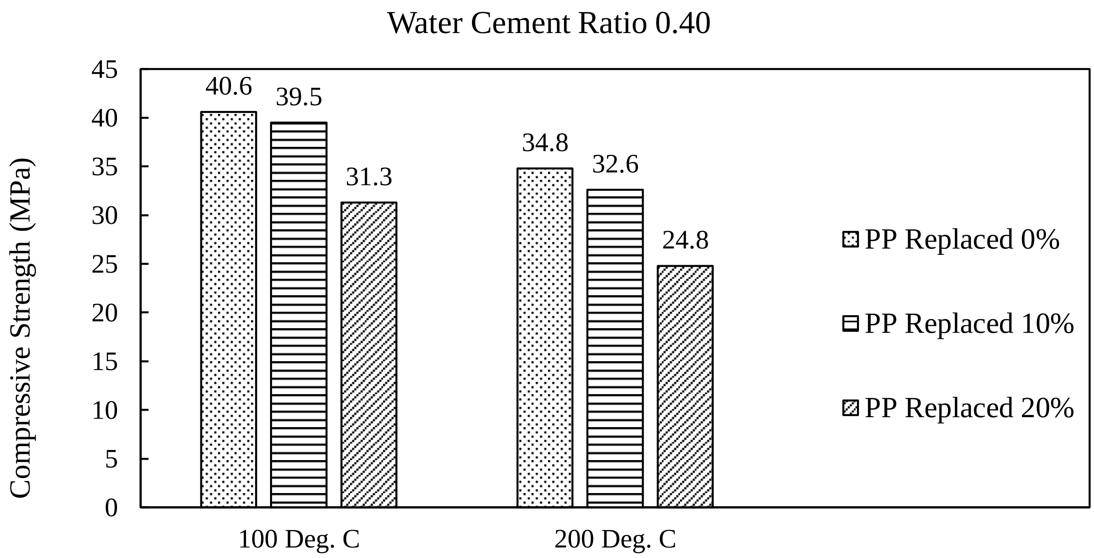


Figure 4. 25: Temperature loading graph.

The results of the compressive strength after high-temperature exposure indicates that, even after an hour, the PP replaced concrete may retain sustainable compressive strength (more than 24 MPa).



(a)

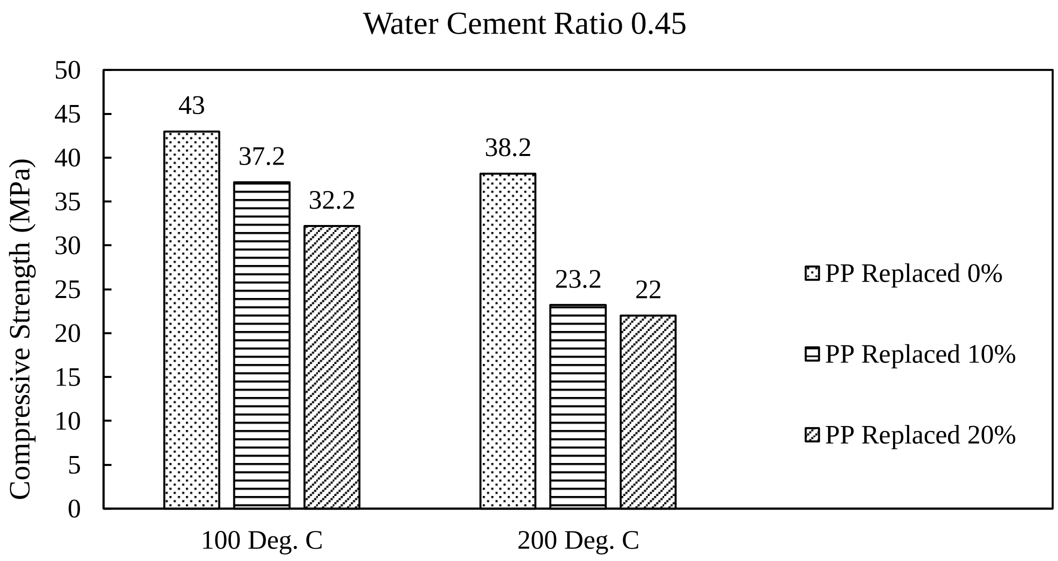


(b)

