

# Performance of waste plastic bottle treated aggregates in rutting resistance of flexible pavement

Usman, N.

Department of Civil Engineering, Hassan Usman Katsina Polytechnic, Katsina Nigeria

## Paper History

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## Abstract:

The aim of this research is to determine the performance of waste plastic bottles (WPB) treated aggregates in an asphalt concrete mixture. The mechanical properties of WPB have improved the engineering characteristic of treated aggregates which in turn increased the rutting resistance of asphalt mixture. The rutting resistance of control and WPB-treated aggregates was determined using resilient modulus, dynamic creep, and wheel tracking tests. The result of the dynamic creep test shows that, resistance to permanent deformation of WPB treated aggregates mix was improved by 78% at 4% WPB treatment, creep stiffness has improved by 321% at 4% WPB treatment and the accumulated strain was reduced by 77% at 4% WPB treatment. The result of the resilient modulus test shows that, the rutting resistance of WPB treated aggregate mix was increased by 11% at 4% treatment. The rutting resistance was then decreased at 6% treatment compared to the control mix. From the wheel tracking test, there was 14% improvement in resistance to permanent deformation for 4% WPB treated aggregates mix, then decreased by 35% at 6% treatment compared to the control mix. Generally, mixtures containing 4% WPB aggregates have higher rutting resistance. Therefore, 4% is the optimum WPB treatment for aggregates against rutting.

Corresponding author

Usman, N.

[nuragafai@gmail.com](mailto:nuragafai@gmail.com)

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## 1. Introduction

Rutting is the accumulation of permanent deformation or permanent strain in asphalt mixes, it is among the major distresses in flexible pavement [1]. Rutting occurs mainly in the asphalt layer and unbound base layer in flexible pavement [2]. Rutting normally surfaces as longitudinal depression in wheel paths along asphalt pavements [3]. Rutting in the asphalt layer is caused by inadequate shear strength which in turn leads to the accumulation of unrecoverable strain from wheel load [4]. Rutting is responsible for many pavements' serviceability-related distresses, it is also termed as a threat to flexible pavement safety performance [2].

In general, rutting occurs in the flexible pavement in three modes namely: loss of material, densification, and lateral plastic flow [5, 6]. In the first mode, material properties play a significant role, i.e. low durable materials result in raveling along the wheel path [7]. For the second and third modes, the failures are characterized as shear-related deformation [8]. In flexible pavement, densification takes place at the rutting early stage while lateral plastic flow takes place during long-term strain accumulation [9].

To tackle rutting distress in the flexible pavement, researchers have used many approaches [10]. Suksiripattanapong [11] investigated the use of high-density polyethylene (HDPE) at percentages of 1, 3, 5, and 7 by weight of total aggregates in asphalt concrete. The result shows that, there have been significant improvements in terms of indirect tensile fatigue and resilient modulus of 5% HDPE-modified asphalt concrete. In another related research, Abed and Bahia [12] modified bitumen with Nano-HDPE, and their findings show a remarkable advantage for keeping the

viscosity of modified bitumen at lower levels which is an advantage for mixing and compaction of asphalt concrete at lower temperatures. In addition, Nano-HDPE-modified bitumen provided better rutting resistance and higher indirect tensile strength.

Moreover, Ullar et al. [13] used low-density polyethylene (LDPE) and high-density polyethylene (HDPE) as partial replacements for aggregates in asphalt concrete. The resulting mixture appears to have less density than the conventional asphalt mixture due to air voids. For rutting resistance, both LDPE and HDPE-modified mixtures have lower permanent deformation compared to the conventional mixture. The resilient modulus of 15% HDPE replaced aggregates mixture shows an improvement of 168% compared to the conventional mixture. There has been considerable improvement in terms of stability, flow, and dynamic modulus of both LDPE and HDPE-modified asphalt concrete mixes.

