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# Enhancing rutting resistance of asphalt binder by adding plastic waste

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**Abstract:** Ras Al Khaimah, UAE is well known in the region for its industrial sectors. As a result, its road network is enduring heavy traffic loads. When accompanied by hot temperatures during the summer these roads fail prematurely due to permanent deformation (rutting). To avoid this problem, asphalt binder with high stiffness should be used, which is expensive and not eco-friendly. The objective of this study was to evaluate the addition of different percentages of plastic waste powder obtained by grinding waste bottle plastics on different asphalt binders' properties. Test results showed that adding plastic waste to asphalt binder increased its viscosity and $G^*/\sin\delta$ values. Furthermore, it was observed that when adding waste plastic, the tested binder grades would meet Superpave Asphalt Binder Specifications for higher binder grades. Thus, adding plastic waste to asphalt binder could be considered as a cheaper and environmental friendly solution, when compared to the use of higher binder grades to reduce rutting in asphalt pavements in Ras Al Khaimah roads.

**Subjects: Polymers & Plastics; Waste & Recycling; Pavement Engineering**

**Keywords: asphalt binder; plastic waste; viscosity; dynamic shear modulus; rutting**

## 1. Introduction

Asphalt pavements are deteriorating rapidly and pavements life is becoming shorter than what asphalt pavements were designed for. In Ras Al Khaimah, UAE it can be clearly noticed that asphalt

### ABOUT THE AUTHORS

The group key research activities are evaluating the performance of asphalt binders and mixes, rock mechanics, traffic safety and awareness, and lately the utilization of plastic waste in construction materials (e.g. asphalt and concrete mixes) as a mean of sustainability and the reduction of unwanted waste. By evaluating the effects of plastic waste on the engineering properties of construction materials and their performance, the right amount can be determined.

### PUBLIC INTEREST STATEMENT

In Ras Al Khaimah, UAE asphalt pavements are failing prematurely than what they were designed for, especially when it comes to permanent deformation along the wheel path. It may be due to heavy traffic loads accompanied with hot temperatures during the summer. To avoid this problem, asphalt binder with high stiffness should be used, which is expensive and not eco-friendly. This study aimed to evaluate the addition of different percentages of plastic waste powder obtained by grinding waste bottle plastics as an asphalt binder performance enhancer, through increasing the asphalt binder stiffness. Test results showed that adding plastic waste to asphalt binder increased its stiffness and resistance to permanent deformation. Thus, no need for using higher grade asphalt binders and above that it will be an environmental friendly solution, since plastic waste is utilized instead of harmful chemicals to enhance the performance of asphalt binders.

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pavements are not performing as expected, especially with permanent deformation (rutting). The causes are expected to be due to high temperatures in the summer combined with heavy traffic loads.

Recently, asphalt pavement materials costs increased tremendously, which paved the way to finding alternative cheaper materials. In addition, more concerns are directed to reserving natural resources and reducing environmental impacts, thus more attention is focused on the use of recycled materials in the asphalt pavement industry (Abu Abdo, 2016). Furthermore, it can be argued that carbon footprint on road construction could be reduced by using recycled materials. The use of recycled waste materials as modifier additives in hot mix asphalt (HMA) could have several economic and environmental benefits (Modarres & Hamedi, 2014; Molenaar, 2012).

Recent studies were conducted to evaluate utilization of recycled materials in HMA and their effects on the performance of flexible pavements (Bdour, Khalayleh, & Al-Omari, 2015; Chavan, 2013; Gawande, Zamare, Renge, Tayde, & Bharsakale, 2012; Hainin et al., 2012; Hong et al., 2013; Karacasu, Okur, & Er, 2015; Maharaj, Ramjattan-Harry, & Mohamed, 2015; Mashaan, Ali, Karim, & Abdelaziz, 2014; Mashaan, Ali, Koting, & Karim, 2013; Pourtahmasb & Karim, 2014; Sangita & Verinder, 2011; Swami & Jirge, 2012), among these recycled materials plastic waste (Abu Abdo & Khater, 2018; Chavan, 2013; Gawande et al., 2012; Sangita & Verinder, 2011; Swami & Jirge, 2012). Results of these studies showed asphalt mixes containing plastic waste exhibited improvement in their engineering properties (i.e. Marshall stability, flow, resistant to water, and resistant to crack propagation).

Vancouver, Canada constructed the first asphalt pavement with recycled plastic in an effort to become the “greenest” city in the world by 2020, it consisted of about 1% plastic waste of the mix by weight (Ridden, 2012). In India, 3,500 tons of plastic waste were utilized to build more than 1,200 km of roads using a compound called polymerized bitumen. Based on their findings, the use of plastic in these roads proved to enhance their resistance to monsoons and everyday wear and tear when compared to traditional pavements and it extended the life of asphalt pavements by two more years (Khulla, 2009).

