WASTE PLASTIC BOTTLE CAP POLYPROPYLENE (PP) AS COARSE AGGREGATE REPLACEMENT IN CONCRETE

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ABSTRACT

Polypropylene (PP) has been widely used by researchers to determine its performance in concrete matrix. Generally, PP will be crushed or reshaped into flakes, fibres or granular shapes. However, the cost and time consumption for processing will increased as the melting point of PP is around 170 ^{o}C. Hence, the novelty of this research was to determine the suitability of the polypropylene cap (without any alteration of shape) as coarse aggregate replacement in concrete. The results of slump test, rebound hammer test and compressive strength test shows that the PP cap were suitable to be replaced as coarse aggregate in concrete. The compressive strength of concrete with PP cap was 27.3 MPa, higher than 20 MPa which is suitable for general concrete work. Furthermore, the compressive strength results of concrete elevated to temperatures (100, 200, 300 and 600 ^{o}C) at the age of 28 days were also studied. From 100 ^{o}C to 300 ^{o}C, the results indicated that concrete with PP cap performed better than the control concrete. The coarse aggregate replaced by PP cap was fixed to 10 %. Based on the experimental results, It was concluded that the PP cap aggregates were suitable to replace as coarse aggregate in concrete.

ABSTRAK

Polypropylene (PP) telah digunakan secara meluas oleh penyelidik untuk menentukan prestasi dalam matriks konkrit. Secara umumnya, PP akan dihancurkan atau membentuk semula ke dalam kepingan, gentian atau bentuk berbutir. Walau bagaimanapun, penggunaan kos dan masa untuk diproses akan meningkat kerana titik lebur PP adalah sekitar 170 ^{o}C. Oleh itu, sesuatu yang baru daripada kajian ini adalah untuk menentukan kesesuaian topi polypropylene (tanpa apa-apa pengubahan bentuk) sebagai pengganti agregat kasar dalam konkrit.Keputusan ujian kemerosotan, ujian tukul pantulan dan ujian kekuatan mampatan menunjukkan bahawa topi PP adalah sesuai untuk digantikan sebagai agregat kasar dalam konkrit. Kekuatan mampatan konkrit dengan PP topi adalah 27.3 MPa, lebih tinggi daripada 20 MPa yang sesuai untuk kerja-kerja konkrit umum.Tambahan pula, keputusan kekuatan mampatan konkrit dinaikkan kepada suhu (100, 200, 300 dan 600 ^{o}C) pada usia 28 hari juga telah dikaji. Dari 100 ^{o}C hingga 300 ^{o}C, keputusan menunjukkan bahawa konkrit dengan PP topi prestasi yang lebih baik daripada konkrit kawalan. Agregat kasar digantikan oleh PP topi ditetapkan kepada 10 %. Berdasarkan keputusan eksperimen, Ia telah membuat kesimpulan bahawa PP agregat penutup adalah sesuai untuk digantikan sebagai agregat kasar dalam konkrit.

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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
MPa	Mega Pascal
±	Plus-Minus

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
BS	British Standard
CEM	Certified Energy Manager
EN	European Standards
MS	Malaysia Standard
NA	Natural Aggregate
OPC	Ordinary Portland Cement
PP	Polypropylene
PP0	Concrete without polypropylene cap
PPA	Concrete with polypropylene cap
PPB	Concrete with polypropylene cap with hole
PET	Polyethylene Terephthalate
RILEM	Reunion International Laboratories Experts Material
YTL	YTL Corporation Berhad

CHAPTER 1

INTRODUCTION

1.1 Background

Quantities of plastic wastes has increased rapidly throughout this decade due to its beneficial properties of low density, light weight and strength. Other important factors such as low cost and friendly design were the reason polymer product becomes an inseparable part of our lives. The one of the most profitable industry in Malaysia was plastic manufacturing. The exports of plastic products from Malaysia to South East Asia, United Kingdom and United State in 2001 were valued at U.S. $1.83 billion (Malaysia Department Statistics, 2002).