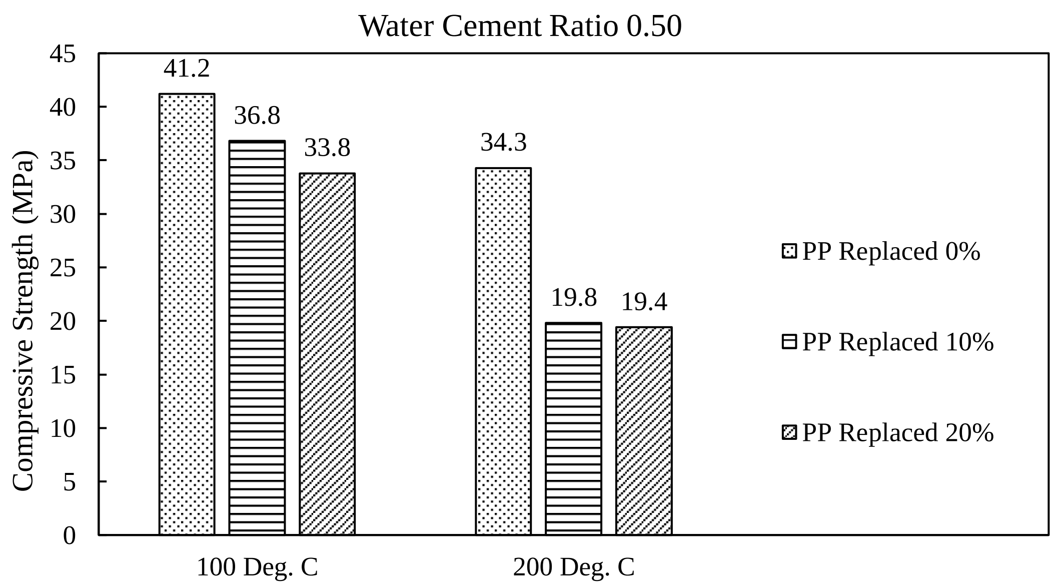
Figure 4. 26: Compressive Strength at High-Temperature Exposure (With Admixture)

For the water-cement ratio of 0.35, at 100°C temperature, compressive strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 8% and 32% respectively. At 200°C temperature, compressive strength reductions for 10% and

20% PP replaced concrete compare to 0% PP replaced concrete is only 23% and 43% respectively. The results shown in Figure 4.26 indicate that 10% PP replaced concrete has a light effect at high temperatures (both 100ºC and 200ºC).



(a)



(b)

Figure 4. 27: Compressive Strength at High-Temperature Exposure (Without Admixture)

For the water-cement ratio of 0.40, at 100°C temperature, compressive strength reductions for 20% PP replaced concrete compare to 0% PP replaced concrete is only 20%. But for 10% PP replaced concrete compressive strength increases by 3% instead compare to 0% PP replaced concrete. At 200°C temperature, compressive strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 6% and 28% respectively. The results shown in Figure 4.25 indicates that 10% PP replaced concrete has less effect at high temperature (both 100°C and 200°C).

For the water-cement ratio of 0.45, at 100°C temperature, compressive strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 13% and 25% respectively. At 200°C temperature, compressive strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 39% and 42% respectively. The results shown in Figure 4.26 indicate that 10% PP replaced concrete has a light effect at high temperatures (both 100°C and 200°C).

For the water-cement ratio of 0.50, at 100°C temperature, compressive strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 10% and 18% respectively. At 200°C temperature, compressive strength reductions for 10% and 20% PP replaced concrete compare to 0% PP replaced concrete is only 42% and 43% respectively. The results shown in Figure 4.27 indicates that 10% PP replaced concrete can be used at high temperature (both 100°C and 200°C) because of its sustainable strength.

4.13 Summary

For evaluating the strength and durability performances of the PP concrete, several tests were done. Based on the test results following general conclusions can be made for PP concrete. With the increasing PP percentage, the workability remains almost similar yet sometimes better. The density decreases with an increased percentage of PP replacement;

that is an indication that PP can be used to produce lightweight concrete with workability like regular concrete.

