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A sustainable model for enhancing road quality with recycled plastic bags

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Abstract

Plastic waste disposal is a serious and growing challenge to all major metropolitan areas around the world. If not disposed of properly, plastic waste can degrade in the environment for several years. This study investigated using recycled plastic bags in road construction. The purpose was to find a reuse for plastic waste and to improve road properties. Traditionally, bitumen is used in road surfacing and coating. Shredded plastic bags were mixed with bitumen in different ratios to determine which ratios could enhance road quality in terms of asphalt strength and durability. To identify the optimal plastic percentage content, Marshall stability, retained strength and stripping tests were applied using various of bitumen to plastic ratios. Results show that a bitumen mixture of 8% recycled plastic was the strongest and most durable for all tests.

Keywords: Asphalt; bitumen; clean environment; plastic bags; recycling.

1. Introduction

Plastic is a non-metallic and highly flexible synthetic polymer that can be heated, formed and molded into different shapes. It is formable, lightweight, corrosion resistant, strong and inexpensive. Thanks to these favorable attributes, the use of plastic has increased exponentially since the second half of the last century. Plastic is used in almost every aspect of daily life but is particularly used in the packing industry as films, covers, bags and containers. Unfortunately, the increased use of plastic has resulted in increased plastic waste because it is not always easily recyclable. Plastic waste is now ranked as one of the major sources of industrial pollutants (Mazandaranizadeh *et al.,* 2017). An integrated waste management system is necessary to reduce and recycle this waste in order to minimize the detrimental environmental effects of this human-created pollution (Duane, 2014; Roy *et al.*, 2015).

A study by Jambeck *et al.* (2015) calculated that 275 million metric tons of plastic waste were generated in 2010 by 192 coastal countries. A significant portion of this waste goes untreated. Consequently, plastic waste has become a serious problem in large metropolitan areas with limited resources (Brems *et al.*, 2013). There are global efforts to increase plastic waste recycling using different approaches. For example, plastic can be used to create energy by utilizing advanced energy recovery mechanisms (Weismann, 1997; Al-Salem *et al.,* 2009). Recycled plastic can be also used in the construction industry as brick material (Shikhar, 2017). In addition, it is possible to recycle plastic by using it as a secondary component in bitumen mixtures used in road construction. Several studies suggest that adding plastic to bitumen mixtures can improve the road quality if the plastic is used efficiently (Appiah *et al.,* 2017; Rajmane *et al.*, 2009). Plastic-mixed roads have already been implemented in India with promising results in terms of cost-effectiveness and road quality (Rajput and Yadav, 2016).

Al Yousifi (2004) suggests that per capita municipal solid waste (MSW) generation amounts to 660kg/year in Kuwait. He also suggests that the plastic waste forms 13% of municipal solid waste (MSW). Thus, based on the current population of 4.5 million people, the total amount of plastic waste in Kuwait is about 386,100 tons. (0.66 tons/kg x 4.5 million x 0.13). Another study by Al-Jarallah and AlEisa (2014) suggests that plastic bags (bags, sacks, wraps) constitute 11.2% of the total MSW. While the ratio of plastic in MSW depends on calculation methods, Kuwait consistently ranks among top polluters per capita. According to a World Bank report by Hoornweg and Bhada-Tata (2012), the plastic MSW is expected to reach 746,673 tons by 2025.

While the ratio of plastic bags in total plastic waste is low, it is gradually increasing due to the increase in population and free availability. Most plastic bags are dumped in landfills along with other wastes. Because plastic bags are lightweight, they are easily moved by the wind, which eventually spreads them across the country and into the ocean. As suggested by AlFadli (2015), solid waste can act as an input in industrial production and be utilized to create energy. A survey conducted by Koushki, AlHumoud, and AlDuaj (2004) revealed that more than 90% of the Kuwaitis and residents stated that they are willing to separate their waste for recycling. Unfortunately, Kuwait lacks any organized recycling initiatives, so recyclable waste continues to go to landfills.

Using plastic bags in road construction would be better alternative than discarding them in landfills. In addition, public awareness of integrated waste management would increase. A further result would be government recycling programs. The mixture of plastic bags with primary asphalt components can strengthen a road's surface coating. This would eliminate potential road gravel after each rain. However, plastic itself cannot be a substitute for bitumen. It can only be added to the bitumen mixture as a supporting material.