Additionally, Nawir and Mansur [14] studied the use of HDPE waste plastic seeds in asphalt concrete. Their findings show an improvement in Marshall Stability and flow. Researchers such as Usman et al. [15] used plastic fibre in the improvement of asphalt concrete performance. From their research, it is noted that waste plastic fibre has reduced the moisture susceptibility of the asphalt concrete mixes.

In another development, Ezzat and Abed [16] investigated the use of polyvinyl chloride (PVC) and styrene butadiene styrene (SBS) in asphalt concrete. There has been a significant reduction of rut depth by 74% in SBS-modified asphalt concrete mixes and a 70% rut reduction in PVC-modified mixtures. This shows that, both PVC and SBS could be used to enhance the rutting resistance of asphalt concrete hence increase its life span.

In this research, polymer waste plastic was used for the treatment of coarse aggregates in asphalt concrete mix for the improvement of mixture rutting resistance.

## 2. Methodology

### 2.1 Materials

Aggregates represent major materials used in the production of asphalt mixes. It is therefore essential to use aggregates that satisfies minimum requirements stated in highway manual of Nigeria's Federal ministry of works. Bitumen binder and additives are also constituents of asphalt mixes, these are vital in cementing the asphalt materials and maintain/improve its strength. In this research, material selection was conducted based on material quality characterizations. The characteristics of aggregates and bitumen binder used in this research are presented in Tables 1 and 2 respectively.

Table 1: Properties of aggregates used

Property	Value
Specific gravity	2.52
Water absorption	0.8%
Aggregates Impact Value	27%
Los Angeles Abrasion	21%
Flakiness	15%
Elongation	17%

Table 2: Properties of bitumen binder used

Characteristics	Value
Penetration at 25°C, 100 g 5 sec, 0.1	83 dmm.
Softening Point,	47 °C
Ductility at 25 °C	>100 cm
Flash Point,	259 °C
Loss on heating,	0.030 % wt.
Viscosity at 135°C	0.487 (Pas)

From Tables 1 and 2, it is noted that both aggregates and bitumen binder have satisfied the requirements for the production of qualitative asphalt mixes. For the waste plastic bottles (WPB), it was obtained from Nigeria's north-western city of Katsina. The bottles were crushed/shredded to smaller sizes for easy coating of aggregates. Table 3 presents the properties of waste plastic bottles used in this research.

Table 3: Properties of waste plastic bottles used

Property	Value
Water Absorption	0.2%
Tensile Strength	51MPa
Elongation at Break	7.5%
Maximum Load at Break	465N
Flexural Strength	96MPa
Specific gravity	1.356g/cm3

### 2.2 Methods

Aggregates gradation was conducted using the Superpave system, and optimum bitumen contents (OBC) were determined using AASHTO T312. Aggregates treatment was performed by coating coarse aggregates with waste plastic bottles at 180°C for percentages of 2, 4, and 6. Asphalt mixes were produced at 165°C and compacted at 155°C. The following tests were performed on control and WPB-treated aggregate mixes.

#### 2.2.1 Dynamic creep test

Dynamic creep test is a well-known process of determining the plastic deformation of asphalt mixes [17 – 19]. The test also offers vital data useful for the analysis of deformation behaviour at the early stage of asphalt mixes, and the performance of the mixture under vehicular loading and its resistance to permanent rutting [20]. Both control and WPB-treated aggregates asphalt mixes were tested at 40°C ±1. The test was observed using IPC UTM-5 universal testing machine. The test was done under haversine load pulse in accordance with the Superpave system [21]. Each asphalt mix consists of six samples compacted at 4% air voids, preheated at a temperature of 40°C for two hours prior to testing.

#### 2.2.2 Resilient modulus test

This test was conducted in accordance with ASTM D4123 using IPC UTM-5 universal testing machine. Test samples were prepared based on their respective optimum bitumen contents at 4% air voids. The test is used intensively to characterize the elastic behaviour of asphalt concrete and to evaluate its quality under cyclic axial loading [22]. Researchers conducted a resilient modulus test at 40°C to evaluate the rutting resistance of the bituminous mixture [23].

