INVESTIGATE THE EFFECTS OF INCORPORATION OF POWDERED FORM PLASTIC AS PARTIAL CEMENT REPLACEMENT ON THE PERFORMANCE OF CONCRETE

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INVESTIGATE THE EFFECTS OF INCORPORATION OF POWDERED FORM PLASTIC AS PARTIAL CEMENT REPLACEMENT ON THE PERFORMANCE OF CONCRETE

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A project report submitted in partial fulfilment of the

requirements for the award of the degree of

Bachelor of Engineering (Honours) Environmental Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"INVESTIGATE THE EFFECTS OF INCORPORATION OF POWDERED FORM PLASTIC AS PARTIAL CEMENT REPLACEMENT ON THE PERFORMANCE OF CONCRETE"** was prepared by **PAN DE WEI** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons) Environmental Engineering at Universiti Tunku Abdul Rahman.

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Date : 22 April 2022

Specially dedicated to

my beloved family members.

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ABSTRACT

Plastic waste is a major component of the global waste stream. The accumulation of vast amounts of plastic waste has led to numerous environmental problems due to its non-biodegradable nature. At the same time, cement manufacturing releases an enormous amount of carbon dioxide into the atmosphere. This research suggested the incorporation of plastic waste in powder form as partial cement replacement in the manufacturing of concrete. Using plastic waste as a replacement for cement will reduce the amount of plastic waste and the demand for cement. As a result, the environmental impact of plastic waste and cement will be lowered. This research replaced a partial amount of cement with plastic waste powder at 4%, 8%, 12%, and 16% by cement weight. The type of plastic waste used in this study is PVC plastic. A total of eight types of tests were conducted to determine the properties of concrete, including slump test, compressive strength test, flexural strength test, porosity test, water absorption test, gas permeability test, chloride penetration test, and SEM-EDX analysis. The experimental results revealed that the workability of concrete with substitution of PWP as partial cement replacement is increased. The concrete specimen with 16% of cement being replaced by PWP obtained the highest workability in this study which is 63 mm. In addition, the mechanical and durability properties of the concrete specimen with 4% of cement being replaced by PWP are similar to the control specimen, which does not contain any PWP. The highest compressive strength of concrete can be produced from this study after being cured for 28 days is 22.88 MPa when 4% of PWP used to partially replace cement. However, the further increment of PWP substitution will reduce the mechanical and durability properties of concrete. Moreover, the cost of manufacturing the 1 m^3 concrete with 4% PWP as cement substitution is RM 215.42 which is lower than the conventional concrete (RM 210.9).

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LIST OF SYMBOLS / ABBREVIATIONS

cm	Centimeter
cm^3 /s	Cubic centimeter per second
˚C	Degree Celsius
g	Gram
kg	Kilogram
N/mm^2	Newton per millimeter square
MPa	Megapascal
MPa/sec	Megapascal per second
m	Meter
m^3	Meter cube
mm	Millimeter
µm	Micrometer
%	Percentage
psi	Pounds per square inch
RM	Ringgit Malaysia
$AgNO_3$	Silver Nitrate
Al_2O_3	Aluminium Trioxide
$CaCO_3$	Calcium Carbonate
CaO	Calcium Oxide
$Ca(OH)_2$	Calcium Hydroxide
$CaSO_4$	Calcium Sulphate
CO_2	Carbon Dioxide

C-S-H	Calcium Silicate Hydrate
C_2S	Dicalcium Silicate
C_3S	Tricalcium Silicate
Fe_2O_3	Ferric Oxide
MgO	Magnesium Oxide
SiO_2	Silicon Dioxide

ASTM	American Society of Testing and Materials
BFSC	Blast Furnace Slag Cement
BPA	Bisphenol A
BS EN	British Standard European Norm
CAGR	Compound Annual Growth Rate
EDX	Energy Dispersive X-Ray Spectroscopy
HAC	High-alumina Cement
HDPE	High-density Polyethylene
HpC	Hydrophobic Cement
LDPE	Low-density Polyethylene
LHC	Low-heat Cement
MPW	Metalized Plastic Waste
MSW	Municipal Solid Waste
OPC	Ordinary Portland Cement
PE	Polyethylene
PET	Polyethylene Terephthalate
PP	Polypropylene
PPEs	Personal Protective Equipment
PS	Polystyrene
PUR	Polyurethane
PVC	Polyvinyl Chloride

RHC	Rapid-hardening Cement
SEM	Scanning Electron Microscopy
SRC	Sulphate-resisting Cement
QSC	Quick-setting Cement
WC	White Cement

C**S**	Control Specimen
PW	PVC Waste
PWP	PVC Waste Powder
PWP4	4 % substitution amount of PWP
PWP8	8 % substitution amount of PWP
PWP12	12 % substitution amount of PWP
PWP16	16 % substitution amount of PWP

CHAPTER 1

INTRODUCTION

1.1 Background

1.1.1 Production and Consumption of Plastic

Over the past decade, plastic production and consumption have risen at a rapid pace. In 2019, the global production of the plastic was approximately 368 million metric tons as shown in Figure 1.1. It is expected that plastic production will rise to almost 600 million tonnes per year in 2025 (Stiftung, 2019). The characteristics of plastic such as low density, low cost, durable, long life, water-resistant, versatile, and lightweight are the factors that have contributed to such tremendous growth (Mohammed et al., 2020). Malaysia has more than 1,300 plastic manufacturing firms, making it a major participant in the worldwide plastics business. Malaysia's plastics industry contributed RM 30.98 billion to the national economy in 2018 with the usage of 2.45 million tonnes of resin to produce plastics (Chen et al., 2021).

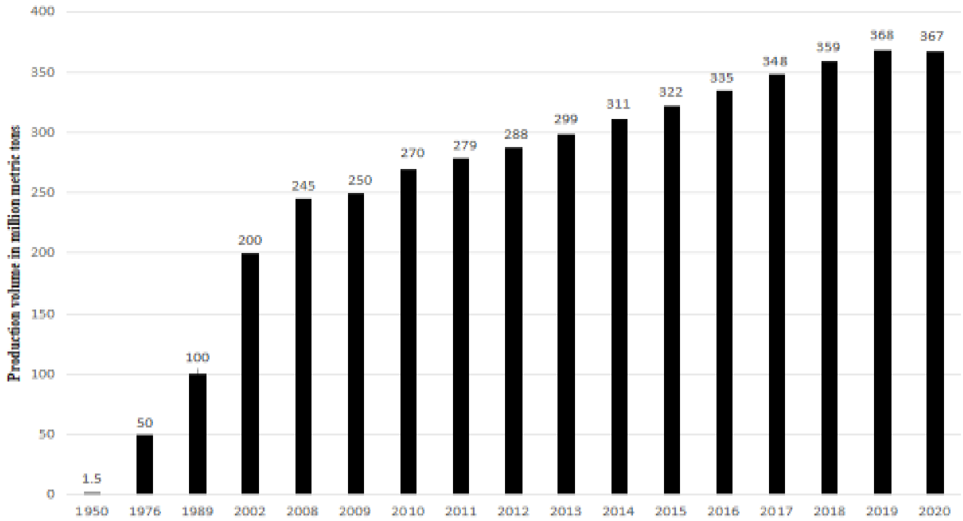


Figure 1.1: Global Plastic Production during 1950-2020 (adapted from Statista, 2021).

Plastic production is increased in tandem with plastic consumption. Almost every aspect of daily life involve plastics, including transportation, telecommunications, clothes, footwear and packaging materials for food, drink and other goods (Thompson et al., 2009). Additionally, plastics have also been used in industrial, medical delivery systems, artificial implants, other healthcare applications as well as water desalination, land/soil conservation, security systems, and other uses (Hossain, Bhowmik and Shaad, 2016). Figure 1.2 displays the distribution of global plastic consumption in 2019. According to the data from Plastic Europe Market Research group, represented in Figure 1.2, the packaging sector is at the dominant position accounting for nearly 40% of plastic consumption, followed by the building and construction sector which accounts (20.4%), the automotive sector (9.6%) and electrical sector (6.2%). Other domains such as appliances, mechanical engineering, furniture, and medical applications are responsible for 16.7% of the total global plastic consumption. In line with worldwide trends, packaging is Malaysia's most significant use for plastics which accounts for 48% of all plastic use (World Bank Group, 2021).

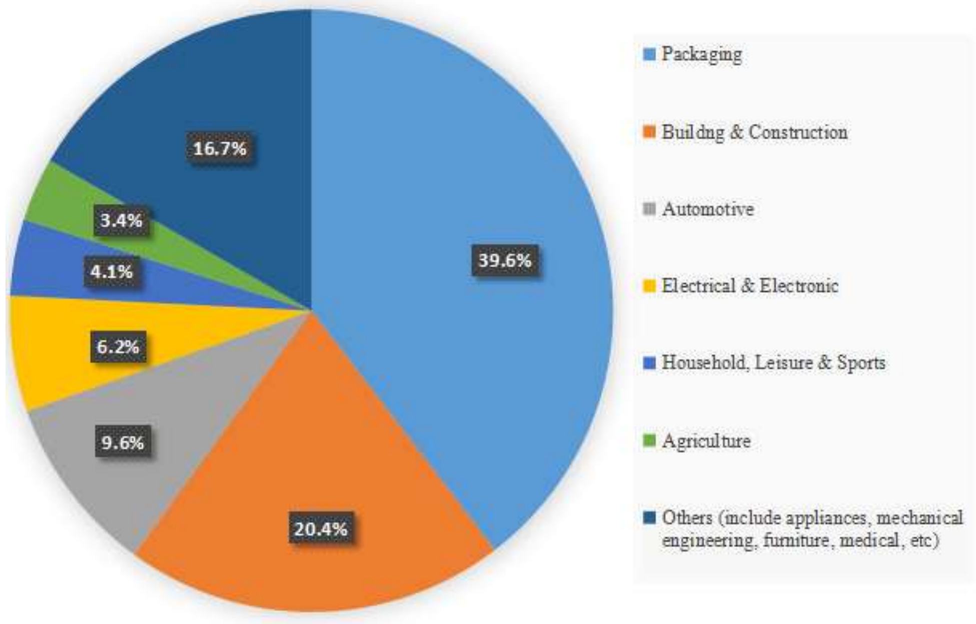


Figure 1.2: Global Plastic Consumption Distribution in 2019 (adapted from Plastics Europe, 2020).

1.1.2 Production and Consumption of Cement

Cement production has grown tremendously since the early 2000s. The industrial production of cement began in the mid-nineteenth century, first with shaft kilns, which were subsequently replaced by rotary kilns as standard equipment across the world (Schneider et al., 2011). In 2020, the production of cement in all over world had reached 4.1 billion tonnes as shown in Figure 1.3. In 2021, Malaysia manufactured around 19.96 million metric tons of cement (Statista, 2022).

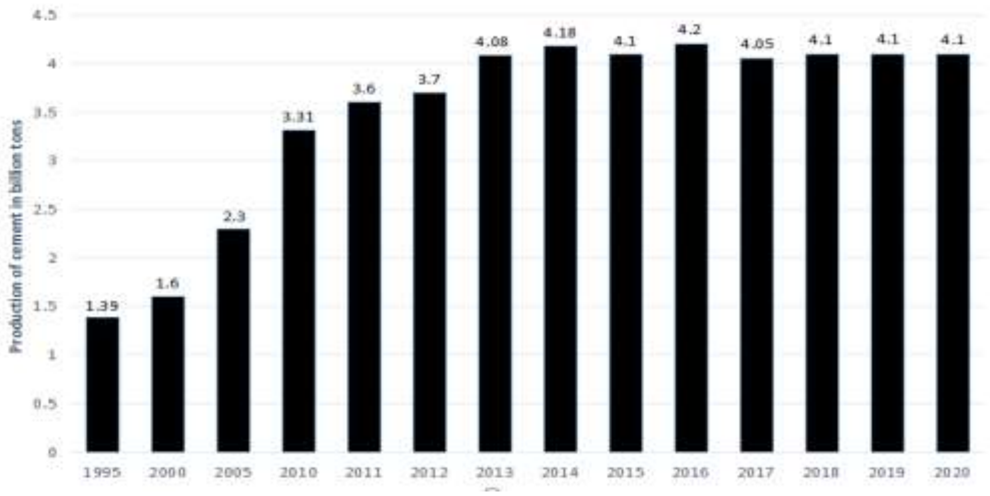


Figure 1.3: Global Cement Production during 1995-2020 (adapted from Statista, 2021).

Cement consumption is often heavily linked to the demand from the construction industry. This is due to cement is an extremely important construction material since it is a major component of important building materials such as concrete and mortar. It is used in the construction of various structures that contributed to the development of the modern world such as buildings, bridges, highways, and roads. According to the different surveys, in 2021 the total volume of cement consumption reached approximately 4.42 billion tonnes. From 2018 to 2021, the compound annual growth rate is approximately 2.96% (Koncept Analytics, 2019). The consumption of the cement has increased due to the certain factors such as increased activities of construction, urbanization, and high population density. The rapid growth of population has increased the demand for residential buildings, increasing the construction of housing complexes. The development of mega infrastructure projects around the world is another key factor for the growth of consumption of cement, especially in emerging economies. For instance, mega construction projects, such as the construction of Merdeka 118 tower in Malaysia is expected to significantly increase cement sales in Malaysia.

1.2 Problem Statement

Plastic has brought prosperity to humans, yet it has also brought limitations and problems as their main advantage has turned out to be the main problem. Being less expensive than traditional materials, plastics allow for single-use in a variety of applications such as food packaging and plastic-based Personal Protective Equipment (PPEs). These items were created to be used only once and then discarded. As a result, the global production of plastic waste (PW) reaches 300 million tons per year as shown in Figure 1.4 and is expected to double in the following decade (Rathore, Chouhan and Prakash, 2021). Moreover, the non-biodegradable plastic has an extremely slow degradation process that takes hundreds to thousands of years to complete. This will cause the accumulation of plastic waste in the environment for a long period if the plastic waste is not managed appropriately. Environmental issues involved with plastic waste have become a significant problem in Malaysia, which is listed eighth among the world's top 10 nations with poorly handled plastic waste. As of 2018, Malaysia generated 0.94 million tons of unmanaged plastic waste annually (Chen et al., 2021).

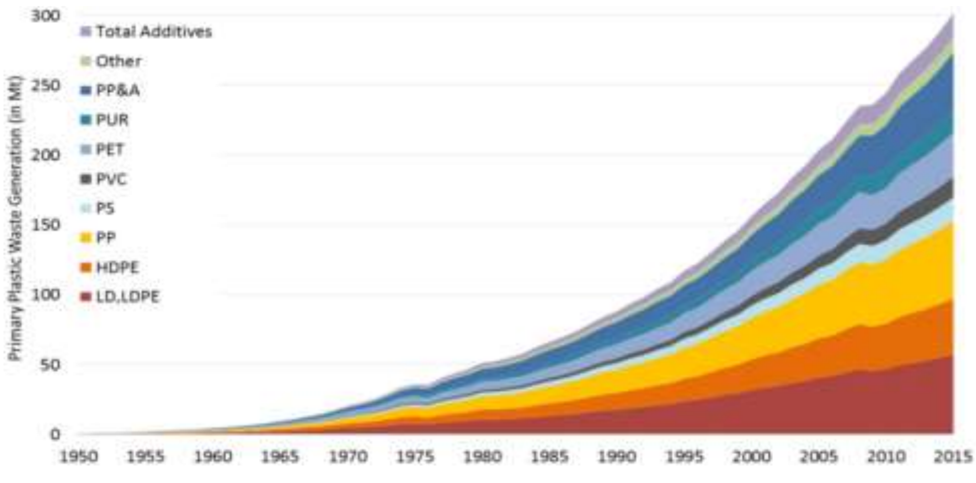


Figure 1.4: Generation of Plastic Waste during 1950-2015 (Adapted from Rathore, Chouhan and Prakash, 2021).

There are several methods of dealing with plastics waste which are land-filling, recycling and incineration (Almeshal et al., 2020). Landfilling and incineration are not favored methods owing to the additional area needs for landfill and the high levels of carbon dioxide and other dangerous chemicals released during burning. Besides that, plastic waste contains Bisphenol A (BPA), flame retardants, phthalates and heavy metals such as lead and cadmium, can leach from landfills and polluted the groundwater (Chen et al., 2021). Recycling plastic is the most effective method rather than land-filling and incineration (Awoyera and Adesina, 2020). It transforms the plastic waste into usable material which generates financial, environmental, and social benefits as a result of its use. Therefore, Recycling is one of the most economically and environmentally sensible ways for dealing with plastic trash on a long-term basis.

On the other side, the cement industry is facing a huge problem which is high carbon dioxide (CO_2) emissions from the production of cement (Schneider et al., 2011). The usage of fossil fuels, as well as the decarbonization of limestone in clinker production, are responsible for the high CO_2 emissions (Stafford et al., 2016). The emission of CO_2 from the cement industry accounts for 5 – 7 % of total worldwide CO_2 emissions (He et al., 2019). Malaysia's CO2 emissions from cement manufacturing climbed from 1,457 thousand metric tons in 1995 to 2,992 thousand metric tons in 2014 (Knoema, 2016). Despite this problem, the production of cement cannot be reduced due to the high consumption of cement by the construction industry. Cement is the major ingredient in concrete where the latter is the major and common building material applied extensively in the construction of buildings. Hence, finding an alternative material as the replacement of cement in the concrete manufacturing process may stop the increasing trend of the production of cement. As a result, non-biodegradable plastic waste is a good choice to use as a replacement for cement. By recycling PW as cement in concrete manufacturing, the environmental problem generated from plastic waste and the production of cement may be solved.

