COMPRESSIVE BEHAVIOUR OF POLYETHYLENE TEREPHTHALATE (PET) AS PARTIAL COARSE AGGREGATE REPLACEMENT IN CONCRETE

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POON SIEW VOON

Thesis submitted in fulfilment of the requirements
for the award of the degree of
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Faculty of Civil Engineering and Earth Resources
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JUNE 2015

SUPERVISOR'S DECLARATION

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Dedicated to my parents,
for their love and devotion
making me be who I am today

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ABSTRACT

In this developing world, the waste generated is gradually increased due to urbanization. Nevertheless, the solid waste in Malaysia is managed or disposed through landfill and partly to recycle. There is 35568 tons of waste being produced per day in Malaysia with the growth rate of 3.59% per year. In this rate of waste generation, the insufficient of landfill can become a significant problem in coming years. Therefore, recycle of solid waste is a compulsory act to prevent further destroying of environment and preserve the natural resources for the use of future generation. Waste accumulation can be solved by alternative solution such as replacement of aggregate by solid waste. The aim of this work is to determine performance of different percentage of Polyethylene Terephthalate (PET) as coarse aggregate replacement and suitability of plastic aggregate in concrete. The effects of natural aggregate and plastic aggregate in shape and behaviour were investigated. Test for slump, rebound hammer, compressive strength, heat absorption and water absorption were carried out to identify the suitability of plastic aggregate replacement. This study focused on the bottle neck of PET as coarse aggregate replacement and compressive behaviour of concrete with PET, varying the percentage of coarse aggregate replacement (10, 20, 30 and 40 vol%). The compressive strength is decreased as the plastic aggregate content is increased compared to conventional aggregate. This study presents an alternative way of recycling PET to reduce solid plastic waste and capacity of landfills.

ABSTRAK

Dalam zaman pembangunan ini, pembandaran merupakan factor peningkatan sisa. Namun begitu, sisa pepejal di Malaysia digurus atau dilupus melalui tapak pelupusan dan sebahagian lagi adalah untuk mengitar semula. Terdapat 35568 tan sampah dihasilkan sehari di Malaysia dengan kadar pertumbuhan 3.59 % setahun. Dengan kandar pertumbuahn ini, kekurangan tapak pelupusan boleh menjadi satu masalah yang besar pada masa yang akan datang. Oleh itu, kitar semula sisa pepejal adalah amalan yang wajib untuk mencegah permusnahan alam sekitar dan memelihara sumber-sumber semula jadi untuk kegunaan generasi masa depan. Pembuangan sisa boleh diselesaikan dengan penyelesaian alternatif seperti penggantian agregat oleh sisa pepejal. Tujuan kajian ini adalah untuk mengidentifikasikan prestasi yang terbaik dalam peratusan Polyethylene Terephthalate (PET) yang berbeza sebagai pengganti agregat kasar dan kesesuaian agregat plastik di dalam konkrit. Kesan agregat semula jadi dan agregat plastik dalam bentuk dan ciri-ciri perlu diidentifikasi. Ujian kemerosotan, pemulihan tukul, kekuatan mampatan, penyerapan haba dan penyerapan air telah dijalankan untuk mengenal pasti kesesuaian penggantian agregat plastik. Kajian ini memberi tumpuan kepada leher botol PET sebagai pengganti agregat kasar dan ciri-ciri mampatan konkrit dengan pengubahan peratusan penggantian agregat kasar (10, 20, 30 dan 40 vol%). Kekuatan mampatan menurun semasa kandungan agregat plastik meningkat berbanding dengan agregat konvensional. Kajian ini membentangkan cara alternatif dengan kitar semula PET untuk mengurangkan sisa pepejal plastik dan kapasiti tapak pelupusan.

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LIST OF SYMBOLS

%	Percentage
mm	Millimeter
N/mm^2	Newton per millimeter square
kg	Kilogram
N	Newton
°C	Degree Celsius
∑	Sum
w/c	Water to cement ratio
mm^2	Millimeter square
min	Minute
µm	Micrometer
MPa	Mega Pascal
±	Plus-Minus

LIST OF ABBREVIATIONS

ABNT-NBR	Technical Standards Brazilian Association
ASTM	American Society for Testing and Materials
BS	British Standard
CEM	Certified Energy Manager
EN	European Standards
FPZ	Fracture Process Zone
MS	Malaysia Standard
NA	Natural Aggregate
OPC	Ordinary Portland Cement
PA	Plastic Aggregate
PA_0	0% of Plastic Aggregate
PA_1	10% of Plastic Aggregate
PA_2	20% of Plastic Aggregate
PA_3	30% of Plastic Aggregate
PA_4	40% of Plastic Aggregate
PET	Polyethylene Terephthalate
RILEM	Reunion International Laboratories Experts Material
SPI	Society of Plastic Industry
WPLA	Lightweight Aggregate

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Urbanization is a common phenomenon for developing country like Malaysia. In 2011, urban population of Malaysia is stated as 72.8 % of its total population (Central Intelligence Agency, 2014). This population rate leads to the flourish of construction sector. Malaysia Key Economic Indicator showed that the construction sector had preliminary record of 3.5 % in growth (Economic Development, 2011). The development of construction has increased the demand of aggregate as it's a raw material for concrete.

Concrete is a common type of construction material which produce by mixing of water, aggregate and cement in different ratio. The growth of demand in concrete is predicted approximately 18 billion tons by 2050 (Khoshkenari et al., 2014). Since the general formula of concrete is 1:2:4 which represent cement, fine aggregate and coarse aggregate, concrete consists around 85 % of aggregate. At this huge usage of aggregate, the increase of mining activity is inevitable. The current mining activities create unsuitability in environment and imbalance in ecologic. Diminution of mining activities is necessary to save the natural resources. Global concerns in the environment awareness also affect the construction concept in strategic planning to reduce environment impact (Henry & Kato, 2014).

In addition, the waste generated is gradually increased due to urbanization. There are few methods of disposal, such as incineration, landfilling and recycling (Albano et al., 2009). Nevertheless, the solid waste in Malaysia is managed or disposed through landfill and partly to recycle. There are 165 landfill areas operating and 35568 tons of waste is produced per day in Malaysia with the growth rate of 3.59 % per year (JPSPN, 2014). In this rate of waste generation, the insufficient of landfill can become a significant problem in coming years. Therefore, recycle of solid waste is a compulsory act to prevent the continuous on destroying environment and preserve the natural resources for the use of future generation (Environmental Protection Agency, 2014). Waste accumulation can be solved by alternative solution such as replacement of aggregate by solid waste.

In Malaysia, plastic waste is at the second highest rank which is 24 % out of total solid waste (The Star, 2012). Even in others countries, the waste of plastic is always within the rank of top five. Plastic waste includes containers, durable waste such as furniture, and non-durable waste such as diapers and medical devices (Solid Waste District, n.d.). Polyethylene Terephthalate (PET) is a type of polymer that mostly used to produce food and beverage containers. It comes with the SPI Resin Identification Code of 1. Recycling of PET is very common in worldwide. PET postconsumer resin is normally used for production of fiber, film and sheet (United States National Postconsumer Plastics Bottle Recycling Report, 2012).

The value of PET mostly falls back to the plastic production sector. The possibility of PET in replacing aggregate can develop a new market for PET postconsumer and also provide an alternative option for construction industry in material selecting. The suitability of the replacement of PET as coarse aggregate in concrete mixing is needed to be identified.

Figure 1.1: Plastic waste

Source: BioEnergy Consult

1.2 PROBLEM STATEMENT

The flourish of construction sector leads to the increase in demands of construction material such as cement and aggregate. The replacement of construction material by waste such as Polyethylene Terephthalate is a solution for the high demand of aggregate.

In concrete mixing, concrete is constituted by 60 % to 80 % of aggregate in volume and 70 % to 85 % of concrete in weight. However, aggregate is a non-renewable source. The continuous of quarrying activities is bringing the negative impact to the environment and shortage of aggregate. The replacement of aggregate is needed to reduce the impact of quarrying.

Polyethylene Terephthalate (PET) is a kind of plastic waste that is increasing directly proportional to human waste. Plastic is occupying 9.27 % in average global waste composition (Waste Atlas report, 2013). This problem is causing the insufficiency of landfill area in the coming years.

The replacement of aggregate by PET is a mutualism solution to solve both problems. The recycle of PET and reduce of quarrying activities can protect and preserve the natural environment.

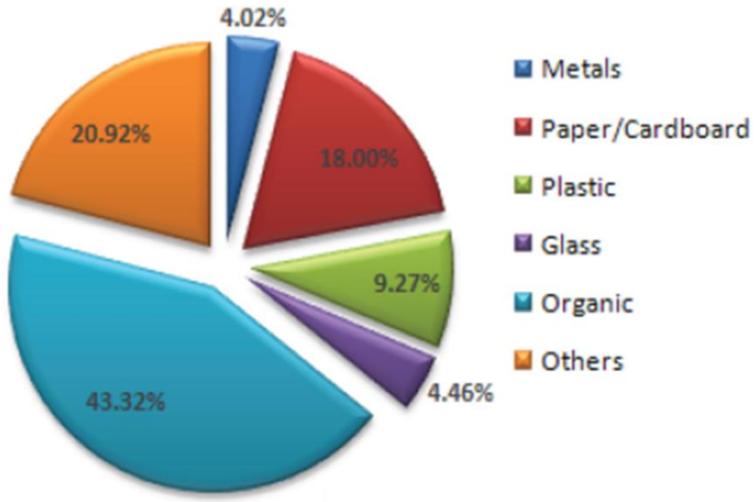


Figure 1.2: Average global waste

Source: Waste Atlas report, 2013

1.3 OBJECTIVE

Replacement of aggregate by Polyethylene Terephthalate (PET) can be a better option to reduce negative impact to environment if it achieves the same function as aggregate.

1. To identify the suitability of replaced aggregate in concrete.
2. To determine and improve the compressive strength of replaced aggregate in concrete.
3. To determine performance of different percentage of PET as coarse aggregate replacement in concrete.

1.4 SCOPE OF STUDY

In this study, certain percentage of Polyethylene Terephthalate (PET) is used to replace coarse aggregate in concrete mixing.

1. The bottle neck of plastic bottle is used and the diameter is fixed at 20 mm to 30 mm, the height is fixed at 15 mm to 25 mm.
2. A layer of polystyrene is filled into the bottle neck.
3. 0, 10 %, 20 %, 30 %, 40 % of Polyethylene Terephthalate (PET) is used to replace coarse aggregate in concrete mixing.
4. The concrete is designed as grade 25 by using Polyethylene Terephthalate (PET), granite, sand, Portland cement and water.
5. The size of the concrete is 100 mm x 100 mm x 100 mm.
6. The specimen is tested at the age of 1 day, 7 days and 28 days.
7. The tests carried out on fresh and hardened concrete are slump test, rebound hammer, compression test, heat absorption test and water absorption test.

1.5 RESEARCH SIGNIFICANT

Reuse of waste product such as Polyethylene Terephthalate (PET) as an aggregate in concrete mixing is a mutualism option for solid waste management and construction industry. It can reduce the negative impact to environment while supporting the development of construction industry. The research can give the advantage to industries, environment and mankind.

The significant of this study are:

1. Reduce the waste production and capacity for landfill.
2. Reduce the use of non-renewable aggregate and maintain the balance of ecosystem
3. Introduce waste product such as Polyethylene Terephthalate (PET) to replace aggregate.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents review of the previous relevant literatures, which includes composition of concrete, compressive strength of concrete and aggregate replacement. In addition, this topic focuses on the replacement of waste material as aggregate in concrete mixing and the negative impact that created by plastic waste. Furthermore, the characteristic and properties of Polyethylene Terephthalate (PET) are discussed in this topic.

2.2 CONCRETE

Concrete is a composite of cement, aggregate and water in a suitable mix proportion. Its raw material has high availability and the characteristic of durability and able to form in many dimension gives it advantage as the primary material in construction (Khoshkenari et al., 2014). The development of country is the main factor of increasing of concrete usage especially in infrastructure systems (Henry & Kato, 2012). The dramatically increases of concrete caused the increase of quarrying which bring negative impact to environment.

