The effect of polyethylene terephthalate (road barrier waste) in concrete for rigid pavement

D Hasan*, N Juhari, M H Rofi and A Albar

Faculty of Civil Engineering, Universiti Teknologi MARA, Cawangan Pulau Pinang, 13500, Permatang Pauh, Penang, Malaysia.

*daliahasan@ppinang.uitm.edu.my

Abstract. Plastic have become a major problem in solid waste management due to its inability to degrade when they are disposed at landfill site. Approximately 0.80 kg/capita to 1.9 kg/capita of municipal solid waste is generated daily in Malaysia, which is expected to increase annually. Cracking of rigid pavement is the phenomenon where the pavement fails under repetitive loading by a load smaller than the load that can cause failure in single application. Other than that, decrements of the flexural strength due to the lower tensile strength can cause the joint spalling. The larger the load, the smaller will be the number of repetition to cause cracks. In this study paper presents the effect of Polyethylene terephthalate (PET) road barrier waste as alternative addition in concrete grade C40 for rigid pavement. The material was obtained from Jabatan Kerja Raya (JKR) Seberang Perai Tengah and it need through cutting process to become fiber with range size about 12mm-15mm length and 3mm-5mm width before to be addition into concrete. Four types of concrete mixes with different percentages of PET road barrier fibers which are 0%, 1%, 2% and 3%. Each specimen consist of six cube samples and one beam. The six cubes represent sample at 3 days, 7 days and 28 days. The beam sized 150mm x 150mm x 750mm was only tested on 28 days of curing. The result obtained on the compressive test, 2% of additive PET road barrier waste shows the highest result compare to the 0% and 1% additive. Compression test result shows 2% of PET road barrier waste fibers as the optimum percentage of PET road barrier additive with the maximum load of 42.13 MPa.

1. Introduction

Polyethene forms the largest part of the plastic, followed by polyethylene terephthalate (PET). PET is a polyester made from compositions of ethylene glycol and terephthalic acids and its chemical name is Polyethylene terephthalate (PET). [1] As PET is highly stable, highly tolerant of pressure, non-reactive, highly resistant to alkaline compared to other fibers, it is good as concrete reinforcing fibers. [2] The plastics road barrier also one of the type of Polyethylene Terephthalate (PET). According to Kumar, Arka, Siddharth and Prasad (2017), a plastic road barrier with highly visible plastic systems that are tough, durable and can withstand impacts from factory vehicles of up to 304KN, equivalent to a 3.5 tonnes vehicle with a head-on impact of 10 mph. [3]
In 2002, the annual use of plastic material in the world amounted to 204 million tons, but in 2013 it was increased to 300 million tons. [4] In addition, the consumption and production of plastics and polymers is expected to grow steadily over the years. Table 1 shows the plastic production of Malaysia by plastic category reported by National Solid Waste Management Department Ministry of Housing and Local Government Malaysia (2011).

| Type of plastic                     | Plastic Production (%) |
|-------------------------------------|------------------------|
| High Density Polyethylene (HDPE)    | 24                     |
| Low Density Polyethylene (LDPE)     | 24                     |
| Polyethylene Terephthalate (PET, PETE) | 13                    |
| Polyvinyl Chloride (PVC)            | 10                     |
| Polypropylene (PP)                  | 13                     |
| Polystyrene (PS)                    | 10                     |
| Polycarbonate (PC)                  | 3                      |
| Acrylonitrilebutadiene-styrene (ABS)| 4                      |
| Polymethyl Methacrylate (PMMA)      | 2                      |
| Others (acrylic, nylon and epoxy resin) | 2               |

Rigid pavement has relatively high resistance as compared to flexible pavement. It has enough strength to overcome local subgrade failures and areas of insufficient support. It is constructed using concrete, generally with the strength of 40 MPa. [5] With decades of construction and use of rigid pavements, it became clear that their longer service life has favorable effect on the sustainability of the environment in comparison to flexible pavements. [5] However, the flexural failure of the pavement is controlled by concrete crushing after the steel yield. Unexpected excessive load on the surface makes it easier for the concrete to fail. Cracking of rigid pavement is the phenomenon where the pavement fails under repetitive loading by a load smaller than the load that can cause failure in single application. The larger the load, the smaller will be the number of repetitions to cause cracks. Other than that, decrements of the flexural strength due to the lower tensile strength can cause the joint spalling. The critical area for tensile strength is at joint between two slabs of concrete pavement. According to Mosa, Atiq and Ismail (2011), joint spalling is the breakdown of the slab near edge of the joint. Normally it occurs within 0.5 m of the joints. Thus, by placing the fiber may contribute to the incremental of tensile strength in the concrete especially at areas near the joints. [6]