In Malaysia, most of our plastic wastes were dispose or abandon and not recycle. In other words, inside the municipal waste stream, the plastic wastes management options were merely incinerated or landfill. This had caused a very serious environmental threat to the environment due to the high volume of municipal solid wastes. The world's annual usage of plastic material has growth from approximately 5 million tons in 1950s to almost 100 million tons in 2001. This tremendous growth of plastic waste should concern to reduce the environmental pollution. Figure 1.1 presents the types and quantities of plastic in municipal solid waste in United States of America (Siddique et al, 2008). Other than that, with the increasing cost of space for landfill and scarcity of natural aggregate, waste utilization has become a desirable alternative to disposal.

Table 1.1: Types and quantities of plastic in municipal solid waste in USA (Subramanian, 2000)

Type of plastic	**Quantity (1000 tons)**
Polyethylene terephthalate (PET)	1700
High density polyethylene (HDPE)	4120
Low density polyethylene (LDPE)	5010
Polypropylene (PP)	2580
Polystyrene (PS)	1990
Other	3130

Plastic bottle cap which is made of polypropylene (PP) is one of the plastic product also known as low modulus synthesis fibers that are effectual in controlling shrinkage cracking (Foti, 2011). Polypropylene cap is a hard but flexible plastic while the body of plastic bottle is made from polyethylene terephathalate (PET), a clear tough plastic (Siddique et al, 2008). Unlikely to PET, the polypropylene cap is excluded in the process of recycling bottle due to its high melting point. The difference of polypropylene cap versus polyethylene terephathalate bottle in melting point is approximately 100 degree Celsius, which dramatically increases the cost of processing polypropylene cap. Obviously, the polypropylene cap was eliminated from selection of recycled due to its value in the market (Garthwaite, 2008).

Figure 1.1: Compressed bales of waste plastic bottles

Incorporate with this situation, the purpose of this study was to fully utilize the polypropylene cap as partial coarse aggregate replacement in concrete in order to provide a desirable alternatives in reduce the negative impact on environment, producing a new composition of concrete and at the same time deplete the pressure on exploit natural resources. Furthermore, the polypropylene cap can greatly improve some of concrete properties due to polypropylene cap has high toughness, lighter in weight and good abrasion behavior (Saikia & Brito, 2012).

1.2 Problem Statement

The production and consumption of plastic has increases substantially worldwide in recent years and has created a huge deposit in the domestic wastes and landfills. For example, around 32 million tons of plastic-based wastes were produced in the year of 2012. However, the rate of recycling plastic bottle was only 31% and the remaining was sent to landfill or incinerate (EPA, 2014). Despite the fact of increasing cost for landfill, polypropylene cap required a significant amount of time, approximately up to hundreds of year to be fully decomposed (to be determined because polypropylene cap have not existed for long enough) due to its very slow degradation rate. At the same time, incineration was also not an advisable option due to the potentially harmful chemical composition of polypropylene cap (Siddique et al, 2008).

On the other hand, high demands for raw materials such as natural aggregate due to the rapid increasing of population and construction development has cause a heavy exploitation on the natural resources. Continuous of natural aggregate quarrying produced issues like damaging the environment and depleting fast, causing a shortage in natural aggregate. Thus, comprising the negative environment impact of polypropylene cap and the depletion of natural aggregate, utilize waste polypropylene cap as partial aggregate replacement in concrete has foreseen to become considerably effective solution for these issues. The development of polypropylene cap aggregate as construction materials are important to both the construction and plastic bottle recycling industry as it is essential to preserves our depleting natural resources.

1.3 Research objectives

It is a tremendous achievement for both the construction and the plastic recycling industries if the polypropylene cap can be used to replace the natural aggregate. The objectives of the study are:

- To determine the suitability of polypropylene cap as partial coarse aggregate replacement in concrete.
- To compare the mechanical properties of polypropylene cap concrete with control concrete.
- To study the effect of hole in polypropylene cap as partial coarse aggregate replacement.
- To study the effect of elevated temperature on the mechanical properties of polypropylene cap concrete and control concrete.

