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Effect of waste polyethylene terephthalate (PET) on properties of road aggregate

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Abstract. Rapid growth of plastics industries in Asia's emerging markets particularly in Malaysia, in one way, it raised expectations for everyday comforts, in the other way it also causes environmental issues. Plastic bottle for recycling can be found from the household waste stream, and most of them are made from Polyethylene Terephthalate (PET).Recycling this plastic into another form might be one of the cheapest and rapid solutions. However, turning this plastic into some other usable form uses energy and this may not become a green waste management solution. In this research, PET is utilized to explore its potential prospects to upgrade asphalt mixture properties. This study investigates the use of waste plastic as modifier for aggregates (plastic coating aggregate). The type of plastic used in this study was waste PET plastic bottle. The shredded waste PET plastic (size 0.075mm to 1.18mm) was mixed with hot aggregate to form a thin layer on the surface of the aggregates. The properties of modified aggregate and unmodified aggregate was tested and compared. 1% and 2% of plastic by weight of aggregate were used to coat the aggregate. The plastic-coated aggregates are tested for impact value and crushing value. The test results had demonstrated that there was an improvement in the properties of plastic coated aggregates.

1. Introduction

The quality of aggregate is very important because it can influence the performance of road construction. Gravel, crushed rock, dust, sand or slag are the example of aggregate. Hot modified asphalt or known by the HMA can be formed by mixing the asphalt binder with the selected and graded aggregate. The main support of the HMA pavement components is based on the weight of the aggregates. This is because approximately 95% of the weight of dense-graded HMA is made up of aggregates. HMA pavement performance is greatly influenced by the characteristics of the aggregates.

Utilization of waste material as secondary material is being researched worldwide. Plastic bottles are one of the waste materials produced in large amounts. Polyethylene terephthalate (PET) plastic bottles are mostly used in the food industry and are known to be durable, safe and good for packing, making it so popular since the last decade [1]. PET is a semi-crystalline, thermoplastic polyester [2] and its glass transition temperature is in the range of 69-155˚C [3]. The material starts to alter and have more crystal properties after heating, which makes its mixture become stronger with higher stability [4].

PET is a good modifier because it allows soft blend at low temperatures and stiffer blends are obtained at high temperatures [5]. PET also acts as a good modifier because it does not produce any gas when heated in a temperature range of 130-180˚C; the material becomes easily softened at a

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temperature of around 130˚C. PET has good binding property [6]; hence, it is used as a binder which can also be mixed with another binder like bitumen to enhance the binding property. In the tropical temperatures of around 22˚C to 32˚C [7], PET shows the sign of stability without being decomposed or degraded at these temperatures [8] which makes PET mainly suitable for use in the tropical climate like Malaysia.

Previous research studies showed that the strength of plastic-coated aggregate was found increased compared to the natural aggregate. The main objective of this study is to evaluate the properties of aggregate by coating PET plastic over it and by blending the plastic in different percentage and comparing the mechanical strength with unmodified aggregate.

2. Materials

2.1Aggregate

There are three types of aggregate in HMA: coarse aggregates, fine aggregates, and mineral filler. Course aggregates are aggregates which are 2.36 mm in size or larger while fine aggregates are those which are sized between 2.36 and 0.075mm. Mineral fillers are the aggregates which are smaller in size, that are, smaller than 0.075mm[9]. Mineral dust or rock dust are always used as mineral fillers which can enhance the strength and density of the mixture. They are incorporated as part of the combined aggregates gradation [9,10]. The aggregate size used for this research was 10mm.

2.2 Polyethylene Terephthalate (PET)

PET is an acronym for polyethylene terephthalate, which is a long-chain polymer belonging to the generic group of polyesters. Polyethylene Terephthalate (PET) is a semi-crystalline, thermoplastic polyester[2]. PET is one of the polyesters which formed by a polymerization reaction between an acid and alcohol [11]. PET is a polymer which easy to handle and also durable and sturdy, has low gas permeability, thermally stable and chemically [3]. For this research, plastic bottle which made by PET was used. The bottles were collected and shredded into small pieces about 0.075mm to 1.18mm in average size. Table 1 shows mechanical properties of PET.

Table 1. Mechanical Properties of PET [3]

Properties	Values
Average molecular weight	30000 - 80000 gmol^{-1}
Density	1.41 gcm^{-3}
Melting temperature	255 - 265 ºC
Glass transition temperature	69 - 155 ºC
Young's modulus	1700 MPa
Water absorption (24 h)	0.5%

3. Methodology

The performed laboratory tests were the Aggregate Impact Value (AIV), and Aggregate Crushed Value (ACV). The results were shown in the Table 2. Standard Specification of Road Work (SSRW) in Malaysia [12] were used to define the mix gradation limits as shown in Table 3.