This research aims at highlighting the possibility of disposing plastic bags waste in an eco-friendly way. In this article, plastic bags were proven to effectively enhance road quality in a cost-efficient manner. For this study, plastic bags were added to bitumen mixtures in different ratios. Industrial tests were conducted to test strength and durability of the mixtures. Results are discussed and conclusions are made as to the value of plastic bag waste addition to bitumen road construction materials.

2. Materials and methods

2.1 Study area

In the last two decades, the population of Kuwait has increased exponentially. According to Gulseven (2016), if the growth keeps its pace, the total population will reach 5 million by 2020, and 7 million in 2030. Public resources are strained due to the density of population that is concentrated mostly on a small coastal strip. Behind the coastal strip is the desert area where landfills cover an extensive land. A study by Alsulaili *et al.* (2014) stated that 76% of the total waste in Kuwait can be recycled.

Landfills occupy 45.5 square-kilometers of Kuwait. This number is expected to increase in the future along with the population growth. There are 16 designated landfill locations, but only five of them are actively utilized. The major landfills are located in Al Jahra, south of 7th Ring Road, Mina Abdullah, Al-Qurain, and Al-Sulaibiya areas. AlRukaibi and AlSulaili (2014) stated that these landfilling sites are in close proximity to residential areas but do not follow international sanitary standards. Kuwait is also prone to extreme weather events. Dust storms are regularly observed in the region, which exacerbates the trash problem in the country (Al-Dousari & Al-Awadh, 2012).

2.2 Test materials

The bitumen (sticky, black, and highly viscous liquid or semi-solid form of petroleum) used in asphalt is a primary element in road construction. Therefore, the quality of the road depends substantially on the quality of the bitumen mix used during construction. Bitumen is a high viscosity organic material that needs to be mixed with some aggregate material during the pre-processing stage. Several tests have been proposed to ensure that the asphalt mix is practical. This means it is affordable, long-lasting, resistant to deformation and fatigue, and is not affected by natural events including rain, and freeze. Depending on the aggregate solid material used, it is possible to come up with differentiated optimal mix ratios (Alataş & Yilmaz, 2013).

Kuwait Ministry of Public Works do not utilize recycled plastic bag waste. The mineral aggregate material forms 4.1% of total mixture used in asphalt. The optimal plastic ratio in the bitumen mixture depends on a variety of factors tested in this research. Marshall stability, retained strength, and stripping value tests were performed in this study to choose the optimal bitumen-mineral mixture. Additionally, shredded plastic materials were added in the mix.

According to Gawande *et al.* (2012), plastic content can be mixed with the bitumen using either a dry or wet process. The dry process was chosen for this study as it is more economical and does not require any extra effort to preheat the plastic. The recycled plastic acts as a strong bonding agent for the bitumen mix, allowing the mixture to withstand high temperatures. As plastic has a long lifetime, the practical lifetime of the asphalt would also be expected to increase.

Waste plastic bags were collected from local co-operatives (supermarkets) and shredded into 2-4 mm pieces using shredding machines. Next, the shredded plastic was mixed at different ratios with the current bituminous mixture used in Kuwait public roads. The bituminous mixture used in the test already contained 4.1% of the mineral aggregate.

Since this study aimed to identify the optimal ratio of plastic content in the asphalt material, several different samples were tested. However, only the mixtures with 0%, 6%, 8%, and 10% plastic by weight were used in this study.

2.3 Methodology

To begin, an asphalt sample was created with 0% plastic content. The asphalt mixture consisted of mineral aggregate, sand and bitumen mixed in a filler. The mineral aggregate was a combination of gravel and crushed stone. The sand contained grinded mineral particles and rock fragments. The filler was added to enhance the mixture and fill any voids that might occur during the process. A digital scale was used to measure the sample weights, and an industrial grade mixer was used to uniformly mix the contents with the semi-fluid bitumen. A heat stabilizer was used to heat the mixture.