The compressive strength of PP concrete decreases but decreasing strength is not significant. From stress vs strain behavior, it has been observed that PP concrete shows better ductility behavior than regular concrete.

Toughness Index of PP concrete is higher than regular concrete. Modulus of Elasticity of PP concrete decreases but the result is satisfactory and shows linear relation with regular concrete. The tensile strength of PP concrete reduces but the reducing rate is minimal. Decreasing of flexure strength for PP concrete is minimum.

The shrinkage value of PP concrete increases but the results remain in the allowable range. Chloride penetrability of PP replaced concrete increases but most of the cases they are in the moderate category. In case of higher temperature, PP replaced concrete reduces its strengths much but shows sustainable strength.

CHAPTER 5 CONCLUSIONS AND RECOMENDATIONS

5.1 General

Waste PP is very harmful to the environment. It is impossible to remove PP wastage or stop the use of PP products from a developing country like Bangladesh. It is necessary to recycle and reuse PP products in such a way that PP cannot affect the environment. On the other hand, our natural resource stone is decreasing day by day for using it as a construction material. Therefore, to find the alternative of natural stones for construction purposes, using PP partially in the concrete as the replacement of coarse aggregate can be a significant way to reduce PP waste from the environment and sustainable way to preserve our natural resource stone. Therefore, in the present study PP waste has been adopted in concrete at various percentages (0, 10 and 20% by volume) as a partial replacement of coarse aggregate. Test of various materials such as cement, stone, PP and sand were performed; and based on the test results concrete mix design was prepared for total 12 combinations of the concrete mixtures with four different w/c ratios (with admixture: 0.35 and 0.4; without admixture: 0.45 and 0.5). Concrete cylinders and beams were water cured for 7 – 90 days and various tests were performed to achieve various fresh, hardened, and durability properties of concrete with PP aggregate. The test includes slump value, density, compressive strength, split tensile strength, flexural strength, pull out strength, chloride ion penetration, and shrinkage. The effect of high temperature in the compressive strength also determined for the polypropylene replacement. By using a digital compressometer with two LVDTs data were also collected for stress vs strain behavior and elastic modulus accordingly.

5.2 Conclusions

Based on the analysis of the test results several conclusions regarding concrete with PP can be made:

a. With the increment in PP percentage, slump value has been also increased. For the water-cement ratio of 0.35, 0.40, 0.45, and 0.50, the ranges of slump values were 85 to 172mm, 103 to 185mm, 108 to 205mm, and 136 to 225 mm respectively. After 15 minutes of mixing, slump value decreases but remained within the same ranges which indicate higher workability performance for a longer duration compared to regular concrete.

b. With the increase of PP percentage, the density of the concrete decreases due to the lower unit weight of PP. At different water-cement ratios, with or without admixture in mix design, the density of concrete decreases linearly between 4 to 10% with the increase of PP content.

c. PP concrete has a lower compressive strength as well as the lower tensile strength. With the increasing amount of PP percentage in the concrete, compressive strength, tensile strength and pull out force of the concrete were decreasing albeit in a lower percentage. It is to be expected as the synthetic nature of the PP provides lesser bonding with the cement mortar compare to the natural stone aggregate. For 10% and 20% PP replacement, the compressive strength reduces between 7 to 16% and 19 to 26 %, respectively.

d. The tensile strength also shows similar nature of decrement with increasing PP percentage. The relative reduction was between 3 to 15% and 20 to 24 % respectively for 10 and 20% replacement.

e. The stress-strain curve of PP concrete containing 10% and 20% replacement indicated that PP replaced concrete has better ductile behavior and toughness index than regular concrete. The toughness increases with increasing PP replacement at 10%, and decreases at 20%. For the water-cement ratio of 0.35, 0.40, 0.45, and 0.50, the ranges of toughness index were +2% to -24%, +33 to -21%, +39 to -24%, and +77 to -11%, respectively.