The global environmental issue is highlighted in every industry and new technology is invented to reduce environmental impact. In Nordic countries, a center of green concrete is established in Denmark to face the challenges of environment. Meanwhile, Norway supported this action by creating the online database and documentaries for green concrete (Henry & Kato, 2012). The green technology in production of concrete and construction is very popular and encouraged in construction sector. Besides, construction industry is affected by its sustainability issue. Basically, the environment impact comes from the construction and erection of buildings. There are few methods to reduce environment impact which are to increase the performance and lifetime of concrete (Müller et al., 2014). Concrete also has its sustainable advantages such as resource efficient, long span life and carbon absorption (Hooton & Bickley, 2014). The additional advantage of reduction in environmental effect is that it can increase the value of concrete in its sustainable advantage.

The direction of development in construction showed its potential in green technology. The new trend of green technology cannot be stopped especially where the natural resources is limited. Replacement of natural resources such as production of cement and aggregate is not a new topic in research finding in response to the environment concerns.

2.2.1 Cement

Cement is the main material in concrete mixing. The behaviour of concrete is influenced by composition of cement (Florea & Brouwers, 2012). Ordinary Portland Cement (OPC) is chosen in this study because it has the basic hydration process in concrete production (Potgieter-Vermaak et al., 2007). Sajedi & Razak (2011) suggested that the fineness of cement is the major factor for its quality especially contribution in compressive strength. In another words, the finer cement gives better compressive strength.

2.2.2 Aggregate

Durability of concrete is also one of the main concerns in construction industry. The destruction of concrete is mostly caused by degradation of concrete when it is exposed to freezing. In concrete mixing, aggregate is the contributor of durability of concrete which has chemical resistance and high density (Skripkiūnas et el., 2013). Fine and coarse aggregate constitutes the largest portion in concrete mixing. Type of aggregate used affects the mechanical properties of fresh and hardened concrete. The depletion of natural aggregate widen the research of replacement aggregate in civil field (Zhang et al., 2013).

Fine aggregate has the role of filling the voids between coarse aggregate to act as workability agent. The voids determine the density and strength of concrete (Zhang et al., 2014). Coarse aggregate is the major determinant in the contribution of concrete durability (Zhao et al., 2012). Gonilho et al. (2009) concluded that the aggregate size and its water content affected concrete durability. However, most of the coarse aggregate is non-renewable sources which required quarrying for the production. There is necessary to find alternatives yet renewable aggregate to replace the non-renewable aggregate to maintain ecology balance.

2.3 COMPRESSIVE STRENGTH OF CONCRETE

Compressive strength of concrete is a fundamental in design. Contribution of cement fineness is undeniable. In addition, Hao et al., (2013) also found that increasing of volume fraction leads to high compressive strength. It means aggregate plays an important role in contribution of compressive strength. However replacement of recycled aggregate had substantial effects on compressive strength of concrete (Mukharjee & Barai, 2014).

Water to cement (w/c) ratio is also one of the influence parameter on the compressive strength (Albano et al., 2009). The smaller water cement ratio gives the better compressive strength. Meanwhile, Koenders et al., (2014) confirmed that the initial moisture content of aggregate influence the development of compressive strength. In the research, dry aggregate with smaller water cement ratio had higher compressive strength as shown in Figure 2.1.

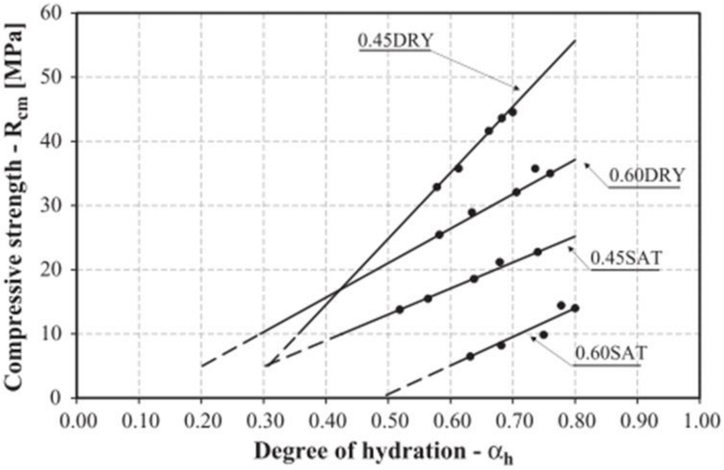


Figure 2.1: Graph of compressive strength against degree of hydration

Source: Koenders et al., 2014

2.4 PREVIOUS RESEARCH OF AGGREGATE REPLACEMENT

Natural aggregate is a non-renewable resource which its depletion of coming years cannot be avoided. The replacement of aggregate in research becomes a trend in research finding to reduce its quarrying effect to the environment. Aggregate contributes 85 % of volume in concrete. The large consumption of aggregate in construction industry creates burden to the environment especially the development of construction industry is flourish.

Besides, the reduction of carbon dioxide can be improved by using recycled concrete as aggregate (Hooton & Bickley, 2014). The environment negative impact can reduce by replace aggregate when the quarrying activity is reduced. Table 2.1 had tabulated the research done on replacement of aggregate.

Table 2.1: Previous Research In Aggregate Replacement Material

No.	Type of aggregate replacement	Researchers
1	Concrete Waste	Mukharjee & Barai, 2014
2	Steel Slag	Netinger et al., 2013
3	Glass	Castro & de Brito, 2013 Kou & Poon, 2013
4	Chipped Rubber	Ganjian et al., 2009
5	Marble Waste	André et al., 2014 Uygunoğlu et al., 2014

2.4.1 Plastic waste as aggregate replacement

Plastic material is malleable. It’s characteristic of low in cost and easy in manufacturing made it used in wide range of product such as packaging, healthcare and medical application. It has become an inseparable product in daily life. However, their waste and environmental management remain a big problem to society. The environmental issue of plastic waste is always highlighted in every sector. Its characteristic of long period biological degradation creates a challenge to mankind (Sánchez & Collinson, 2011).

Many studies were carried out since 1993 on the research of plastic waste in concrete. It was started with Bayasi and Zeng on the effect of polypropylene fibres on the properties of concrete. Later in 1997, Al-Manaseer and Dalal conducted the study on slump test with plastic aggregate (Siddique et al., 2008).

Choi et al., (2005) has conducted an initial study on the properties of concrete using waste PET bottle as aggregate replacement. From his investigation, lightweight aggregate made from plastic waste (WPLA) is used to replace fine aggregate in ratio. The result showed that compressive strength on 28 days decreased as the water cement ratio and replacement ratio increased. It achieved 21.8 N/mm^2 with water cement ratio of 0.53 and replacement ratio of 0.75.

Batayneh et al. (2007) conducted a study of plastics as a substitution of fine aggregate. In this study, 0, 5, 10, 15, 20 % of plastic is replaced in concrete with constant water cement ratio of 0.56. The result showed that concrete at 0 % of plastic substitution had the highest compressive, splitting and flexural strength. The relationship of the strength and percentage of plastic substitution is shown in Figure 2.2.

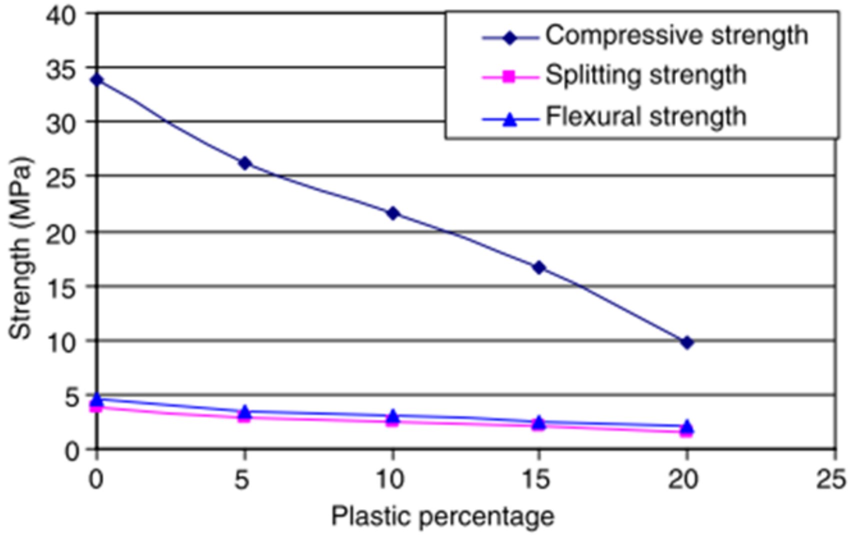


Figure 2.2: Relationship of the strength and percentage of plastic substitution

Source: Batayneh et al.,2007

2.5 PROPERTIES OF PET IN CONCRETE

Polyethylene Terephthalate (PET) has fastest consumption growth rate in worldwide (Bratek et al., 2013). It means that the growth is directly proportional to the waste of plastic. The main stream waste of PET came from food packages and soft drinks.

The properties of moisture barrier, high shatter resistance and exceptional gas made it suitable for the production of bottle (Gürü et al., 2014). Plastic aggregate created more free water and its properties of non-absorption water increased the slump.

Besides, it is lighter in weight compared to natural aggregate. This creates the potential of PET in development of lightweight concrete (Saikia & Brito, 2014).

The rheological properties such as flow and the compaction in concrete are changed by the addition of PET. Plasticity and consistency of fresh concrete decreased as the PET content increased (Albano et al., 2009). In addition, compressive strength increased proportionally to the resin content which also shown the characteristic of resin in filling the voids (Jo et al. 2008).

The shape of PET affected the properties of its in concrete. Saikia & Brito (2014) showed the shape of PET aggregate is affeceting the design of water cement ratio. In that research, the smooth and nearly spherical PET aggregate increase the slump value while reduces water cement ratio.

2.6 ENVIRONMENT ISSUE OF PLASTIC WASTE

The issue of waste management is the main concern in protecting environment especially plastic waste which has the characteristic of non-biodegration. Plastic waste contributes to land occuption and groundwater contamination issue to the environment (Yu et al., 2014). Argument on disposal method of plastic is never abated or satisfied by citizens.

An alternative solution is studied by many researches in the disposal and recyled due to the limited space and high cost of landfills (Zia et al., 2007). There are numbers of economic and environmental friendly solutions are sucessfully tested and conducted after years of research (Howard, 2002). The basic option for plastic waste management is mechanical recycled, landfill, incineration and feedstock recyclyed. Generally, mechanical recyclying is the best option (Rigamonti et al., 2014). Therefore, it appeared to have so many studies in plastic waste replacement of addition especially in the field of construction.

A mutual advantages is created while the field of construction has the environmental issue in emission of carbon dioxide in production of cement and quarying activities for aggregate. The problem can be solved by replacement or addition of plastic waste in concrete. A few of researches have been conducted on the plastic fiber replacing cement, plastic waste replace aggregate or plastic waste reinforce in the concrete. The table of replacement or addition of plastic waste in concrete is tabulated in Table 2.2.

Table 2.2: Replacement or addition of plastic waste in concrete

No.	Type of plastic	Features	Researchers
1	Polyethylene Terephthalate	Replacement of aggregate in concrete	Silva et al., 2013
2	Polyolefin and Polyethylene Terephthalate	Replacement of aggregate in mortar	Iucolano et al., 2013
3	Polyethylene Terephthalate	Replacement of aggregate in Modified Asphalt	Rahman & Wahab, 2013
4	Polyethylene Terephthalate	Reinforcement of concrete	Foti, 2013
5	Polyethylene Terephthalate	Addition in cement	Mahdi et al., 2013

2.7 CONCLUDING REMARK

From the literature of this study, many researches on the replacement of plastic waste had been conducted especially replacement in fine aggregate. However, the replacement bottle neck of PET as coarse aggregate with a layer of polystyrene had not been done yet. It is important to determine the suitability of this type aggregate in concrete mixing.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter reviews the test to be carried out to examine the suitability of replacement plastic waste as coarse aggregate in concrete composition. The main objective of this research is to collect the data through slump test, rebound hammer, compression test, heat absorption and water absorption test. The properties of material and tests for concrete composition are complying to standard documentaries. Figure 3.1 is the flow chart of this research. The Gantt chart of the research is tabulated in Table 3.1.