Table 2. Limitations of aggregate in terms ofpercentage loss for several tests

Test	Average % Loss
Aggregate crushed value	<30%
Aggregate impact value	< 25%

Table 3. Proposed mix gradation

% Passing	20 mm	14 mm	10 mm	5 mm	3.35 mm	1.18 mm	0.425 mm	0.15 mm	0.075 mm
Proposed Mix	100	95	81	56	47	26	18	10	6
Minimum Limit	100	90	76	50	40	18	12	6	4
Maximum Limit	100	100	86	62	54	34	24	14	8

3.1 Aggregate crushing value test

The aggregate crushing value is a value that indicates the crushing-resistance capability of an aggregate. The specifications need to be considered in this test were: (1) length of the three layers whether they were approximately equal; (2) the condition of the aggregate, that is, whether it was perfectly dry and clean; and, (3) sieving, whether it was carefully done. The crushing value of good quality aggregate to be used in surface course must not more than 30% aggregate loss. The objective of the test was to determine the mechanical strength of the aggregate together with the aggregate crushing value. This experiment was based on the SSRW in Malaysia [12], on par with the British Standard (BS 812 Part: III) [13].

The test started with heating the aggregate at temperature of 160˚C and PET plastic was added according to designated percent to coat the aggregate. Figure 1 shows the PET plastic used for the aggregate coating. After the aggregate was left to room temperature, it was weighed as M1and then placed into a cylinder in three layers. Each layer needed to be tamped 25 times using the tamping rod. The plunger was inserted after the aggregate surface was levelled. The sample was placed between the platens of the testing machine and loaded in a uniform rate so that the required 400kN would be achieved in 10 minutes. The load was discharged and then the crushed aggregate in the cylinder was placed into a tray. The sample was transferred from the tray and sieved through 2.36mm sieve. The sample which could pass through the 2.36mm sieve was weighed and marked as M2. Loss of aggregate weight (M3) can be seen through the difference of coated aggregate weight before crushing M1 and coated aggregate weight after crushing M2. The experiment was repeated for a new sample to get average value. Figure 2 shows the process of aggregate coating.

Figure 1. Plasticsize 0.075mm to 1.18mm used to coat the aggregate

Figure 2. Process of aggregate coating

3.2 Aggregate impact value test

The aggregate impact value is a measure of resistance to gradually applied compressive load. In this study, the objective of the test was to determine the aggregate impact value of road stones in the laboratory and to assess their suitability in road construction based on the impact value. This experiment was aligned with the specifications in SSRW in Malaysia [12], and on par with the British Standard (BS 812 Part: III) [13].

The test began with the aggregates being sieved and the particles which passed through the 14 mm sieve were collected and retained on 10 mm sieve. The aggregates were washed and dried at a constant temperature range of 105˚C to 110˚C and then the sample was left to cool down at room temperature. The aggregate was heated at temperature of 160˚C and then PET plastic was added according to designated percent to coat the aggregate. After the aggregate cold at room temperature, it was weighed as M1 then placed into the cylinder in three layers. Each layer tamped 25 times with the tamping rod. The aggregate was weighed for measurement. The weight of this aggregate was used for the duplicated test on the same material. The aggregate from the cylindrical measure was transferred to the cup in 3 layers, each layer was compacted by tamping in 25 strokes with the tamping rod. The hammer was released to fall freely on the aggregate. The test sample was subjected to a total of 15 blows. The aggregate sample was removed from the cup and sieved through a 2.36 mm sieve. The particles which passed through the 2.36 mm sieve were weighed as M3 (Weight Loss). The experiment was repeated with the new aggregate samples. Figure 3 shows the aggregate coated by PET.