1.4 Scope of work

In general, the coarse aggregate used in concrete production should be hard, dense, no harmful chemicals and durable. However, the composition of plastic bottle may be varies in size, hardness, shape and chemical composition. Therefore, only the mineral water PP plastic bottle caps are chosen as coarse aggregate replacement.

Other scopes of study are as follow:

- 3 types of composition are be used to produce the concrete, the first type is PP0 which is the control concrete without any replacement of polypropylene cap. The second concrete is PPA which is the plastic concrete with 10% replacement of polypropylene cap as coarse aggregate by volume. The last one is the PPB which is also the similar plastic concrete with 10% replacement of polypropylene cap. However, the polypropylene cap for PPB has a hole punch through by a puncher and hammer manually.

- The mix design of grade 30 concrete has been developed using polypropylene cap, crushed granite,river sand, Ordinary Portland Cement and tap water.
- The consistency test was carried out to ensure that the mix design was adequate to produce a grade 30 concrete.
- The 100 x 100 x 100 mm sized cube has been chosen as the dimension of cube for destructive test.
- The specimens were being tested at the age of 7, 14 and 28 days with according to the standard recommendation (BS 1881).
- The concrete properties can be obtained by carry out the destructive and non-destructive tests such as slump test, compressive test, density test, rebound hammer test, fire resistance and consistency test.

1.5 Significance of the study

The adoption of polypropylene cap as replacement of coarse aggregate will bring significant impacts on the environment and society. The significance of the studies are state as follow:

- To reduce the space required for the landfill of polypropylene cap.
- To diminish the pressure on exploiting the natural resources.
- To introduce the potential of polypropylene cap as coarse aggregate.

In terms of novelty, the success achievement of the research was not only produce a new composition of plastic concrete but also lower the production cost of the concrete. This would contribute greatly in the construction industry as well as reduce the negative environment impact. In addition, the applicability of the new concrete in the construction industries was considered as a huge leap as the strength of concrete more than $30N/mm^2$ was feasible in structural work.

CHAPTER 2

LITERATURE REVIEW

Literature review is a chapter that reviews the study and reading made to the related topic. It is a synthesis and analysis of particular relevant published work, journal and proceeding, relating all the times to the purpose of this research study and rationale. In this chapter, the properties and composition of the concrete as well as the component inside will be discussed. Since the topic is related to polypropylene cap, the properties of it are pointed out in this chapter. Furthermore, the strength of the concrete with polypropylene cap replacement as coarse aggregate are also discussed.

2.1 Concrete

Concrete which has greater properties like better versatility, availability and economy compared with the other structural materials are one of the vital materials for structures and been widely used worldwide. Almost all structural in construction such as building, houses, dams, retaining walls, bridges, ports, etc are made with concrete (Beycioglu & Yılmaz, 2014). The main component of concrete is comprised of cement, water, fine and coarse aggregate. According to Hanssanpour et al. (2012), concrete is a brittle structure just like glass and it has low tensile strength and shear capacity. Hence the brittleness of the concrete is increased with the increase of strength in concrete. Thus, leading the concrete yields to cracking. However, studies of fiber reinforced concrete had shown as an alternative solution for this problem.

In this study, polypropylene cap concrete is expected to perform better than normal concrete in terms of ductility and toughness. Polypropylene cap as known as synthetic fiber are claims to be more effective in the post-crack phase of concrete due to its "sewing effect". The effect of the fiber acts on the crack of the concrete is similar to a bridging created between the cracks of the concrete. Thus, increased the ductility and toughness of the concrete (Foti, 2011). Table 2.1 represents the concrete usage with respects to its concrete grade.