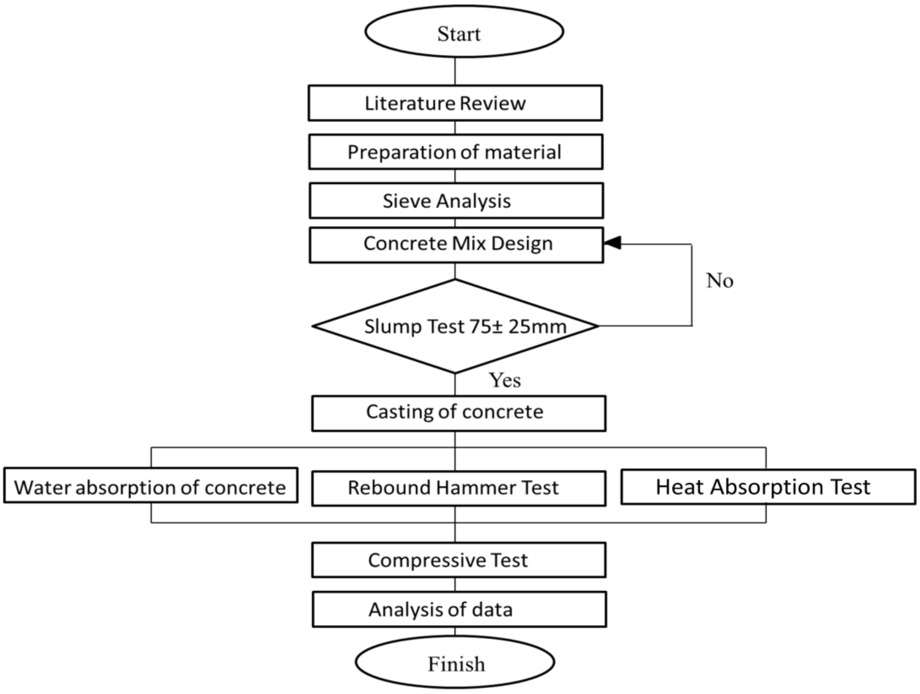


Figure 3.1: Flow chart of this research

Table 3.1: Gantt Chart of research

	Month		September				October				November				December			
	Activities																	
Choose research area	Register with potential supervisor	■																
	Brainstorm on Research Idea		■	■	■	■												
Preliminary research	Searching for research gap and determine the problem statement			■	■	■	■	■	■									
	Construct the research objective and scope of research						■	■	■									
Decide research topic	Study past research			■	■	■	■	■	■	■	■	■	■					
	Construct literature review and methodology								■	■	■	■	■					
Decide methodology	Work Schedule & Expected Outcome													■	■			
Finalise topic & methodology	Supervisor certify for research proposal															■	■	

3.2 PREPARATION OF MATERIAL

Study was carried out on Ordinary Portland Cement, river sand (fine aggregate), granite and bottle neck of plastic bottle (coarse aggregate) and water. The bottle neck of plastic bottle would replace the coarse aggregate in percentage. The ratio of concrete is used 1:2.24:2.15 which respectively to cement, fine aggregate and coarse aggregate. All materials for concrete mixing are needed to prepare carefully and store in the right place before used to ensure the quality of concrete specimens.

3.2.1 Ordinary Portland Cement

Ordinary Portland cement (OPC) has the basic ingredient of concrete, and mortar. Cement is always the main material in concrete mixing. Ordinary Portland cement of Orang Kuat which is one of the brands that produced by YTL is used in this study. A package of OPC is 50 kg. It is certified to MS 522-1: 2007 (EN 197-1: 2000), CEM I 42.5N / 52.5N and MS 522: Part 1: 2003. The packaging of cement is shown in Figure 3.2. In order to ensure the permeability, the cement was sieved. The cement was poured into a clean and dry bucket to ensure the accuracy of cement used.

3.2.2 Fine aggregate

The role of fine aggregate is to fill the void between coarse aggregate. It is also minimize the probability of shrinkage and cracking of concrete. In this study, the river sand is used as fine aggregate and it is shown in Figure 3.3. Sieve test is carried out before concrete mix design to investigate the category of fine aggregate. The fineness modulus was calculated as below equation. After calculated, the fineness modulus is 3.697. In preparation, fine aggregate was dried 24 hours in the oven with the temperature 105 °C before used in casting.

The fineness modulus is calculated as Eq. (1):

$$\text{Fineness Modulus} = (\sum \text{Cumulative percent retained}) / 100 \qquad (1)$$

Figure 3.2: Orang Kuat Cement

Figure 3.3: River Sand

3.2.3 Coarse aggregate

There are two types of coarse aggregate used in this study which are natural granite and bottle neck of plastic bottle. The function of coarse aggregate is to resist applied load and provide durability for concrete. Natural granite was dried in oven for 24 hours at the temperature of 105 °C and then sieved before used. Figure 3.4 is the sample of natural granite used in this study.

Meanwhile, the bottle neck of plastic bottle was cleaned and filled with a 10 mm thickness of polystyrene inside to avoid voids while mixing. Its size is then fixed at the diameter of 20 mm to 30 mm and the height of 15 mm to 25 mm. The plastic aggregate used is shown in Figure 3.5. The replacement of the plastic aggregate is 0, 10 %, 20 %, 30 %, and 40 % in concrete mixing by volume.

At first, PET plastic bottle is collected from friends and others events. The bottle neck of collected plastic bottles are cut out and cleaned up by water. Only the bottle neck of the plastic bottle is needed. Then, 15 mm thick of polystyrene was cut out as same as the diameter of the bottle neck and filled in the hollow part of the bottle neck. These recycled aggregate is kept in dry condition and waited for used.

Figure 3.4: Natural Granite

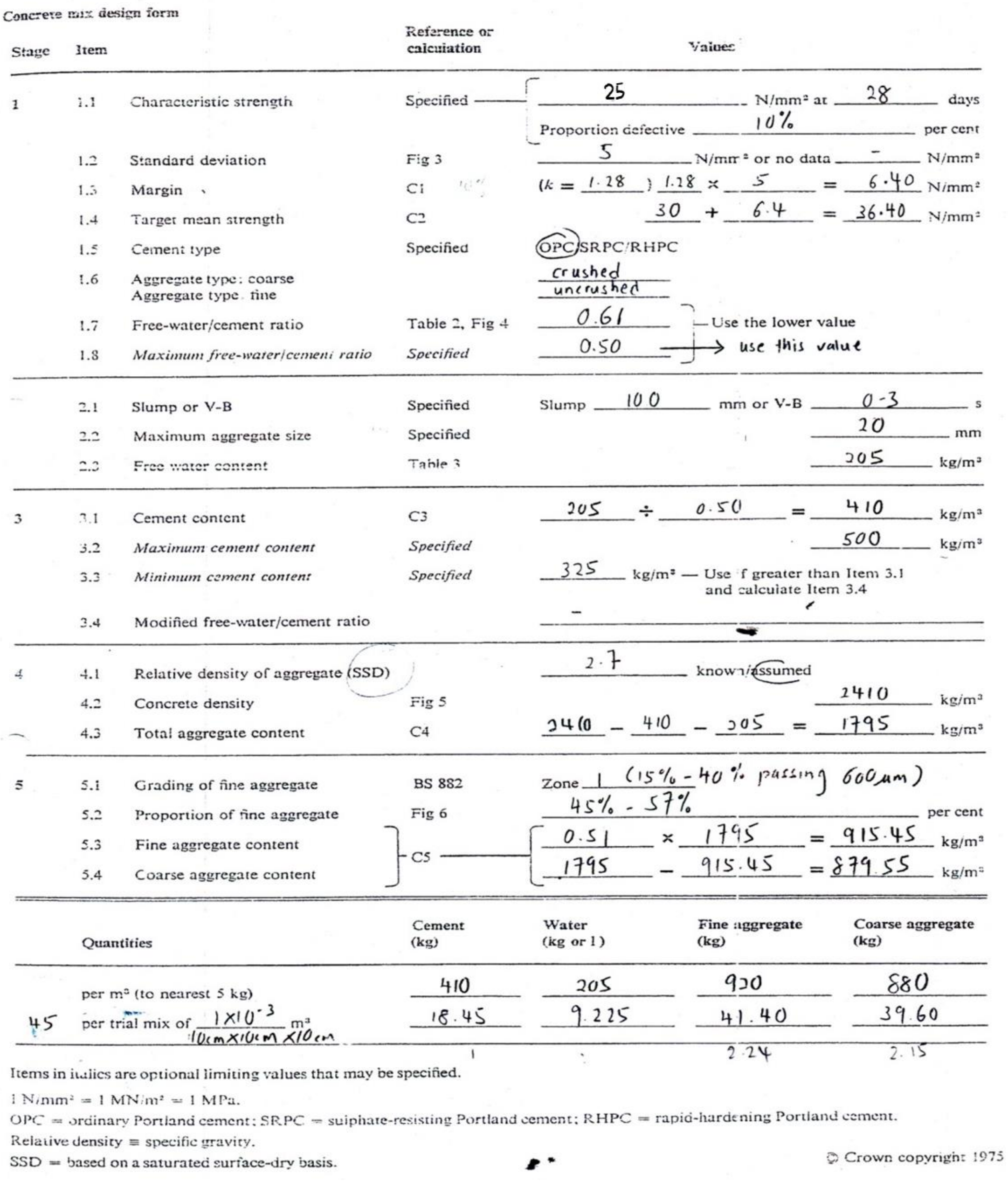
Figure 3.5: Bottle neck of plastic bottle

3.2.4 Water

Water is also a material in concrete design. The volume of water used is calculated in concrete mix design. The quality of water has to be controlled to ensure the quality of concrete. In this study, the tap water supplied at laboratory was used in concrete mixing. The source of water supplied is under the control of Pahang Water Works Department which is free from heavy metal.

3.3 CONCRETE MIX DESIGN

Concrete mix design is used to control the uniformity of concrete. In this study, 0.50 and 0.55 water cement (w/c) ratio is used. In addition, the grade of concrete selected is 25 N/mm^2 at 1, 7 and 28 days. Five different percentage replacement of aggregate was used by volumetric method of coarse aggregate. Detail of concrete mix design is shown in Figure 3.6. The mix proportion is tabulated in Table 3.2.



Concrete mix design form

Stage	Item		Reference or calculation	Values
1	1.1	Characteristic strength	Specified	25 N/mm^2 at 28 days Proportion defective 10% per cent
	1.2	Standard deviation	Fig 3	5 N/mm^2 or no data - N/mm^2
	1.3	Margin	C1	(k = 1.28) 1.28 × 5 = 6.40 N/mm^2
	1.4	Target mean strength	C2	30 + 6.4 = 36.40 N/mm^2
	1.5	Cement type	Specified	[✓ OPC]/SRPC/RHPC
	1.6	Aggregate type: coarse Aggregate type: fine		crushed uncrushed
	1.7	Free-water/cement ratio	Table 2, Fig 4	0.61 — Use the lower value
	1.8	*Maximum free-water/cement ratio*	*Specified*	0.50 → use this value
2	2.1	Slump or V-B	Specified	Slump 100 mm or V-B 0-3 s
	2.2	Maximum aggregate size	Specified	20 mm
	2.3	Free water content	Table 3	205 kg/m^3
3	3.1	Cement content	C3	205 ÷ 0.50 = 410 kg/m^3
	3.2	*Maximum cement content*	*Specified*	500 kg/m^3
	3.3	*Minimum cement content*	*Specified*	325 kg/m^3 — Use if greater than Item 3.1 and calculate Item 3.4
	3.4	Modified free-water/cement ratio		-
4	4.1	Relative density of aggregate (SSD)		2.7 known/[✓ assumed]
	4.2	Concrete density	Fig 5	2410 kg/m^3
	4.3	Total aggregate content	C4	2410 − 410 − 205 = 1795 kg/m^3
5	5.1	Grading of fine aggregate	BS 882	Zone 1 (15% - 40% passing 600μm)
	5.2	Proportion of fine aggregate	Fig 6	45% - 57% per cent
	5.3	Fine aggregate content	C5	0.51 × 1795 = 915.45 kg/m^3
	5.4	Coarse aggregate content	C5	1795 − 915.45 = 879.55 kg/m^3

Quantities	Cement (kg)	Water (kg or l)	Fine aggregate (kg)	Coarse aggregate (kg)
per m^3 (to nearest 5 kg)	410	205	920	880
45 per trial mix of 1×10^{-3} m^3 10cm×10cm×10cm	18.45	9.225	41.40	39.60
	1		2.24	2.15

Items in italics are optional limiting values that may be specified.

1 N/mm^2 = 1 MN/m^2 = 1 MPa.

OPC = ordinary Portland cement; SRPC = sulphate-resisting Portland cement; RHPC = rapid-hardening Portland cement.

Relative density ≡ specific gravity.

SSD = based on a saturated surface-dry basis.