Hınıslıoglu and Agar (2004) examined the use of plastic waste as an asphalt binder modifier with 4, 6 and 8% by weight of asphalt binder content. Test results showed that mixes with 4% plastic waste were highly resistant to permanent deformation (rutting) and yielded the highest Marshall stabilities and the smallest flows. Al-Humeidawi (2014) evaluated the use of plastic waste to enhance the engineering properties of asphalt mixes. Results showed that Waste Plastic Modified Bitumen (WPMB) mix resulted in higher Marshall stability, higher retained stability, and higher indirect tensile strength than a traditional mix with an increase of 10% in Marshall stability, 7% in Marshall retained stability and 9% in indirect tensile strength. Attaelmanan, Feng, and Al-Haididy (2011) studied the practicality of modifying asphalt binder by the addition of different percentages of plastic waste. Results illustrated that with the increase of plastic waste content, penetration values and temperature susceptibility decreased and softening point increased. In addition, stability, tensile strength ratios (TSRs), and resilient modulus values at high temperatures for the tested modified asphalt mixes were higher with smaller strain values. Abu Abdo (2017) suggested that HMA with 0.2% plastic waste would enhance the performance of these mixes and mixes with 0 and 0.5% plastic waste performed similarly. Thus, by utilizing 0.5% plastic waste by weight of aggregates in HMA, flexible pavement design would become eco-friendlier and more sustainable, since a big amount of plastic waste could be used without effecting the performance of HMA.

## 2. Scope

In Ras Al Khaimah, UAE newly constructed asphalt pavements are deteriorating faster than anticipated, especially when it comes to rutting. One of the typical solutions is to use higher binder grade, which may be infeasible, especially with today’s budget cuts and economic constraints. In this study, the effect of adding different percentages of plastic waste powder to asphalt binder grades on its stiffness was investigated to determine the optimum percentage of plastic waste in asphalt mixes for future projects in Ras Al Khaimah.

## 3. Experimental program

### *3.1. Materials*

Three asphalt binders were evaluated in this study; low binder grade AC60-70 and Two Superpave asphalt binders: PG64-22 and PG76-22. Plastic waste was obtained by collecting waste mineral water plastic bottles. Plastic bottles were then cut, shredded, then grinded to obtain plastic waste powder with a particle size passing 150 μm and retained on 75 μm sieves. Then the plastic waste powder was added to the tested asphalt binders at 0.2, 0.5, 1.0, and 5.0% by weight when samples were prepared for testing. In addition, a control sample with 0% plastic waste was prepared (control sample) for comparison.

### *3.2. Lab tests*

#### *3.2.1. Rotational viscosity test*

The Rotational Viscosity Test (ASTM D4402/D4402M-15 (ASTM, 2015)) was conducted as an indicator of stiffness of the asphalt binder with different percentage of plastic waste. Tests were conducted at different temperatures; 85, 95, 105, 115, 125, and 135°C. The results of these tests were used as an indicator of asphalt binder stiffness, since Lee, Chiub, Kana, and Chena (2004) showed that rotational viscosity had a strong correlation with the stiffness of the asphalt binder.

#### *3.2.2. Binder dynamic shear modulus (|G*|) test*

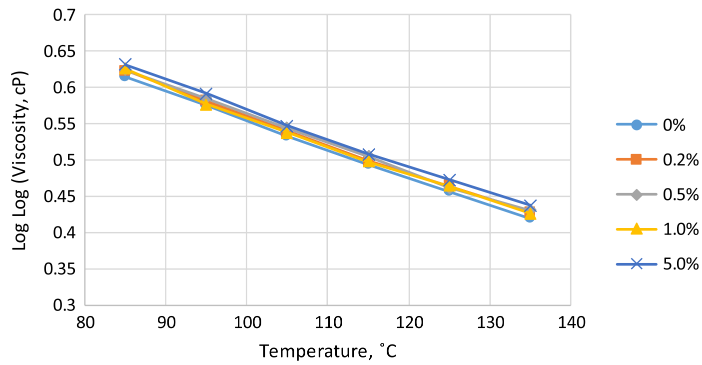
The Binder Dynamic Shear Modulus (|$G^*$|) and Phase Angle ($\delta$) was determined using the Dynamic Shear Rheometer (AASHTO T315-12 (AASHTO, 2012)). All asphalt binders with different plastic waste percentages were tested at 46, 52, 58, 64, 70, 76, 82°C to match Superpave high end binder grades. Tests were conducted on neat and aged asphalt binders. The aging process was conducted via the Rolling Thin-Film Oven (RTFO) procedure (AASHTO T 240-13 (AASHTO, 2013)) to simulate the short-term aging of asphalt binders.