This study was aimed to minimize the excessive waste product from the plastic waste by utilizing it as concrete additive, hence the environmental problem can be prevented. The utilization of Polyethylene Terephthalate (PET) in concrete promotes environmentally friendly (eco-friendly) and encourages researchers to investigate the use of other by-products from the major type of wastage, plastic waste, which will ultimately lead to their development as a more environmentally friendly way of generating energy. This study was developed new concrete invention in construction industry where it can improve the workability of the concrete and increase the strength of the concrete in term of compression and flexural.

2. Material and methods

2.1 Materials and equipment preparation
The materials and equipment used were 150 mm x 150 mm x 150 mm for concrete cubes mould, and 150 mm x 150 mm x 750 mm for concrete beam mould. Ordinary Portland Cement (OPC), PET fiber water, and aggregates. The aggregate was sieved using sieving apparatus that and it was collected from the retained of 10 mm sieve and passing of 20 mm sieve. PET road barrier that was cut into fibers with the range of 15 mm – 25 mm length and thickness of 5 mm – 6 mm by using grinder.

2.2. Slump test
The slump test was conducted according to BS 1881: Part 102: 1983. The procedure of slump test is concrete was filled in 3 layers. Each layers were tamped 25 times by using rounded end steel rod. After that, the mould were held firmly against its base. The mould was lifted vertically but slowly. Then, the mould are placed beside the concrete and height of slump was measured.

2.3. Curing process
Curing is the process to maintain an adequate moisture content and temperature in concrete at an early age so that the mixture has been designed to achieve properties. Curing starts immediately after placing concrete in water so that the concrete develops the desired strength and durability. Samples were cured in an asbestos tank with clean water and the water was maintained at room temperature. The samples was curing for 7 days, 14 days, and 28 days.

2.4. Compression test
The compression test was carried out by using compression machine at UiTM’s heavy lab, for 150 mm x 150 mm x 150 mm cube, the pace rate was set up to 6.80 kN/sec.

2.5. Flexural test
The flexural test for This study was carried out using the Universal Testing Machine (UTM) as showed in Plate 3.12 to apply load on the beam. For this study, the mechanic load cell had been set up into 0.05mm/sec. The peak load has been recorded as the maximum load can applied on the beam with various percentage of PET road barrier waste.

3.0 Results and discussion
Several tests were conducted to achieve the objective on this research. The tests conducted were slump test, compression test and flexural test. The result and data collected from the tests were analyzed, tabulated and plotted. All the result was recorded from various desired percentage of PET road barrier waste as additive in concrete. The slump was measured, and the type of slump was determined to verify the workability of concrete. The collected data for compression test and flexural is very crucial to show the performance of PET road barrier waste as additive in concrete. The comparison between control mix and percentage of PET used as additive in concrete has been analyzed. This slump test was conducted to determine the workability and consistency of concrete. Theoretically, the wet mixture is more workable rather than the dry mixture and the workability of concrete can be determined by the slump measurement and the type of slump.
Table 2. Data of slump test

| Percentage of PET Road Barrier Waste | Slump (mm) | Type of Slump |
|-------------------------------------|------------|---------------|
| 0%                                  | 30         | True Slump    |
| 1%                                  | 109        | Shear         |
| 2%                                  | 117        | Shear         |
| 3%                                  | 135        | Shear         |

Table 2 shows the result from the slump test with different percentage of PET road barrier waste as additive in concrete. The result shows that all samples exhibited shear slump except control sample (0%) that displayed true slump. All slump height was measured from top of the cone and all of them were specified in the range of 30 to 135 mm. The higher the slump, the higher the workability of the concrete. The result of 3% PET fiber shows the highest slump for this experiment. It is because of the fiber does not have a bonding agent to the concrete and causing the concrete to increase in slump. By comparing the 0% of PET fiber to rest of PET fiber percentage used in this study, it results in the lowest degree of slump.

The compression test has been conducted on day 7, 14, and 28 days after the curing process. The total cube were 24 cubes with different percentage of PET road barrier waste addition. Six (6) cube samples were tested for each percentage of PET fiber addition. The compression test was carried out in accordance to BS 1881-108: 1983. At 28 days, compression test was conducted to determine the designed strength of cube samples.