1.3 Aims and Objectives

The objectives of this study are listed as below:

i) To determine the optimal substitution ratio of plastic waste powder in concrete.

ii) To investigate the effects of plastic waste powder in concrete by comparing the properties of concrete with and without plastic waste powder.

iii) To determine the characterization of concrete such as workability, compressive strength, flexural strength, water absorption, porosity, gas permeability of concrete.

1.4 Scope of Study

The scope of study in this research is to investigate the performance of concrete using varying proportion of plastic waste powder as cement substitute. The type of plastic waste used in this is study is PVC plastic. The proportions of PVC waste powder (PWP) to replace cement in concrete specimens for this study are 4%, 8%, 12%, and 16% particularly. The concrete without PWP were served as the control specimen of this study. Several tests were conducted in this research to investigate the impact of PWP on the properties of concrete. In fresh concrete state, the slump test was conducted in order to determine the workability of concrete. In harden concrete state, the mechanical and durability properties of concrete were tested. The mechanical properties of concrete specimens were investigated by conducting compressive strength test, flexural strength test and Scanning Electron Microscopy (SEM) test whereas the durability of concrete specimens were determined by undergoing water absorption, porosity, gas permeability, and chloride penetration test. Prior to the testing, the concrete specimens were cured in a water tank for 7, 14, and 28 days, respectively.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of Plastic

Plastic is a man-made material that is widely used for a variety purpose. In the definition of plastic, Millet et al., (2018) explained that: “The word plastic is derived from a Greek word “plastikos”. The meaning of plastikos is to be formed in different shapes. This refers to the material’s malleability, or plasticity during manufacture, which allows it to be cast, pressed, or extruded into a variety of shapes”. Plastic is a synthetic polymeric material. It has high molecular weight and manufactured from a wide range of organic compounds such as vinyl alcohol vinyl chloride, vinyl acetate, ethylene, and so on. The raw materials of plastic are usually natural gas, oil, coal, and crude oil (Ilyas et al., 2018).

2.1.1 History of Plastic

Several centuries Before Christ, men were already developing plastics by using natural materials such as rubber, shellac, horn and turtle scale which have plastic properties. The development of artificial, synthetic plastics only began in the late 18th century (Millet et al., 2019).

In the 1850s, Alexander Parkes developed the thermoplastic nitrocellulose by processing cellulose with nitric acid. Thermoplastics is a general term that refers to plastics that are characterized by the ability to be moulded when heated and retained their shape when cooled. Alexander Parkes develop the material called Parkesine in England in 1856 (Geyer, 2020). Parkesine is known as the first man-made polymer but it was not totally synthetic at the time (Rhodes, 2018). Hence, it was a commercial failure (Geyer, 2020). Over a decade later, in 1869, celluloid was created by the American inventor John Wesley Hyatt by combining camphor with Parkesine (nitrocellulose). Celluloid became famous as it could be manufactured into a photographic film. As a result, Celluloid was the first man-made polymer to achieve commercial success (Geyer, 2020)

According to the history, in the early 1900s, the first synthetic polymer in the world was created by Las created by Baekeland. He combined formaldehyde with phenol to form the synthetic thermoset (Geyer, 2020). In 1907, Baekeland filed patents in the United States and other countries for the new material as Bakelite. The invention of Bakelite and Celluloid is known as the beginning of the plastic age, despite the fact that their production volumes were negligible in comparison to current production volumes. (Geyer, 2020). The invention of Bakelite and Celluloid also opened the doors to many of now-familiar synthetic plastics which are cellophane in 1913, then polyvinyl chloride in 1927, polyethylene in 1935, polyurethane and nylon in 1937 and 1938 respectively as well as polystyrene in 1944 (Chalmin, 2019). The important events in plastic’s history are shown in Table 2.1.

According to different surveys, the production of plastic more than doubled to almost 25 million metric tonnes between 1950 and 1970 (Chalmin, 2019). Many plastic products have first appeared in this period such as the world's first Tupperware appeared in 1946, the first plastic draining rack appeared in 1950 and the first plastic bottles appeared in 1968 (Chalmin, 2019). In 1980, the total production of plastic was approximately 60 million metric tons over the world. In 2000, plastic production had been reached 187 million metric tons, then in 2010, the volume of plastic production reached to 270 million and 367 million in 2020 (Statista, 2021). Since 1950, plastic manufacturing has grown at an annual pace of 8.5 percent on average (Chalmin, 2019).

Table 2.1: Important Event in the Plastic's History (Rhodes, 2018; Chalmin, 2019).

Year	Event
1862	The first man-made plastic, called Parkesine invented by Alexander Parkes.
1869	John Wesley Hyat invented Celluloid by adding camphor to Parkesine (nitrocellulose) as a plasticise.
1907	Leo Baekeland invented the first entirely synthetic thermosetting resin known as Bakelite by condensing formaldehyde with phenol.
1913	Edwin Brandenberger made the first flexible and perfectly transparent material which is cellophane.
1927	Waldo Semon plasticise Polyvinyl Chloride by combining it with a variety of additives.
1933	The most used plastic in the world, polyethylene was created by E.W. Fawcett and R.O. Gibson.
1937	Polyurethane was discovered by Dr Otto Bayer.

1938	The first nylon was produced by Wallace Hune Carothers.
1944	developed The Polyethylene was developed by Ray McIntire .
1954	The Polypropylene was discovered by Giulio Natta.

2.1.2 Production of Plastic

The production of plastics begins with drilling and extracting the raw material from the reserves. . The process to extract the raw material is done by the heavy machinery. After extraction, the collected raw material is sent through the pipes to the petrochemical refinery. The column of distillation is utilized in the refinery process to separate the heavy crude oil into groups of lighter materials, known as fractions. Fraction is a combination of chains of hydrocarbon with different sizes, weights, and boiling temperatures. One of these fractions, naphtha is the is the central compound to produce plastic It is heated through a process known as steam cracking. This process breaks it down into benzene, ethylene, propylene, and several other products. All of these compounds are then further processed in petrochemical facilities through polymerisation to create polymers. (Andrady, 2015).

Polymerisation is a process of linking the monomers such as ethylene, propylene, and butylene to form polymers. This process results from two kinds of chemical reactions called condensation and addition. The monomers are chemically linked together into chains that form the chains of long polymer. Each polymer has its belongings, structure, and size depend on the basic monomers that are used in the process. These polymers, which are formed from the polymerisation process, are used as raw materials in the production of plastic items such as plastic bags, food containers and drink bottles (Andrady, 2015).

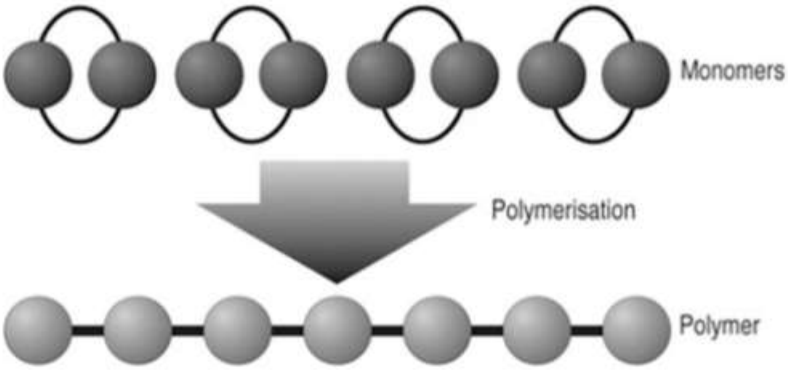


Figure 2.1: Polymerisation Process (adapted from Andrady, 2015).

Polymers formed from the polymerisation process are in the form of powders, granules, or laces, which are subsequently gaining special properties by adding additives. The term "additives" refers to chemical substances that are incorporated into polymers to enhance their performance. functionality, and ageing properties (Hahladakis et al., 2018). The additives can be divided into 4 categories which are shown in Table 2.2.

Table 2.2: Type of Additives (Hahladakis et al., 2018).

Categories	Example
Functional additives	Antistatic agents, Plasticizers, Stabilizers, curing agents, Lubricants, Slip agents, Foaming agents flame retardants.
Colourants	Soluble azocolorants, Pigments
Fillers	Talc, Clay, Mica, Barium sulphate, Kaolin, Talc, Calcium carbonate,
Reinforcements	Carbon fibres, Glass fibres

2.1.3 Type of Plastics

Plastic is classified into two types: thermoplastic and thermoset. Thermoplastic is a type of plastic which can be melted and recast repeatedly on heating. The commonly used thermoplastics are (high and low density) polyethylene (PE), polyethylene terephthalate (PET), polypropylene (PP), polyvinyl chloride (PVC) and polystyrene (PS). The thermoset is a type of plastic which cannot be heated and remoulded forming, for example, polyurethane (PUR), epoxy and silicone (Rhodes, 2018). There are more than 100 types of plastic, but only six are commonly used and found in Municipal Solid Waste (MSW) - all of which are thermoplastics: PE (high and low density), PP, PET and PVC. Table 2.3 summarize the most common used plastics.

Table 2.3: Most Common Used Plastics (National Solid Waste Management Department, 2011; Siddique, Khatib and Kaur, 2008).

Name of plastics	Symbol	Properties	Uses
Polyethylene Terephthalate (PET)		• Clear and tough • Resistance to heat and chemical attacks • High strength and stiffness	• Food container and plastic drink bottles. • Fiber for clothing and carpets.
High-density polyethylene (HDPE)		• High rigidity • High impact strength. • Resistance to chemical attack.	• Container for non-food items such as shampoo and cleaners. • Crinkly shopping bags and freezer bag • Reusable shipping containers.

Polyvinyl chloride (PVC)		• Grease, oil and chemical resistance. • High impact strength. • Excellent weatherability.	• Pipe for sanitary and plumbing as well as their fittings. • Garden hose
Low-density polyethylene (LDPE)		• Soft and flexible • Resistance to acids and bases.	• Carrier bags and heavy-duty bags • Black plastic sheet. • Container lids.
Polypropylene (PP)		• Low density • High melting point • High resistance to chemical and environmental	• Houseware and furniture. • Medicine container. • Bottle caps • Drinking straw.
Polystyrene (PS)		• Stiffness in foamed as well as rigid forms. • Low density in foamed form. • Low heat conductivity and excellent insulation in foamed form.	• Food service packaging. • Foam packing that protects furniture and electronics devices. • Building insulation.

2.1.4 Recyclable Plastic

The symbol of universal plastic resin is the three chasing arrows forming a triangle with a number from 1 to 7 inside it, which are shown in Table 2.3 does not indicate that the product is recyclable. It is only an indication of the type of plastic. The number is a code of identification of resin that identifies the type of plastic used in the material. Table 2.4 summarize recyclable plastic.

Table 2.4 Recyclable Plastic (National Solid Waste Management Department, 2011; Siddique, Khatib and Kaur, 2008).

Name of plastic	Uses for plastic made from recycled waste plastic
Polyethylene terephthalate (PET)	• Polyester fibre • Films and sheet • Packaging and container for food, drinks and non-food items.
High-density polyethylene (HDPE)	• Plastic bottles for non-food items such as, cleaning-agent, shampoo. • Compost bins and mobile rubbish bins. • Agricultural pipes • Film and sheet.
Polyvinyl chloride (PVC)	• Detergent bottles, tiles, plumbing pipe fitting • Film and sheet
Low-density polyethylene (LDPE)	• Film for builders, industry, packaging and plant nurseries • Compost bins, kerbside recycling crates
Polypropylene (PP)	• Automobile application such as battery cases, signal light and battery cables. • Compost bins, kerbside recycling crates

2.1.5 Non-recyclable Plastic

Plastic #6 (PS) is not commonly recycled. Besides that, the plastic with colour and multilayer material also faced difficulty to be recycled. The reason of these plastics cannot be recycled and the impact of these plastic on recycling will stated at Table 2.5.

Table 2.5: Non - Recyclable Plastic (Chandra et al., 2016; World Bank Group, 2021).

Type of plastic	Reasons for not being able to recycle
Polystyrene (PS)	• Polystyrene foam is typically comprised of 95% of air so it is not cost-effective to store or transport it to recycling plant. • It is challenging to clean as its porous nature. • Not enough material left after breaking it down to make new products.
Coloured plastics	• When plastics are coloured, the value of recycled products is reduced because the colour of these plastic cannot be returned to its "natural" colour.
Plastic with multilayer materials	• Recycling equipment can only recycle one type of resin at a time. • The product with abundance of composite or multilayer materials such as electronic waste are difficult disassembled or separated which cause them cannot be recycled.

2.2 Cement

Cement is a very fine substance with adhesive as well as cohesive properties that serve as a binding medium for discrete materials (Madeeasy, 2019). Cement is made by burning and crushing stones that include clay, lime carbonate, and a little amount of magnesia carbonate (Vishnukanth and Rao, 2006). When cement and water are mixed, it forms a paste that hardens and binds aggregates (fine and coarse) together to form a hard durable mass which is known as concrete (Madeeasy, 2019). The cement manufacturing process consists primarily of grinding the raw materials, mixing raw materials in specific proportions, and burning the material in a massive rotating kiln at temperatures as high as 1450 ºC until the material sinters and partly fuses forming ball known as clinker. The clinker is then cooled and ground into a fine powder, and the finished product is known as cement.

Cement used in the construction industry can be divided into two categories which are hydraulic and non-hydraulic (Dunuweera and Rajapakse, 2018). Hydraulic cement sets and hardens relatively quickly in the presence of water due to the hydration process which is a chemical action between cement and water and produces a stable and water resistance product (Madeeasy, 2019). This enables for setting in wet environment or underwater and protect the hardened materials from the attacks of chemicals (Madeeasy, 2019). The most popular type of hydraulic cement used in construction is Portland Cement. On the other hand, the non-hydraulic cement is made from the calcination of gypsum or limestone. The hydration's products are not water resistant (Dunuweera and Rajapakse, 2018). As a results, it does not set in wet or underwater environments, but rather when it is in dry condition and reacts with carbon dioxide in the atmosphere (Dunuweera and Rajapakse, 2018). After it has been set, it is possible for it to be attacked by an aggressive chemical (Madeeasy, 2019).

2.2.1 Ingredients of Cement

Cement can be manufactured either by burning and crushing the natural cement stones that contain clay, carbonates of lime and a little quantity of carbonate of magnesia or artificially by burning calcareous and argillaceous materials at a very high temperature (Vishnukanth and Rao, 2006). The example of argillaceous and calcareous material will be shown in Table 2.6. Artificial cement is stronger as compared to the natural cement, so the use of natural cement in practice is limited use. The most widely used artificial cement is Ordinary Portland Cement (OPC).

Function and composition of various ingredients in Ordinary Portland Cement are shown in Table 2.7.

Table 2.6: Examples of Argillaceous and Calcareous Material (Madeeasy, 2019).

Argillaceous	Calcareous
• Shale and clay • Blast furnace slag • Slate	• Cement rock • Limestone • Chalk • Marine shells • Mari

Table 2.7: Composition and Function of Ingredients in Ordinary Portland Cement (Vishnukanth and Rao, 2006; Madeeasy, 2019).

Ingredients	Composition (%)	Function
Calcium Oxide (CaO)	62%	• It provides strength and soundness to the cement.
Silicon Dioxide (SiO_2)	22%	• It gives quick setting property to imparts strength to cement.
Aluminium Trioxide (Al_2O_3)	5%	• It imparts quick setting property to cement
Calcium Sulphate ($CaSO_4$)	4%	• It increases the initial setting time of cement.

Iron Oxide (Fe_2O_3)	3%	• It imparts solidity as well as give colour to cement.
Magnesium Oxide (Mgo)	2%	• It imparts hardness and colour to cement.
Sulphur (S)	1%	• It provides soundless to cement
Alkalies	1%	• The majority of the alkalies that come from the raw material are removed by the flue gases during heating and leaving just a trace. • Excess alkalies present in cement will cause efflorescence.

2.2.2 Type of Cement

The cement with specific features that used for desired performance in each environment condition is being created by altering the chemical composition of OPC, adding additives, or utilizing alternative raw materials. In addition to OPC, several different cements available in the market are shown in Table 2.8.

Table 2.8: Type of Cement (Dunuweera and Rajapakse, 2018; Vishnukanth and Rao, 2006).

Cements	Descriptions
Rapid-hardening Portland Cement (RHC)	• This type of cement gains high strength rapidly in early days. • It is used where a rapid strength development required.

Low-heat cement (LHC)	• This type of cement is less reactive and slower rate of strength development, but it has the same ultimate strength as other types of strength. • It is typically used in the construction of large-scale concrete structure such as dam where temperature rise caused by heat of hydration can be severe.
Sulphate-resisting cement (SRC)	• This type of cement is chemically resistant, particularly to sulphates. • It is usually used in concrete structures that are prone to deterioration due strong alkaline conditions such as canal linings, and culverts.
Blast furnace slag cement (BFSC)	• This cement is made in a blast furnace during the pig iron manufacturing process and contains the basic cement ingredients alumina, lime, and silica. • This cement has the same properties as ordinary cement and is more affordable to make due to the utilization of slag, which is a waste product.
White cement (WC)	• White cement has the same qualities as ordinary Portland cement but contains less than 1% iron oxide which is responsible for the greyish color or cement. • It is used for floor finishing, plastering, and decorative work.
Coloured cement (CC)	• Coloured cement is basically the Portland cement with 5 to 10%

	colouring pigments added before grinding. • Colored cement is used in the finishing of flooring, exterior surfaces, imitation marble, and window frames.
Air-entraining cement (AEC)	• This cement is manufactured by grinding OPC clinker with a little amount of an air-entraining agent. • It has excellent workability, a strong resistance to freezing and thawing, and a low water/cement ratio, which results in less shrinkage.
Hydrophobic cement (HpC)	• This sort of cement is made by adding water-repellent additives to decrease its wetting ability. • It is typically used in areas with a high rainfall or high humidity to prevent water absorption during storage.