f. Modulus of Elasticity decreases with increasing PP Replacement. For 10 % PP replacement, the reduction of MOE was between 4 to 20 % and for 20% PP replacement it was between 9 to 25 %.

g. There was around 10~34 % deviation with standard sample for the Chloride Ion Penetration values but he results of the chloride ion penetrability of PP replaced concrete indicates with the replacement of PP there is almost no effect on the durability aspect in terms of chloride ion penetration compare to the regular concrete without PP as all the samples are fallen under moderate to low penetrability category.

h. The results of the compressive strength after high-temperature exposure indicates that, even after an hour, the PP replaced concrete may retain sustainable compressive strength. For all the water-cement ratios the relative reduction was between 3 to 32 % and 6 to 43 % for 100°C and 200°C, respectively.

The results of the compressive, tensile, and flexure strength test of PP replaced concrete indicates that PP can be used for structural concrete safely. The structure, made by PP concrete is lighter than regular concrete due to the lower unit weight of PP. Moreover, from the stress vs strain curve, it has been observed that PP concrete shows better ductility behavior compare to the regular concrete. In the case of toughness and modulus of elasticity, PP concrete shows a satisfactory result. Furthermore, PP concrete shows an acceptable durable property. Although PP concrete has more shrinkage and chloride ion penetration values compare to the regular concrete, the effect is minimal and remains within the acceptable range. In case of higher temperature exposure, the compressive strength of PP replaced concrete has reduced but shown a sustainable result. As PP replaced concrete shows satisfactory results both for strength and durability, it can be concluded that the recycled PP can be adopted as partial replacement of coarse aggregate in concrete used for structural purposes.

5.3 Recommendations for Future Study

The findings of this study suggest some further avenues for future use and research. The use of PP concrete as an alternative to the regular concrete in construction is a green concept. Some of the possible research scopes are mentioned below:

a. The water permeability test under hydraulic pressure is recommended for further study.

b. A rapid chloride penetration test (RCPT) is recommended for further study.

c. Though the shrinkage value of concrete beam is measured only for 7days and 35 days, it can be measured for an extended period to analyze the shrinkage behavior of concrete at different ages.

d. Analysis of the microstructure of concrete is the modern approach to examine the interfacial transition zone of concrete. The microstructure of the concrete mixes can be analyzed using Scanning Electron Microscope (SEM) which practically would help to visualize the microstructure of the hydrated cement paste.

REFERENCES

[1] H. I. Abdel-Shafy and M. S. M. Mansour, “Solid waste issue: Sources, composition, disposal, recycling, and valorization,” *Egypt. J. Pet.*, vol. 27, no. 4, pp. 1275–1290, Dec. 2018, doi: 10.1016/j.ejpe.2018.07.003.

[2] M. Braun and W. Amelung, “Plastics in soil: Analytical methods and possible sources,” *Sci. Total Environ.*, vol. 612, pp. 422–435, Aug. 2017, doi: 10.1016/j.scitotenv.2017.08.086.

[3] A. Akhtar and A. Sarmah, “Construction and demolition waste generation and properties of recycled aggregate concrete: A global perspective,” *J. Clean. Prod.*, vol. 186, Mar. 2018, doi: 10.1016/j.jclepro.2018.03.085.

[4] T. Naik and G. Moriconi, “Environmental-friendly durable concrete made with recycled materials for sustainable concrete construction,” Oct. 2005.

[5] H. Abdelmoti and M. Mustafa, “Use of Polypropylene Waste Plastic Pellets as Partial Replacement for Fine Aggregate in Concrete,” vol. 9, pp. 37–43, Feb. 2019.

[6] Igor Novak and Zdenko Spitalsky, “polyolefin in Packaging and Food Industry. In Polyolefin Compounds and Materials,” *Fundam. Ind. Appl. - Switz. Springer Int. Publ.*, p. chapter. 7, P. 181-199.

[7] NobelPrize.org. Nobel Media AB 2020, “The Nobel Prize in Chemistry 1963.” Accessed: Jun. 14, 2019. [Online]. Available: https://www.nobelprize.org/prizes/chemistry/1963/summary/.