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Figure 3.6: Concrete Mix Design

Table 3.2: Mix proportion table

Mix Type	**NA**	**PA_0**	**PA_1**	**PA_2**	**PA_3**	**PA_4**
Cement (kg)	3.69	3.69	3.69	3.69	3.69	3.69
Water (kg)	1.85	2.03	2.03	2.03	2.03	2.03
w/c ratio	0.50	0.55	0.55	0.55	0.55	0.55
Fine Aggregate (kg)	8.28	8.28	8.28	8.28	8.28	8.28
Coarse Aggregate (kg)	7.92	7.92	7.92	7.92	7.92	7.92
Natural Granite (%)	100	100	90	80	70	60
Plastic Bottle (%)	0	0	10	20	30	40

3.4 CASTING, MOULDING AND DEMOULDING

The specimens were casted in the size of 100 mm x 100 mm x 100 mm according to BS 1881: Part 108: 1983 and shown in Figure 3.7. In order to produce a standard size, all the moulds were cleaned. All the materials were weighted according to concrete mix design form before mixing. Then, the fresh concrete was poured into respective moulds. The specimens were also compacted by three layer of tamping rod layer to reduce the void in specimens. The specimens were covered up with plastic cover after casting to avoid evaporation and change of temperature. The specimens were left in laboratory for 24 hours. After removed the specimen from the moulds, the specimens were cured in different condition.

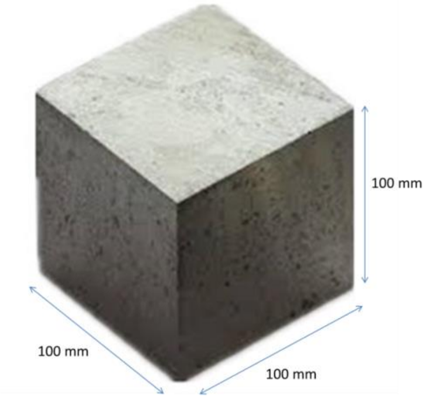

Figure 3.7: Specimen Size

3.5 CURING

Curing is the key in controlling moisture content and temperature. The properties of hardening are very dependent on this process. Curing has the strong influence in durability, and strength of the concrete (Prommas & Rungsakthaweekul, 2014). In this study, the specimens were cured in the water tank at the temperature of 26-29 °C as shown in Figure 3.8. In order to maintain the temperature, a layer of plastic was used to cover up the water tank. The period of curing is 1, 7 and 28 days. This method is carried out according to BS 1881: Part 111: 1983.

Figure 3.8: Curing Tank

3.6 TEST FOR AGGREGATE

3.6.1 Sieve Test

Sieve test is also called a gradation test which divides aggregate into particular size. The objective of this test is to classify the class of fine and coarse aggregate. Concrete mix design needs the information of sieve analysis to decide the mix proportion of sample. Fine aggregate and coarse aggregate have the same procedure which followed the standard of BS 812: Part 103.1:1985. However, the sieve set of fine aggregate was 0, 0.15, 0.30, 0.60, 1.18, 2.36, 5.00 and 10 mm; the sieve set for coarse aggregate was 0, 2.36, 5.00, 10.00, 14.00, 20.00 and 37.50 mm.

First, 3 kg of the aggregate was dried in oven at temperature of 105 °C for 24 hours. The sieve set as shown in Figure 3.9 was arranged in a stack from larger opening size to smaller opening size on the mechanical sieve shaker as shown in Figure 3.10. The 3 kg sample was poured on top of the sieve and the cover plate of sieve shaker was tightened. The time of 5 minutes was set to the sieve shaker and then start button was pressed. Then, each sieve with the sample in it was weighted. The percentage of passing was calculated. Grading Curve of aggregate was plotted according to BS 882.

Figure 3.9: Sieve Set

Figure 3.10: Sieve Shaker

3.7 TEST FOR FRESH CONCRETE

3.7.1 Slump Test

Slump test is empirical test that tested for workability. Its main objective is to measure the consistency of fresh concrete. This test is widely used in construction site for detecting the change in workability. In this study, the test would be carried out according to BS 1881: Part 102: 1983. First, the slump cone was cleaned and wetted and place on a steel plate. The slump cone was filled in one-third of fresh concrete of its height. That layer was tamped uniformly with 25 strokes by using tamping rod. The slump was filled in with second and third layer of fresh concrete and repeated tamping process. Then, the slump cone was lifted slowly in vertical direction. The height between the slump cone and fresh concrete was measured. The slump result normally is classified into true slump, shear slump and collapse slump as shown in Figure 3.11.

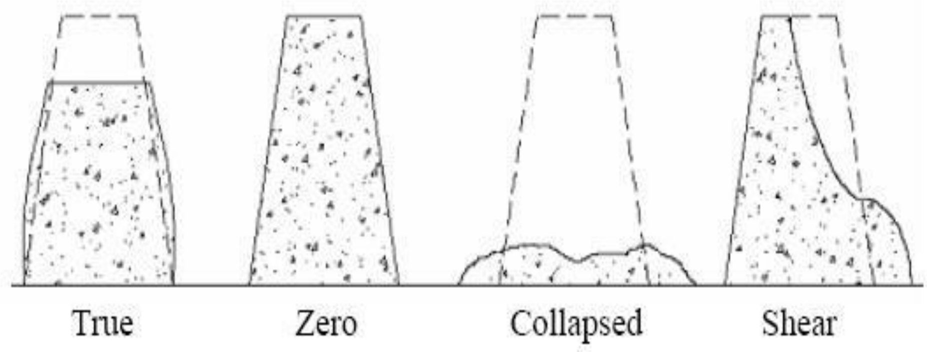

Figure 3.11: Slump result

3.8 TESTS FOR HARDENED CONCRETE

3.8.1 Rebound Hammer Test

Rebound hammer test is also known as surface hardness test. This test is to measure the elastic properties of concrete specimen according to BS 1881: Part 202: 1986. It is also used to estimate the compressive strength. First, the surface specimen of 28th day was cleaned and dried. The smooth surface was picked for the test. Nine to twelve readings of the specimen within 300 mm^2 was taken as shown as Figure 3.12. 20-50 mm grid was used to locate the impact points in tested area. The plunger was located and pressed strongly on the impact point in right angle until the spring-loaded mass was released. The hammer was locked and the reading was recorded. The average reading was calculated.

Figure 3.12: Rebound Hammer Test

3.8.2 Compressive Strength Test

Compressive strength test is conducted to determine the strength of concrete under crushing loads. This test was carried out by following the standard of ASTM C 39-03. In this test, the dimension and weight of each specimen was measured. The bottom and the upper part of the specimen were cleaned. Then, the specimen was placed in compression testing machine as shown in Figure 3.13 and the load was applied continuously until it was failed. The maximum load was recorded. Then, the compressive strength of the specimen was calculated.

The compressive strength is calculated as Eq. (2):

$$\text{Compressive strength} = (\text{maximum load carried} / \text{average cross section}) \qquad (2)$$

Figure 3.13: Compressive testing machine

3.8.3 Heat Absorption Test

Heat absorption test is conducted to determine the strength of concrete under different temperature. This test was carried out on the 28th day of the specimens at the temperature of 40 °C, 60 °C, and 80 °C. First, the hardened concrete was removed from the water curing tank and then the surface specimen was wiped by a dry cloth to prevent free water on the surface. The specimen was then cooled down for 1 hour and dried in oven at suggested temperature of for 1 hour as shown in Figure 3.14. After that, the specimen was left to cool down for 1 hour before going through compressive strength test.

Figure 3.14: Heating in oven

3.8.4 Water Absorption Test

Water absorption tests the amount of water absorbed by concrete sample. The test was carried out on the 28th day of the specimens. First, the hardened concrete was removed from the water curing tank. Then, the surface specimen was wiped by a dry cloth to prevent free water on the surface. The specimen was weighted quickly and dried in oven at the temperature of 105 °C for 24 hours. After that, the specimen was left to cool down for 1 hour and weighted again. The specimen was repeated to be dried in oven, cooled down for 1 hour and weighted again until the specimen has the constant mass. The final constant mass was considered as the dry mass.

Another test was carried for plotting the graph of water absorption by mass versus time. Few of new specimens were immersed in water for 0, 1, 2, 3, 4, 5, 10, 20, 30, 40, 50, 60 min as shown in Figure 3.15. The percentage of the water absorption by mass was calculated.

The water absorption by mass is calculated as Eq. (3):

Water absorption by mass (%) = [(mass of specimen - dry mass) / dry mass] x 100% (3)

Figure 3.15: Immersing in water

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter reviews the results and discussions of test in previous chapter which determine the performances of Polyethylene Terephthalate (PET) as partial coarse aggregate replacement in concrete composition. The mix design was developed based on the different percentage of partial replacement of PET in concrete. The results and discussions are mostly focused on the properties of concrete such as slump test, rebound hammer, compression test, heat absorption test and water absorption test. In addition, test on aggregate was only carried through sieve test which shows the gradation of aggregate in particular size. All the result of tests regarding the partial percentage replacement and different water cement ratio are discussed in this chapter.

4.2 AGGREGATE CHARACTERISATION

4.2.1 Sieve Analysis Test

Concrete consists 85 % of coarse aggregate in volume and weight, therefore, the gradation of aggregate is an influential factor in mix concrete design. The sieve analyses of fine and coarse aggregate were shown in Table 4.1 and Table 4.2 respectively. Table 1 shown that the highest percentage of retained was at the range of 2.36 mm – 5.00 mm. Fine aggregate passing 600 µm is 18.52% which make it falls under Zone I, 15% - 40%. The fineness modulus of the river sand was 3.697 after calculated. Meanwhile, the highest coarse aggregate percentage retained was fall in the range of 10 mm - 14 mm.

The fineness modulus of the natural granite was 3.236 after being calculated. The grading curve was plotted in Figure 4.1.

Table 4.1: Fine aggregate sieve analysis result

Sieve Size (mm)	**Mass Retained (kg)**	**Percentage Retained (%)**	**Cumulative Percentage Passing (%)**	**Cumulative Percentage Retained (%)**
10.00	0.002	0.05	99.95	0.05
5.00	0.093	3.11	96.84	3.16
2.36	0.857	28.58	68.26	31.74
1.18	0.744	24.80	43.46	56.54
0.60	0.748	24.95	18.52	81.48
0.30	0.468	15.61	2.90	97.10
0.15	0.077	2.58	0.32	99.68
0.00	0.010	0.32	0.00	100.00
Total	**3.000**			

Table 4.2: Coarse aggregate sieve analysis result

Sieve Size (mm)	**Mass Retained (kg)**	**Percentage Retained (%)**	**Cumulative Percentage Passing (%)**	**Cumulative Percentage Retained (%)**
37.50	0.000	0.00	100.00	0.00
20.00	0.346	11.53	88.47	11.53
14.00	0.870	28.98	59.48	40.52
10.00	0.962	32.08	27.41	72.59
5.00	0.801	26.68	0.73	99.27
2.36	0.013	0.42	0.31	99.69
0.00	0.009	0.31	0.00	100.00
Total	**3.000**			

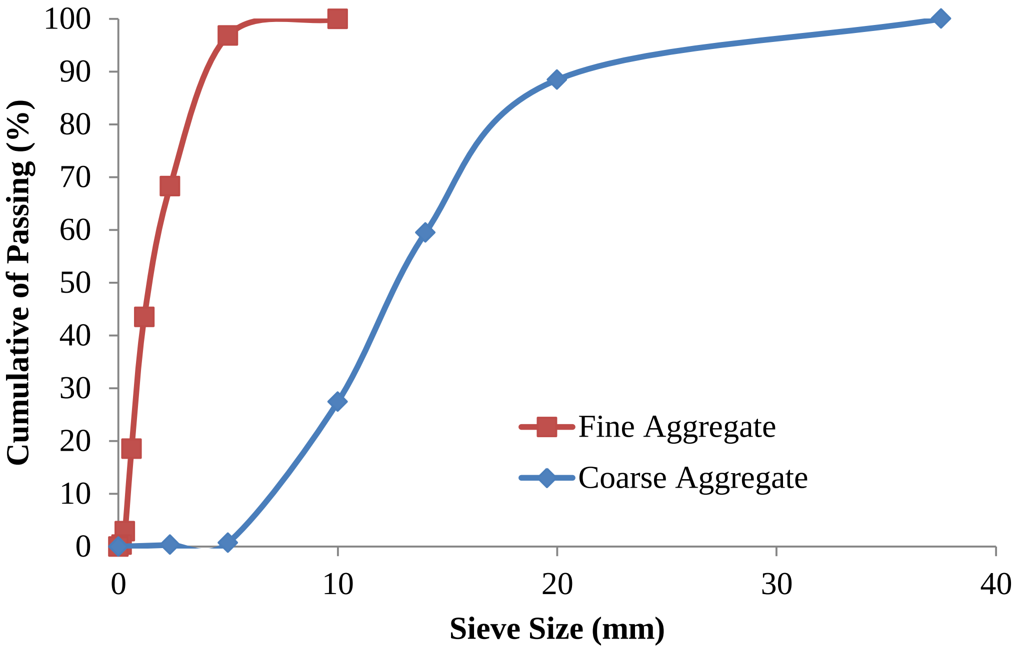

Figure 4.1: Grading curve of fine and coarse aggregate

Beygi et al., (2014) stated that Fracture Process Zone (FPZ) during crack was affected by the volume and the size of coarse aggregate. As the size of coarse aggregate increased, the fracture toughness was increased. In this study, the size of plastic aggregate was fixed at the range of 20 mm to 30 mm in diameter and 15 mm to 25 mm in height. The size and volume of these aggregate were relatively high compared to normal aggregate which can be graded in few range. Therefore, the fracture toughness should be increased as the plastic aggregate content increased.