2.3 Concrete

Concrete is a composite material consisting of cement, sand, aggregate and water. It is the most widely used man-made construction material in the world and is second only to water as the most utilized substances on the planet (Gambhir, 2004). When the freshly mix concrete is placed in forms and left to cure for a period of time, it become hard like a rock. (Rao and Vishnukanth, 2006). Concrete has been used in practically every sort of construction, including highways, canal linings, bridges, and dams, as well as the s most iconic and artistic building built in the world. The concrete is a popular material in the construction field because it has a remarkable mechanical compressive strength, high durability, superior fire resistance and longer design life. The qualities of ingredients, the mix proportion, the type of compaction method and any other controls used during the placement, compaction and curing all have an effect on the properties of concrete. The concrete technology advancements have led the way for making the best use of locally accessible resources via prudent mix proportioning and competent craftsmanship, resulting in produce concrete that meets performance criteria (Gambhir, 2004).

2.3.1 Application of Concrete

Concrete of varying strengths may be used for different purposes. The concrete with a compressive strength value of 10MPa, 15 MPa and 20 MPa is defined as ordinary concrete (Gambhir, 2004). This type of concrete is utilized for the loadbearing walls, concrete road, slabs, and beams, as well as non-structural components such as noise barriers (Neville, 2002). On the other side, the concrete with a compressive strength value of range from 25 MPa to 55 MPa is defined as standard concrete (Gambhir, 2004). This type of concrete is used for the construction of house slab, driveways, walkways, footing, beams and column for one or two storey buildings (Neville, 2002).

Additionally, concrete that has a compressive strength of 60MPa or above is referred to as high strength concrete (Gambhir, 2004). This type of concrete is often used in a mega building construction project because this type of building required concrete that is high in compressive strength to support the load of mega structure building. It is frequently utilised for the lower floor columns of a high-rise structure in order to reduce the overall size of the column required for the project. It is also utilised in the construction of a bridge, in which the use of high strength concrete allows for a reduction in the number of required spans (Neville, 2002).

2.3.2 Concrete Making Materials

Concreting is a composite material that is made by mixing a certain amount of cement with aggregate and water to form a solid mass. The admixture such as air-entraining agents and superplasticizers can be used to increase the performance of concrete by adding it in the concrete mix. The cement commonly used in concrete production is Portland Cement. It makes up around 10% of the entire volume of the concrete mix. Fine and coarse aggregates are the two types of aggregates that are often used in making concrete. The aggregates are often obtained from adjacent sand, gravel or rock deposits. Around 60% to 80% of the volume of the concrete body is composed of aggregates. In the aspect of water, any water that is potable can be utilized as mixing water for mixing or curing of concrete (Gambhir, 2004).

A suitable mix of water to cement is critical for producing high-quality concrete. The quality of the concrete is highly reliant on the quality of the paste (cement + water), which is in turn dependent on the water-cement ratio utilised and the degree of curing. Additionally, in properly made concrete, the aggregate used in concrete production should be free of contaminants, hard, strong, and appropriately shaped and graded. The aggregate should not contain any potentially harmful that might result in physical or chemical changes such as cracking, swelling, softening, or leaching. For effective usage of paste, a well-graded aggregate with a low void content is needed. Each aggregate particle should be entirely coated in paste, and the space between them is totally filled with paste. Additionally, the water used to mix and cure concrete should also be free of any harmful contaminants (Gambhir, 2004).

Moreover, the use of admixtures in concrete should provide an improvement that cannot be economically achieve by modifying the proportion of water, cement, and aggregate, and it should have no adverse effect the concrete’s performance. The admixtures have a specific chemical composition and can be used to alter the properties of concrete in certain ways. A proper assessment of the additive’s impact on the properties of concrete is necessary before using the additive.

Table 2.9: Function of Ingredient in Concrete (Gambhir, 2004).

Materials	Function
Cement	• Act as binder to bind the find and coarse aggregates together. • It chemically react with water and give hardened cement most of its significant engineering properties.
Coarse aggregate	• Act as the main load-bearing component of concrete.
Fine aggregate (sand)	• Asist in filling the open spaces in between the coarse aggregate.
Water	• Crucial for the chemical reaction between cement and aggregates. • Served as lubricant between the fine and coarse aggregate and makes concrete more workable.
Admixtures	• Enhance the properties of concrete. • Mostly utilized for particular purposes.

2.3.3 General Properties of Concrete

When concrete is freshly mixed, it is a soft and highly fluid material known as fresh concrete. As it hardens, it goes through a process of set and hardening, which turn it into hardened concrete. The properties of hardened concrete that are most important in practical application are those that relate to its strength, durability, shrinkage and creep deformation. In order to achieve these objectives in the most cost-effective manner, the fresh concrete, in addition to having an appropriate composition in terms of quality and quantity of cement, the fresh concrete must meet the requirement from mixing stage until it is transported, set in formwork, and compacted in order to accomplish these goals economically. Therefore, the fresh concrete must be homogenous, stable and cohesive (Gambhir, 2004).

The various requirement of fresh concrete mentioned above are referred together as workability. The workability of concrete in its fresh stage is the most important criterion to consider. It depicts the simplicity with which the freshly mixed concrete may be placed, consolidated, and finished. The fresh concrete should be workable and sufficiently mobile to be placed in the form surrounding the reinforcement, as well as capable of being cast into the desired shape without jeopardizing continuity or homogeneity (Gambhir, 2004).

In the aspect of hardened properties of concrete, the strength of concrete is commonly considered its most valuable property as the strength usually provide an overall picture of concrete quality. The strength of concrete includes compressive strength, flexural strength and tensile strength. Among the numerous strengths of concrete, the determination of compressive strength has garnered the most attention, as concrete is built to withstand compressive strength in the first place (Gambhir, 2004). Concrete is also known for its massive compressive strength. Compressive strength is defined as the maximum compressive load that the concrete can withstand before its cracking. Besides from the compressive strength, concrete also has exhibits tensile and flexural strength, with compressive strength is often being used to estimate these properties. The concrete’s tensile strength is around 10 to 20 percent of the compressive strength whereas the concrete’s flexural strength is approximately 15 to 20 percent of the compressive strength (Lamond and Pielert, 2006).

Apart from the mechanical strength properties of concrete, the durability of concrete is another important property of harden concrete. It is the ability of concrete to sustain a long period of time without severe deterioration caused by weathering, chemicals and abrasion. One of the main characteristics of concrete that affect it durability is the concrete’s permeability of fluids and gas. If a substance is incapable to penetrate concrete, it cannot damage it. Hence, low permeability may improve the concrete's durability, corrosion resistance and resistance to chemical attack. On the other hand, the permeability of concrete depends upon micro and macro cracks, voids and pores developed during production and services. Larger porosity and void in concrete will increase the permeability of concrete which in turn decrease the durability of concrete as the gas, chemical or other potentially deleterious substances are easier to flow through the concrete. Hence, the porosity, permeability as well as the durability of concrete are all importance properties of concrete which directly related to each other's (Lamond and Pielert, 2006).

2.4 Previous Research on Plastic Waste in Concrete

Numerous research on incorporation of plastic waste products in concrete have been done in recent years. Figure 2.2 shows the increase in number of scholarly articles published in the last two decades on the use of plastic waste in concrete. The majority of these research investigate the use of plastic as a substitute for aggregate or as fibre reinforcement material. In comparison to aggregates or fibre reinforcement, less study has been conducted on the utilization of plastic waste as cement substitute

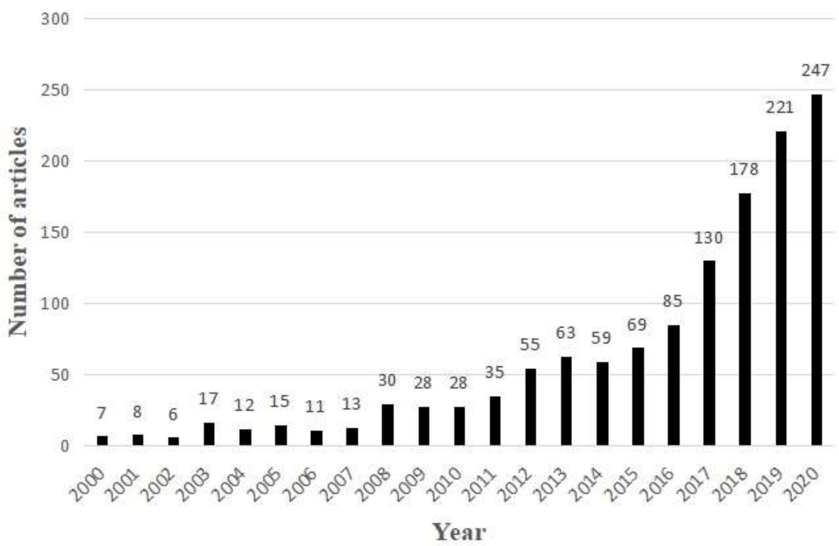


Figure 2.2: Number of Scientific Articles Published on the Use of Plastic Waste in Concrete (According to SCOPUS).

2.4.1 Incorporation of Plastic Waste as Aggregate Replacement

Generally, plastic waste has been utilized as fine or coarse aggregate replacement in concrete. Table 2.10 summarises the reviewed experimental research results that have been evaluate regarding the utilization of plastic waste as fine and coarse aggregate replacement in concrete. According to the findings of several studies shown in Table 2.10, the property of fresh concrete such as workability have shown a different trend in results when aggregate is replaced by plastic waste. In the studies conducted by Ismail and Al-hashmi., (2008) as well as Akçaözoğlu and Atis., (2013) where plastic is utilised as fine aggregate in concrete, the workability of concrete has decreased significantly as the percentage of plastic waste increased. The angular and non-uniform aggregate particles reduce the fluidity of the concrete mixture, which has resulted in a drastic drop in workability as the plastic waste in concrete increased. (Ismail and AL-Hashmi, 2008).

An opposite trend in the workability of concrete is observed when the plastic waste is utilized as coarse aggregate in the concrete. Ramesen, Babu and Lal, (2015) reported that the workability of concrete increased as the proportion of plastic waste increased to 40%. This improvement was attributed to the smoother surface and hydrophobicity properties of the plastic particle which unable to absorb water. The excess of water helps to enhance workability (Ramesan, Babu and Lal, 2015). Similar findings have been reported by Islam, Meherier and Islam., (2016), who found an increased in the slump of fresh concrete for replacement levels up to 50%. The authors attributed this to the smooth texture of plastic particle which produces less friction between particles than rough-textured natural aggregates, and the round form of plastic particles results in less surface area and voids than natural aggregates, resulting in improved workability.

On the other hand, most authors found a gradual decrease in compressive strength of concrete with increasing plastic weight percentage when the plastic waste is utilised as either coarse aggregate replacement or fine aggregates replacement. The low adhesion between cement paste and the surface of plastics, as well as the fact that plastic is a hydrophobic material, which limits the quantity of water necessary for cement hydration, are responsible for the reduction in compressive strength of concrete (Ismail and AL-Hashmi, 2008). Islam, Meherier and Islam., (2016) further explained that, due to the plastic waste has no water absorption ability, water will accumulate in the transition zone, causing it to become extremely porous. This additional porosity will result in a decrease in compressive strength.

However, some authors observed a different pattern. For instance, Yang et al., (2015) reported that the compressive strength of concrete is increased when the replacement level of fine aggregate by plastic waste up to 15%. They explained that this unusual and unexpected results is due to the plastic particles can fill certain voids in concrete. Moreover, Azhdarpour et al., (2016) discovered that by replacing 5% and 10% of the fine aggregates with PET plastics, the concrete’s compressive strength increased by 39% and 8%, respectively. However, the further increase of replacement still resulted in a continued decline in compressive strength. According to the authors of this study, this is due to stress redistribution between soft and (plastic) hard inclusions (sand) at low replacement levels, which results in stress transfer to strong (sand) inclusions and delays failure. When the amount of soft inclusions is increased, the stresses at the inclusion interface rise, resulting in a reduction in strength.

Table 2.10: Past Research about Utilizing Plastic Waste as Aggregate Substitution in Concrete

Substituted materials	Type of Plastic Waste	Plastic Waste Replacement level	Findings	Source
Fine aggregate	PE and PS	10% - 20%	• As the proportion of plastic waste in concrete increases, the workability and compressive strength of the concrete decrease.	(Ismail and AL-Hashmi, 2008)
Fine aggregate	PET	30% - 60%	• The concrete's properties such workability and compressive strength decreases as the proportion of plastic waste in concrete increased.	(Akçaözoğlu, Akçaözoğlu and Atiş, 2013)
Coarse aggregate	PET	5% - 40%	• The workability of concrete mixes improved as the proportion of plastic waste in concrete increased up to 40%. • The compressive strength of concrete increased by 9.4% for a mix containing 30% plastic aggregate.	(Ramesan, Babu and Lal, 2015)
Coarse aggregate	PET	20% - 50%	• Concrete's workability improves as the proportion	(Islam,

			of PET plastic waste increases. • Concrete's compressive strength decreases as the proportion of plastic aggregate in concrete increases.	Meherier and Islam, 2016)
Fine aggregate	PET	30% - 60%	• As the amount of plastic aggregate in concrete increases, the compressive strength development decreases gradually.	(Hannawi, Prince and Bernard, 2013)
Fine aggregate	LDPE	10% - 40%	• The workability and compressive strength of concrete increase as proportion of plastic waste in concrete increased up to 40%.	(Guendouz et al. 2016)
Fine aggregate	PET	20% - 50%	• By substituting 5% and 10% of the concrete aggregates with plastic pieces, the compressive strength of concrete increased by 39% and 7.6%, respectively.	(Azhdarpour, Nikoudel and Taheri, 2016)
Fine aggregate	PP	10%-30%	• The compressive strength of concrete is enhanced when up to 15% of aggregate replaced by cement.	(Yang et al., 2015)

2.4.2 Incorporation of Plastic Waste as Fibre Reinforcement

Aside from using plastic waste as a fine or coarse aggregate substitute, the use of plastic waste as fibre reinforcement in concrete also has received increasing attention in the research community in recent years. A fibre reinforced concrete is one that contains fibrous components to strengthen the durability and structural integrity of the concrete. Numerous fibre types are utilized in concrete mixes in this respect, including glass fibre, steel fibre, synthetic fibres, natural fibres, and pre- or post-consumer waste fibres (Sandanayake et al., 2020). Recent years have seen an increase in efforts to produce fibres from plastic waste and then use them as reinforcement in concrete. Numerous studies have examined the impact of plastic waste fibres on the performance of concrete.

According to the study of Shahidan et al., (2018), which incorporated 0.5%, 1%, 1.5% and 2.0% (by volume of concrete) with 50 mm length and 5 mm width of PET fibre into concrete, the workability and compressive strength of concrete decrease with the increment of plastic fibres in concrete mixtures. According to the authors, the explanation for the loss in workability is because of the inclusion of PET fibre in concrete results in increased friction between the particles, leading to reduce workability of the concrete mix. Moreover, the authors indicated the loss of compressive strength was caused by fibres bundling during mixing and pouring as well as by the fact that the gap between fibre surfaces is the concrete's weakest part, hence early fractures were discovered during compression loading.

In the same manner, the loss of strength in concrete was reported in some other research. For example, Mohammed and Rahim, (2020) conducted a study to determine the mechanical strength of concrete incorporating various length and volume percentages of PET fibres waste. It is observed that when the volume and length of the fibre waste increased, the concrete's compressive strength decreased significantly. The findings of this study showed that using long fibre (40 mm length) will lead to a higher loss strength compared to using short fibre (20 mm length). The loss of strength can be due to defects between the PET fibre surface and the concrete, which cause crack extension and rupture.

In contrast to the aforementioned results, a research study was conducted by l-Hadithi and Abbas, (2018), reported adding 1% (by volume of concrete) of PET bottle fibres into concrete increase the compressive. According to the authors, the increase in strength may be due to the fibres being distributed appropriately within the mix. As a result, the fibres lower the envelope of the micro fractures, lengthening the time required for failure. Similarly, Afroughsabet and Ozbakkaloglu., (2013) research showed that the addition of polypropylene fibres into concrete mixes significantly increased compressive strength of concrete. The compressive strength of the control mix was 82.6 MPa in 28 days and it increased to 92.8 MPa just by adding 0.45% of Polypropylene fibers with a 12-mm length. This is because the fibre has the ability to constrain crack extension, lower the degree of stress concentration, change the direction of cracking, and retard the development rate of cracks (Afroughsabet and Ozbakkaloglu, 2015).