[8] M. Masuelli, “Introduction of Fibre-Reinforced Polymers − Polymers and Composites: Concepts, Properties and Processes,” 2013, pp. 3–40.

[9] Statista, "Global production of plastic since 1950." Accessed: Jun. 12, 2019. [Online]. Available: www.statista.com/statistics/282732/global-production-of-plastics-since-1950.

[10] M. Islam, A. K. M. R. Islam, and S. Meherier, "An Investigation on Fresh and Hardened Properties of Concrete while Using Polyethylene Terephthalate (PET) as Aggregate," *Int. J. Civ. Environ. Struct. Constr. Archit. Eng.*, vol. 9, pp. 558–561, Jan. 2015.

[11] L. Lebreton and A. Andrady, "Future scenarios of global plastic waste generation and disposal," *Palgrave Commun.*, vol. 5, Dec. 2019, doi: 10.1057/s41599-018-0212-7.

[12] Creative Mechanisms, "Everything You Need To Know About Polypropylene (PP) Plastic," *www.creativemechanisms.com*. https://www.creativemechanisms.com/blog/all-about-polypropylene-pp-plastic (accessed Jan. 29, 2020).

[13] M. Rahman, "Recycled Polymer Materials as Aggregates for Concrete and Blocks," *J. Chem. Eng. IEB*, vol. 27, pp. 53–57, Jan. 2012, doi: 10.3329/jce.v27i1.15859.

[14] Waste Concern, "Prospects of Plastics Waste Recycling in Bangladesh," *Prospects of Plastics Waste Recycling in Bangladesh*, May 02, 2016. https://wasteconcern.org/prospects-of-plastics-waste-recycling-in-bangladesh/.

[15] P. Laura, "Planet or Plastic," *National Geographic*. https://www.nationalgeographic.com/magazine/2018/06/plastic-planet-waste-pollution-trash-crisis/ (accessed Jan. 27, 2020).

[16] M. Hassanpour, P. Shafigh, and H. Mahmud, "Lightweight aggregate concrete fiber reinforcement – A review," *Constr. Build. Mater.*, vol. 37, pp. 452–461, Dec. 2012, doi: 10.1016/j.conbuildmat.2012.07.071.

[17] F. paolo La mantia, M. Morreale, and Z. Ishak, “Processing and mechanical properties of organic filler–polypropylene composites,” *J. Appl. Polym. Sci.*, vol. 96, pp. 1906–1913, Jun. 2005, doi: 10.1002/app.21623.

[18] A. Grover, A. Gupta, S. Chandra, A. Kumar, and S. Khurana, “Polythene and Environment,” *Environ. Sci. Int. J. Environ. Physiol. Toxicol.*, vol. 5, pp. 1091–1105, Jun. 2015.

[19] A. Ammalaa *et al.*, “An overview of degradable and biodegradable polyolefins,” *Prog. Polym. Sci.*, vol. 36, pp. 1015–1049, Dec. 2010, doi: 10.1016/j.progpolymsci.2010.12.002.

[20] Businesswire, “Global Polypropylene (PP) Market Size, Demand Forecasts, Industry Trends & Updates (2018-2025),” 2018. Accessed: Jan. 12, 2019. [Online]. Available: https://www.businesswire.com/news/home/20181008005560/en/Global-Polypropylene-PP-Market-Size-Demand-Forecasts.

[21] A. Attanasio, A. Largo, I. L. Alvarez, F. Sonzogni, and L. Balaceanu, “Sustainable aggregates from secondary materials for innovative lightweight concrete products,” *Heron*, vol. 60, pp. 5–25, Jan. 2015.

[22] “ASTM C192/C192M.” ASTM International, 2015.

[23] R. S. Ravindrarajah and A. J. Tuck, “Properties of hardened concrete containing treated expanded polystyrene beads,” *Cem. Concr. Compos.*, vol. 16, no. 4, pp. 273–277, 1994, doi: https://doi.org/10.1016/0958-9465(94)90039-6.

[24] K. Lai, S. Rasiah, W. Pasalich, and B. Hall, “Deformation Behaviour of Reinforced Polystyrene Concrete Beam,” 1996.