## 4. Results and discussion

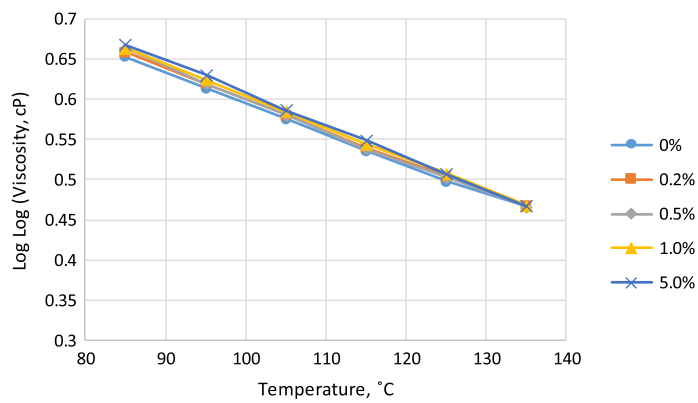
Praticò, Casciano, and Tramontana (2011) conducted a cost life-cycle cost on asphalt binder quality. They concluded that asphalt binder viscosity had a big effect on the expected pavement life and need to be taken into consideration. Therefore, asphalt binder samples with different plastic waste percentages were evaluated and their rotational viscosity was determined at different temperatures. Viscosity results were plotted in a log-log scale vs. temperature (Figure 1), which is a common practice in the industry and by binder suppliers to assist in determining mixing and compaction temperatures. Furthermore, it is an indicator of temperature susceptibility of the binders. Results showed that with the increase of plastic waste, asphalt binder viscosity increased, especially at lower temperature range (85–115°C). As an example, PG 64-22, which is typically used in Ras Al Khaimah, showed an increase of viscosity at 85°C of 15, 29, 30, and 42% for added plastic waste of 0.2, 0.5, 1.0, and 5.0%, respectively. However, PG 76-22 with 1.0%, and 5.0% plastic waste yielded a higher viscosities than 3 Pa.s at 135°C, which is not acceptable by Superpave Binder specifications.

Superpave Asphalt Binder specifications states that an asphalt binder should yield minimum $G^*/\sin\delta$ of 1.00 kPa (neat asphalt binder) and 2.20 kPa (RTFO aged asphalt binder) when tested at upper grade temperature (e.g. 64°C for PG 64-22 and 76°C for PG 76-22) to resist rutting (Mamlouk & Zaniewski, 2011). Table 1 lists $G^*/\sin\delta$ values for tested neat asphalt binder samples with different plastic waste contents, the green cell indicated that the sample passed Superpave rutting requirement for neat asphalt binders. It was observed that AC 60-70 with no plastic waste was equivalent to PG 58. However, when tested at 64°C, AC 60-70 did not meet the specified Superpave requirement of minimum 1.00 kPa. However, AC 60-70 with added 0.2 and 0.5% of plastic waste met the requirement. Thus, it became equivalent to PG 64 and equivalent to PG 70 when 1.0 and 5.0% of plastic

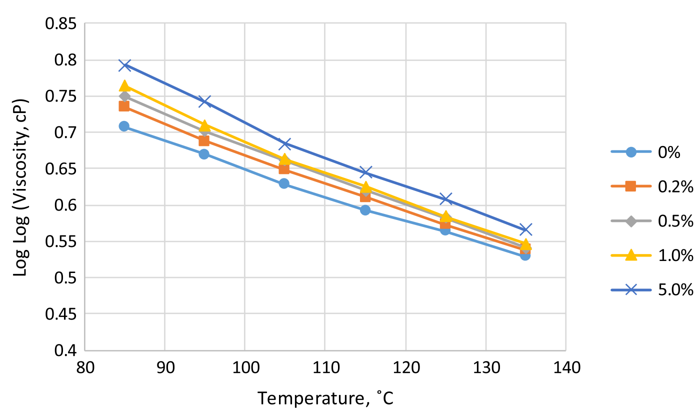
**Figure 1. Rotational viscosity results of tested asphalt binders with different plastic waste contents.**




(a) AC 60-70




(b) PG 64-22




(c) PG 76-22

waste were added. Similarly, PG 64-22 and PG 76-22 with different plastic waste contents showed an increase of $G^*/\sin\delta$ on higher testing temperatures than specified.

To ensure that asphalt binders samples met all Superpave Asphalt Binder specifications for rutting resistance, passing neat asphalt binder samples were aged using RTFO and retested at the same temperatures. Results showed that all tested asphalt binder samples yielded minimum $G^*/\sin\delta$ of 2.20 kPa (e.g. PG 64-22 with 0.2 and 0.5% at 70°C and PG 76-22 with 0.2 at 82°C), as illustrated in Table 2. Thus, an improvement in rutting resistance would be expected, as indicated by the increase of $G^*/\sin\delta$ on higher testing temperatures.