Table 2.1: Concrete Grade and Usage

Concrete Grade (N / mm^2)	Ratio of Cement, Sand and Aggregate	Usage
10	1 : 4 : 8	Blinding Concrete
15	1 : 3 : 6	Mass Concrete
20	1 : 2.5 : 5	Light Reinforce Concrete
25	1 : 2 : 4	Reinforce Concrete
30	1 : 1.5 : 3	Heavy Reinforced Concrete Pre-cast
35	1 : 1.5 : 2	Pre-stress Concrete/Pre-cast
40	1 : 1 : 1	Very Heavy Reinforced Concrete Pre-Stress/Pre-cast

2.1.1 Cement

According to Paraside and Prochorov (1979), cement is the general term for a classification of factitious, inorganic, powered, mainly hydraulic binding materials. After the interaction with water, fluid solutions of salts, or other aqueous, they form a pliant mass that solidify with time and becomes a hardened solid, rocklike body. Cement can be claimed as one of the most essential materials in construction and it is mainly used to make concrete and mortar.

According to Portland Cement Association, (2010), one of the most common hydraulic cement is Ordinary Portland Cement. The history of Portland Cement can be simplified as

- In 1976, John Smeaton was the first to understand the chemical properties of cement.
- In 1824, James Parker and Joseph Aspdin were the first to carry the patent for Portland cement and it was filed in England. The Portland cement is made by burning powdered limestone and clay.
- In 1845, Isaac Johnson made a prototype of modern cement with burning mixture of clay and chalk.

The chemical composition of Ordinary Portland Cement (OPC) are as shown in the Table 2.2.

Table 2.2: Chemical composition of OPC

Component	**Composition (%)**
Tricalcium Silicate	50
Dicalcium Silicate	25
Tricalcium Aluminate	10
TetracalciumAluminoferrite	10
Gypsum	5

The quality of Ordinary Portland Cement is assured and Table 2.3 represents the Standards and Specification of Cement in Malaysia. In this study, OPC will be chosen as the cement for all mixing concrete as it is common and widely available.

Table 2.3: Standards and Specifications of Cement in Malaysia (Malaysia Standard Specification of Cement, 2014)

Main Type	Notation		Clinker Content (%)	Content of other Main Constituents (%)
CEM I	Portland Cement	CEM I	95-100	0-5
CEM II	Portland - Slag Cement	CEM II/A-S	80-94	6-20
		CEM II/B-S	65-79	21-35
	Portland-silica fume Cement	CEM II/A-D	90-94	6-10
	Portland-Pozzolanic Cement	CEM II/A-P	80-94	6-20
		CEM II/B-P	65-79	21-35
		CEM II/A-Q	80-94	6-20
		CEM II/B-Q	65-79	21-35
	Portland-fly ash cement	CEM II/A-V	80-94	6-20
		CEM II/B-V	65-79	21-35
		CEM II/A-W	80-94	6-20
		CEM II/B-W	65-79	21-35
	Portland-burnt shale cement	CEM II/A-T	80-94	6-20
		CEM II/B-T	65-79	21-35
	Portland-limestone cement	CEM II/A-L	80-94	6-20
		CEM II/A-LL	80-94	6-20
		CEM II/B-L	65-79	21-35
		CEM II/B-LL	65-79	21-35
	Portland-composite cement	CEM II/A-M	80-94	6-20
		CEM II/B-M	65-79	21-35
CEM III	Blast furnace cement	CEM II/A	35-64	36-65
		CEM II/B	20-34	66-80
		CEM II/C	5-19	81-95
CEM IV	Portland fly ash cement	CEM IV/A	65-89	11-35
	Pozzolanic fly ash cement	CEM IV/B	45-64	36-55

CEM V	Composite cement	CEM V/A	40-64	36-60
		CEM V/B	20-38	62-80

2.1.2 Aggregate

Aggregates are granular materials are granular materials such as natural gravels, sands and crushed stones. It's a material of various sizes and shapes, it's also one of the important material used in producing concrete. Generally, aggregate occupy 70-80% of the concrete volume and have significant influence on the properties of concrete. Thus, it should be strong and hard, free from undesirable impurities, chemically stable and durable. The suitability of aggregate for concrete are depending on the concrete design limitation, to secure the quality of the concrete, both fine and coarse aggregate need to be quality sized before applying in accordance with the Standards required (Yunusa, 2011).