[25] T. R. Naik, S. S. Singh, C. O. Huber, and B. S. Brodersen, “Use of post-consumer waste plastics in cement-based composites,” *Cem. Concr. Res.*, vol. 26, no. 10, pp. 1489–1492, 1996, doi: https://doi.org/10.1016/0008-8846(96)00135-4.

[26] B. Sabaa and S. Rasiah, “Engineering properties of lightweight concrete containing crushed expanded polystyrene waste,” *Fall Meet. Symp. MM Adv. Mater. Cem. Compos. Dec. 1997*, 1997.

[27] K. G. Babu and D. S. Babu, “Behaviour of lightweight expanded polystyrene concrete containing silica fume,” *Cem. Concr. Res.*, vol. 33, no. 5, pp. 755–762, 2003, doi: https://doi.org/10.1016/S0008-8846(02)01055-4.

[28] B. Chen and J. Liu, “Properties of lightweight expanded polystyrene concrete reinforced with steel fiber,” *Cem. Concr. Res.*, vol. 34, no. 7, pp. 1259–1263, 2004, doi: https://doi.org/10.1016/j.cemconres.2003.12.014.

[29] M. Elzafraney, P. Soroushian, and M. Deru, “Development of Energy-Efficient Concrete Buildings Using Recycled Plastic Aggregates,” *J. Archit. Eng.*, vol. 11, 2005, doi: 10.1061/(ASCE)1076-0431(2005)11:4(122).

[30] Y.-W. Choi, D.-J. Moon, J.-S. Chung, and S.-K. Cho, “Effects of waste PET bottles aggregate on the properties of concrete,” *Cem. Concr. Res.*, vol. 35, no. 4, pp. 776–781, 2005, doi: https://doi.org/10.1016/j.cemconres.2004.05.014.

[31] D. S. Babu, K. G. Babu, and T. H. Wee, “Properties of lightweight expanded polystyrene aggregate concretes containing fly ash,” *Cem. Concr. Res.*, vol. 35, no. 6, pp. 1218–1223, Jun. 2005, doi: https://doi.org/10.1016/j.cemconres.2004.11.015.

[32] H. A.K., M. Arabani, and M. Karami, “Applications of expanded polystyrene (EPS) beads and polyamide 66 in civil engineering, Part Two: Stabilization of clayey sand by lime/polyamide-66,” *Compos. Interfaces - COMPOS INTERFACE*, vol. 13, pp. 451–459, 2006, doi: 10.1163/156855406777408593.

[33] D. Babu, ko ganesh babu, and W. Tiong-Huan, “Effect of polystyrene aggregate size on strength and moisture migration characteristics of lightweight concrete,” *Cem. Concr. Compos.*, vol. 28, pp. 520–527, 2006, doi: 10.1016/j.cemconcomp.2006.02.018.

[34] M. Batayneh, I. Marie, and I. Asi, “Use of selected waste materials in concrete mixes,” *Waste Manag.*, vol. 27, no. 12, pp. 1870–1876, Jan. 2007, doi: 10.1016/j.wasman.2006.07.026.

[35] Z. Z. Ismail and E. A. AL-Hashmi, “Use of waste plastic in concrete mixture as aggregate replacement,” *Waste Manag.*, vol. 28, no. 11, pp. 2041–2047, 2008, doi: https://doi.org/10.1016/j.wasman.2007.08.023.

[36] W. C. Tang, Y. Lo, and A. Nadeem, “Mechanical and drying shrinkage properties of structural-graded polystyrene aggregate concrete,” *Cem. Concr. Compos.*, vol. 30, no. 5, pp. 403–409, 2008, doi: https://doi.org/10.1016/j.cemconcomp.2008.01.002.

[37] Y. W. Choi, D. J. Moon, Y. J. Kim, and M. Lachemi, “Characteristics of mortar and concrete containing fine aggregate manufactured from recycled waste polyethylene terephthalate bottles,” *Constr. Build. Mater.*, vol. 23, no. 8, pp. 2829–2835, 2009, doi: http://dx.doi.org/10.1016/j.conbuildmat.2009.02.036.