Table 1. *G*/sin δ* (kPa) results for neat binder samples

| Plastic waste content | Test temperature (°C) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 46 | 52 | 58 | 64 | 70 | 76 | 82 |
| *AC 60-70* | | | | | | | |
| 0% | 9.27 | 3.42 | 1.43 | 0.65 | – | – | – |
| 0.2% | 19.57 | 8.15 | 3.68 | 1.71 | 0.84 | – | – |
| 0.5% | 30.01 | 11.21 | 4.62 | 1.98 | 0.92 | – | – |
| 1.0% | 33.01 | 12.63 | 5.28 | 2.39 | 1.17 | 0.60 | – |
| 5.0% | 33.50 | 12.14 | 5.03 | 2.28 | 1.16 | 0.59 | – |
| *PG 64-22* | | | | | | | |
| 0% | 12.26 | 5.71 | 2.84 | 1.55 | 0.79 | – | – |
| 0.2% | 17.53 | 7.87 | 3.61 | 1.79 | 1.12 | 0.71 | – |
| 0.5% | 29.35 | 12.47 | 5.56 | 2.67 | 1.43 | 0.76 | – |
| 1.0% | 39.44 | 17.97 | 8.61 | 3.99 | 1.92 | 1.06 | 0.59 |
| 5.0% | 55.30 | 24.40 | 11.35 | 5.30 | 2.49 | 1.37 | 0.78 |
| *PG 76-22* | | | | | | | |
| 0% | 23.41 | 11.22 | 6.00 | 3.45 | 2.02 | 1.24 | 0.74 |
| 0.2% | 36.10 | 16.39 | 8.66 | 4.93 | 2.93 | 1.91 | 1.20 |
| 0.5% | 38.93 | 19.32 | 10.35 | 5.91 | 3.45 | 2.09 | 1.35 |
| 1.0% | 42.58 | 22.11 | 12.15 | 6.93 | 4.10 | 2.55 | 1.58 |
| 5.0% | 82.73 | 49.71 | 34.36 | 21.93 | 12.47 | 7.73 | 4.00 |

Table 2. *G*/sin δ* results for aged (RTFO) asphalt binder samples

| Binder grade | Plastic waste content | Test temperature (°C) | *G*/sin δ* (kPa) | Equivalent binder grade |
|---|---|---|---|---|
| AC 60-70 | 0% | 58 | 2.35 | PG 58 |
| | 0.2% | 64 | 2.23 | PG 64 |
| | 0.5% | 64 | 2.58 | PG 64 |
| PG 64-22 | 0% | 64 | 3.18 | PG 64 |
| | 0.2% | 70 | 2.30 | PG 70 |
| | 0.5% | 70 | 2.93 | PG 70 |
| | 1.0% | 76 | 2.18 | PG 76 |
| | 5.0% | 76 | 2.81 | PG 76 |
| PG 76-22 | 0% | 76 | 2.74 | PG 76 |
| | 0.2% | 82 | 2.66 | PG 82 |

## 5. Summary and conclusions

Based on the results of this study, the following observations were made:

- PG76-22 was designed to better resist rutting than PG64-22 and AC 60-70 at the same temperatures and tests results showed that PG76-22 have the highest viscosity then PG64-22 then AC 60-70 at different temperatures. Thus, viscosity could be used as an indicator of better performance asphalt binder.
- Adding plastic waste to asphalt binder increased its viscosity for all tested asphalt binders. Thus, it is expected that adding plastic waste to asphalt binder would increase it stiffness, which would enhance its rutting resistance at operational temperature.

- Adding plastic waste to asphalt binder met Superpave Asphalt Binder Specification at 135°C for all tested asphalt binders, except for PG 76–22 with 1.0%, and 5.0% plastic waste, which yielded higher viscosities than 3 Pa.s at 135°C.
- Results showed that adding 0.2 and 0.5% plastic waste would meet Superpave Asphalt Binder Specification of $G^*/\sin\delta$ for neat and RTFO aged for higher binder grades than tested. For example, PG 64-22 with 0.2 and 0.5% plastic waste would be equivalent to a PG 70. While adding 1.0 and 5.0% plastic waste to PG 64-22 would meet Superpave Asphalt Binder specifications of $G^*/\sin\delta$ similar to PG 76.

In conclusion, adding plastic waste to asphalt binders could be considered as an eco-friendly solution to problem of having too much waste plastic and an economical solution to enhance the rutting resistance of asphalt binders without the need of using more expensive modified and higher binder grades. With the addition of up to 5.0% plastic waste, asphalt binder resistance to rutting would be equivalent to a higher asphalt binder grade (two grades), which would have a huge impact on costs and the environment on the short and long run.

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