#### 2.2.3 Wheel tracking test

Wheel tracking test is essentially important in determining the rutting susceptibility of asphalt mixes. Laboratory wheel tracking does simulate the field stress situation and condition experienced by asphalt mixes compared to static and uniaxial repeated loading tests [24]. This test is also useful to determine the dynamic stability of bituminous mixture [25]. The test was conducted using CRT-WTEN wheel tracking machine. The test samples of 150mm diameter and 60mm thickness were prepared in the laboratory at 5% air voids. The samples were cured in the environmental chamber at 60°C for a period of 4 to 16 hours as stated in BS 598-110:1998. Each sample was tracked for a period of 45 minutes under a solid rubber tyre tracker of a load 700N at a rate of 21±2 cycles per minute. The deformation was measured at every minute by a single sensitive 25mm stroke LVDT placed at the centre of the sample. The test was conducted on control and WPB treated-aggregate asphalt mixes.

## 3. Result and discussion

### 3.1 Dynamic creep test

Fig. 1 shows a result of permanent deformation from the dynamic creep test, from the result it is evident that the rutting characteristics of WPB-treated aggregate asphalt mixes have been improved.

From Fig. 1, the resistance to the permanent deformation of the mixes was considerably increased by 67% at 2% WPB-aggregate treatment and 78% improvement at 4% WPB-aggregate treatment. Also at 6% treatment, the resistance to permanent deformation was increased by 47%. Fig. 2 is the creep stiffness plot of control and WPB-treated aggregate mixes. From the Figure, the improvement of creep stiffness is 188%, 321%, and 91% at 2%, 4%, and 6% WPB-aggregate treatment respectively. This improvement is due to the stability and tensile property provided by WPB [26]. Fig. 3 shows the accumulated strain of control and WPB-treated mixes subjected to a dynamic creep test. At 2% WPB treated aggregates mix, the accumulated strain was reduced by 66% and 77% at 4%. The strain resistance at 6% treatment was improved by 47% compared to the control asphalt mix.

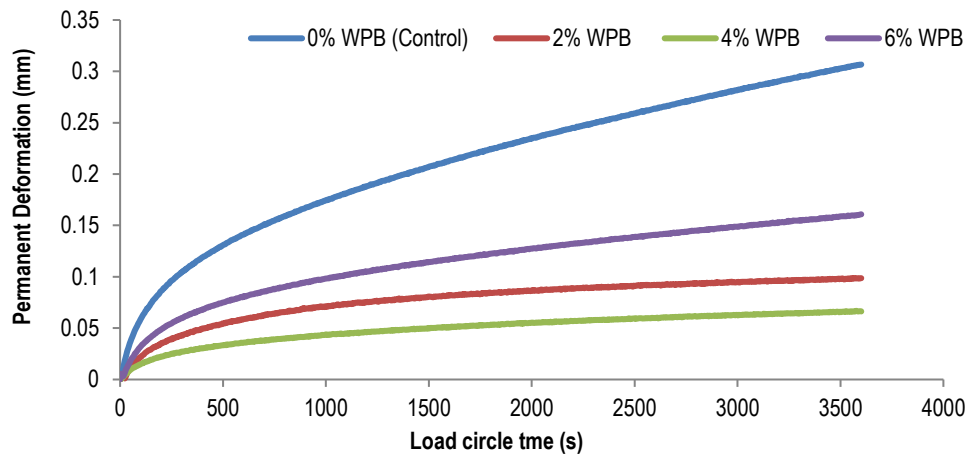


Figure 1: Permanent deformation of control and WPB-treated aggregates asphalt mixes