[38] S. C. Kou, G. Lee, C. S. Poon, and W. W. L. Lai, “Properties of lightweight aggregate concrete prepared with PVC granules derived from scraped PVC pipes,” *Waste Manag.*, vol. 29, pp. 621–8, 2008, doi: 10.1016/j.wasman.2008.06.014.

[39] S. Akçaözoğlu and C. D. Atiş, “Effect of Granulated Blast Furnace Slag and fly ash addition on the strength properties of lightweight mortars containing waste PET aggregates,” *Constr. Build. Mater.*, vol. 25, no. 10, pp. 4052–4058, 2011, doi: http://dx.doi.org/10.1016/j.conbuildmat.2011.04.042.

[40] P. Lima, M. Leite, and E. Santiago, “Recycled lightweight concrete made from footwear industry waste and CDW,” *Waste Manag.*, vol. 30, pp. 1107–13, 2010, doi: 10.1016/j.wasman.2010.02.007.

[41] M. Frigione, “Recycling of PET bottles as fine aggregate in concrete,” *Waste Manag.*, vol. 30, no. 6, pp. 1101–1106, 2010, doi: https://doi.org/10.1016/j.wasman.2010.01.030.

[42] J. O. Akinyele, R. W. Salim, and G. Oyeti, “Use of Recycled Polypropylene Grains as Partial Replacement of Fine Aggregate in Reinforced Concrete Beams,” *Eng. Struct. Technol.*, vol. 6, no. 4, pp. 184–190, Oct. 2014, doi: 10.3846/2029882X.2015.1070697.

[43] R. V. Silva, J. de Brito, and N. Saikia, “Influence of curing conditions on the durability-related performance of concrete made with selected plastic waste aggregates,” *Cem. Concr. Compos.*, vol. 35, no. 1, pp. 23–31, 2013, doi: https://doi.org/10.1016/j.cemconcomp.2012.08.017.

[44] B. M. A. Herki, J. Khatib, and E.-S. Negim, “Lightweight Concrete Made from Waste Polystyrene and Fly Ash,” 2013.

[45] S. Akçaözoğlu and C. Ulu, “Recycling of waste PET granules as aggregate in alkali-activated blast furnace slag/metakaolin blends,” *Constr. Build. Mater.*, vol. 58, pp. 31–37, 2014, doi: https://doi.org/10.1016/j.conbuildmat.2014.02.011.

[46] M. J. Islam, M. S. Meherier, and A. K. M. R. Islam, “Effects of waste PET as coarse aggregate on the fresh and harden properties of concrete,” *Constr. Build. Mater.*, vol. 125, pp. 946–951, 2016.

[47] Baboo Rai, S. Tabin Rushad, and Bhavesh Kr, “Study of Waste Plastic Mix Concrete with Plasticizer,” *Int. Sch. Res. Netw.*, vol. Volume 2012, Article ID 469272, p. 5, Mar. 2012, doi: doi:10.5402/2012/469272.

[48] Y. Xu, L. Jiang, J. Xu, and Y. Li, “Mechanical properties of expanded polystyrene lightweight aggregate concrete and brick,” *Constr. Build. Mater.*, vol. 27, no. 1, pp. 32–38, 2012, doi: https://doi.org/10.1016/j.conbuildmat.2011.08.030.

[49] RS Ravindrarajah, “Bearing strength of concrete containing polystyrene aggregate.,” in *National Research Council Canada*, 1999, pp. 505–514.

[50] R. Madandoust, M. M. Ranjbar, and S. Y. Mousavi, “An investigation on the fresh properties of self-compacted lightweight concrete containing expanded polystyrene,” *Constr. Build. Mater.*, vol. 25, no. 9, pp. 3721–3731, 2011, doi: https://doi.org/10.1016/j.conbuildmat.2011.04.018.

[51] R. Wang and C. Meyer, “Performance of cement mortar made with recycled high impact polystyrene,” *Cem. Concr. Compos.*, vol. 34, no. 9, pp. 975–981, 2012, doi: https://doi.org/10.1016/j.cemconcomp.2012.06.014.