Table 2.11: Past Research about Utilizing Plastic Waste as Fibre Reinforcement in Concrete

Type of Plastic Waste Fibre	Dosage in Concrete	Fibre Size	Finding	Source
PET waste fibre	0.5, 1, 1.5 and 2.0 vol %	Length = 50 mm Width = 5mm	• The workability and strength of concrete declined with an increase in the proportion of PET waste fibre in concrete.	(Shahidan et al., 2018)
PET waste fibre	0.25, 0.5, 0.75, 1, 1.25 and 1.5 vol%	Length = 20, 40 mm Width = 1.2 mm	• The concrete's compressive strength decreases with the addition of PET fibre in concrete. • Using short fibre in concrete lead to a relatively small strength loss.	(Mohammed and Rahim, 2020)
PET waste fibre	0.25, 0.5, 0.75, 1, 1.25 and 1.5 vol%	Length = 40 Width = 4 mm	• The concrete's compressive strength enhanced as the volume of fibre increase up to 1%.	(Al-Hadithi and Abbas, 2018)
PP waste fibre	0.15, 0.30 and 0.50 vol%	Length = 12 mm	• By adding 0.15%, 0.30% and 0.50% (by volume of concrete) PP fibre into concrete, the compressive strength at 28 days increased by 10%, 11% and 13%, respectively.	(Afroughsabet and Ozbakkaloglu, 2015)

HDPE waste fiber	0.4, 0.75, and 1.25 vol%.	Length = 23, 30 mm Diameter = 0.25, 0.4 mm	• There is no visible effect on the compressive strength of concrete. The compressive strength of concrete does not alter significantly when the 0.4, 0.75 and 1.25% of HDPE waste fibre added into the concrete mix.	(Pešić et al., 2016)
Metalized PP waste fiber	0.5, 1.0, 1.5, and 2 vol%	Length = 5, 10, 20 mm Width = 1 mm	• Workability reduced with increased dosage of metalized plastic waste fiber for all test conditions. • As the percentage of metalized plastic waste (MPW) fibres in concrete increased, the compressive strength decreased. • Concrete mixes with longer fiber length will cause a greater reduce in strength of concrete.	(Bhogayata and Arora, 2017)

2.4.3 Incorporation of Plastic Waste as Cement Replacement

Despite aforementioned studies, there is a shortage in literatures that discuss usage of plastic waste as powder to replace cement in concrete. This is most likely owning to the non-cementitious nature of plastic, which has a negative effect on mechanical properties of concrete when mixed with cement paste (Sandanayake et al., 2020). Nevertheless, a few academies have conducted this study, with the majority of them showing that replacing cement with plastic powder has an adverse effect on the concrete's properties. Table 2.12 summarises the experimental research results that have been evaluate regarding the utilization of plastic waste as cement replacement in concrete.

Most of the research reported that the incorporation of plastic waste as cement replacement in concrete will deplete the fresh and hardened properties of concrete. The poor adhesive strength between plastic particles and cement paste, the hydrophobic characteristic of plastic which restrict the movement of water and the absence of cementitious compound in plastic that are responsible for the strength development in concrete are all reasons for the unfavourable output obtained when cement was replaced by plastic waste (Gesoglu et al., 2017; Kindi et al., 2021; Patil, Waysal and Dholakiya, 2020) .

However, a research paper published recently by Manjunatha et al., (2021) reported that the partial substitution of cement with plastic powder have a beneficial effect on mechanical properties of concrete. The findings of this study underlined that the compressive strength of concrete was improved when the amount of cement replaced by PVC powder was increased up to 15%. They attribute the positive result to the PVC powder's small particle size and specific gravity, which aided in voids packing and makes concrete dense when compared to control mix. Nonetheless, the further increment of PVC powder replacement level to 20% and higher will result in the decrease of compressive strength.

Table 2.12: Past Research about Utilizing Plastic Waste as Cement Substitution in Concrete

Substituted materials	**Type of Plastic Waste.**	**Plastic Waste Replacement level**	**Findings**	**Source**
Cement	PVC	5% - 25%	• The compressive strength of concrete was adversely influenced by using plastic powder to replace cement.	(Gesoglu et al., 2017)
Cement	PET	5% - 15%	• The use of PET resin as cement replacement decreases compressive strength at all ages of concrete.	(Patil, Waysal and Dholakiya, 2020)
Cement	PVC	15% - 35%	• The compressive strength of the plastic cement exhibited a decreasing trend for an increase in percentages of polyvinyl chloride in the concrete mix. • Concrete with 15% plastic waste replacement as partial replacement of cement may be used for structural applications as it obtains the strength value which is just slightly less than the normal concrete.	(Kindi et al., 2021)
Cement	PVC	5% - 30%	• The compressive strength of concrete is improved when the amount of cement replaced by PVC powder was increased up to 15%.	(Manjunatha et al., 2021)

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discussed the materials needed to make concrete, the process of making concrete and the laboratory tests to determine the workability, mechanical and durability properties of concrete. All laboratory tests performed in this study is in accordance with the British Standard European Norm (BS EN). The flow chart shown in Figure 3.1 summarize the whole process of this research. The detail of each step of this methodology will be further explained in the following section

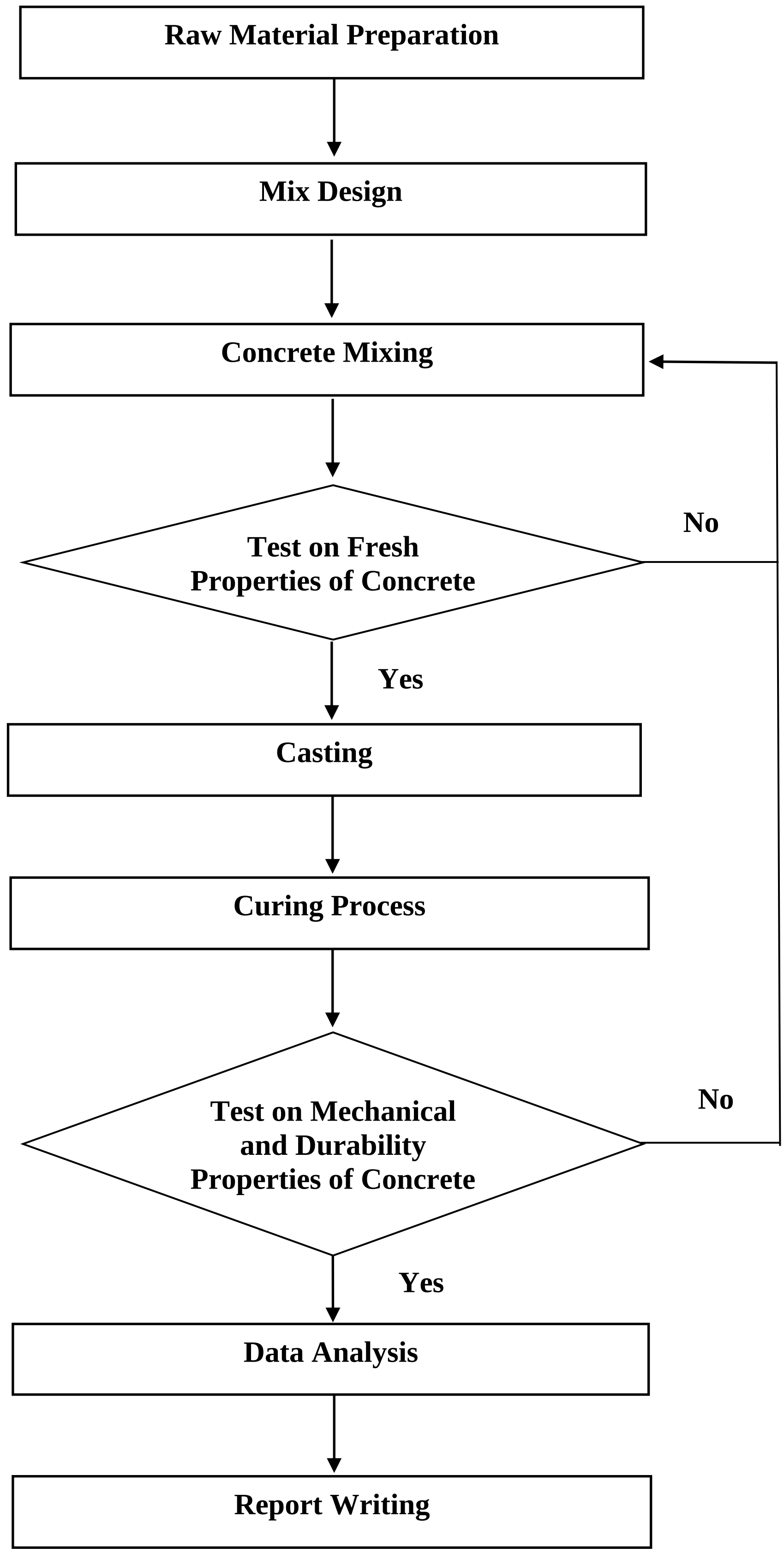


Figure 3.1: Flow Chart of Overall Process of This Study

3.2 Raw Material Preparation

3.2.1 Water

Water is an important component of concrete. Combining water with cement will occur the hydration process, which helps produce the concrete's desired properties. The water must be clean and free from any impurities and contaminants as it will affect the hydration process of the specimens (Olugbenga, 2014). According to MS EN 1008, the use of potable water as mixing water for the mixing process of fresh concrete is permissible. In this research study, tap water is used as mixing water to mix the specimen.

3.2.2 Cement

Ordinary Portland Cement (OPC) is chosen as the cement to be used in the production of concrete in this research. OPC is a type of hydraulic cement that hardens and sets when it is mixed with water. The cement used in this research is Hume Panda Ordinary Portland Cement which shown in Figure 3.2. It is a Type 1 Portland cement in accordance with MS EN 197-1.

Figure 3.2: Ordinary Portland Cement.

3.2.3 Plastic Powder

The type of plastic selected for this research is Polyvinyl Chloride (PVC). PVC is an industrial input that is used in both virgin and recycled form to manufacture goods. It is the world's second most extensively used synthetic polymer (Manjunatha et al., 2021). It can be used in granules or powder form. For this research, the PVC powder was obtained from Shen Fei Enterprise in Ipoh, Perak, Malaysia. It is a company produce recycled PVC raw materials by grinding the PVC scraps into fine powder using pulverize machine. Figure 3.3 show the PVC waste powder (PWP) that utilized in study.

Figure 3.3: PVC Waste Powder

3.2.4 Aggregate

Aggregate commonly consists of crushed stone, sand, crushed blast-furnace slag, gravel, and rock quarries (Collivignarelli et al., 2020). The aggregates come in a variety of shapes and sizes which included both fine and coarse aggregates. According to MS EN 12620, the aggregate which can pass through 4.75 mm sieve is classified as fine aggregates whereas the aggregate with a size larger than 4.75mm is classified as coarse aggregate. Therefore, sieve analysis is needed to carry out to determine and separate coarse aggregate and fine aggregate from mixed aggregates.

In this research study, the aggregates passing through 20 mm sieves and remain on the 4.75 mm and 10 mm were used as the coarse aggregates. Sand was utilized as fine aggregate in this study. Prior to utilizing them into making concrete, the coarse aggregate and sand were dried by putting them in an oven for 24 hours at a temperature of around 100 ℃ to ensure that the coarse aggregate and sand do not retain any moisture. Figures 3.4 and 3.5 show the coarse aggregate and sand that used for this study.

Figure 3.4: Coarse Aggregate.

Figure 3.5: Sand as Fine Aggregate.

3.3 Concrete Mix Design

The mix proportions of the ingredients in a concrete mix, such as cement, sand (fine aggregate), coarse aggregate, and PWP, are determined to ensure that the concrete with the required strength and durability is created. In this experimental study, four different percentages of PWP are applied to replace the cement to determine the effect of plastic powder on the concrete properties. The cement will be partially replaced by 4%, 8%, 12%, and 16% of plastic powder in the concrete mix and there will be no substitute for cement in the control specimen.

The target grade of concrete produced in this experiment is M20 concrete. M20 concrete is a type of concrete that has a compressive strength of 20 N/mm after 28 days of curing. Furthermore, the mix proportion (water: cement: aggregate) ratio is 1:1.5:3 and the water-cement ratio are 0.55. These ratios are decided based on the standard according to British Standard as shown in Table 3.1. The mix proportion of concretes which were 0%, 4%, 8%, 12% and 16% of cement were replaced as showed in Table 3.2. The concrete specimens in this research are named as CS, PWP4, PWP8 PWP12 and PWP16 which is based on the proportion of PWP in concrete.

Table 3.1: British Standard for Concrete Mix Design (Gambhir, 2004).

Grade of Concrete	Concrete Mix Ratio (Cement: Sand: Aggregates)	Water-Cement Ratio	Compressive Strength	
			MPa (N/mm^2)	Psi
M7.5	1:4:8	0.40	7.5	1087
M10	1:3:6	0.45	10	1450
M15	1:2:4	0.50	15	2175
M20	1:1.5:3	0.55	20	2900
M25	1:1:2	0.60	25	3625

Table 3.2: Mix Proportion of Cube (100 mm x 100 mm x 100 mm) Concrete Specimen.

Sample	Materials (g)				
	PWP	**Cement**	**Sand**	**Coarse aggregate**	**Water**
CS	0	388	580	1163	213
PWP4	16	372	580	1163	213
PWP8	31	357	580	1163	213
PWP12	47	341	580	1163	213
PWP16	62	326	580	1163	213

Note: CS - Control specimen

PWP4 - 4 % substitution amount of PWP

PWP8 - 8 % substitution amount of PWP

PWP12 - 12 % substitution amount of PWP

PWP16 - 16 % substitution amount of PWP

3.4 Concrete Mixing

All the ingredients of concrete are mixed by hand. The hand mixing process is carried out on a none-absorbent platform. First, the cement and fine aggregate are thoroughly mixed together. The coarse aggregate is then mixed with the cement and fine aggregate until the mixture becomes homogeneous. Following that, a deep hole is dug at the center of mixture pile and fill it with water. The mixture from the sides is folded inward to the hole and continue to mix it until the concrete appears to be homogeneous and consistent.

3.5 Casting of Concrete

The procedures of casting are according to BS EN 12390-2:2009. The ready mixed concrete is transferred to mold for casting. Before placing the concrete inside the mold, the inner surface of the mold is oiled with a thin layer of black oil to prevent the concrete from sticking to it. This will ease the removal of mold after the hardening of concrete. During the mixing and transporting of fresh concrete into the mold, air will be entrapped in the fresh concrete which will reduce the quality and strength of concrete. Hence, roughly 25 times compaction is needed for each concrete cube to eliminate the air bubble trapped in the fresh concrete. After the mold is fully filled with fresh concrete, the top surface was levelled and smoothen with a trowel.

3.6 Curing Process

The curing process is an important step as it protects concrete from moisture loss after the concrete has been placed. The durability and strength development of concrete specimens are both influenced by this process. The concrete specimens must undergo a curing process before being used for laboratory tests to ensure that hydration and strength development is carried out with enough water. The curing requirement is changed depending on the surrounding environment condition. A longer curing period is required in the presence of low ambient temperature.

The curing process in this research is performed in compliance with BS EN 12390-2:2009. After casting, the concrete specimens are kept in the laboratory to air-dried for 24 hours which is also known as air curing. After 24 hours, the casting mold is removed, and the concrete specimen is submerged into water to cure for 7, 14 and 28 days.

3.7 Fresh Concrete Test

The fresh concrete test is carried out in this research in order to determine the workability of fresh concrete paste. Workability is the most important parameter of fresh concrete to consider. It defines the ease with which concrete can be mixed, placed, transported, consolidated, and finished with the least amount of loss of homogeneity (Hoang and Pham, 2016). Slump test was carried out to determine the workability of fresh concrete paste.

3.7.1 Slump Test

The slump test is carried out in compliance with the BS EN 12350-2:2009. The fresh concrete mix is placed in the cone mold in three layers. A tamping rod is used to compact each layer by tamping 25 times throughout its depth and the tamping should be done uniformly over the cross-section of each layer. After that, the top level of concrete is strike off and levelled using the tamping rod. The cone mold is then lifted upward carefully without imparting any lateral or torsional motion to the concrete. Once the cone mold is removed, the concrete started to slump. The difference in height between the cone mold and the slumped concrete, referred to as slump value is measured. Table 3.2 shows the description of workability according to slump value. Figure 3.6 show the equipment for slump test.

Figure 3.6: Equipment for Slump Test.

Table 3.3: Description of Workability and Magnitude of Slump (Jackson and Akomah, 2018).

Description of Workability	Slump Value (mm)
No slump	0
Very low	5-10
Low	15-30
Medium	35-75
High	80-155
Very high	160-to collapse

3.8 Hardened Concrete Test

The hardened concrete test is carried out to measure the mechanical and durability properties of concrete in the hardened form where it is sufficiently strong and can withstand the loads that are applied to it. The compressive strength, flexural strength, water absorption, porosity, gas permeability and chloride test are all performed on hardened concrete.

3.8.1 Compressive Strength Test

The compressive strength test is conducted to measure the maximum compressive load, which the concrete can withstand without cracking. The compressive strength test is not only a test for the most significant mechanical property of concrete, it also helps in determining whether the mix proportions of various materials is correct or not to produce the concrete with desired strength. Therefore, the compressive strength test can be considered the most important test of concrete.