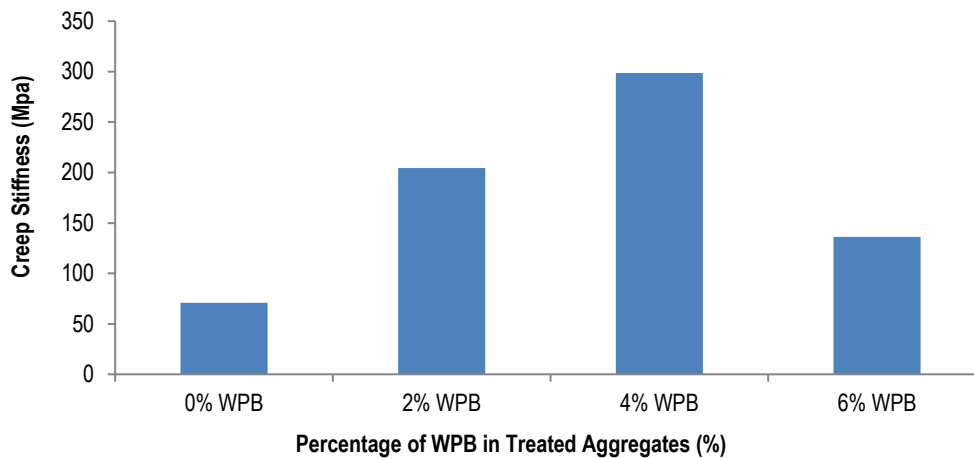


Figure 2: Creep stiffness of control and WPB treated aggregates mixtures

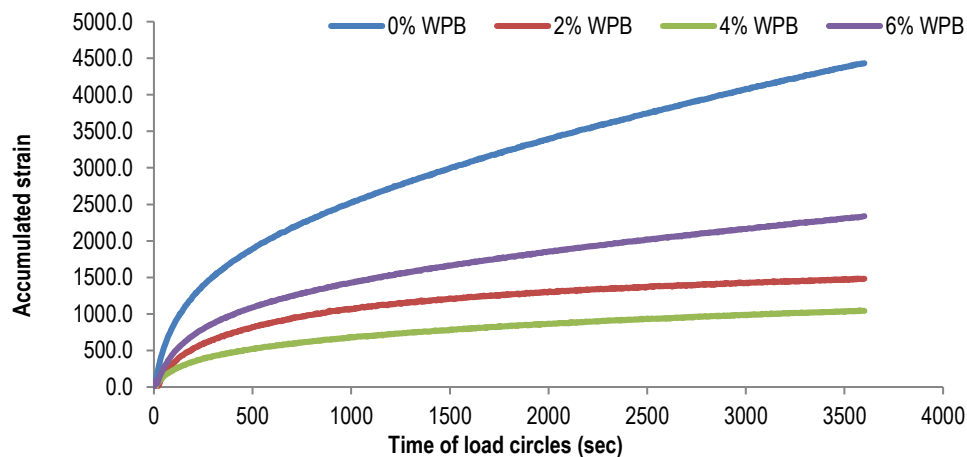


Figure 3: Mean accumulated strain at load cycles of control and WPB-treated aggregates mixtures

### 3.2 Resilient modulus test

Fig. 4 shows resilient modulus test results at 40°C, the test samples were tested under a 1000 ms resting period. From Fig. 4,

the resilient modulus value for 2% and 4% WPB treated aggregates asphalt mixes was adequately increased compared to the control mixture. This is due to the increased stiffness of WPB-treated aggregate mixes.

