Utilization of polyethylene terephthalate (PET) in asphalt pavement: A review

A. F. Ahmad[1], A. R. Razali[1], I. S. M. Razelan[2]

[1]Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
[2]Faculty of Civil Engineering a and Earth Resources, University Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang, Kuantan, Pahang

E-mail: amaninafarhana.ahmad@gmail.com

Abstract. The quantity of plastics used throughout the world is increasing every year. Municipal solid wastes (MSW), manufacturing processes and service industries produce a lot of waste plastic materials. The increasing awareness among consumers about the environment has contributed to the concerns over disposal of generated wastes. The growing number of plastic materials every year and limited landfill conditions causes many alternatives exist for the disposal of plastic waste. This paper provides a summary of the study on the utilization of polyethylene terephthalate (PET) in road construction. Data from researcher show that PET can improve some properties of modified asphalt mixture. Having considered the economic and environmental prudent angles, utilization of PET as an additive to asphalt mixture is suitable to be used for road pavement.

1. Introduction

Plastics are regularly utilized substances which play an essential part in practically every part of our lives. The increasing of plastic waste throughout the world need appropriate end-of-life management. Most amount of plastics can be found in containers and packaging (i.e. bottles, cup, etc.) and also can be found in disposable good (e.g. medical device) and durables (e.g. furniture, building materials, tires, etc.) [1]. Compared to other materials, plastics always be selected because of their properties such as easy processing, low density, good chemical resistance, good mechanical properties, good electrical insulating properties, low cost and good thermal properties. There are two main field directions of plastic application for post-production and post-consumer which are used as material recycling of waste polymer and used as alternative fuel in power plants.

In 2002, the world's annual consumption of plastic material was 204 million tons, but it was increased to 300 million tons in 2013[2]. Furthermore, consumption and production of plastics and polymers are expected to be continuously growing in next year. Table 1 show the plastic production by plastic category in the Malaysia [3].

Table 1. Plastic Production by Plastic Category in The Malaysia [3]

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
Acrylonitrilebutadienne-styrene (ABS)	4
Polymethyl Methacrylate (PMMA)	2
Others (acrylic, nylon and epoxy resin)	2

In Malaysia, approximately 0.80 kg/capita to 1.9 kg/capita of the municipal solid waste is generated daily, and this is expected to increase every year [4]. Plastic waste is the third largest waste after putrescible waste and paper [3]. Most of the plastic waste is drinking bottles which are made from PET.

There are two main types of plastic which are thermosetting and thermoplastics. Heating can cure thermosetting plastic. It can melt and shape then stay solid after have solidified. During this process, the chemical reaction is irreversible. Another type of plastic is thermoplastic which this cannot undergo chemical charge in composition and it also reversible. Table 2 shows the examples of thermoplastics and thermosetting materials [5]. Therefore, thermoplastic or thermosetting can be used as an additive to the bituminous mixture.

Table 2. Examples Of Thermosetting And Thermoplastics Materials.

Thermoplastics	Thermosetting
Polyethylene Terephthalate (PET)	Bakelite
Polypropylene (PP)	Epoxy resins
Polyvinyl Acetate (PVA)	Melamine resins
Polyvinyl Chloride (PVC)	Polyesters
Polystyrene (PS)	Polyurethane
Low density polyethelene (LDPE)	Urea – Formaldehyde
High density polyethylene (HDPE)	Alkyd resins

In this paper, the review of PET as an additive to the bituminous mixture in road making was presented in detail.

2. Polyethylene Terephthalate (PET)

PET is the most used thermoplastic polyester. 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 [6]. PET is one of the polyesters which formed by a polymerization reaction between an acid and alcohol [7]. PET is a polymer which easy to handle and also durable and strong, has low gas permeability, thermally stable and chemically [8]. With it good properties, PET was used widely in the form of the automobile part, lighting product, food packaging, electronics, sports tools, x-ray sheets, house ware, textile, power tools and photographic applications [7]. There are 60% of PET productions in term of bottles synthetic fibers [9].

3. Sources Of PET Wastes

Waste PET source can be subdivided into three which are foils, bottle, and cord from tires. Foils have two small problems with material recycling which is related to utilization of additive in production and molecular weight of PET. The bottle also has the same problem with foils, and it also has another one problem which is impurities problem. The cord from tires has big material recycling problem which is pollution of ground tire rubber and metals. Most of this waste is used as alternative fuel. Figure 1 shows the recycled textile fibre from used tired and Table 3 shows the compositions of waste tire cord.