Compressive strength tests are conducted in accordance with BS EN 12390-3:2009. The compressive strength of concrete is determined using a compressive test machine that apply a constant rate of loading on 100 mm × 100 mm × 100 mm concrete cubes specimen until the occurrence of failure in the specimen.. The concrete's compressive strength can be calculated using Equation 3.1 which is shown below:

$$f_c = \frac{F}{A_c} \tag{3.1}$$

where:

f_c = Compressive strength of concrete, Mpa (N/mm^2);

F = Maximum load at failure, N;

A = Cross-sectional area of concrete, mm^2.

3.8.2 Flexural Strength Test

The flexural strength test is conducted to evaluate the concrete's capacity to withstand the bending stress without cracking. This test is carried out in accordance with the BS EN 12390-5:2009 standard. The center point loading method is used to determine the flexural strength by using the T-machine universal testing machine. A 40 mm x 40 mm x 160 mm concrete prism specimen is placed on the loading points and centred the loading MPa/s (N/mm^2.s) to 0,06 MPa/s (N/mm^2.s) is applied to the prismatic concrete specimen until the test specimen failed and cracks appeared. The maximum load sustained is recorded and the flexural strength is calculated by using Equation 3.2 as shown below:

(3.2)

$$f_{cf} = \frac{3 \times F \times I}{2 \times b \times d^2}$$

where:

f_{cf} = Flexural strength, MPa (N/mm^2)

F = Maximum load at failure, N

L = Distance between two supporting rollers, mm

b = Width of concrete specimen, mm

d= Thickness of concrete specimen, mm

3.8.3 Water Absorption Test

The water absorption test is conducted to measures the amount of water that penetrates concrete when submersed into the water. Water absorption is also considered to be a key parameter about the performance of concrete as it will affect the durability and strength of concrete.

The water absorption test is carried out based on BS1881-122:2011. Before the testing, the cured concrete cube is dried in an oven for 24 hours and the initial mass of the cube concrete specimen is measured after being taken out from the oven. After that, the concrete cube is placed into the water for 30 minutes. The final weight of the concrete cube taken out from water after 30 minutes is measured. The water absorption of the concrete cube is calculated by using Equation 3.3 as shown below:

$$\mathrm{W.A.} = \frac{\mathrm{W_{sat}} - \mathrm{W_{dry}}}{\mathrm{W_{dry}}} \times 100\% \qquad (3.3)$$

where:

W.A. = Water adsorption of concrete, %

W_{sat} = Saturated surface dry weight of concrete, kg

W_{dry} = Oven-dried weight of specimen, kg

3.8.4 Porosity Test

The porosity test is carried out to determine the porosity of concrete samples following BS 1881-122 standard. This test is based on Archimedes' principle. A buoyant force is measured on a concrete specimen that is submerged in water. Additionally, the porosity test also provides as estimate of the pore volume in concrete.

The cylinder specimen with diameter of 45 mm and a height of 40 mm are put into over to dry for 24 hours and the oven-dried weight of cylinder specimens, W_{dry} is measured. Next, the concrete specimens are placed in the desiccators and the vacuum pump is turned on for 15 minutes before being turned off for 3 hours and then turned back on for another 15 minutes. After that, the vacuum pump is turned off and the concrete specimens are kept in desiccator that is filled with water for 24 hours. After that, the concrete specimens are taken out and placed in the water buoyant apparatus and the buoyant force balance is used to measure the weight of displaced water, W_{wat}. After that, the surface of concrete specimens is wiped to remove all the free water from the surface and the weight is measured and recorded as saturated surface dry weight, W_{sat}. The porosity of the concrete cube specimen can be calculated according to Equation 3.4:

$$P_r = \frac{w_{sat} - w_{dry}}{w_{sat} - w_{wat}} \times 100\ \% \qquad (3.4)$$

where:

P_r = Porosity of hardened concrete specimen, %

W_{sat} = Saturated surface dry weight of specimen, kg

W_{dry} = Oven dried weight of specimen, kg

W_{wat} = Weight of specimen in water, kg

3.8.5 Gas Permeability Test

The gas permeability test is carried out to determine the rate at which air and gases can move through concrete. Concrete with high gas permeability will have lower durability of concrete and cause defection of concrete. This test is carried out based on BS 1881-122 standard. In this test, the concrete specimens in cylindrical shape with diameter and height of 45mm and 40 mm respectively are used. The concrete specimens are dried in an oven for 24 hours prior to being placed into the airtight vessel. Following that, the airtight vessel is filled with gas at a specified pressure. After that, the time taken for the air to travel a specific distance within the cylinder concrete specimens is measured and recorded. The gas permeability of the concrete can be calculated using the formulas below:

$$K = \frac{2P_2(1.76\ x\ 10^{-6})VL}{A({P_1}^2 - {P_2}^2)} \tag{3.5}$$

Where:

K	=	Gas permeability, m^2
P1	=	Absolute applied pressure bars (atmosphere pressure), usually 2 bars
P2	=	Pressure at which the flow rate is measured (atmosphere pressure), usually 1 bar

A = Cross sectional areas of specimens, m^2

L = Length of Specimen, m

V = Flow rate, cm^3 / s

$$V = \frac{\frac{D^2}{4}\pi h}{T} \tag{3.6}$$

Where:

V = Flow rate, cm^3 /s

D = Flowmeter diameter, cm

H = Length read on flowmeter, cm

T = Average time, s

$$A = (\frac{D^2}{4}\pi) \tag{3.7}$$

Where:

A = Cross sectional area of specimen, m^2

D = Diameter of specimen, m

3.8.6 Chloride Penetration Test

Initially, chloride penetration test is carried out to investigate the ability of concrete to resist the chloride ions due to the chloride penetrability has a determining impact on the durability of concrete. The chloride ions will corrode the steel in reinforce concrete. The plastic powder used in this research is PVC powder which contain chlorine element. Hence, this test is modified to determine whether the chlorine element inside the PVC powder can affect the durability of concrete specimen.

The 100 mm × 100 mm × 100 mm concrete specimen cubes are used for this test. After the concrete cube cured for 28 days, the cubes are split into half using a hardware machine. 0.1 M silver nitrate ($AgNO_3$) are then sprayed on the split surface of concrete to determine is there any chloride ions in the concrete. The colour of the split surface of concrete is observed and recorded. White precipitate of silver chloride will form when silver nitrate solution reacts with chloride.

3.8.7 Scanning Electron Microscopy (SEM) Test

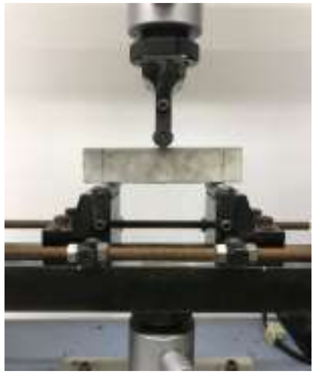
Scanning Electron Microscopy Test is conducted to observe the microstructure of the concrete specimen. It is an experiment that applied electron beam to scan a concrete specimen which being crushed into powder form in order to produce magnified image for analysis. Small amount of concrete specimen in powder form is required for the test. The magnification of SEM image is set to 10000 times for analysis.

3.9 Summary of Equipment and Laboratory Test

All of the laboratory tests conducted in this study are summarized in Table 3.4.

Table 3.4: Summary of Laboratory Tests

Type of Laboratory Test	**Picture**	**Age of Concrete (day)**	**Dimension of Mould**	**Standard**	**Procedures**
Compressive Strength Test		7, 14, 28	Cube 100 mm x 100 mm x 100 mm	BS EN 12390-3:2009	1. A cube concrete specimen is placed in the compressive test machine after the excess moisture from the surface of cube is wiped. 2. A constantly distributed stress is applied on the cube specimen until failure of specimen. 3. The maximum load at failure is recorded. 4. The cube concrete specimen is taken out and the machine is cleaned.

Flexural Strength Test		7, 14, 28	Beam 40 mm × 40 mm × 160 mm	BS EN 12390-5:2009	1. The distance of the centre point is fixed. 2. A beam concrete specimen is placed in the the T-machine universal testing machine after the free water from the surface of specimen is wiped. 3. A load is applied on the specimen continuously until the failure of concrete specimen. 4. The maximum load capacity is recorded when the fracture condition is observed
Water Absorption Test		7, 14, 28	Cube 100 mm x 100 mm x 100 mm	BS 1881-122:2011	1. The cube concrete specimen is placed in the oven at temperature of 105 ˚C. 2. After 24 hours, the concrete is taken out from oven and left it to cool down before being tested. 3. The oven-dried weight of the concrete is measured before placing it into water. 4. After 30 minutes, the concrete specimen is taken out from water and saturated weight of concrete specimen is measured.

Porosity Test	 	7, 14, 28	Cylinder 45 mm × 40 mm	BS EN 1881-122	1. The cylinder concrete specimen is placed in the oven at temperature of 105 ˚C. 2. After 24 hours, the concrete taken out from oven and left it to cool down before being tested. 3. The oven-dried weight of concrete is measured before placing it into the desiccator that is filled with water to a height of approximately 1 cm above the concrete. 4. The vacuum pump is turned on for 15 minutes. 5. It is allowed to run for 15 minutes again after rest for 3 hours. 6. After that, the vacuum pump is switched off and the specimens are stayed in desiccator for 24hours. **7.** After 24 hours, the concrete is taken from the desiccator and the weight of displaced water are measured by using the buoyant force balance. **8.** The saturated weight of concrete specimen is

					measured as well.
Gas Permeability Test		7, 14, 28	Cylinder 45 mm × 40 mm	BS EN 196-6:2010	1. The cylinder concrete specimen is placed in the oven at temperature of 105 ˚C 2. After 24 hours, the concrete taken out from oven and left it to cool down before being tested. 3. The cylindrical concrete specimen is placed into placed into the airtight vessel and the airtight vessel is then filled with gas at a specified pressure. 4. The time taken for air bubble to travel a certain distance is recorded.

Chloride Penetration Test		28	Cube 100 mm x 100 mm x 100 mm	-	1. The cube concrete specimen which undergoes curing process of 28 days is cut into half using a hardware machine. 2. The 0.1 M $AgNO_3$ solution is sprayed onto the split surface of a cube concrete specimen. 3. The colour change on split surface of concrete cube is observed and recorded.
Scanning Electron Microscopy (SEM) Test		28	Small amount of concrete in powder form	-	1. The concrete specimen which undergoes curing process of 28 days is crushed into powder form. 2. Small amount of concrete specimen in powder form is scanned with an electron beam to produce a magnified image for analysis.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

The proportions of PVC waste powder (PWP) to replace cement in concrete specimens for this study are 0%, 4%, 8%, 12%, and 16% particularly. The results of fresh, mechanical and durability properties concrete specimens were discussed in this chapter. The fresh properties tested in the study is workability. The mechanical properties tested in this study are compressive strength and flexural strength whereas durability properties tested are water absorption, porosity and gas permeability of concrete specimens. Scanning Electron Microscopy (SEM) analysis was also conducted to determine the influence of PWP inclusion on the concrete's microstructure. Furthermore, economic appraisal is carried out to estimate the influence of PWP as partial cement replacement on the cost of concrete making process.

4.2 Analysis of Elemental Composition of PVC Waste Powder

The elemental composition of PWP was analysed by conducting Energy Dispersive X-Ray Spectroscopy (EDX) test. The EDX results are shown in Table 4.1.

Table 4.1: Elemental Composition of PWP.

Element	**Composition**	
	Weight (%)	**Atomic (%)**
Oxygen (O)	42.53	62.53
Chorine (Cl)	55.28	36.67
Copper (Cu)	1.35	0.50
Zinc (Zn)	0.83	0.30

From the EDX analysis, O, Cl, Cu and Zn are the major elements of PWP. From Table 4.1, EDX analysis of indicates that the amount of elements O and Cl is significantly higher compared to the elements Cu and Zn. The masses of O and Cl elements are 42.53% and 55.28% respectively which can be observed as shown in Table 4.1. The high chlorine element in PWP may have an adverse effect on the steel reinforced concrete as the chlorine element may induce the corrosion of steel. The effect of chlorine element in PWP on concrete will be further discussed in Section 4.9.

4.3 Workability

Workability is the critical parameter of the freshly mixed concrete that determines how easy the concrete can be placed, consolidated, and finished without losing its homogeneity (Bahij et al., 2020). Concrete's workability is influenced by a number of factors which are water-cement ratio, grading of fine and coarse aggregate, and the amount and characteristic of admixture used in the mix (Babafemi et al., 2018). The concrete slump, defined as the decrease in the height of the slumped concrete, is commonly used to describe the workability of the fresh concrete. The workability of concrete specimens with different substitution portions of PWP, as measured in terms of loss of slump value and the description of workability for each fresh concrete sample are shown in Figure 4.1.

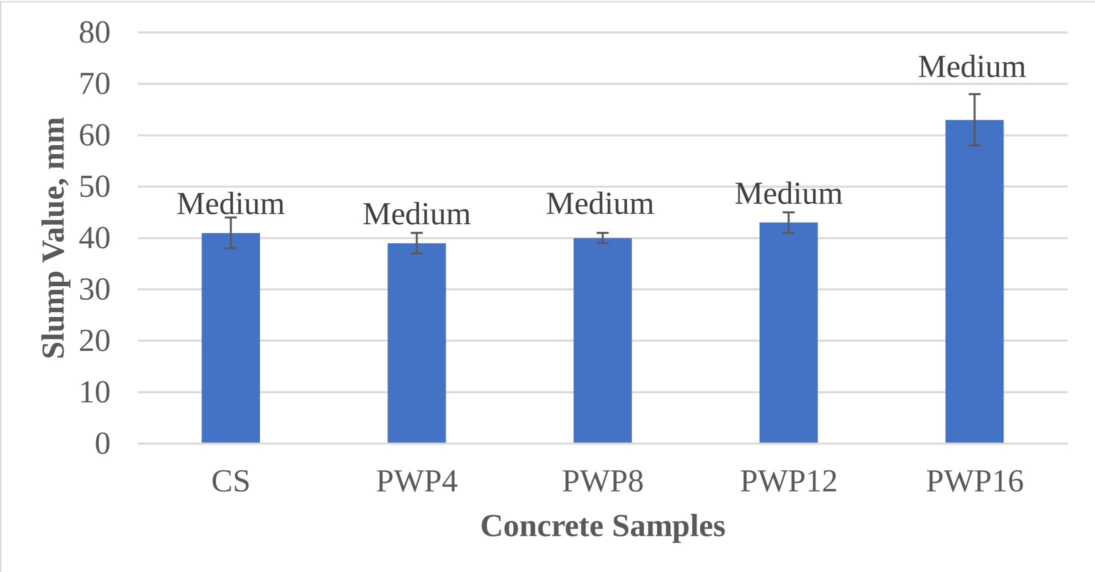


Figure 4.1: Workability of Different Types of Freshly Mixed Concrete.

All the fresh concrete specimens with different PWP replacement levels exhibited a true slump in this research. True slump is defined as a uniform drop of fresh concrete without disintegration. This indicates that replacing cement with PVC waste powder (PWP) at any of the substitution levels investigated in this study does not affect the cohesiveness of the mix, resulting in no shear or collapse slump. Figure 4.2 displays a true slump of concrete mix observed in this research.

As indicated from figure 4.1, the workability of concrete in terms of the slump measurement is not appreciably changed when the percentage replacement of cement with PWP increased from 4% to 12%. The slump value of the control specimen, PWP4, PWP8, and PWP12, is 41 mm, 39 mm, 40 mm, and 43 mm, respectively. PWP4, PWP8 and PWP12 specimens can obtain slump values nearly similar to the control specimen (41 mm). The slump value difference between the PWP12 and control is <5%, this indicated that replacing up to 12% of cement with PWP did not affect the workability of concrete.

In contrast with other specimens, the PWP16 specimen showed a higher increase in workability. This is due to the increased amount of free water in the mix. The reduction in the amount of cement in concrete will result in less water is being used to hydrate the cement. Moreover, the water-cement ratio in this research is fixed. Hence, when the amount of cement replaced by PWP increases, the actual water-cement ratio of the concrete increase, resulting in a higher fluidity and subsequently increased the workability of concrete. The same behavior was noticed by Guendouz et al. (2016) who used LDPE plastic powder to sand in concrete. The authors explained that this is because plastic has lower water absorbability compared to sand. The higher amount of replacement of LDPE, the workability was higher as more free water was available in the mixture.

Figure 4.2: True Slump.

4.4 Compressive Strength

The compressive strength of the grade M20 concrete specimens was tested after curing period of 7 days, 14 days, and 28 days. Figure 4.3 depicts the compressive strength test results for all concrete sample of this study.