The presence of plastic aggregate which was bigger in size compared to aggregate also affect the compactness of concrete. Vu et al., (2011) reported that increase of coarse aggregate size results in better compactness of concrete as the deviatoric behaviour was influenced and resulted in 0 MPa to 650 MPa varies in confinement levels. Generally, the size of coarse aggregate increased helps in fracture toughness and compactness of concrete. However, the shape and surface texture were also other influents which affect the strength of concrete performance.

4.3 FRESH CONCRETE PROPERTIES

4.3.1 Slump Test

Slump test is used to determine the workability and uniformity of concrete. Slump result was mostly affected by water to cement ratio (w/c) which slump value increased as water to cement ratio increased. The slump result of different plastic aggregate content was shown in Table 4.3. At the 0 % of plastic aggregate replacement, the water to cement ratio was decided as 0.50 for NA mix design. However, the result of the slump value was less than the requirements which was 15 mm as shown in Figure 4.2. Therefore, all other mix design used water to cement ratio of 0.55 caused the results to fall in the acceptable range of 75 ± 25 mm.

Table 4.3: Slump result of different mix type

Mix Type	Water to Cement ratio	Slump Value (mm)	Slump Type
NA	0.50	15	Almost Zero Slump
PA_0	0.55	60	True Slump
PA_1	0.55	65	True Slump
PA_2	0.55	65	True Slump
PA_3	0.55	65	True Slump
PA_4	0.55	70	True Slump

Figure 4.2: Slump result of NA

Figure 4.3: Slump result of PA_2

From Figure 4.4, all the slumps were classified as true slump as the shape of the result and the range of slump value are within 50 mm to 100 mm. The result was increased 5 mm at each increment stage. However the result remained constant at 65 mm for PA_1, PA_2 and PA_3. The increment can be attributed by non-absorptive characteristic of plastic aggregate. According to Yang et al. (2015) and Saikia & Brito (2014), the fluidity was increased with increase of free water content. Plastic aggregate has less water absorption ability compared to natural granite. As the plastic aggregate content increased, the free water content was increased. The result of Yang's also showed that the partial replacement of plastic particles as fine aggregate increased the slump flow diameter approximately 100 mm while the percentage of replacement increased 5 % in slump flow test.

Other than that, the nearly spherical shape and slippery surface texture of plastic aggregate were also attributed to the result of slump value increased. Choi et al. (2005) concluded that the slump value increased due to the spherical, smooth surface and absorption of plastic aggregate when plastic aggregate is partially replace fine aggregate in mix. Silva et al. (2013) and Ghernouti et al. (2015) reported the similar result as plastic aggregate was replaced coarse and fine aggregate. Addition of pellet PET aggregate also increased the slump value due to the smooth surface of plastic aggregate which comply to NP EN 12350-2 (Saikia & de Brito, 2012). Khaloo et al. (2015) also stated that the higher slump flow easier within the compaction of concrete which mean better workability of concrete. In conclusion, the increase of slump value was attributed by the characteristic of plastic aggregate such as low water absorption, spherical shape and smooth surface.

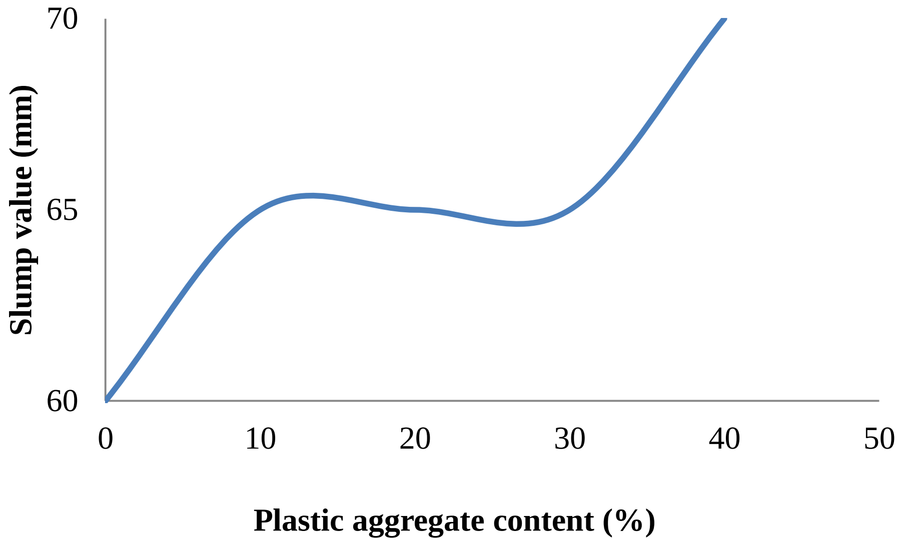

Figure 4.4: Slump result of w/c 0.55

4.4 HARDENED CONCRETE PROPERTIES

4.4.1 Rebound Hammer Test

Rebound hammer test is a type of non-destructive test which used to determine the compressive strength. The rebound hammer result of 28th day was tabulated in Table 4.4. From Figure 4.5, the best result of plastic aggregate content was 10% which achieved 23.50 N/mm^2 and the strength increased 17.5 % compared to PA$_0$. However, all the compressive strength from rebound hammer test did not reach the design grade which was 25 N/mm^2. The trend of rebound hammer result was different compared to compressive strength test as the highest strength among all the mix type was PA$_0$. In addition, the rebound value of PA$_2$, PA$_3$ and PA$_4$ were lower compare to PA$_0$ which acted as controlled concrete.

Table 4.4: Rebound hammer result of different mix type

Mix Type	Rebound Value (R)	Compressive Strength (N/mm^2)
PA$_0$	26.22	20.00
PA$_1$	28.75	23.50
PA$_2$	24.86	18.00
PA$_3$	24.54	17.75
PA$_4$	24.74	17.90

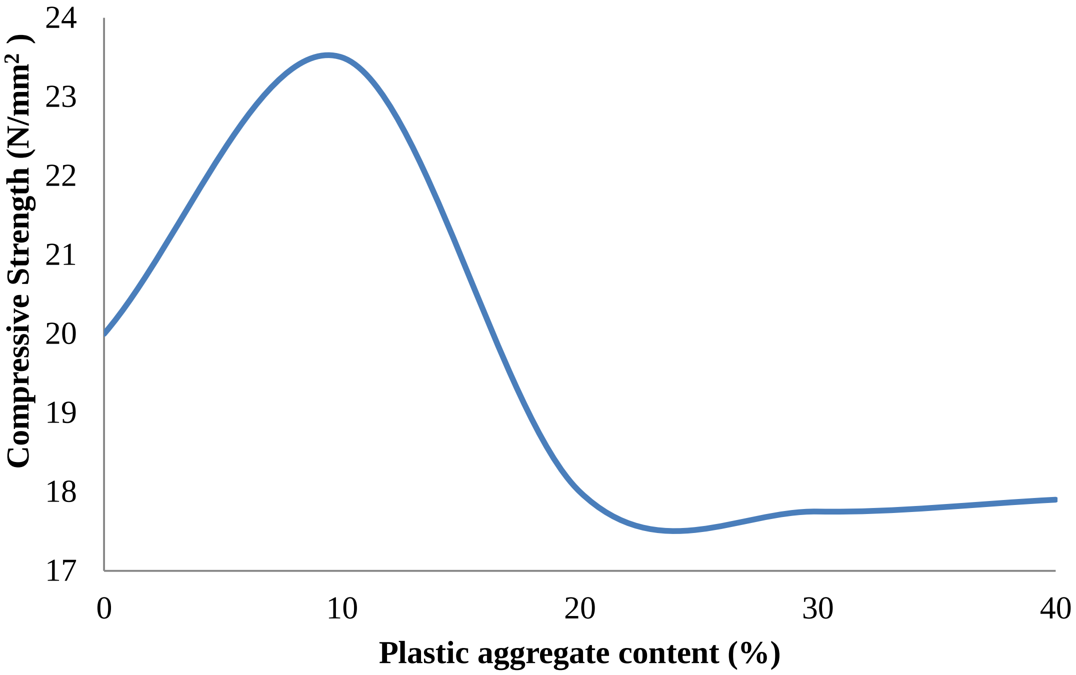

Figure 4.5: Rebound hammer result of different plastic content

The hardness of concrete surface which also represented the compressive strength was correlated with the rebound value. Meanwhile, the hardness of concrete was attributed to porosity of the concrete. The aggregate properties such as hardness and density had high influences on the rebound value (Breysse, 2012). In addition, the rebound value was only sensitive to surface of concrete which rebound value can only indicate the surface properties and strength. Al-Mufti & Fried (2012) reported that the result of rebound hammer was influenced by the surface roughness and regularity of the concrete.

Subramaniaprasad et al. (2014) also supported that the properties of plastic which were soft and elastic provide less effect on rebound hammer result. The surface of plastic content concrete was softer compared to conventional concrete. The soft plastic aggregate was floated on the surface of concrete when moulding process was carried. The surface of plastic aggregate was too weak to support the momentum of rebound hammer. After the rebound hammer test, PA_1, PA_2, PA_3 and PA_4 has small crack and spoilt surface as shown in Figure 4.6.

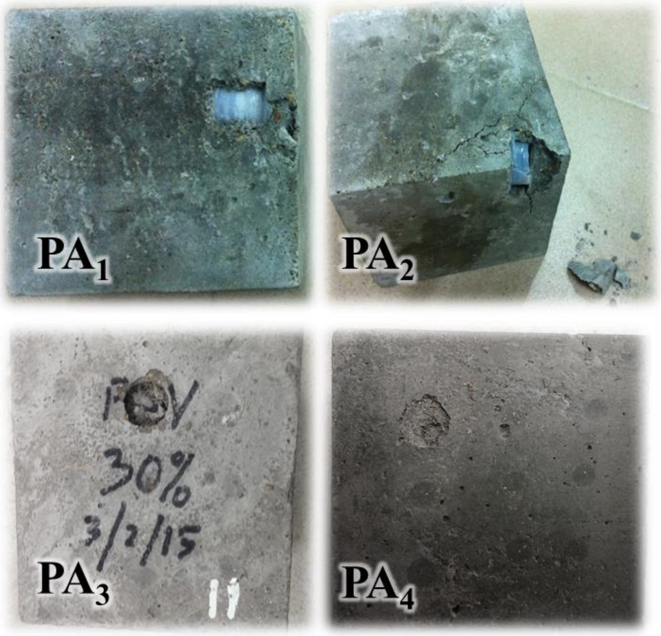

Figure 4.6: Spoilt surface of PA

The reliability of rebound hammer was relatively small due to the damaged of concrete (Correia et al., 2014). The correlation between rebound hammer result and compressive strength was less significant in partial replacement of coarse aggregate by plastic aggregate. Conclusively, the rebound hammer result was not reliable to concrete that contain plastic aggregate as this test is carried to determine the surface hardness.

4.4.2 Compressive Strength Test

Compressive strength is the main properties and characteristic for hardened concrete. In this study, the test was carried on 1st, 7th and 28th day on three specimens. Table 4.5 was shown the compressive strength of different plastic content at different curing age.