The asphalt mixture was heated to 150^{o} C in a special apparatus to have a wheel-like cylindrical shape. The mixture was left in the oven for 4 hours. Next, asphalt molds were compacted into a stronger form by a mechanical hammer with a force of 75 blows on both sides. The molds were left to cool at room temperature. These steps were repeated while adding plastic content to the asphalt mixture before the heating process at different ratios (6%, 8%, 10%). Each sample was labeled according to its plastic content. Samples were prepared according to industry standards: each sample had a diameter of 100 mm and a height of 64 mm. The final test samples are shown in Figure 1. Once the samples cooled, the asphalt quality tests were applied.

Fig. 1. Asphalt mixture samples

2.3.1 Marshall stability test

The Marshall stability test estimates the maximum load that can be carried by a test specimen under standard testing temperatures. The resistance of the test specimen is measured in kilograms per testing area. A special machine known as Marshall stability apparatus (Figure 2) is used to calculate the results of the test. The flow value is defined as the deformation of the maximum load where structural failure begins. The sample weights were recorded in dry air, water, and while saturated with water. The steps to conducting the Marshall stability tests are as follows:

First, the weight of the compacted dry asphalt specimen was recorded. Second, the compacted dry asphalt specimen was submersed under water for 4 minutes. Third, the weight was recorded. Fourth, the asphalt specimen was towel-dried and the weight was recorded again. Finally, using the Marshall stability apparatus, flow and stability tests were performed until the specimen started to deform.

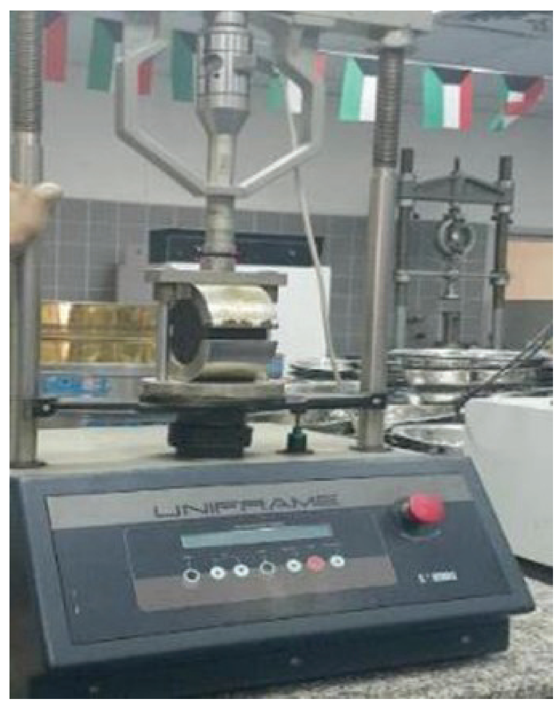

Fig. 2. Marshall stability tester

2.3.2 Retained strength test

The retained strength test determines resistance to fracture. Specifically, it is designed to measure the effects water has on a sample during compacting. The steps for the retained strength test are as follows:

First, the asphalt specimens were put into the versa tester machine (Figure 3) and then embedded to load.

Second, the tested samples were placed between the ring and the bar. Third, the load jack provided a vertical load toward the sample to give it a cylindrical shape. Fourth, 0.25 gram of the sample was added, and the vertical load was applied. This step was repeated until the mold was full. The aim was to obtain homogenous and durable samples which can resist the testing pressure. Fifth, the samples were left to cure in an oven for 24 hours at 60^o C. After that, the samples were taken from the oven and allowed to cool at room temperature. Next, half of the specimens were left in the water for a day. Then all test specimens were compressed in the compressive strength machine where the load was applied. Finally, the load pressure was recorded for both dry and wet samples.

Fig. 3. Versa tester machine

2.3.3 Stripping test

The stripping test was used to quantify the strength of the bond between the mineral aggregate and bitumen mix. It is measured as the ratio of uncovered area to the total area of aggregate. This test comprises the following steps:

First, samples in aggregate raw form were heated to 135^o C. Second, the samples were transferred to a beaker to cool to the room temperature for 3 hours. Third, enough distilled water was added to the beakers to completely submerge the coated aggregate materials. Fourth, the beakers were covered and kept in the water bath at 25^o C for 18 hours. Next, the beakers were cooled to room temperature. Finally, the stripping value was estimated for each specimen (Figure 4).