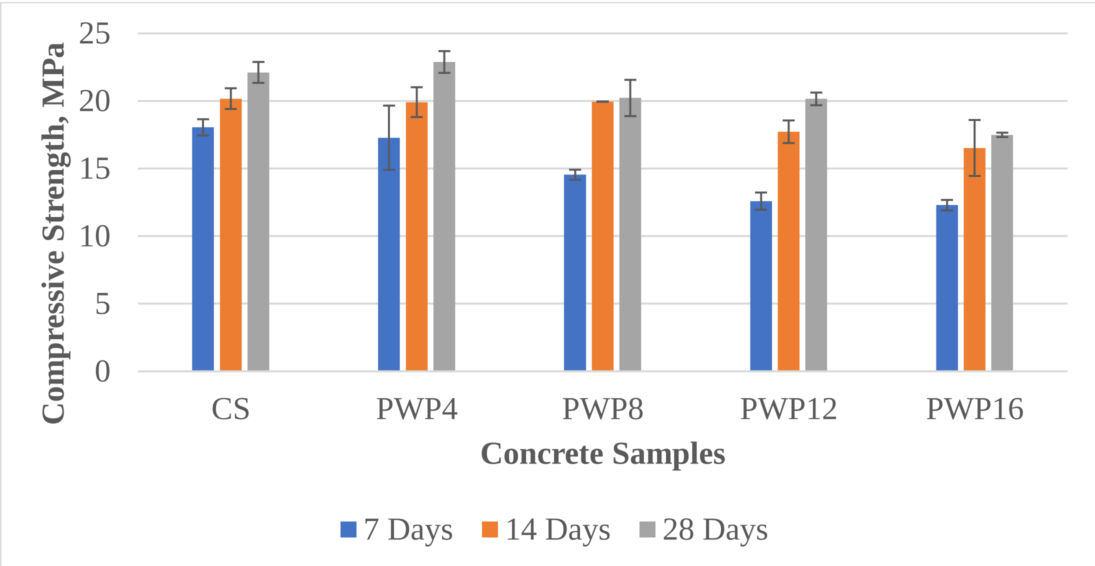


Figure 4.3: Compressive Strength of Concrete Samples after Curing of 7 Days, 14 Days, and 28 Days.

Figure 4.3 shows that the compressive strength of concrete at all replacement levels increased as the curing period increased. This is because a more extended curing period can prevent the water loss from concrete and allow the concrete to undergo continuing hydration process. The product of the hydration process, which is calcium silicate hydrate (C-S-H), a gel structure, will contribute to the development strength of concrete. Thus, as the curing period increases, the strength-forming C-S-H gel will increase, thereby increasing the strength of concrete (Elinwa, Fowosere and Jesse, 2020)

Furthermore, from Figure 4.3, it can be further noticed that the PWP4 concrete specimen at 28 days achieved a strength that is similar to the control specimen. The compressive strength of CS is 22.11 MPa, whereas the compressive strength of PWP4 concrete is 22.88 MPa. Despite the fact that the lesser amount of cement compared to the control specimen, PWP4 concrete can maintain the strength value of the control specimen. This can be attributed to the PWP's filler effect. The added PWP can act as a filler to fill the intergranular voids between cement particles and aggregate and, therefore, improve the concrete's compactness (Moosberg-Bustnes, Lagerblad and Forssberg, 2004). In other words, the filler effect may compensate for the loss of cement during the hydration process in the PWP specimen.

However, further increment of substitution level to 8% or above will decrease compressive strength with increased PWP. The PWP8, PWP12 and PWP16 specimen show a 8.5%, 9.0% and 20.9% of strength reduction respectively. It is due to the filler effect of PWP is not enough to compensate for the adverse effect of reduction in cement. The total amount of cement particles that would have been involved in the hydration process with mixing water will be decreased as much as the increase of PVC replacement level. This would decrease the amount of hydration production that would have otherwise occurred through the interaction between the cement and water and thus reduce the development of the strength of concrete.

Furthermore, the phenomenon of PVC powder floating toward the surface concrete can be observed in this research. Gesoglu et al., (2017) explained that the occurrence of this phenomenon is encouraged by the vast difference in specific gravity between PVC waste powder and other concrete compositions. This phenomenon will weaken the interlocking between cement paste and PVC particles. Moreover, Manjunatha et al., (2021) also reported that the incorporation of PWP in concrete may lead to the loss of cohesiveness between ingredient particles, lowering compressive strength. Another possible reason for the decrease in compressive strength caused by increasing the PVC ratio is the hydrophobic nature of PWP. This property may limit the amount of water required for cement hydration from entering the concrete specimen's structure during the curing stage (Bolat and Erkus, 2016).

Nevertheless, the concrete specimens at 28 days with all the replacement levels except 16% meet the research's target strength, 20 MPA. On the other hand, the PWP4 concrete specimen has obtained the highest compressive strength in this study which is 22.88 MPa. Moreover, the strength reduction in PWP8 and PWP 12 concrete specimen are less than 10%. Hence, based on the result mentioned above in the compressive strength test, the maximum percentage of PWP to replace the cement is 12% (PWP12), however, the optimum substitution portion of PVC powder waste for partial cement replacement is 4% (PWP4).

4.5 Flexural Strength

The flexural strength of concrete can determine the concrete's capacity to endure severe bending stress before breaking. The flexural strength of all concrete samples was tested after curing period of 7 days, 14 days, and 28 days. The flexural strength test results are presented in Figure 4.4.

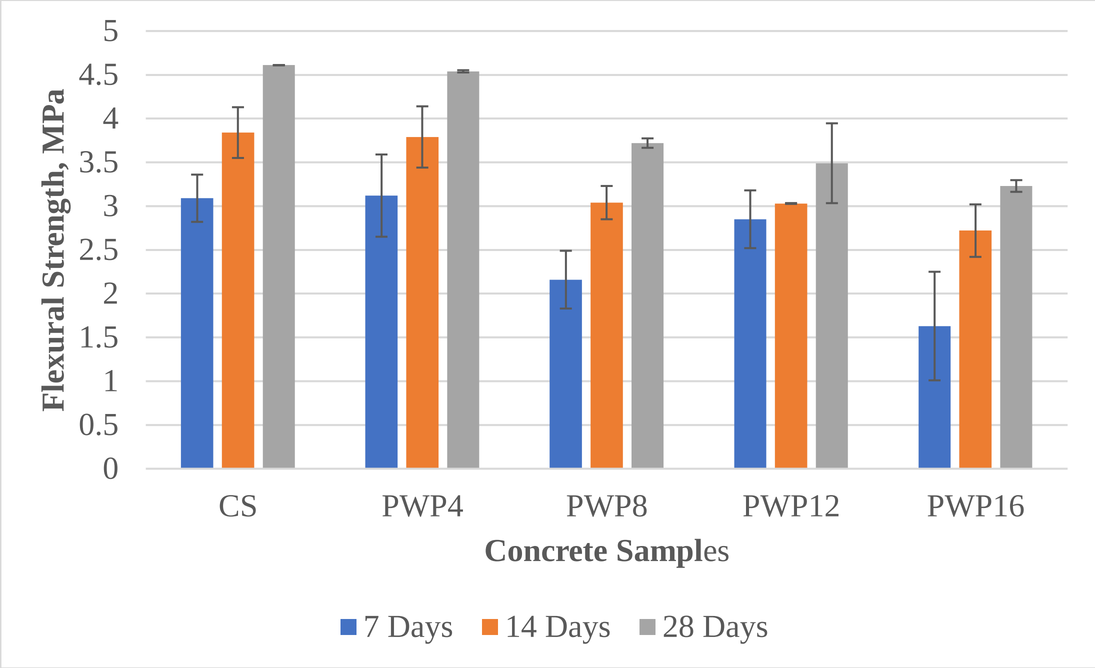


Figure 4.4: Flexural Strength of Concrete Samples after Curing of 7 Days, 14 Days, and 28 Days.

Figure 4.4 clearly shows that the curing period's duration and the replacement level of cement affect the flexural strength in the same way that it affects the compressive strength. The flexural strength of all specimens increased with curing ages. Moreover, the trend of flexural strength with different replacement levels of PWP is also quite same as the compressive strength, where the PWP4 specimen can attain a flexural strength value that is relatively similar to the control specimen (CS). The flexural strength of CS is 4.61 MPa, whereas the flexural strength of PWP4 concrete is 4.54 MPa the further increment of the replacement level to 8% and above will decrease flexural strength. The PWP8, PWP12 and PWP16 specimen show a 19.3%, 24.3% and 29.9 % of strength reduction respectively. The flexural strength reduction in PWP8 and PWP12 specimen are more pronounce compared to the reduction in compressive strength. The factors used to explain the reduction in the flexural strength were the same as those used to justify the decrease in the compressive strengths (Gesoglu et al., 2017). As previously stated, the incorporation of PWP as partial cement replacement in concrete will reduce the amount of hydration process and its product, C-S-H gel, and therefore reduce the strength development of concrete. Moreover, the hydrophobic nature of

PWP which restrict the movement of water as well as the weak cohesion between PWP and cement paste are also contribute to the reduction in flexural strength. Nevertheless, the flexural strength test results were still agreed with the outcome of the compressive strength test, which is 4% is the optimum substitution portion of PWP to replace the cement partially.

4.5.1 Relation between Compressive Strength and Flexural Strength

Concrete's compressive strength is frequently considered when designing the structures, however for particular applications, such as road pavement construction, the flexural strength is critical. (Neville, 2002). Compressive strength and flexural strength are all more or less directly related, and a change in either one will typically be reflected similarly in the other one, but not to the same extent (Concrete Manual, 2005). In other words, when compressive strength increase, so does the flexural strength but at a different pace. The relation between compressive strength and flexural strength for this study was showed in Figure 4.5.

From the Figure 4.5, there is a linear relationship between the compressive strength and flexural strength. The equation generated from the relationship of flexural strength and compressive strength was y = 0.2409x -1.1235 with coefficient efficiency (R2) of 0.6975 as shown in Figure 4.5. In statistical analysis, the R^2 value or coefficient efficiency is a measure of how well the regression prediction fits the data. The regression prediction fits more perfectly to the data as the R2 is closer to 1.

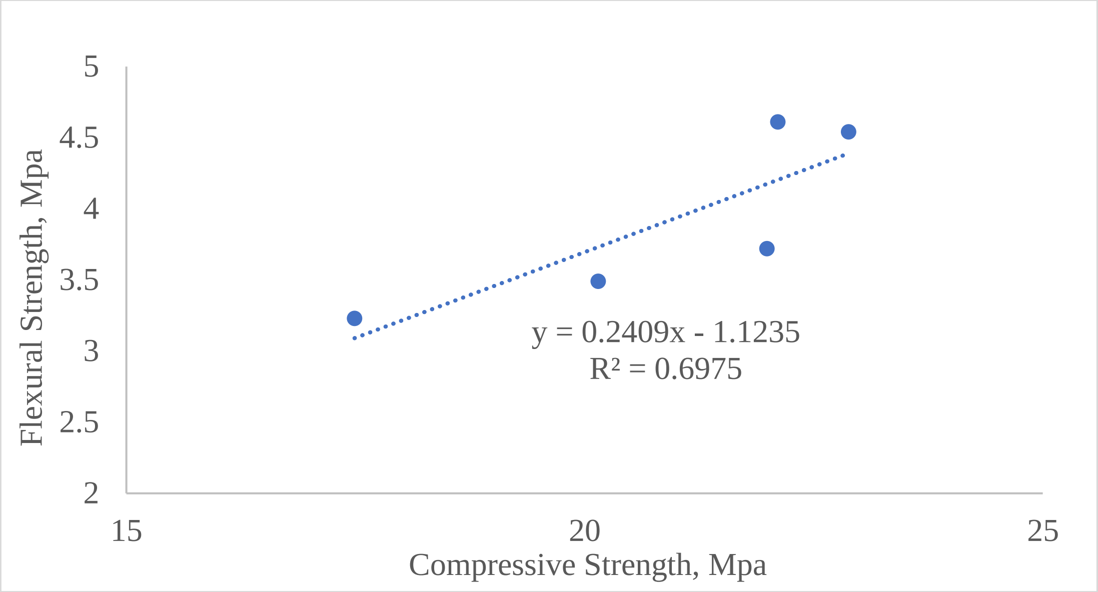


Figure 4.5: Relation between Compressive Strength and Flexural Strength.

4.6 Porosity

A concrete's porosity is influenced by its microstructure, proportional to the number of pores and voids in concrete, including entrapped air, capillary pores and gel pores (Neville, 2002). Generally, the strength of concrete will be influenced by the volume of all voids and pores in concrete. The porosity of concrete specimens with curing age of 7 days, 14 days and 28 days was tested. The results of the porosity test are shown in Figure 4.6.

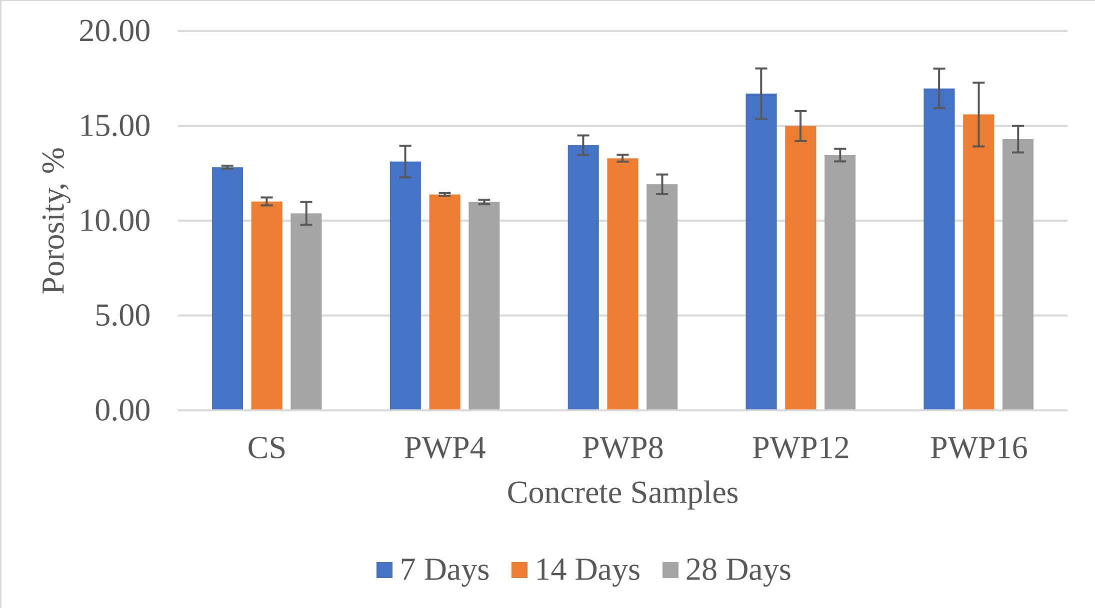


Figure 4.6: Porosity of Concrete Samples after Curing of 7 Days, 14 Days, and 28 Days.

According to Figure 4.6, the result shows that the porosity of all concretes decreased with the increase of the curing period. This is due to a more extended curing period that will allow the concrete to experience a higher degree of hydration. The hydration product, C-S-H gel, will be sufficient to fill the pore in concrete. As hydration proceeds, the volume of the pores is continuously reduced as a result of the development of the hydrated gel, which has a bulk volume greater than the un-hydrated cement's original volume (Lamond and Pielert, 2006).

Furthermore, the porosity of concrete at all ages appeared to increase with the increase in the amount of cement replaced by PWP. This means that the inclusion of PWP as a replacement of cement will increase the number or volume of pores in the concrete. This attribute to the fact that the hydrophobic nature of plastic powder could easily trapping the air during the mixing process which result in air voids in the concrete (Bahij et al., 2020). Furthermore, the inclusion of PWP in concrete does not aid in decrease the porosity of concrete due to lack of cementitious material in PWP which responsible for the formation of C-S-H gel to fill to the pore. Moreover, as the PWP replacement increase, the amount of cement available for the hydration process decrease. This means that the product of cement hydration, C-S-H gel is decrease as well when the replacement of cement with PWP increased. As a result, the C-S-H gel volume is not sufficient to fill the pores in concrete. Asides from the less of hydration product, the amount of free water will increase as well due to the reduction of cement amount used it for hydration process. Hence, after the water for hydration had been used for hydration, excess free water will gradually move towards the concrete's surface and ultimately evaporate. The spaces formerly occupied by water becomes the pores, resulting in the porous nature of the concrete (Neville, 2002).

Although the porosity is appeared to be increased with the increase of cement replacement level with PWP, the porosity of PWP4 concrete specimen at all ages can still achieve a similar porosity to the control specimen with just a slight reduction. The control specimen's porosity after curing for 7, 14 and 28 days were 12.82%, 11.02% and 10.39%, respectively, whereas the porosity of the PWP4 concrete specimen after curing for 7, 14 and 28 days were 13.12%, 11.39% and 10.99%. From these results, it can be noticed that the increment from the porosity of the control specimen to the PWP4 specimen at ages is all less than 1%. Therefore, based on the porosity's results, the optimum substitution portion of PVC powder waste for partial cement replacement is 4% which is in tally with the strength test result.

4.6.1 Relation between Porosity and Strength

The relation between the porosity and concrete strength (compressive and flexural strength) for this study is shown in Figures 4.7 and Figure 4.8. All the plots in the line graph are based on the 28 days results of porosity, compressive strength, and flexural strength. The graphs represented in Figure 4.7 and Figure 4.8 show an inverse relationship between the concrete strength and porosity. This indicated that the greater the porosity of concrete, the lower the strength. This may be due to the pores weakening the cement bond and decreasing the ability of concrete to resist the load (Neville, 2002).

In general, the inverse relationship between porosity and strength is deemed the fundamental principle in concrete study. As shown in Figures 4.7 and 4.8, the relation of the porosity and the compressive as well as the relation of porosity and flexural strength has a very high R2 value of 0.8047 and 0.9164 respectively, which are closer to 1. This indicates that porosity is the crucial factor governing the strength of concrete.