Table 4.5: Compressive strength table result

Plastic Content	Curing Age (day)	Compressive Strength (N/mm^2)
0%	1	19.907
	7	23.203
	28	27.595
10%	1	15.441
	7	21.135
	28	26.317
20%	1	11.570
	7	17.409
	28	22.121
30%	1	5.950
	7	16.115
	28	18.181
40%	1	4.341
	7	10.495
	28	12.496

Figure 4.7 was shown the compressive strength at different curing age. The compressive strength was increased as the curing day was increased. 1st day compressive strength is known as precast strength. Precast strength of PA_0 achieved 19.907 N/mm^2 which is 72.13 % of 28th day. The precast strength of plastic content concrete compared to 28th day compressive strength was decreased from 58.67 % to 34.74 %. It means that after replacement of plastic aggregate, the precast strength of concrete was decreased as plastic content was increased. The trend of strength-gain curve of conventional concrete was different with the replacement of plastic aggregate replacement concrete.

The strength of 1st day was decreased from approximately 20 N/mm^2 to 4 N/mm^2 as the plastic content was increased which showed the biggest range compared to others curing age. Meanwhile, the strength of 7th and 28th day was decreased from approximately 23 N/mm^2 to 10 N/mm^2 and 27 N/mm^2 to 12 N/mm^2 respectively.

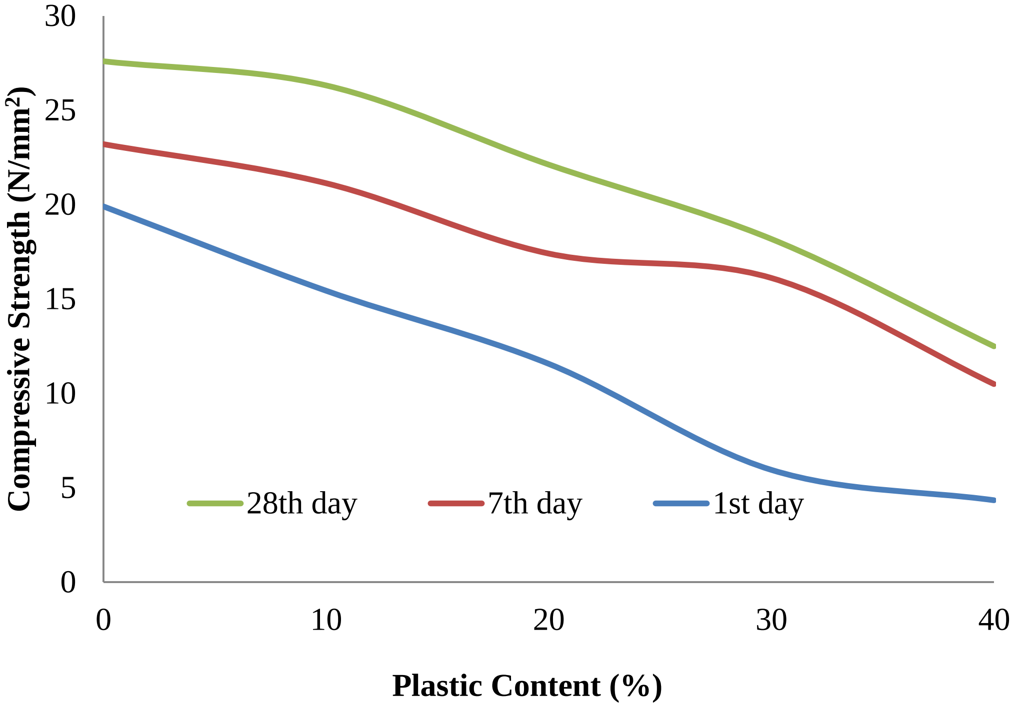

Figure 4.7: Compressive strength versus plastic content graph

In Figure 4.8, the compressive strength was increased as the curing age was increased. However, the compressive strength was decreased as the plastic content is increased. The compressive strength of PA$_1$ was considered as idealise result compared to others replacement even the strength was lower than PA$_0$ as the strength of PA$_1$ was 26.317 N/mm^2 which was 1.2 N/mm^2 smaller than the PA$_0$. In compressive strength result, only PA$_0$ and PA$_1$ passed the design grade of 25 N/mm^2. In addition, PA$_1$ achieved 95.37 % of the PA$_0$ compressive strength at 28th day. At the same time, PA$_2$, PA$_3$ and PA$_4$ reached 80.16 %, 65.89 % and 45.28 % of the PA$_0$ compressive strength respectively. In another words, the compressive strength compared to PA$_0$ was decreased gradually as the plastic content increased.

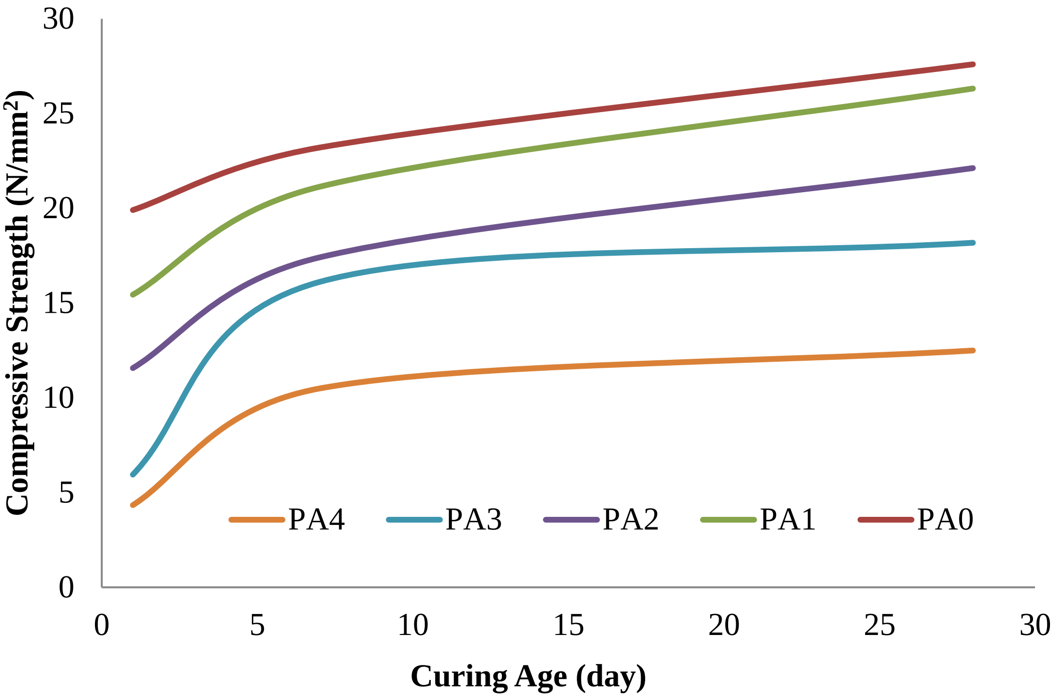

Figure 4.8: Compressive strength-gain curve

Rossignolo & Agnesini (2002) and Choi et al. (2009) shared the similar result which comply to Technical Standards Brazilian Association (ABNT-NBR) and ASTM C 109 respectively. These authors evaluated that the increment of plastic content decreased the compressive strength. The mechanical bond of plastic aggregate was not as strong as natural aggregate and friction resistant of plastic aggregate was weak. In conclusion, the replacement of plastic aggregate was not significantly contributed to the matrix strength.

The characteristic of plastic aggregate which was low in compressive strength was also another influent in strength reduction (Siddique et al., 2008). On the other hand, Albano et al. (2009) stated that the compression strength of concrete was not contributed by the replacement of plastic aggregate which comply with ASTM C 192. The replacement of coarse aggregate by plastic aggregate reduced the compressive strength as natural granite was the main contributor in durability. The author also reported that 10 % of plastic content showed a better grade of compressive strength in concrete. The weak interfacial transition zone between plastic aggregate and cement paste caused lower compressive strength compared to PA_0.

The reduction in compressive strength was affected by few factors which were the bonding strength and the size of plastic aggregate (Silva et al., 2013). Panyakapo & Panyakapo (2008), and Frigione (2010) concluded that the low bonding between plastic aggregate and the cement paste reduced the compressive strength in concrete due to the non-absorptive water properties of plastic aggregate. Hannawi et al. (2010) and Akçaözoğlu et al. (2013) also stated that the increment strength of the plastic aggregate replacement concrete was lower than conventional concrete due to the connection between cement paste and PET aggregate was weak. On top of that, the plastic aggregate was also larger than natural granite which variant the level of packing of concrete and caused strength reduction.

In conclusion, using PET as partial coarse aggregate replacement produced negative effect in the concrete quality due to the weak mechanical bond of plastic aggregate and cement paste (Araghi et al., 2015). The compressive strength of PA_1 was considered as idealise result compared to others replacement percentage even the strength is lower than PA_0.

4.4.3 Heat Absorption Test

Heat absorption is a test the change of compressive strength under different temperature. The melting point of plastic aggregate was lower than natural aggregate as it can affect the compressive strength of concrete when expose to high temperature. Table 4.4 showed the compressive strength after exposed to 40 °C, 60 °C and 80 °C.

Table 4.6: Heat absorption table result

Temperature (°C)	**Compressive Strength, N/mm^2**				
	PA_0	**PA_1**	**PA_2**	**PA_3**	**PA_4**
40	33.526	28.298	25.599	19.170	15.882
60	32.669	25.076	20.080	18.153	15.518
80	28.495	25.179	19.488	16.060	16.258

The graph result of heat absorption test was shown in Figure 4.9. All the specimens experienced decrease in compressive strength while temperature increased. PA_0 had better compressive strength in all the mix type and decreased 17.65 % when the temperature increases until 80 °C. In plastic aggregate replacement concrete, 10 % of plastic content showed the best result which was still achieved design grade of 25 N/mm^2 after 80 °C. In addition, PA_1 achieved 84.41 %, 76.76 % and 88.36 % of the PA_0 strength at the temperature of 40 °C, 60 °C and 80 °C respectively. Meanwhile, the compressive strength of others mix type decreased gradually with the increase of temperature. Others than PA_0 and PA_1, most of the mix type did not achieve the design grade as all the compressive strength were lower than 25 N/mm^2.

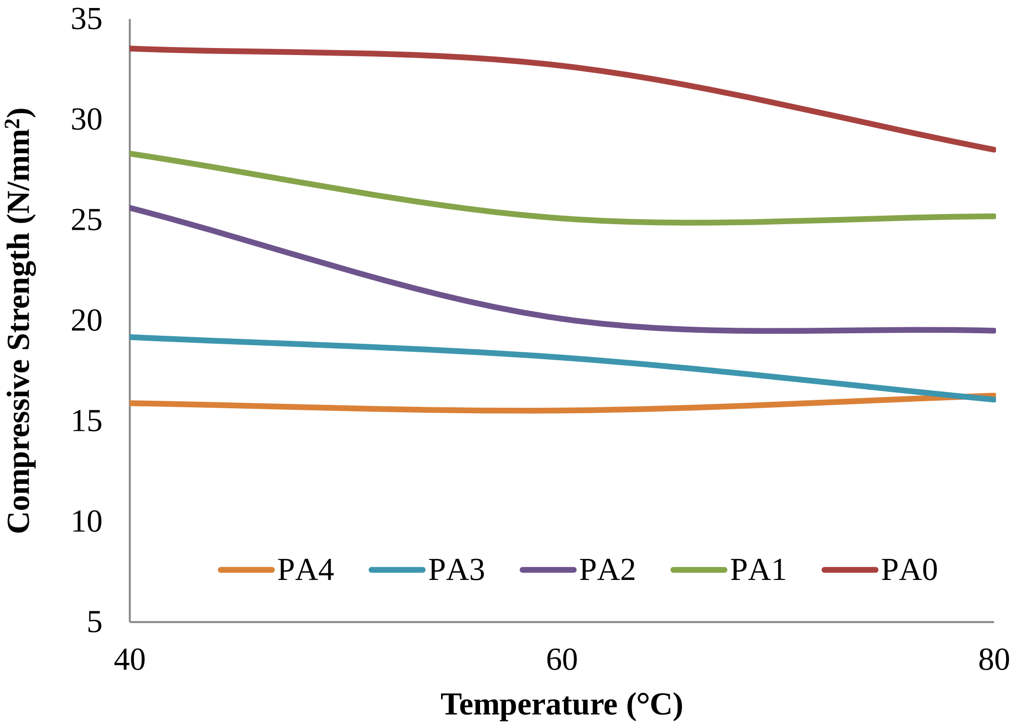

Figure 4.9: Heat absorption graph result

Haddad et al., (2013) and Uysal & Tanyildizi (2012) shared that the similar result which the compressive strength decreased when exposed to elevated temperature on replacement of plastic aggregate and addition of plastic fibre respectively. Correia et al. (2014) explained that this trend was caused by the high porosity of plastic content produced low resistance plastic aggregate replacement concrete towards elevated temperature. Plastic aggregate created large void with the cement paste which contributed to the higher porosity. Besides, the polystyrene layer was melted after heating in oven caused the void in concrete and affects the compressive strength of concrete as shown in Figure 4.10. The pores in concrete contain air which affected the thermal conductivity become lower (Mounanga et al. 2008).