Figure 1. Recycled textile fibre from used tires. [10]

PET can be used as an additive to the bituminous mixture in road construction which acts as the modifier for asphalt, and this can solve the waste PET recycling problem [11]. This initiative can increase lifespan and improve the engineering properties of modified materials.

Table 3. Compositions Of Waste Tire Cord [10]

Compositions	Weight percent (%)
Polyethylene therephthalate (PET)	77.6
Polyamide (PA)	18.7
Polypropylene (PP)	3.7

4. Utilization of Polymers In Asphalt Pavement

Asphalt has been used in road construction as the aggregate binder [12]. However, it is well known that asphalt mixture has several temperature weaknesses which are low temperature cracking damage, medium temperature fatigue and high-temperature rutting (Figure 2).

(a) (b)

Figure 2. (a) Rutting; (b) Fatigue cracking

Properties of asphalt can be improved by controlling the refines process or selecting the proper starting crude oil, which this two are very difficult to achieve [11]. Therefore, the most favoured method to improve the quality of asphalt is its modification. Asphalt becomes harder by air blowing. Asphalt can be softened by using diluents oils or fluxing agents. The other method to improve asphalt quality is the addition of polymers [11]. Rheological properties of asphalt are commonly improved by asphalt modification with a polymer [13]. Asphalt mixture should have a good property to resist rutting and shove under heavy load traffic and increasing of road users. Therefore, the stability of asphalt mixture is supposed to be good enough to handle traffic problem. The flow of the road surface depended on stability in the bituminous mixture. Flow is the capability of pavement bituminous mixture to adjust movement is subgrade and gradual settlement without cracking [14]. Asphalt viscoelastic properties depended on the chemical composition, and it will affect the performance of asphalt. Pavement defect did not only depend on traffic load but it also due to the ability of asphalt mixture to undergo temperature change which can cause cracking at low-temperature and rutting at a high-temperature region. Improvement of road performance is necessary because nowadays, there are increasing traffic factor, for example, higher traffic volume, higher tire pressure, and heavier loads. A better performance pavement needs asphalt which has good bonding between aggregate and less expose to low-temperature cracking and high-temperature rutting. Utilization of waste plastic and virgin plastic such as Polyethylene terephthalate (PET), polypropylene (PP), low density polyethylene (LDPE), ethylene vinyl acetate (EVA), acrylonitrilebutadienne-styrene (ABS), high density polyethylene (HDPE), Polystyrene-butadiene-styrene (SBS), rubber latex, Chloroprene Rubber (CR), polyolefines, Polyethylene (PE) and polyvinyl chloride (PVC) in asphalt mixture can improve the properties such as softening point, resistance to rutting, durability, viscoelastic property and fatigue life [15-25].

4.1 PET In Road Asphalt Mixture

Polymer modified asphalt which used virgin polymer to improve asphalt characteristic was already successfully done for many years [14]. Recently, the recycled polymer such as waste PET was used in substitution of commercial virgin material. Besides that, waste tire also has been used which it give positive effect to the pavement [14]. Using of the polymer such as PET in asphalt pavement whether with hot mix technique or cold mix technique is intended to improve stripping, thermal cracking, temperature susceptibility, fatigue damage and rutting resistance. They are used when better durability and performance are needed. Much of the time, they are chosen to decrease life cycle costs [11]. The polymer which used as modified binders gives a better improvement to cohesion and adhesion properties [15]. Action Program (WRAP) has mentioned that PET is the most plastic waste that can be recycled from a household waste stream [26]. It can be used as an additive to the bituminous mixture. There are many researchers that studies on this topic and many reports were published in the last years. A. Hassan, H. Ganjidoust, and Maghanaki [27] have used waste PET in the form of 3mm granules pallet in their studies. The waste PET was added as a partial fine aggregate with the bituminous mixture which used 60/70 bitumen grade and 12.5 mm aggregate grading. It was blended at 140˚C-180˚C and then compacted with 50 blows each side by using Marshall hammer. From these studies, the result proved that utilization of PET granulated (5% total weight of the bituminous mixture) to replace 20% of fine aggregate can improve the Marshall with the highest stability and lowest flow. Other than that, PET properties which are semi-crystalline and low glass transition temperature made it most effective as an additive [14].