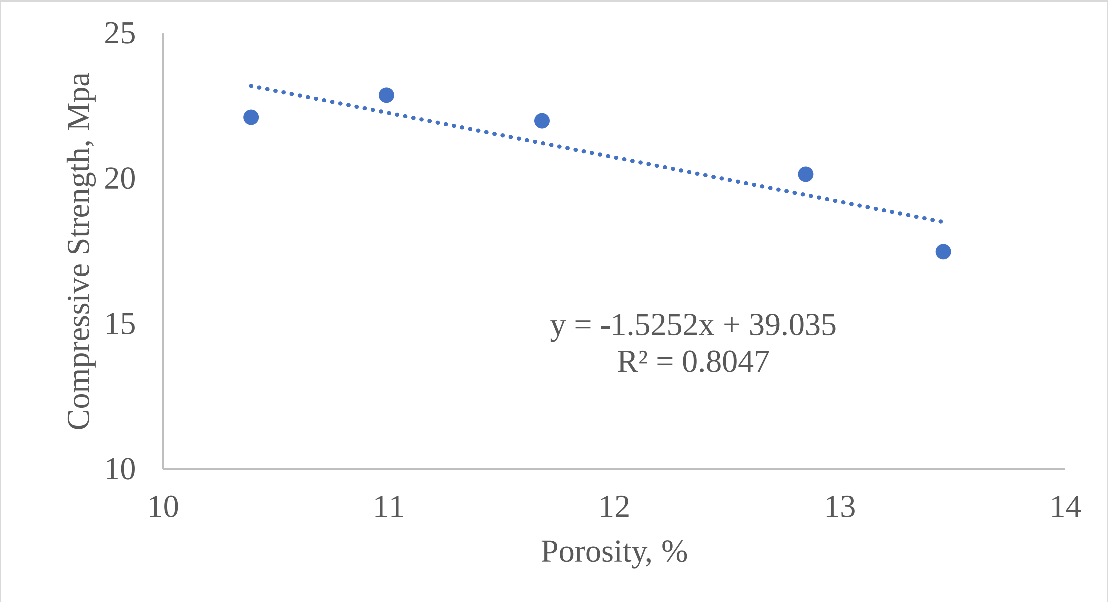


Figure 4.7: Relation between Porosity and Compressive Strength

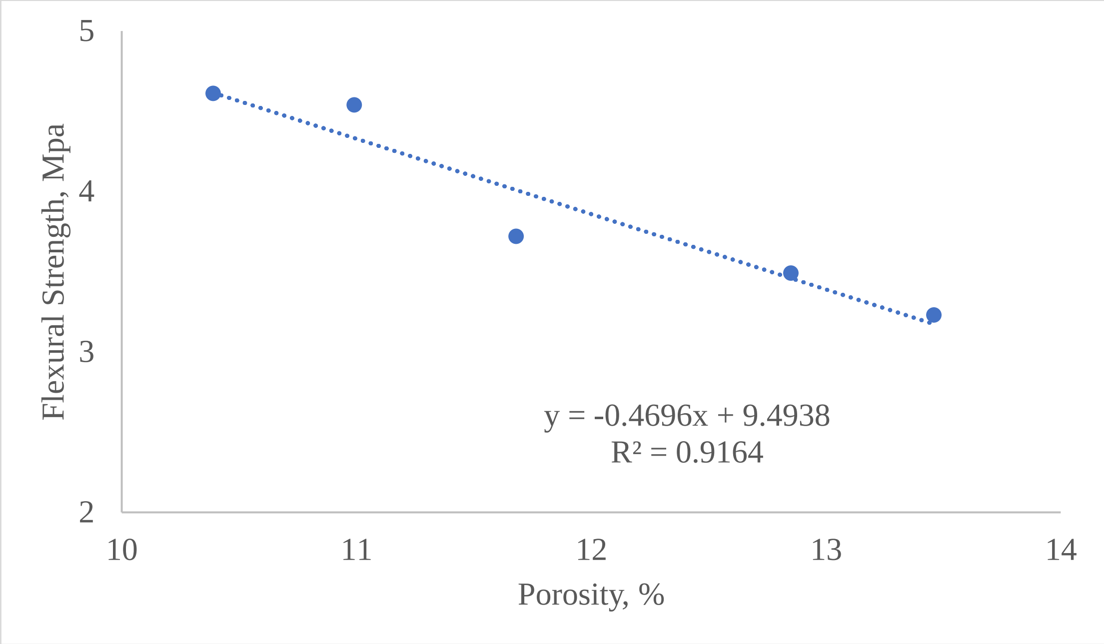


Figure 4.8: Relation between Porosity and Flexural Strength

4.7 Water Absorption

The water absorption of concrete specimens with curing ages of 7 days, 14 days and 28 days was tested to figure out the water holding capacity of the concrete. The results of the water absorption test are depicted in Figure 4.9. It is presented as a percentage and is calculated by taking into account the rate of weight difference which is the weight gain of dried specimen upon immersion in water.

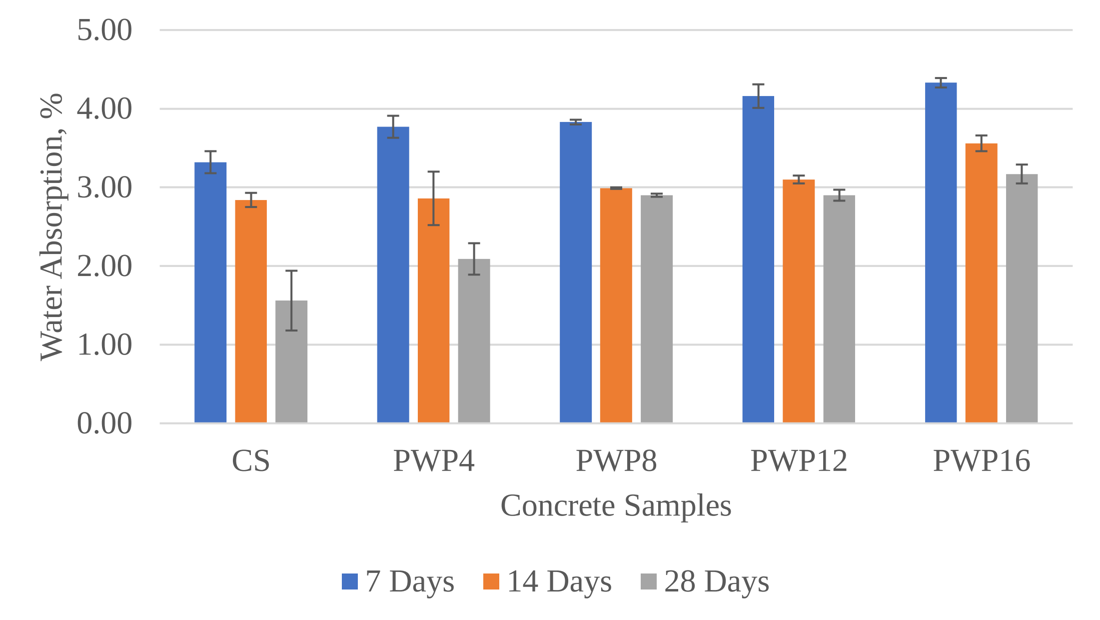


Figure 4.9: Water Absorption of Concrete Samples after Curing of 7 Days, 14 Days, and 28 Days.

Figure 4.9 clearly shows that the curing affects the water absorption much like the porosity, where the water absorption of all specimens decreases with increase in curing ages. The prolonged curing period enables an adequate cement hydration process to occur, allowing C-S-H gels to develop and fill the pores and voids in the specimen, increasing the resistivity to absorption (Lamond and Pielert, 2006).

On the other side, the outcome of this result demonstrated that the PVC waste powder plays a negative role in reducing the water absorption capacity of concrete. The incorporation of the PWP in making concrete results in increasing the water absorption rate of all ages of concrete. Water absorption is increases with the increment in permeability of concrete. The permeability is influenced by the porosity of concrete. The effect of the hydrophobic nature, absence of cementitious material of PWP and the decrease in amount of cement for hydration on the porosity of concrete was discussed at Section 4.6.

Moreover, this finding agreed with the research study by Geetha Devi et al., (2021) who reported that the concrete's water absorption rate increase when more cement is replaced with PVC powder. According to the authors, the higher amount of PVC powder resulted in higher surface area availability than the Portland cement which will increase the absorption rate. Moreover, the polyvinyl chloride (PVC) particles will result in partial coverage of partial aggregate surface and leave some empty spaces.

4.7.1 Relation between Water Absorption and Porosity

Efforts were made to study the relation between water absorption and the porosity of concrete. From Figure 4.10, it can be noticed that there is a linear relationship between water absorption and porosity. It appears that the water absorption increases with an increase in porosity. In other words, an increase in the water absorption rate means an increase in the permeability of the concrete specimen. Thus, the water absorption of concrete can indicate the degree of porosity inside the concrete. The y = 1.7235x + 7.5239 is an equation shown in the figure, and the R2 with the coefficient of 0.832 is displayed in the graph shown in Figure 4.10.

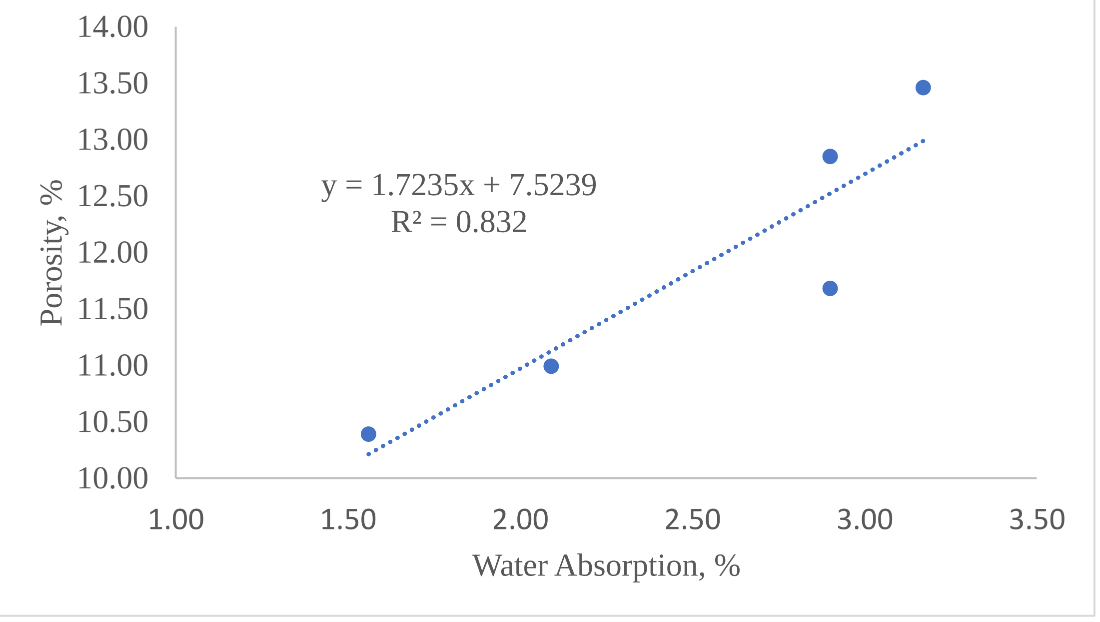


Figure 4.10: Relation between Water Absorption and Porosity.

4.8 Gas Permeability

Gas permeability test is conducted to determine the ease of air or gases that can penetrate the concrete. Gas permeability is relevant to the durability of concrete under the various condition of exposure. The gas permeability of concrete specimens with curing age of 7 days, 14 days and 28 days were tested. The results of the porosity test are depicted in Figure 4.11.

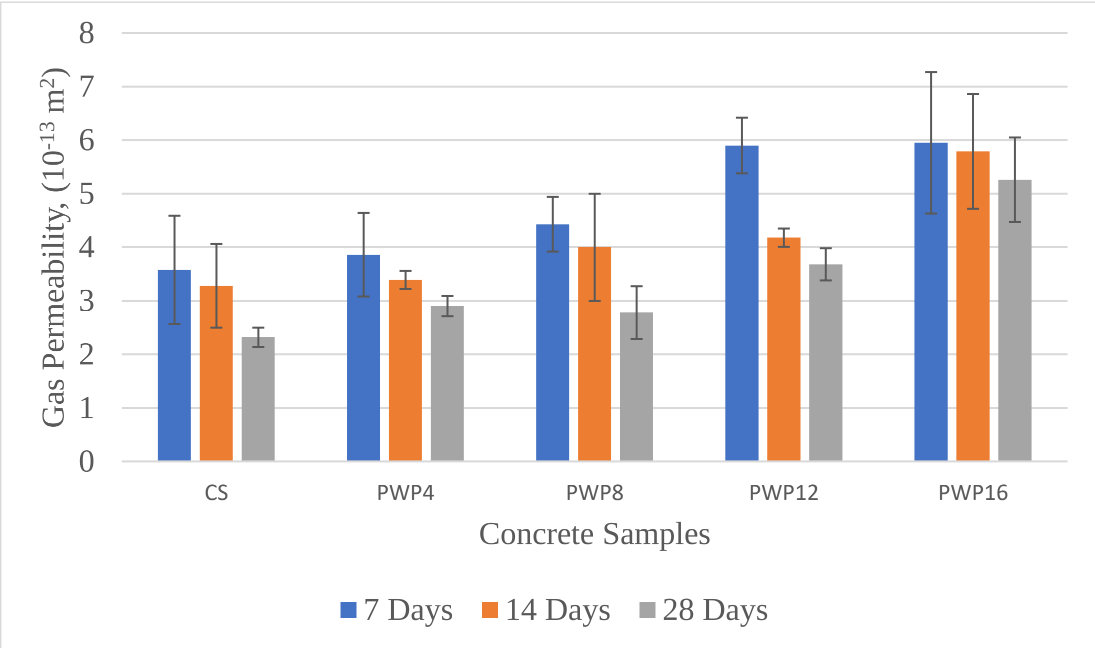


Figure 4.11: Gas Permeability of Concrete Samples after Curing of 7 Days, 14 Days, and 28 Days.

Similar to other durability properties discussed above, the gas permeability of concrete also decreases with the increase in the curing age of concrete. With age, the gas permeability decreases because gel gradually fills the void and pore space, making the concrete more impermeable. The reduction of pores will impede the diffusion of air.

As expected, the gas permeability of concrete in all age increase with PWP replacement corresponding to the increase of porosity occurring with the increment of PWP replacement. According to the results, the gas permeability of concrete after 28 days of curing increased from 2.32 to 5.26 10^{-13} m^2, regarding the substitution of cement with PWP from 0 to 16%. As mentioned earlier, lack of cementitious material in PWP and reducing cement in concrete will decrease hydration products such as C-S-H gel. As a result, more pores will be left in concrete due to insufficient gel to fill the pores. Consequently, the concrete specimen becomes more permeable and allows more air to diffuse through its body.

4.9 Chloride Attack

Chlorides have little effect on the conventional hardened concrete itself, but they will corrode the steel in reinforcement concrete. Corrosion of steel reinforcement is one of the significant causes contributing to the reinforced concrete structure deterioration. In this research, PVC powder which contains chlorine elements, is incorporated into the concrete making process. Hence, this test is conducted to determine whether the chlorine from the PVC powder will affect the durability of the concrete specimen. It was determined using the colorimetric method by spraying Silver Nitrate ($AgNO_3$) solution on the concrete sample. If there is a presence of chloride, the silver will react with chloride, forming a whitish color of silver chloride. On the other side, if there is no chloride ion in that region, the reaction between silver ions and hydroxyl ions occurs, resulting in the formation of Silver Hydroxide (AgOH), which causes the concrete surface to turn into brown color (Pontes, Reus and Calvo, 2021). Figure 4.12 shows the color change on the split surface of the PWP16 specimen after spraying $AgNO_3$ solution on the split surface.

Figure 4.12: The split surface of PWP16 specimen before and after spraying $AgNO_3$.

As shown in Figure 4.12, the split surface of the PWP16 concrete specimen has become brown colour after spraying the $AgNO_3$ solution on the split surface of the concrete. This indicated that there is no sign of free chloride ions that can react with silver ions. This might be due to the C-Cl bond is not broken as the concrete specimen is not exposed to strong ultraviolet light or higher temperatures to initiate the broken of C-Cl bond. Hence, the Cl element is still bonded to the C atom on the polymer chain. Therefore, Cl is not free and cannot make new bonds with other elements or chemical compound until the C-Cl bond is broken. This indicated that there are no free Cl ions to corrode the steel if the PVC powder is used in making concrete for this study. However, this finding is not applicable in the long run. If the concrete is continually exposed to sunlight for a more extended period of time, the temperature and the exposure to UV light will be high enough for the initiation of breaking the C-Cl bond and release the free Cl ion to react with steel in the concrete. Thus, further investigation is needed to study the effect of chlorine elements in PVC powder on the durability of concrete.

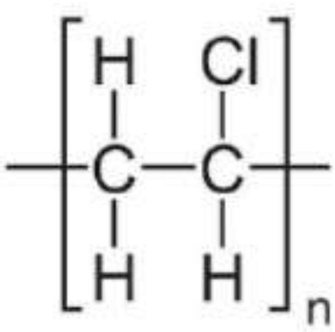


Figure 4.13: Structural Formula of PVC (adapted from Mohamed, Tuhaiwer and Razzaq, 2016).