Table 3. Compression test results

| Days | Strength of Concrete (MPa) |
|------|----------------------------|
|      | 0% | 1% | 2% | 3% |
| 7    | 29.11 | 29.62 | 29.93 | 28.98 |
| 14   | 36.21 | 36.83 | 37.96 | 37.40 |
| 28   | 40.56 | 41.07 | 42.13 | 41.60 |

Note: Result shows the average of two samples

Table 3 showed the result of compression test for each sample. During 7 days of curing, the compressive strength achieved its 65% of the design strength. Table 3 shows the increase of strength on 7 days proportionate to the increment of the percentage of PET road barrier waste in the concrete. The strength of concrete was increased from 29.11 MPa for the control sample (0% PET) to 29.62 MPa, 29.93 MPa and 28.98 MPa of 1%, 2% and 3% of PET road barrier waste, respectively. Table 3 displayed the increase of compressive strength with the increase of age. The strength for 0% of PET road barrier waste was increased from 29.11 MPa to the 36.21 MPa. For 1% of PET road barrier waste, the strength was increased from 29.62 MPa to the 36.83 MPa. Next, for 2 % of PET road barrier waste, the strength still increased from 29.93 MPa to the 37.96 MPa. For 3% of PET road barrier waste also showed the increment of its strength from 28.98 MPa to the 37.40 MPa.

During 28 days of curing, all of the samples achieved 99% - 100% of the designed strength. The strength of the control sample was increased from 36.21 MPa to the 40.56 MPa. Similar increment trend were observed for other samples with 1%, 2% and 3% of PET road barrier waste in strength from 36.83 MPa, 37.96 MPa and 37.4 MPa increase to 41.07 MPa, 42.13 MPa and 41.6 MPa. 0% of PET road barrier fiber showed the lower strength of concrete.

Crack pattern on cube after compression test showed the ductility of the concrete. One of the characteristics of concrete is brittle. Figure 1 showed the cube of control sample after compression test. The cube shows the major of cracks compare to the cube that contain PET road barrier fiber that only shows the minor/smaller cracks on Figure 2.
The flexural test was conducted on the beam sample at 28 days after curing. The maximum load had been applied on beam until the beam failed. Figure 3 and Figure 4 showed the data for each percentage of PET road barrier fiber in concrete.
**Figure 3.** Load – time graph for 0% of PET road barrier fiber

**Figure 4.** Load – time graph for 3% of PET road barrier fiber
Figure 5 showed the comparison of peak load for each percentage of PET road barrier waste fiber in concrete beam. Control sample of beam 0% percentage of PET road barrier the highest load applied on beam until failed is 30.43 kN. The peak load is starting increase when the percentage of PET road barrier is increase 1% and 2% with loads 84.95 kN and 93.77 kN. However, at 3% of PET road barrier the load starting to decrease until 86.44 kN. All beams underwent flexural failure except for the beam sample 3% of PET road barrier as shown in figure 3 that experienced shear failure.

Figure 6. 3% of PET Road barrier beams failure in shear

4. Conclusions
The result obtained on the compressive test, 2% of additive PET road barrier in concrete shows the highest result compare to the 0% and 1% additive. It shows 2% of PET as the optimum percentage of additive in concrete with strength 42.13 MPa. However, the compressive strength started to at 3% of PET road barrier additive of 41.60 MPa during 28 days of curing. It can be concluded for 3% quantity of PET road barrier waste additive had loosed their bonding with concrete. It has been affected the strength where it starts to drop. Based on Hatta and Hashim (2017) studies, adding a higher amount of PET also made the stiffness of the mixture decreased which can cause increasing fatigue life of concrete [5]. The evidence from this study suggest that the PET road barrier can be use in concreting work...
especially for rigid pavement. It can avoid the progressive failure on concrete rigid pavement if the load was reach to the maximum.

Acknowledgement
In the name of Allah, the Most Benevolent and Most Merciful. All praises to ALLAH and Peace be upon His messenger, Muhammad S.A.W. The authors are very grateful with His permission; this paper has been successfully done. The authors are very thankful to Allah S.W.T for giving them the strength and patience to complete this paper. Finally, the authors would like to acknowledge Universiti Teknologi MARA (UiTM) for financial support in this research work.

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