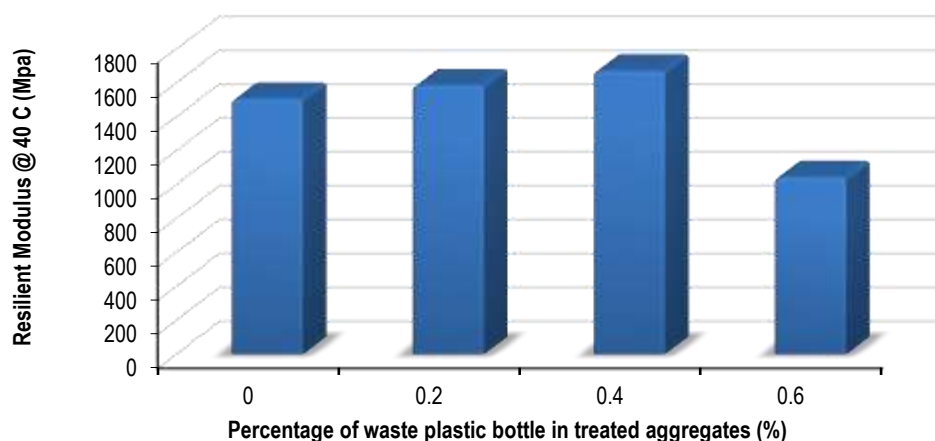


Figure 4: Values of resilient modulus at 40°C

### 3.3 Wheel tracking

Fig. 5 shows the result of the wheel tracking test. At 60°C the resistance to permanent deformation of the control mixture was improved by 5% at 2% WPB treatment, it is also improved by 14% at 4% WPB treated aggregates mixture. But decreased at 6%

treated aggregates mixture by 35%, therefore 4% WPB aggregates treatment is the optimum content against rutting deformation. The improvement of deformation in WPB aggregates mixture is attributed to the nature of the test i.e. confined deformation test which basically simulates field loading condition.

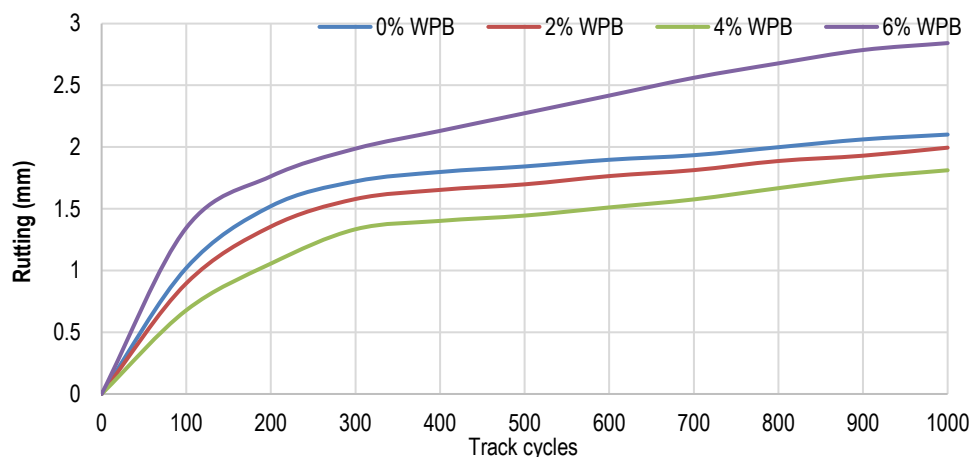


Figure 5: Plot of wheel tracking test result

Furthermore, this development was due to the rutting-resisting effect of WPB-treated aggregates in the mixture. It also shows the durability potential of the treated mixes. Additionally, the improvement was caused by WPB which holds the sticky bitumen at test temperature causing stabilized mixture, it also formed a three-dimensional network that reinforced the asphalt mixture structure against fluidity.

## 4 Conclusions

The aim of this research was achieved by treating aggregates with WPB and be used in an asphalt mixture. The mechanical properties of WPB improved the engineering characteristic of treated aggregates which in turn increased the rutting resistance of the asphalt mixture. The rutting resistance of control and WPB-treated aggregate mixes was determined using resilient modulus, dynamic creep, and wheel tracking tests. The result of the dynamic creep test shows that, resistance to permanent deformation of WPB treated aggregates mix was improved by 78% at 4% WPB treatment, creep stiffness has improved by 321% at 4% WPB treatment and the accumulated strain was reduced by 77% at 4% WPB treatment. The result of the resilient modulus test shows that, the rutting resistance of WPB-treated aggregate mixes was increased by 11% at 4% treatment. The rutting resistance was then decreased at 6% treatment compared to the control mix. From the

wheel tracking test, there was 14% improvement in rutting resistance for the 4% WPB treated aggregates mix, then decreased by 35% at 6% treatment compared to the control mix. Generally, mixtures containing 4% WPB aggregate mixes have higher rutting resistance. Therefore, 4% is the optimum WPB treatment for aggregates.

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