E Ahmadinia and friends [17] conducts the evaluation on the effect of using waste PET to the engineering properties of SMA mixture. They carried out laboratory test on mechanical properties of asphalt mixture when 0%, 2%, 4%, 6%, 8%, and 10% of PET was blended into the mixture. The best proportion of PET that they have been found was 6% by weight of asphalt. Furthermore, utilization of PET gives a better effect on the properties of SMA, for example, increasing of stiffness and viscosity of asphalt at normal temperature. However, usage of PET as an additive was not given any satisfaction to improve the elasticity of asphalt significantly and on heating. There are three different forms of plastic waste have been used in road pavements which are in the forms of binder modifier, mixture reinforcement, and aggregate replacement. T. B Moghaddam and M. R. Karim [28] chose the second option for their studies which they have investigated the effect of adding waste PET into asphalt mixture. The results of the investigation showed that stability of asphalt mixture become higher when PET was added compared to the virgin mixture. The best PET amount is 0.4% to achieve better stability. However, the flow of the mixture would be increase when added a high amount of PET. Other than that, adding a higher amount of PET also made the stiffness of the mixture decreased which can cause increasing fatigue life. Z. N. Kalantar and his friends [15] have studied about utilization of PET as an additive into the bituminous mixture. The binder was blended at 150˚C with five different proportion of PET which are 2%, 4%, 6%, 8%, and 10% by weight of optimum bitumen content. The results showed better resistance against rutting and permanent deformations after comparing it with the conventional binder. The results also showed that the increasing amount of PET would increase the softening point of the mixture. From this results, it can be concluded that tendency of binder to soften in hot weather would reduce if the resistance of the binder to the effect of heat increase. Although a lot effort have been made to test different type of plastic waste in asphalt mixture, however all those plastics cannot match the properties given by PET. There is no gas evolution when PET is heated in the temperature range of 120˚C-165˚C and it start decompose at temperature 270˚C but there is still no harmful gas evolution [29].

4.2 PE In Road Asphalt Mixture

Awwad and Shbeeb on 2007 which used PE in their investigation and they are studies about the amount and best type of PE that should be used in the asphalt mixture [30]. There are two types of PE which are LDPE and HDPE and these used to coat the aggregate. From their results, it shows that grinded HDPE gives a better engineering property to the mixture. 12% by weight of asphalt content is the proposed amount of modifier. Added of this modifier also have increased the voids of mineral aggregate and air voids, reduce the density and increase the stability. C. Fuentes-Audén and friends [31] also studies the impact of PE on modified asphalt properties. From their research, the amount of PE used should not more than 5% because it will make viscosity which decreases the possibility of the mixture. Besides that, using of recycled PE can improve resistance to thermal fatigue, rutting and cracking. Donnchadh Caseya et al., 2008 [18] has studied about utilization of waste HDPE, LDPE, PET, ABS, and PVC in a bituminous mixture and they have concluded that LDPE and HDPE were the best recycled material to use. They have pointed out 4% is the ideal amount of recycled LDPE and HDPE as an additive to asphalt binder.

4.3 Fibre In Road Asphalt Mixture

Several investigations were made on the impact of fibre as an additive to the bituminous mixture. In Stone Mastic Asphalt (SMA), hot aggregate mixed is coated by hot asphalt then laid and rolled. Asphalt function as a binder. SMA has their disadvantages which can cause defective spots on the pavement where the water cannot flow over the roads. The cost of road construction will increase because of the process in using anti-stripping agents and it also has a limited use only [32-35].

Because of their great improvement effect, fibre becomes well known as a modifier. There are two types of common fibres modifier which are mineral fibres and cellulose fibres. They have been broadly utilized in various type of asphalt mixture, particularly in HMA with Open Grade Friction Concrete (OGFC) which also known as stone mastic asphalt (SMA) [36]. SMA has been used for over 20 years among European countries and if was created in the 1960s in Germany [37] & [38]. In 2004, B. J. Putman and Amirkhanian [39] did the comparison between waste CR from used tires and carpet fibres to the performance of SMA mixture. From their investigation, the result shows that the toughness of the mixture has been improved, but the moisture susceptibility or pavement deformation has no significant difference.

Shiuh and Kuie-Yi [40] was reported that polyester fibres are often used to increase durable and strength of asphalt fibre mastic at high temperature. They have investigated the performance of engineering properties of asphalt when used cellulose fibre and polyester as an additive. From their studies, the results show that the load-carrying ability of asphalt-fibre mastics can be increased when there is a good adhesion between asphalt and polyester fibres.

5. Conclusions

The major points that can be drawn from the data gathered from some scientific works of literature are as follows:

Based on scientific reports, experimental works and researches proved that plastic waste such as recycled PET suitable to be used to the bituminous mixture in road making. Utilizing of PET would improve properties of flexible pavement such as increasing of stability, stiffness and viscosity, hence it can improve stripping, thermal cracking, temperature susceptibility, fatigue damage and rutting resistance.

Last but not least, utilizing polymers as a modifier to the bituminous mixture would solve the problem of safe disposal of waste plastic materials in an eco-friendly way.

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