Fig. 4. Stripping test visual estimation

3. Results

3.1 Marshall stability test

The Marshall stability test results are listed in Table 1. Compared to the test material with no plastic mix, the asphalt mixture with 8% plastic had the highest values.

Table 1. Marshall stability test results

Plastic Content	Bulk Specific Gravity	Corr. Stability (kg)	Flow
0%	2.554	2245	13.14
6%	2.520	2243	12.77
8%	2.534	2656	14.01
10%	2.497	2155	13.57

The mixture with 8% plastic content had the highest correlation stability and provided the maximum flow.

3.2 Retained strength test

Table 2 shows the test data for the dry and wet process measurements for the 0% and 8% plastic content samples.

Table 2. Retained test strength results

Dry Process Measurements		
Plastic Content	Bulk-Specific Gravity	Stress (kg/cm^2)
0%	2.460	30.22
8%	2.471	36.86
Wet Process Measurements		
Plastic Content	Bulk-Specific Gravity	Stress (kg/cm^2)
0%	2.463	23.86
8%	2.457	32.37

Compared to the traditional mixture with no plastic, the 8% plastic mixture withstands substantially higher stress amounts under both dry and wet conditions. Since the plastic-added mixture performs better in wet conditions, it could reduce the amount of road gravel that commonly occurs after heavy rains. Road degradation begins when gravel is pulled from the surface.

3.3 Stripping test

The void air pockets in the asphalt mixture are an undesirable side effect of the bitumen mixture process. The air pockets weaken the chemical bonds in the asphalt mixture. Therefore, minimal air pockets are preferable in asphalt. The stripping test required visual estimation of the coated area. This study used four mixture samples (2 with no plastic and 2 with 8% plastic). The averages are compared in Table 3.

Table 3. Stripping test results

Plastic Content	Coated %	Non-coated %
Sample 1 0% plastic	94%	6%
Sample 2 0% plastic	92%	8%
0% Plastic Average	93%	7%
Sample 3 8% mix	96%	4%
Sample 4 8% mix	94%	6%
8% Plastic Average	95%	5%

The stripping test results suggest that adding plastic to a bitumen mixture can reduce air pockets. The bitumen mixture blended with 8% plastic content only had 5% of the non-coated area, whereas the mixture with no plastic showed 7% of the non-coated area. Thus, the inclusion of plastic into the mix had a 28% reduction in air pockets. This is a significant result which suggest that by simply adding 8% plastic into a bitumen mixture, undesirable air pockets can be drastically reduced.

4. Discussion

Using plastic bags as a binding component in a bitumen mixture has several benefits. It is an environmentally friendly process that will reduce plastic waste. It may also raise awareness in society that plastics can and should be recycled. Knowing that recycling plastic may help in better road construction, the society will be more motivated to engage in the segregation of municipal solid waste. The government may feel the need to push for mandatory recycling programs if there are cost-effective uses for plastic waste.

Comparative laboratory proved that asphalt with a plastic mixture has more favorable properties compared to non-plastic mixtures. This finding agrees with results from Hinislioğlu and Ağar (2004). They suggested that high density polyethylene can improve asphalt quality. Public roads can be constructed to have stronger quality performance, as shown by the increased Marshall stability values. The retained strength rest results show that plastic-mixed roads will also support higher rainwater resistance. The amount of gravel after rain storms would decline because of the better bonding of the bitumen-plastic mixture.

The results also suggest that mixing plastic can improve the strength of the asphalt so it can withstand higher pressure under both wet and dry conditions. This finding concurs with research by Abdo (2017) which claims that adding plastic waste can enhance the performance of an asphalt mix used in public roads. The stripping test results also showed that asphalt air pockets can be significantly reduced, resulting in fewer potholes. Figure 5 summarizes the superiority of the plastic-mixed asphalt sample compared to non-plastic asphalt samples.