4.10 Scanning Electron Microscopy (SEM)

The development and distribution of hydration products of hydrated cement paste in five different concrete mix proportions after curing period of 28 days are depicted in the figures below (Figures 4.14 to Figure 4.18). The microstructure of all concrete specimens with substitution of PWP are examined and compared with the control specimen. Tricalcium silicate (C_3S) and Dicalcium silicate (C_2S) are the main compounds of the Portland Cement (Neville, 2002). In the presence of water, the hydration reaction between C_2S and C_3S in cement occurs. The hydration product such as calcium silicate hydrate (C-S-H), calcium hydroxide and some minor compounds slowly begin to accumulate on the outer periphery of hydrated cement nucleus (Pecker, 2020). The hydration product will progressively occupy the space previously filled by water. In a fully hydrated cement paste, the C-S-H gel accounts for about 60 to 70% of the volume of solid (Basquiroto de Souza, Sagoe-Crentsil and Duan, 2022).

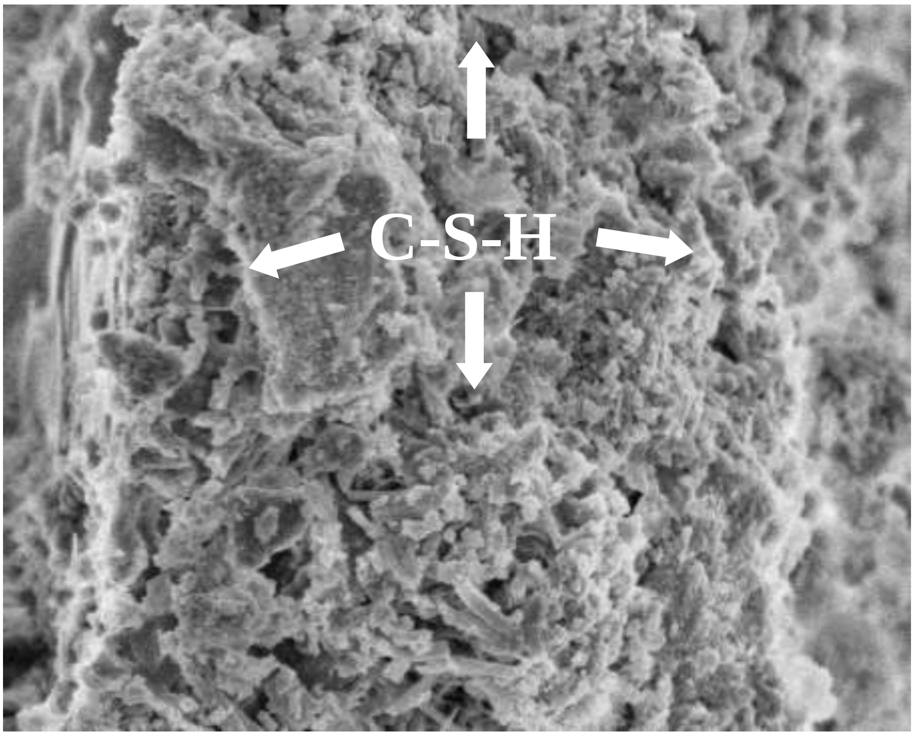


Figure 4.14: SEM Micrograph of CS at the Magnification of × 10000.

From the SEM micrograph of CS as shown in Figure 4.14, it can be clearly appreciated that the C-S-H gel was widely spread in the hydrated cement paste and this was the primary factor for higher strength growth. The process of forming calcium carbonate, $CaCO_3$ on the exterior surface of the concrete is known as carbonation. Carbonation is the process whereby carbon dioxide (CO_2) combines with calcium hydroxide ($Ca(OH)_2$) in concrete to form calcium carbonate ($CaCO_3$) on the exterior surface of the concrete. Thus, these growth and dispersion of mineral components contributed to develop strength of concrete specimen (Saran and Magudeswaran, 2017).

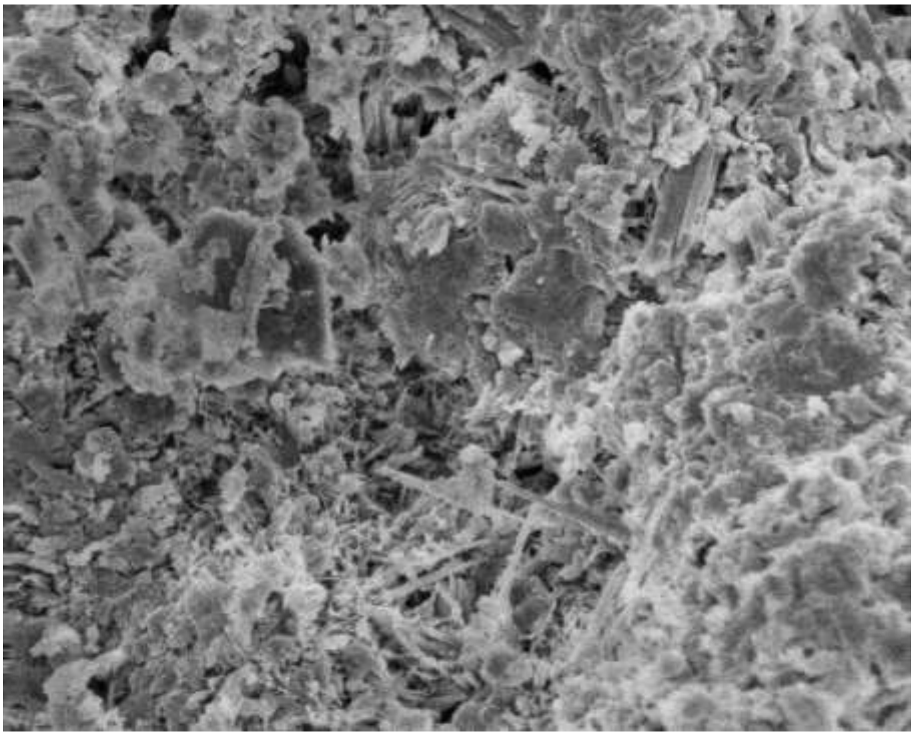


Figure 4.15: SEM Micrograph of PWP4 at the Magnification of × 10000.

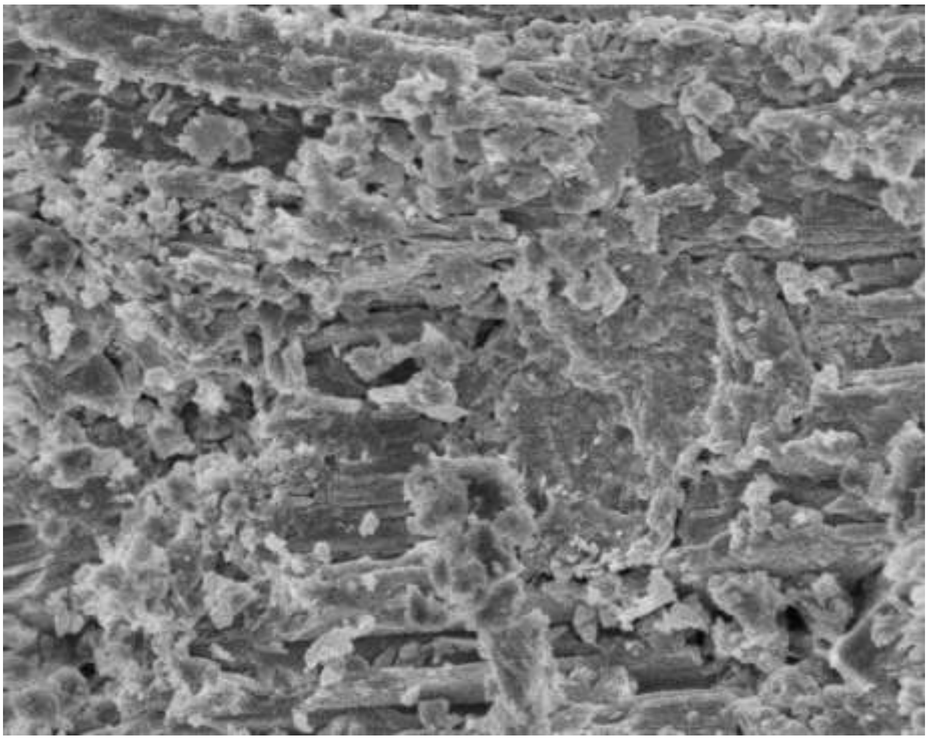


Figure 4.16: SEM Micrograph of PWP8 at the Magnification of × 10000.

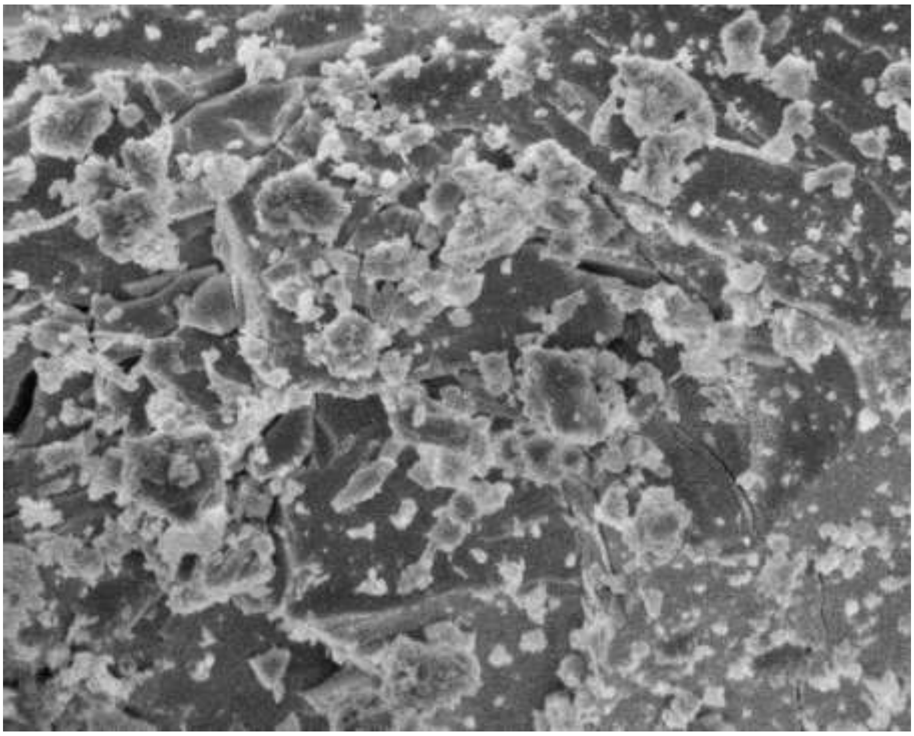


Figure 4.17: SEM Micrograph of PWP12 at the Magnification of × 10000.

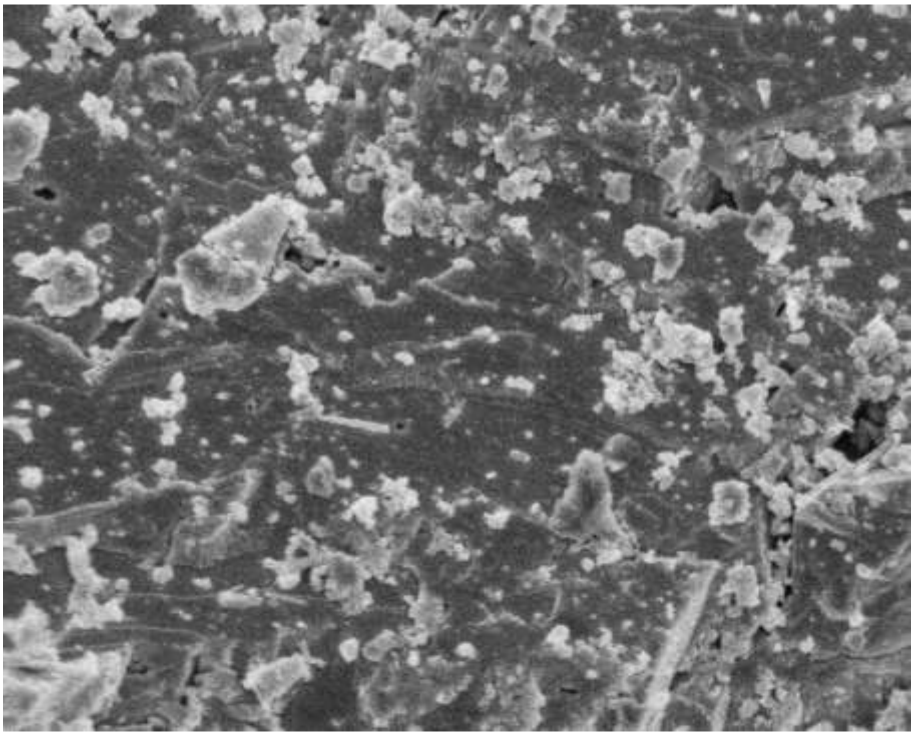


Figure 4.18: SEM Micrograph of PWP16 at the Magnification of × 10000.

Figure 4.15 to Figure 4.18 display the SEM micrograph of PWP4, PWP8, PWP12 and PWP16 concrete specimen. These are the microstructures of concrete samples with varying amounts of PWP used to replace cement. In the view of, it can be seen that the distribution of C-S-H decreased with the increase in the amount of PWP replacement in concrete. This is because of the lack of chemical reaction between the $Ca(OH)_2$ in cement and PWP which result in the decrease of C-S-H formation. Hence, the presence of non-reacted particle, PWP in the mix will cause the range of development of C-S-H become lesser and subsequently affect the strength of concrete. Additionally, the SEM micrographs of all concrete specimen is in line with the strength test's result of this study.

4.11 Economic Appraisal

The aspect of the economy is also crucial in determining the feasibility of adding PVC waste powder into concrete as a partial replacement for cement. Therefore, an economic appraisal is conducted to evaluate the difference between the cost of producing conventional concrete and PVC powder concrete in this research. The cost of PWP4 specimen is estimated since the optimum substitution portion for PWP to replace cement in this research is 4%. The estimated cost for manufacturing 1 m^3 of conventional concrete and for PWP4 concrete are shown in Table 4.2.

Table 4.2: Estimated Cost for Manufacturing of 1 m^3 PVC Powder Concrete with 4 % of PWP Substitution and Conventional Concrete.

Materials	Price Per Unit (RM)	Conventional Concrete		PVC Powder Concrete	
		Amount for $1m^3$ concrete	Total Price (RM)	Amount for $1m^3$ concrete	Total Price (RM)
Cement	0.38/kg	388 kg	147.44	372 kg	141.36
Sand	0.041/kg	580 kg	23.78	580 kg	23.78
Coarse Aggregates	0.038/kg	1163 kg	44.194	1163 kg	44.194
PWP	0.098/kg	-	-	16 kg	1.568
Total Price (RM)			**215.42**		**210.9**

From Table 4.4, the cost of making $1m^3$ of PWP4 concrete is lower than that of conventional concrete. The price is lower from RM 215.42 to RM 210.9. This is due to the reduced cost of cement when a portion of cement is replaced by PWP. The price of cement per kg is RM0.38, whereas the price of PWP per kg is just RM0.098. Although it is only a small cost-saving, the total cost reduction might be enormous if a large amount of cement is utilized in construction work. If the PWP4 concrete is used to construct the floor slab with dimension of 100 m^3, it can save up to RM 500. Therefore, it is proved that the utilization of PWP in concrete production is feasible. Moreover, this approach will help the company shift from a linear to a circular economy. The current linear economy in the construction industry results in immense consume vast amounts of natural resources and disposal of the product at the end of its life cycle. By utilizing plastic waste to replace cement, the construction companies can transit to a more efficient circular economy that can reduce the consumption of natural resources, improved recycling and save money by reusing waste as input materials.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

All of the objectives specified in Chapter 1 have been successfully accomplished in this research. First, the PVC waste powder (PWP) has been incorporated as cement replacement in concrete. its influence on properties of concrete. Secondly, the effects of PWP in concrete were investigated by comparing the properties of concrete with and without plastic waste powder. Lastly, the optimum substitution ratio of PWP as partial cement replacement was identified. The following conclusions can be drawn based on the results of this study:

1. The incorporation of PWP as partial cement replacement improved the workability of concrete mixtures.
2. The incorporation of PWP reduced the strength of concrete, however, the PWP may be used to replace up to 12 % of the cement in concrete because it results in a small reduction in strength.

3. The optimal substitution percentage of PWP for partial cement replacement is 4% since it results in a strength value that is nearly similar to the control specimen.
4. The incorporation of PWP will increase the porosity, water absorption, and gas permeability of concrete, which in turn decreases the durability of concrete.
5. The usage of PWP as partial cement replacement in concrete can reduce the cost of concrete production process.

Based on this study, it can be concluded that the use of plastic waste as partial cement replacement will adversely affect the mechanical and durability properties of concrete. This is mainly due to the non-cementitious nature of plastic. Nevertheless, the concrete with low dosage of plastic waste as cement replacement still can achieve the quality that is similar to the normal conventional concrete (M20). After all, the utilization of plastic waste as cement replacement in concrete is considered as a new development in engineering and construction field. Hence, further studies and improvements are still required to determine the long-term effects of incorporation of plastic waste powder as cement replacement in concrete.

5.2 Recommendations

Several recommendations are made for further improvement in the research of plastic waste powder incorporation as cement replacement in concrete. The recommendations are proposed as follows:

1. Increase the substitution portion of plastic waste powder as partial cement replacement in order to further explore the effect of plastic waste incorporation on the performance of concrete.
2. Extend the curing period to evaluate the mechanical and durability properties of concrete with plastic waste more accurately.
3. Conduct further studies using different type of plastic waste such as PET, LDPE, and HDPE to replace cement.
4. Conduct more tests to determine the details characteristics of concrete such as the thermal conductivity, sound insulation, chemical resistance of concrete with the incorporation of plastic waste powder as partial cement replacement.

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