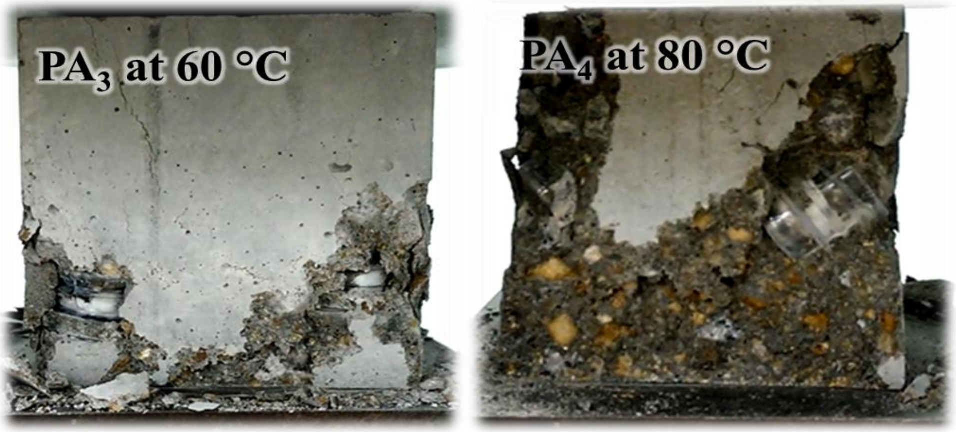

Figure 4.10: Concrete after compression test

The thermal stability of PET replacement concrete was decreased as the temperature increased since the activation energy is decreased (Albano et al., 2009). The thermal behaviour of plastic aggregate replacement concrete was depended on the thermo-degradable behaviour of PET.

Akçaözoğlu et al. (2013) and Yesilata et al. (2009) stated that thermal conductivity coefficient of plastic aggregate replacement concrete is low. On the other hand, Saikia & Brito (2012) evaluated that the plastic content was increased due to the low thermal conductivity coefficient of plastic aggregate. However high plastic content was required to remain the low plastic content which implied the loss of mechanical strength of concrete (Pacheco-Torgal et al., 2012).

In another words, the plastic aggregate replacement concrete cannot withstand high temperature as the melted polystyrene created voids that affected the compressive strength of concrete. The high porosity of plastic aggregate in concrete also was a factor on reduction of compressive strength.

4.4.4 Water Absorption Test

Water absorption was an important factor in durability of cementitious systems (Castro et al. 2011). The absorption level indirectly affects the durability and performance of concrete. The result of water absorption was shown in Table 4.7 and Figure 4.11.

Table 4.7: Water absorption table result

Time (min)	**Mass Increment (%)**				
	PA$_0$	**PA$_1$**	**PA$_2$**	**PA$_3$**	**PA$_4$**
0	0.00	0.00	0.00	0.00	0.00
5	2.01	1.90	2.14	2.02	2.09
10	2.66	2.36	2.69	2.62	2.77
15	3.06	2.58	2.94	3.08	3.26
20	3.37	2.78	3.16	3.45	3.65
25	3.64	2.89	3.27	3.76	3.98
30	3.86	2.96	3.34	3.90	4.28
35	4.04	3.01	3.40	4.19	4.56
40	4.20	3.07	3.45	4.44	4.81
45	4.35	3.11	3.48	4.66	5.01
50	4.48	3.14	3.52	4.84	5.21
55	4.58	3.17	3.55	5.01	5.38
60	4.67	3.20	3.58	5.15	5.53
70	4.81	3.23	3.61	5.30	5.72
80	4.89	3.26	3.62	5.45	5.87
90	4.96	3.27	3.65	5.63	5.98
100	5.02	3.29	3.67	5.74	6.09
110	5.06	3.31	3.69	5.85	6.17
120	5.10	3.32	3.71	5.90	6.24
180	5.33	3.37	3.77	6.09	6.41
240	5.38	3.40	3.80	6.13	6.50
1440	5.50	3.56	3.98	6.20	6.62

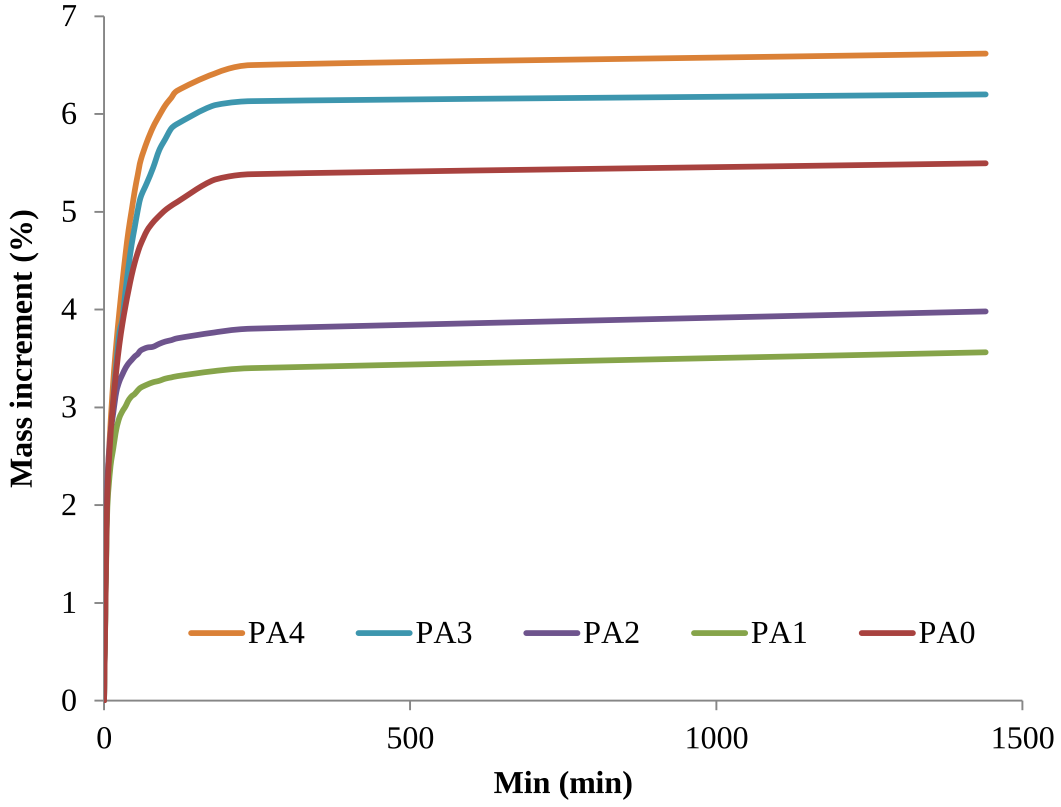

Figure 4.11: Water absorption graph result

From the data presented in Figure 4.11, the mass was increased as the plastic content increased. PA_1 has the best water absorption level as it had the lowest mass increment in percentage as it only absorbed 64.73 % of water compared to conventional concrete. Meanwhile, PA_2 had second lowest water absorption mass increment which only absorbed 72.36 % of water compared to conventional concrete. On the other hand, the PA_3 and PA_4 absorbed 12.73 % and 20.36 % more of water compared to conventional concrete.

Albano et al. (2009) stated that the reason of increment was due to the porosity of plastic aggregate. The factor of concrete porosity was based on the aggregate type which can provide porosity and alter the cement paste. Plastic aggregate provides a different porosity level compared to natural aggregate. This was shown in Figure 4.4 where result of the mass increment PA_0 is laid between PA_2 and PA_3.

Hannawi et al. (2010) investigated that as the plastic content became higher, the higher the water absorption level when the test was carried out according to RILEM 49TER 1984. The higher replacement of PET as fine aggregate increased the porosity of cementitious material which also caused the increase in permeability. The bond between plastic aggregate and paste was weaker compared to ordinary aggregate.

In addition, the sorptivity of cement mortar by partial replacement of PET aggregate to fine aggregate showed the same result as Figure 4.4 which was after 25 % replacement, the sorptivity of higher replacement was increased compared to control mortar (Choi et al., 2009). In other words, the plastic content was increased when the porosity increased and thus increased the water absorption.

4.5 SUMMARY

This study identifies the compressive behaviour of PET as partial replacement of coarse aggregate compare to conventional concrete. Another part of the study is to identify the optimum percentage of replaced aggregate from the range of 0 %, 10 %, 20 %, 30 % and 40 % which has best compressive behaviour.

Based on the result, the partial replacement of coarse aggregate by PET aggregate in concrete reduced the compressive strength compared to conventional concrete. However, the replaced aggregate concrete was only decreased in the range of approximately 95 % until 45 % of the conventional concrete. Furthermore, one of the partial plastic aggregate replacement concrete still achieved the design grade of 25 N/mm^2.

The characteristic of PET aggregate affected the behaviour of plastic aggregate replacement concrete. The properties of plastic aggregate which were slippery, non-angular, non-absorptive of water and low melting point gave very big impact in most of the tests. The influence of the properties was increased as the plastic content is increased.

The replacement of coarse aggregate by PET aggregate also caused higher porosity which affected the result in every test carried in this study. The negative effects appeared in all the tests which caused reduction in strength especially the low bonding and weak interfacial transition zone between PET aggregate and cement paste.

In summary, the replaced aggregate caused the reduction of strength in concrete. The properties of aggregate had the great influences in the strength of concrete as aggregate was the main contributor in strength.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

The objectives of this research are to identify the suitability of PET as partial coarse aggregate replacement in concrete and determine the compressive strength of replaced aggregate in concrete. The bottle neck of PET bottle was used as plastic aggregate as partial replacement from the range of 0 %, 10 %, 20 %, 30 % and 40 % in concrete. All the specimens had subjected to 1, 7 and 28 days of water curing before undergo slump test, rebound hammer, compression test, heat absorption test and water absorption test.

5.2 CONCLUSIONS

Based on the finding and analysis in Chapter 4, several conclusions are drawn as follows:

i. The increase of slump value is attributed by the characteristic of plastic aggregate such as low water absorption, spherical shape and slippery surface. As the plastic content increases, the slump value is increased when the fluidity and free water content is increased. The slump value fall in the range of 60 mm to 70 mm at water cement ratio of 0.55.

ii. The result from the rebound hammer test is not reliable as the test is limited to determine the surface hardness. The floating and soft plastic aggregate is the main factor causing the non-reliable result. Besides, after the rebound hammer test, the surface of the plastic aggregate specimens are spoilt and cracked.

iii. The replacement of plastic aggregate caused the reduction of compressive strength. The weak bonding between plastic aggregate and cement paste reduced the compressive strength in concrete. The optimum percentage of replacement in compressive behaviour is 10 % as it achieved 95.37 % of conventional concrete strength.

iv. The compressive strength after exposed to elevated temperature is reduced as the plastic content increased. The high porosity of plastic aggregate replacement concrete produced lower resistance of concrete toward the elevated temperature. The best compressive strength result after exposure is 10 % of plastic content as it still achieved compressive strength that is higher than design strength of 25 N/mm^2 after heating 80 °C in oven and achieved approximately 76 % to 88 % of conventional concrete strength at 40 °C, 60 °C and 80 °C.

v. The porosity and the weak bonding between cement paste and plastic aggregate showed that the higher the plastic content, the higher the water absorption in mass increment. The lowest mass increment is 10 % of plastic content which achieved 64.73 % of water compared to conventional concrete which shown the best water absorption level among the replacement.

vi. PET aggregate is suitable to replace coarse aggregate as the compressive behaviour is closed to conventional concrete and fall within the design strength. However, improvement can be made to reduce the negative effect produced from properties of plastic.

vii. The optimum percentage of replacement in all the tests is 10 % of plastic content as all the behaviour is closed to conventional concrete and the strength is within the approximately range of 75 % to 95 % of conventional concrete.