Generally, aggregate can be categories as fine aggregate or coarse aggregate. The size of fine aggregate in concrete construction are normally smaller than 4.75 mm and equal or larger than 75 µm. While the coarse aggregate are with particle size equal to or larger than 4.75 µm. The main functions of aggregate are to reduce the cost of concrete, produce workable yet cohesive concrete, reduce the heat of hydration of concrete, reduce the shrinkage of concrete (Lamond & Pielert, 2006).

According to Farrag and Yehia (2014), there are various effect of aggregate on the concrete and it is as followed:

- In terms of absorption, the aggregate may affect the effective mixing water and thus reducing the compressive strength and durability. Hence, aggregates are pre-soaked or pre-wetted with water in order to achieve saturated surface dry state.
- In terms of specific gravity factor, it is depending on the internal structure of aggregates. Generally, aggregates with specific gravity factor more than 1.3 can be used to produce high strength concrete..
- In terms of density, aggregates will significantly affects the mechanical and durability of the concrete. Typically, high dense concrete mixes are made from high

bulk density aggregates and packing density is very vital in enhancing durability features and creates a uniform microstructure.

- In terms of shape, angular aggregates are helpful in achieving well packed concrete mixes thus resulting in high strength. In contrast with that, round aggregates do not contribute to lower workability as opposed to angular aggregates.

In this study, the fine and coarse aggregate are natural gravel and river sand respectively.

2.1.3 Superplasticizer

According to U.S. Department of Transportation (2014), superplasticizers also known as high range water reducer is use to achieve flowing concrete with high slump in the range of 175-225mm. It's normally used in heavily reinforced concrete and situation where appropriate consolidation by vibration cannot be easily achieved. Other than that, superplasticizers are able to reduce the water requirements up to 12-25% without affecting the workability of the concrete and lower the permeability.

The main intention of using superplasticizer is to increase the cement paste fluidity, with the superplasticizer the water required can be reduced. Since the high water to cement ratio will decrease the strength and durability of the concrete (Zheng & Sui, 2009).

2.1.4 Durability

According to Monteiro et al. (2009), durability of a concrete is defined as the ability to resist chemical attack, abrasion, weather action, or any deterioration. Similarly, the Portland Cement Association, (2010) also states that durability of a concrete is the ability to last a long time without significant deterioration. The durability of the concrete will not only affect the life span of the concrete but also affect the environment. A durable material helps in preserving the natural resources and decreases the wastes to the environment. The environmental issues such as depletion of natural resources and pollution from construction wastes can be reduced.

According to Ramezanianpour et al. (2013), polypropylene fibers are able to increase the resistance of the concrete to the ion penetration which is the salt attack with rapid chloride penetration test (RCPT).

2.1.5 Workability

Siddique et al. (2008) defines that the workability of concrete is the ease that concrete can be mixed, moved, placed and finished simply without segregation. The slump test, K-test and inverted slump cone can beused fordetermining the workability of concrete. Slump test is used widely at the site to determine the workability of the concrete. The mold for slump test is a frustum of cone, 305 mm high and it is carried out per ASTM C 143-78. The concrete is filled in the cone and then lifted slowly, the concrete is then slump due the removal of supporting cone. The difference in height of concrete is called slump.

Bayasi and Zeng (1993) studied the effects of polypropylene fibers on both the slump and inverted slump cone tests of the concrete mixes. They reported there is an increase in the inverted slump cone time and for the fiber volume fractions that are less than or equal to 0.3%, fiber does not show any significant effect on the workability of fresh mixed concrete and the results are rather inconsistent. However, the polypropylene fiber shows a more obvious effect with the 19 mm fibers compared with the 12.7 mm fibers. It can be concluded that in their studies, the workability of the concrete is improved with the longer fibers. However, the mix ability of the concrete becomes more difficult.

According to Al-Manaseer and Dalal (1997), the slump is increased with the incorporation of plastic aggregate in the concrete. The concrete comprised of 50% plastic aggregates appears to have a higher cone slump compared with the concrete without plastic aggregates. Due to the almost non-absorptive properties of plastic aggregates, the concrete tend to have more free water and thus increases the slump.