Figure 3. aggregate coated by PET

4. Results and Discussion

The experiment results of aggregate test produced aggregate quality value to classify the stones in respect of their toughness property. This experiment was conducted in accordance with the SSRW in Malaysia [12]. Percent of aggregate loss was calculated by using equation 1. Table 4 shows the result of aggregate impact value tests while Table 5 shows the result of aggregate crushing value test. A comparison between unmodified aggregate (No PET) and PET coated aggregate is presented below.

$$\%Loss = \frac{M3}{M1}(100) \quad (1)$$

Where

M1 is weight of coated aggregate before test

M3 is weight of coated aggregate on pan after test

Table 4. Result of the aggregate impact value tests

% of plastic	Sample	Aggregate size (mm)	Weight of Crushed Agg. (g)			% Loss	Ave % loss
			M1	M2	M3		
0	1	10-14	315.33	259.93	55.24	17.52	16.99
	2		309.95	259.06	50.99	16.45	
1	1	10-14	299.68	256.41	46.56	15.54	15.57
	2		301.00	254.85	46.96	15.60	
2	1	10-14	333.90	305.43	34.54	10.34	11.50
	2		307.80	275.81	38.95	12.65	

Table 5. Result of the aggregate crushing value

% of plastic	Sample	Aggregate size (mm)	Weight of Crushed Agg. (g)			% Loss	Ave % loss
			M1	M2	M3		
0	1	10-14	2660.43	1970.00	680.00	25.56	25.46
	2		2660.32	1982.00	674.67	25.36	
1	1	10-14	2739.84	2263.30	505.78	18.46	18.68
	2		2747.82	2250.66	519.40	18.90	
2	1	10-14	2479.75	2098.65	422.81	17.05	17.33
	2		2501.08	2103.19	440.43	17.61	

4.1. Aggregate impact value tests - PET content relationships

The percent of aggregate loss of the unmodified aggregate is higher than the PET coatedaggregate. The trend shows that as the content of PET increased, the percent loss of aggregatewould be decreased. Figure 4 shows the percent loss of aggregate of PET coated aggregate. Table 6 shows the categories of aggregate impactvalues.

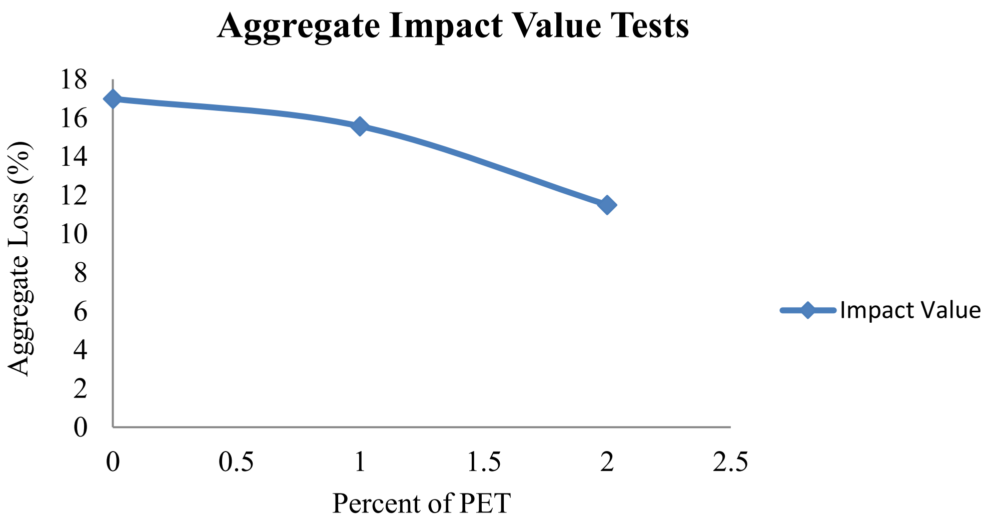

Figure 4. Aggregate impact value test

Table 6. Category of impact value [12]

Aggregate Impact Values	Category
<10%	Exceptionally strong
10-20%	Strong
20-30%	Satisfactorily for road surfacing
>35%	Weak for road surfacing

The percentage loss of aggregate impact indicated that the experiment results could be accepted as they were in the range of strong for road surfacing. According to the SSRW in Malaysia, percentage of aggregate loss for impact value for wearing course should be below 25% [12]. The aggregate impact test would be an important test to access the suitability of aggregate with regards to the toughness for the usage in a pavement construction. Aggregate impact value test would help to determine the ability of road stones to sustain pounding action or impact due to traffic load would indicate any possibility for the stones to break into smaller pieces. It would also be a test to indicate the resistance of the stone to fracture under repeated impact in order to produce a quality pavement.

4.2. Aggregatecrushing value tests - PET content relationships

The percent of aggregate loss of the PET coated aggregate is lower than unmodified aggregate. With 2% of PET plastic coating, it was observed that aggregates loss was found to be at 17.33%. Figure 5 shows the percent of aggregate loss of modified aggregate decreases continuously by the increasing of the modifier content.