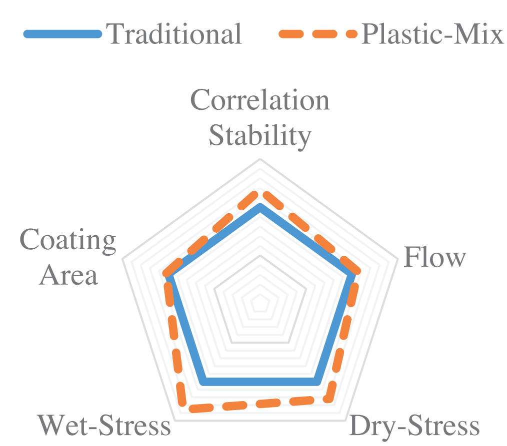

Fig. 5. Traditional vs plastic-mix bitumen performance indicators

Compared to the base mixture, the plastic-infused mixture can handle 36% more stress under wet conditions and 22% more stress under dry conditions. It also scored 18% higher in terms of correlation stability and 7% higher in terms of the flow. In addition, the coating area increased from 93% to 95%.

5. Conclusions

This research investigated the use of plastic bag waste in asphalt mixtures. Adding plastic waste to asphalt is a better environmental use of plastic waste and including plastic as a binding agent improves asphalt quality. The current asphalt mixture used in public roads includes 4.1% mineral aggregate, whereas the rest of the mixture is bitumen. Besides the current mixture, 3 more test mixtures were created to include 6%, 8%, and 10% plastic on top of the 4.1% mineral aggregate.

The test results suggest that an asphalt mixture with 8% plastic content is superior for all performance indicators. By mixing bitumen with plastic, it is possible to have public roads that have structurally stronger integrity. The reduction of air pockets in asphalt can in turn reduce potholes and prevent gravel on roads during wet weather conditions. The addition of plastic may increase the stability and durability of the roads in all weather conditions. However, further research is needed to claim that plastic-mixed asphalt is superior to traditional asphalt in real life situations. As mentioned by Liu *et al.* (2017), the rheological characteristics of alternative modified bitumen binders depend on the actual environmental factors which might be substantially different than controlled laboratory conditions. The method used in this research follows the principles of circular economy which, when applied, could have great potential in Kuwait (Gulseven & Mostert, 2017). Further research should include testing of actual roads made with recycled plastic-bitumen mixtures.

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نموذج مستدام لتعزيز جودة الطرق باستخدام الأكياس البلاستيكية المُعاد تدويرها

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الملخص

تمر الظروف البيئية في الكويت بمشكلات مختلفة أهمها مشكلة التخلص من النفايات. فقد أصبحت مشكلة التخلص من النفايات من أكبر التحديات التي تواجهها المدن الحضارية الكبرى في العالم، والتي إن لم يتم استخدام الطريقة السليمة للتخلص منها سوف تتسبب في تدهور البيئة لعدة سنوات. كذلك هناك قصور في أداء الجهات المسؤولة عنها حيث أن لدينا مشكلة في قلة الوعي البيئي وعدم الاهتمام بتوفير الطرق الصحيحة للتخلص من النفايات. ولحل هذه المشكلة تم اختيار إعادة تدوير الأكياس البلاستيكية كحل أمثل حيث أنها تمثل نسبة كبيرة من المخلفات البلاستيكية بالكويت، ومن خلال الحصيلة العلمية ومراجعة البحوث الدراسية المنشورة تمت الاستفادة من الأكياس البلاستيكية باستخدامها في عملية رصف الطرق. وكانت المنهجية المتبعة هي إضافة نسب مختلفة من الأكياس البلاستيكية المقطعة إلى أجزاء صغيرة على الخلطة الإسفلتية واختبار كل نسبة على حدى. وكان الهدف من إضافة البلاستيك على الخلطة الإسفلتية المستخدمة في رصف الطرق هو لزيادة قوة تحمل ومتانة الإسفلت، وتم عمل اختبار المارشال على العينات لقياس مدى استقرار المادة تحت تأثير الضغط، كما تم عمل اختبار تحمل الضغط إلى نقطة الانكسار، وأخيراً تم اختبار تفكك جزيئات الخليط عند تعرضه للماء. هذه الاختبارات تمثل العوامل البيئية في واقعنا الحالي. وبناءً على نتائج الاختبارات تم التوصل إلى أن إضافة 8% من البلاستيك إلى الخلطة الإسفلتية هي الأفضل من ناحية الاستدامة والقوة.