[52] P. Asokan, M. Osmani, and A. D. F. Price, “Assessing the recycling potential of glass fibre reinforced plastic waste in concrete and cement composites,” *J. Clean. Prod.*, vol. 17, no. 9, pp. 821–829, 2009, doi: https://doi.org/10.1016/j.jclepro.2008.12.004.

[53] J. Galvão, K. Portella, A. Joukoski, R. Mendes, and E. Ferreira, “Use of waste polymers in concrete for repair of dam hydraulic surfaces,” *Constr. Build. Mater.*, vol. 25, pp. 1049–1055, 2011, doi: 10.1016/j.conbuildmat.2010.06.073.

[54] N. Saikia and J. de Brito, “Use of plastic waste as aggregate in cement mortar and concrete preparation: A review,” *Constr. Build. Mater.*, vol. 34, pp. 385–401, 2012, doi: http://dx.doi.org/10.1016/j.conbuildmat.2012.02.066.

[55] L. Ferreira, J. de Brito, and N. Saikia, “Influence of curing conditions on the mechanical performance of concrete containing recycled plastic aggregate,” *Constr. Build. Mater.*, vol. 36, pp. 196–204, 2012, doi: https://doi.org/10.1016/j.conbuildmat.2012.02.098.

[56] J. M. Irwan and F. Sheikh Khalid, “Relationship between compressive, splitting tensile and flexural strength of concrete containing granulated waste polyethylene

terephthalate (PET) bottles as fine aggregate," *Adv. Mater. Res.*, vol. Volume 795, pp. 356–359, 2013, doi: 10.4028/www.scientific.net/AMR.795.356.

[57] A. B. Fraj, M. Kismi, and P. Mounanga, "Valorization of coarse rigid polyurethane foam waste in lightweight aggregate concrete," *Constr. Build. Mater.*, vol. 24, no. 6, pp. 1069–1077, 2010, doi: https://doi.org/10.1016/j.conbuildmat.2009.11.010.

[58] R. Serrano, A. Cobo, M. Prieto, and M. González García, "Analysis of fire resistance of concrete with polypropylene or steel fibers," *Constr. Build. Mater.*, vol. 122, pp. 302–309, Sep. 2016, doi: 10.1016/j.conbuildmat.2016.06.055.

[59] "ASTM C143/C143M," *Stand. Test Method Slump Hydraul.-Cem. Concr.*, vol. PA 19428-2959, 2015, doi: 10.1520/C0143_C0143M-15.

[60] "ASTM C39/C39M," *Stand. Test Method Compressive Strength Cylind. Concr. Specim.*, vol. PA 19428-2959, 2015, doi: 10.1520/C0039_C0039M-15A.

[61] ASTM, "ASTM C496/C496M." ASTM International, 2011.

[62] ASTM, "ASTM C78 / C78M-18, Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)," *ASTM Int.*, 2018, doi: 10.1520/C0143_C0143M-15A.

[63] ASTM International, "ASTM C900-19, Standard Test Method for Pullout Strength of Hardened Concrete," *ASTM Int. West Conshohocken PA 2019 Wwwastmorg*, 2019, doi: 10.1520/C0900-19.

[64] ASTM International, "ASTM C157 / C157M-17, Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete," *ASTM Int.*, 2017, doi: 10.1520/C0157_C0157M-17.

[65] ASTM International, "ASTM C469 / C469M-14, Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression," 2014, doi: 10.1520/C0469_C0469M-14.

[66] AASHTO, "AASHTO TP 95. 2012. Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration," *Am. Assoc. State Highw. Transp. Off.*, 2012.

[67] ASTM, "ASTM C33 / C31M-18, Standard Specification for Concrete Aggregates,." ASTM International, 2013.

[68] S. Rahman and M. A. Azad, *Effects on Properties of Coarse Aggregate with Respect to Different Sources*. 2020.

[69] Bartos, M. Sonebi, and Tamimi, *Workability and Rheology of Fresh Concrete: Compendium of Tests*. 2002.

[70] ACI, "ACI 318-14." American Concrete Institute, 2014.