5.3 RECOMMENDATIONS

This study is mainly focus on the compressive behaviour of Polyethylene Terephthalate (PET) as partial coarse aggregate replacement in concrete and others properties such as water absorption level and heat absorption level of replacement concrete. Researches on others performances such as flexural behaviour, durability, modulus elasticity are needed to understand the influence and produce better mix type to be applicable in industry. The following suggestion is made for further research by:

i. The changes in shape and size of plastic aggregate to reduce the effect of spherical shape, slippery surface and create stronger bonding between plastic aggregate and cement paste (Ferreira et al., 2012).

ii. The application of fly ash to act as "filler effect", improve workability of concrete and reduce the porosity of plastic aggregate replacement concrete (Tonet & Gorninski, 2013).

iii. The application of resin to increase the compressive strength of plastic aggregate replacement concrete (Vidales et al., 2014).

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APPENDIX A1

REBOUND HAMMER RESULT

Plastic content	**Surface**	**Specimen 1**								
0%	face 1	26	28	26	22	25	29	23	29	30
	face 2	24	24	31	28	23	22	28	28	26
	face 3	29	26	22	23	28	24	26	25	24
10%	face 1	34	32	32	30	28	29	34	32	32
	face 2	26	32	30	30	27	26	29	16	17
	face 3	16	22	22	29	23	32	32	25	32
20%	face 1	28	28	32	27	30	30	31	31	28
	face 2	31	34	20	30	30	29	32	30	16
	face 3	19	21	26	22	20	21	31	18	16
30%	face 1	26	24	24	26	25	30	27	25	32
	face 2	23	31	28	24	22	25	25	21	20
	face 3	26	28	26	25	26	27	21	19	21
40%	face 1	28	28	28	21	22	24	27	23	32
	face 2	28	32	28	27	24	19	21	22	18
	face 3	19	19	27	31	22	24	24	20	14

Plastic content	**Surface**	**Specimen 2**								
0%	face 1	32	25	28	31	26	29	28	23	22
	face 2	24	28	22	27	24	22	25	28	30
	face 3	20	29	31	20	23	26	24	28	25
10%	face 1	27	30	32	28	28	28	32	32	32
	face 2	28	28	27	26	25	32	28	30	31
	face 3	30	28	28	32	34	34	36	34	24
20%	face 1	17	16	20	23	23	28	31	29	32
	face 2	23	31	26	28	18	24	25	21	22
	face 3	20	22	18	19	18	23	22	26	26
30%	face 1	28	14	23	29	22	30	28	26	31
	face 2	23	25	26	28	25	22	19	24	25
	face 3	19	27	24	21	24	26	16	21	22
40%	face 1	20	28	29	20	23	29	28	29	32
	face 2	25	30	28	26	24	25	16	24	25
	face 3	27	29	28	26	26	30	23	25	26

APPENDIX A2

REBOUND HAMMER RESULT continued

Plastic content	Surface	Specimen 3								
0%	face 1	28	23	26	28	29	30	30	30	26
	face 2	22	26	32	28	26	25	28	27	28
	face 3	26	24	28	28	26	28	25	27	21
10%	face 1	30	31	25	24	26	28	29	30	29
	face 2	29	32	31	28	29	30	27	27	28
	face 3	30	27	28	32	27	32	27	32	28
20%	face 1	28	29	27	22	28	28	25	22	25
	face 2	24	25	28	25	24	23	27	22	22
	face 3	23	22	21	24	21	26	28	26	27
30%	face 1	24	25	25	24	19	26	28	18	20
	face 2	25	21	28	28	27	30	27	28	24
	face 3	21	19	26	29	20	28	25	25	23
40%	face 1	27	20	23	24	22	23	22	27	24
	face 2	26	26	23	25	24	22	27	25	23
	face 3	28	23	26	27	23	25	22	22	22

Plastic content	Total Rebound Number	Average
0%	2124	26.22222
10%	2329	28.75309
20%	2014	24.8642
30%	1988	24.54321
40%	2004	24.74074

APPENDIX B

COMPRESSIVE STRENGTH RESULT

		Compressive Strength (N/mm^2)			
Plastic Content	**Curing Age**	**Specimen 1**	**Specimen 2**	**Specimen 3**	**Average**
0%	1	19.799	19.797	20.125	19.907
	7	25.025	22.159	22.425	23.203
	28	28.663	26.146	27.976	27.595
10%	1	16.184	15.776	14.363	15.441
	7	22.516	21.549	19.340	21.135
	28	24.359	25.797	28.795	26.317
20%	1	10.480	12.881	11.349	11.570
	7	16.395	15.689	20.143	17.409
	28	21.984	23.033	21.346	22.121
30%	1	4.618	6.351	6.881	5.950
	7	15.624	16.446	16.275	16.115
	28	17.635	18.562	18.346	18.181
40%	1	4.071	4.967	3.985	4.341
	7	10.396	9.633	11.456	10.495
	28	13.549	11.588	12.351	12.496

APPENDIX C

HEAT ABSORPTION RESULT

		Compressive Strength (N/mm^2)			
Percentage	**Temperature**	**Specimen 1**	**Specimen 2**	**Specimen 3**	**Average**
0%	40	34.753	34.657	36.205	35.205
	60	33.567	28.654	29.030	30.417
	80	29.091	29.976	32.535	30.534
0%	40	32.251	33.149	35.178	33.526
	60	32.732	31.965	33.310	32.669
	80	27.292	29.155	29.038	28.495
10%	40	27.862	26.825	30.207	28.298
	60	25.633	23.169	26.426	25.076
	80	24.963	25.198	25.376	25.179
20%	40	26.659	25.012	25.126	25.599
	60	21.069	19.521	19.650	20.080
	80	18.997	19.964	19.503	19.488
30%	40	18.512	20.169	18.829	19.170
	60	17.181	18.324	18.954	18.153
	80	16.567	16.125	15.488	16.060
40%	40	14.264	15.937	17.445	15.882
	60	15.324	16.122	15.108	15.518
	80	16.582	17.126	15.066	16.258

APPENDIX D1

WATER ABSORPTION RESULT

	Plastic content			
	0%			
Time (min)	Specimen 1	Specimen 2	Specimen 3	Mass increment (%)
0	2146.98	2191.98	2162.98	0.00
5	2190.03	2236.19	2206.48	2.01
10	2204.50	2249.73	2220.45	2.66
15	2213.58	2258.33	2229.26	3.06
20	2220.61	2264.68	2235.94	3.37
25	2226.84	2270.09	2241.75	3.64
30	2231.66	2274.55	2246.37	3.86
35	2235.81	2278.19	2250.26	4.04
40	2239.45	2281.62	2253.79	4.20
45	2242.85	2284.73	2257.03	4.35
50	2245.74	2287.39	2259.80	4.48
55	2248.31	2289.45	2262.11	4.58
60	2250.24	2291.32	2264.01	4.67
70	2253.49	2293.91	2266.92	4.81
80	2255.38	2295.77	2268.79	4.89
90	2256.97	2297.05	2270.22	4.96
100	2258.28	2298.29	2271.50	5.02
110	2259.40	2299.16	2272.49	5.06
120	2260.37	2299.90	2273.34	5.10
180	2262.99	2307.07	2278.20	5.33
240	2264.47	2308.08	2279.44	5.38
1440	2266.91	2310.47	2281.85	5.50

APPENDIX D2

WATER ABSORPTION RESULT continued

	Plastic content			
	10%			
Time (min)	Specimen 1	Specimen 2	Specimen 3	Mass increment (%)
0	2156.08	2167.46	2171.51	0.00
5	2196.32	2209.28	2212.72	1.90
10	2206.36	2219.37	2222.83	2.36
15	2211.56	2223.48	2227.51	2.58
20	2215.66	2227.88	2231.78	2.78
25	2218.65	2229.99	2234.34	2.89
30	2220.47	2231.05	2235.79	2.96
35	2221.66	2232.03	2236.88	3.01
40	2223.35	2233.05	2238.24	3.07
45	2224.12	2234.02	2239.12	3.11
50	2224.73	2234.43	2239.63	3.14
55	2225.64	2235.1	2240.42	3.17
60	2226.14	2235.84	2241.04	3.20
70	2226.85	2236.43	2241.70	3.23
80	2227.44	2236.9	2242.23	3.26
90	2227.64	2237.35	2242.56	3.27
100	2228.14	2237.81	2243.04	3.29
110	2228.47	2238.03	2243.31	3.31
120	2228.81	2238.26	2243.60	3.32
180	2229.68	2239.61	2244.72	3.37
240	2230.41	2240.18	2245.37	3.40
1440	2233.57	2244.03	2248.89	3.56

APPENDIX D3

WATER ABSORPTION RESULT continued

	Plastic content			
	20%			
Time (min)	**Specimen 1**	**Specimen 2**	**Specimen 3**	**Mass increment (%)**
0	2095.90	2089.86	2091.35	0.00
5	2140.33	2134.86	2136.03	2.14
10	2151.94	2146.46	2147.63	2.69
15	2157.66	2151.23	2152.87	2.94
20	2162.28	2155.63	2157.38	3.16
25	2164.90	2157.56	2159.65	3.27
30	2166.62	2158.83	2161.14	3.34
35	2167.91	2160.22	2162.48	3.40
40	2169.04	2161.10	2163.49	3.45
45	2169.79	2161.81	2164.22	3.48
50	2170.67	2162.42	2164.96	3.52
55	2171.20	2162.95	2165.49	3.55
60	2172.07	2163.65	2166.27	3.58
70	2172.67	2164.23	2166.86	3.61
80	2173.03	2164.25	2167.05	3.62
90	2173.64	2164.88	2167.67	3.65
100	2174.15	2165.35	2168.16	3.67
110	2174.42	2165.70	2168.47	3.69
120	2175.01	2165.91	2168.87	3.71
180	2176.00	2167.38	2170.10	3.77
240	2177.02	2168.00	2170.92	3.80
1440	2180.63	2171.78	2174.61	3.98

APPENDIX D4

WATER ABSORPTION RESULT continued

	Plastic content			
	30%			
Time (min)	Specimen 1	Specimen 2	Specimen 3	Mass increment (%)
0	2039.77	1960.78	1994.13	0.00
5	2080.57	2000.62	2034.33	2.02
10	2093.35	2012.14	2046.44	2.62
15	2101.04	2022.55	2055.49	3.08
20	2107.10	2031.16	2062.83	3.45
25	2113.66	2037.16	2069.09	3.76
30	2119.40	2037.22	2071.92	3.90
35	2124.63	2043.38	2077.61	4.19
40	2129.32	2048.82	2082.67	4.44
45	2133.32	2053.72	2087.12	4.66
50	2136.79	2057.30	2090.64	4.84
55	2139.58	2061.45	2094.11	5.01
60	2141.98	2064.60	2096.88	5.15
70	2145.45	2066.87	2099.73	5.30
80	2148.57	2069.87	2102.79	5.45
90	2151.12	2074.46	2106.37	5.63
100	2153.36	2076.84	2108.67	5.74
110	2154.60	2079.94	2110.85	5.85
120	2156.35	2080.11	2111.80	5.90
180	2160.32	2083.67	2115.55	6.09
240	2161.45	2084.26	2116.40	6.13
1440	2164.88	2083.66	2117.77	6.20

APPENDIX D5

WATER ABSORPTION RESULT continued

	Plastic content			
	40%			
Time (min)	**Specimen 1**	**Specimen 2**	**Specimen 3**	**Mass increment (%)**
0	1930.47	1911.28	1954.23	0.00
5	1972.59	1949.50	1995.09	2.09
10	1984.18	1963.82	2008.28	2.77
15	1992.22	1974.92	2018.02	3.26
20	1998.36	1983.53	2025.53	3.65
25	2003.42	1991.08	2031.95	3.98
30	2008.15	1997.95	2037.86	4.28
35	2012.38	2004.57	2043.38	4.56
40	2016.35	2010.15	2048.24	4.81
45	2019.27	2014.88	2052.14	5.01
50	2022.46	2019.36	2056.05	5.21
55	2025.07	2023.15	2059.30	5.38
60	2027.61	2026.51	2062.31	5.53
70	2030.74	2030.47	2065.92	5.72
80	2033.45	2033.54	2068.86	5.87
90	2035.60	2035.88	2071.14	5.98
100	2037.60	2037.93	2073.20	6.09
110	2039.41	2039.16	2074.75	6.17
120	2041.20	2040.17	2076.17	6.24
180	2046.64	2041.36	2079.53	6.41
240	2049.51	2041.89	2081.26	6.50
1440	2052.02	2043.90	2083.55	6.62

APPENDIX E

PHOTO OF LABORATORY PREPARATION