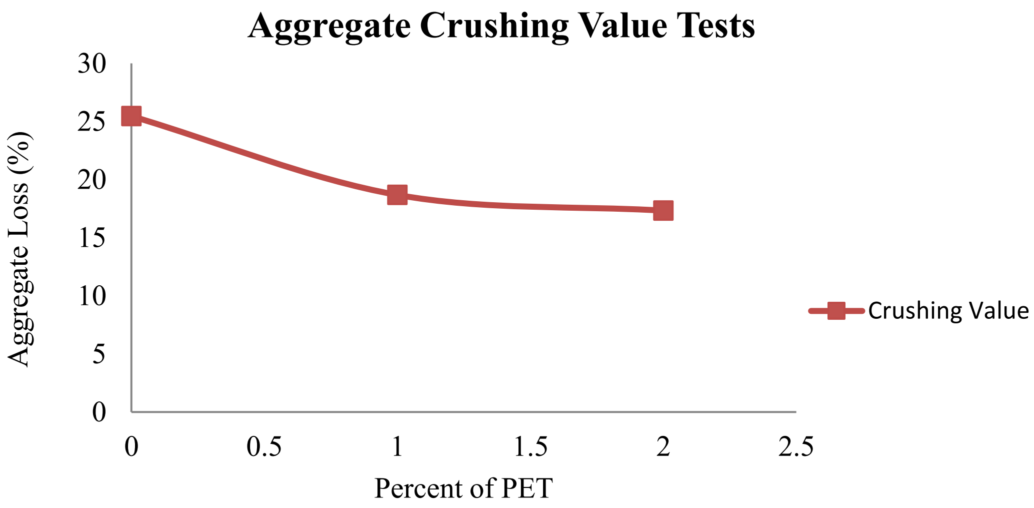

Figure 5. Aggregate crushing value test

The aggregate crushing value is a value which indicates the ability of an aggregate to resist crushing. Based on the test results, 17.33%, 18.68% and 25.46% of aggregate loss was recorded, which complied with the SSRW in Malaysia. Therefore, it can be concluded that aggregate crushing value has provided a relative measure of resistance to crushing under a gradually applied compressive load. To achieve high quality of pavement aggregate possessing low aggregate crushing value would be preferred. Good quality aggregate for surface course layer pavement would be aggregate which would have an aggregate crushing value lower than 30%. As this study aimed to apply the mixture to surface course layer, therefore such aggregate quality would be accepted and was good enough for this study.

It was founded that there is significant improvement in the strength properties of the aggregates coated with molten PET plastics. This is due to the fact that when the plastic was coated over the aggregate, the aggregate surface is covered with a thin layer of plastic polymer. The layer of polymer also fills the pores at the surface and there is no water absorption. Therefore, there is significant improvement in the basic properties of theaggregate like impact and crushing values.

The brittleness of the aggregate is measured as Impact value. Coating of waste polymers over the aggregate reduces the voidsand air cavities present in the aggregates (Table4). The layer formed helps in preventing cracking. Strength of aggregate was increased when it was coated. This was proved by decreasing of impact and crushing value of the aggregate compared to the plain aggregate. To compared with the study by Rajasekaranet. al. [14], they used waste plastics namely films, cups and foamsas their modifier. Their result also showed the same trend of this study which percent of aggregate loss was decreased when amount of plastic increased. The comparison of their result and this study is shown as in Table 7. Impact value test in this present study show lower percent of aggregate loss compared to the research by Rajasekaranet. al. [14]. This might be because of different type of plastic used. Rajasekaranet. al. used more than one type of plastic to mix in the aggregate to coat the aggregates. Different type of aggregatehas different softening point. Therefore, mixing of more than one plastic in the aggregate would render coating issue since the plasticscannot melt properly at the same temperature. This led to the plastic cannot coat the aggregate very well.

Table 7. Comparison result

% of plastic	Study by Rajasekaran et. al.		This study	
	AIV (%)	ACV (%)	AIV (%)	ACV (%)
0	25.4	25	16.99	25.46
1	21.20	21	15.57	18.68
2	18.50	20	11.50	17.33

5. Conclusion

In dry process, the aggregate is modified by coating with PET plastic polymers and produced a new modified raw material for flexible pavement. Coating of polymers on the surface of the aggregate has resulted in many advantages and ultimately helps to improve the quality of flexible pavement. The coating of plastics over aggregate also improves the quality of the aggregate.In term of economic value, utilization of recycled PET could reduce road construction cost because this material is not expensive and it also easy to be found. It can be concluded that the performance of the aggregates is improved with the addition of waste plastic into them.

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