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Effect of Adding LDPE Bags on Rutting and Stripping Behaviour of Asphalt Mix

***Saad Khan* [1)*] *and Hamza Marjan* [2)]**

[1)] National Institute of Civil Engineering, School of Civil and Environmental Engineering, National University of Sciences and Technology, Campus H-12, Islamabad, Pakistan. * Corresponding Author.
E-Mails: saadkhanawan4all@gmail.com; skawan.tn19@student.nust.edu.pk
[2)] National Institute of Civil Engineering, School of Civil and Environmental Engineering, National University of Sciences and Technology, Campus H-12, Islamabad. Pakistan. E-Mail: hmarjan.tn19@student.nust.edu.pk

ABSTRACT

Disposal or incineration of waste low-density polyethylene (LDPE) bags is a major problem, as it causes pollution. The pavement over time gets deteriorated by vehicular traffic, which mostly results in rutting and other distresses. This research is based on the performance evaluation of hot mix asphalt (HMA) modified with LDPE. Aggregates National Highway Authority Pakistan (NHA) gradation B, bitumen grade 60/70 and waste LDPE bags from the dump yards of Islamabad (Pakistan) were used in this study. Penetration, ductility and softening-point tests were conducted with bitumen modified with different contents of waste LDPE bag flakes; i.e., 0%, 2%, 4%, 6% and 8% to figure out the optimum modifier content (OMC). Marshall testing was performed for the determination of optimum bitumen content (OBC). Using OBC and incorporating LDPE contents as a replacement for OBC, HMA samples were tested for performance evaluation, including rutting resistance and moisture susceptibility and compared with the performance of unmodified HMA. It was observed that 4% of LDPE as a replacement for OBC in the HMA can be used as OMC and yielded better performance results than unmodified asphalt mix. Rutting resistance was improved by 20.86% and tensile strength ratio (TSR) for moisture susceptibility evaluation was above the specified limit of 80%.

KEYWORDS: Waste LDPE bags, Low-cost bitumen modifier, Performance evaluation, Performance improvement, Cost comparison, Sustainable environment.

INTRODUCTİON AND LITERATURE REVİEW

The generation and utilization of low-density polyethylene (LDPE) bags is increasing tremendously with the passage of time, as they are excessively used for carrying different household products and are thrown away even after a single use. These LDPE bags are non-biodegradable products, which implies that the waste plastic, when dumped at disposal sites, does not decompose or diminish and prevails in the earth, affecting the natural framework badly. Awoyera *et al.* (2020) found that a huge cost associated with land filling is not a suitable option in comparison with its ineffectiveness in controlling pollution due to incineration. LDPE bags, being burnt or dumped on certain sites, cause air and soil pollution by producing dioxins which are quite injurious to the health of inhabitants. The outflow of CO_2 is a noteworthy sympathy for people residing on this planet and world groups, as it is an essential greenhouse gas.

Pakistan's road network is about 2,63,775 km long and is currently going through a transportation revolution (https://nha.gov.pk/). Under the present government, we have seen immense sums of income committed to the development of underpasses and overhead scaffolds and repairing and widening of existing roads. If plastic is really enhancing the properties of roads, now would be the ideal time to utilize plastic in roads and unlock its full capacity. So, this research is carried out to check whether the

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utilization of waste LDPE bags in pavement construction can really enhance flexible pavement performance. Rutting resistance testing and moisture susceptibility testing were performed according to the American Society for Testing and Materials (ASTM) and the American Association of State Highway and Transportation Officials (AASHTO) standards for the determination of an optimum LDPE percentage that can replace bitumen content in HMA.

Moisture susceptibility is the moisture damage to asphaltic pavements caused by water that traps inside of aggregates of the asphalt mix because of the low compaction temperature and can be described as a reduction in strength of a bond between aggregates and asphalt binder and loss in durability. It can cause a complex form of pavement deterioration and distress to perceive due to the different formations of its physical appearance. This distress can be raveling, rutting, cracking or shoving. It has become a serious concern for the bituminous pavement performance. (pavementinteractive.org)

Rutting is the distress of flexible pavements that occurs in the wheel-path mostly at high temperatures. It is also known to be pavement permanent deformation. Once rutting has occurred, pavement does not recover to its original position and may require rehabilitation or reconstruction. The major causes of rutting are insufficient compaction, weak subgrade and plastic deformation of the asphalt mix. (pavementinteractive.org)

Yuetan *et al.* (2021) stated that lacking appropriate approaches for plastic waste treatment, a huge production of plastic waste will create environmental issues globally. Incorporating plastic waste into asphalt-concrete mixtures unveils improvements in fatigue resistance, rutting resistance and moisture susceptibility. Plastics having low melting points improve the rutting resistance and fatigue resistance of asphalt mixes. Plastics with higher melting points reduce the ductility of mixes.

Genet *et al.* (2021) focused on the effects of utilization of waste plastic as modifier for bitumen. Optimum bitumen content (OBC) of unmodified mixes was found to be 5.16% of the total weight of aggregates and OBC of LDPE-modified mixes was found to be 6.5%. The stability of the LDPE-modified asphalt mix was 33% higher, but the flow was decreased by about 5.7%.

According to Fengchi Xu *et al.* (2021), the most effective way to solve disposal problems of waste plastic and reduce harmful emissions that cause pollution is the use of waste plastic as an asphalt binder modifier. Performance of modified asphalt is mostly dependent on the dosage of waste plastic in binder, waste plastic pre-treatment method and blending method.

Grady (2021) argued that incorporation of waste plastic increases stiffness-related properties whether plastic thoroughly mixes in asphalt or not. Tensile strength and deformation resistance also increases by using plastic as a bitumen modifier.

According to Jain *et al.* (2021), ethylene vinyl acetate (EVA) was used to modify bitumen grade VG-30 for an increase in rut resistance of the asphalt mix. Indian standards are followed in the methodology of this research. The rutting test was performed with a single wheel tracker and 6% of EVA was found to be an optimum modifier content beyond which stability decreases. Asphalt-mix properties can be further improved by using more advanced techniques with other modifiers, preferably with waste materials.

Lubis *et al.* (2020) investigated that LDPE bags with different percentages of weight of asphalt were added and tests were conducted for the determination of stability and permanent deformation. The results showed that utilization of LDPE in the asphalt mix up to a specific content (6%) can improve the performance of the HMA mix, especially decreasing the rate of deformation. Crack resistance was also improved. As rutting and crack resistance are evaluated, moisture susceptibility needs to be determined too.

According to Sabzoi Nizamuddin *et al.* (2020), linear low-density polythene LLDPE revealed that softening-point temperature and viscosity were increased while ductility and penetration values reduced with the increase in the content of LLDPE. It showed that the modified bitumen in HMA mixes have more ability to resist permanent deformation at higher temperatures.

Arminda Almeida *et al.* (2020) found that LDPE content of 6% of the weight of the asphalt binder yielded better performance test results. LDPE presented a bit lower moisture resistance in samples, but the results were above 80%. HMA samples modified with LDPE presented a higher indirect tensile strength (ITS) value and improved rut resistance along with stiffness. Carlos

Rodrigues et al. (2020), utilizing LDPE as an asphalt binder modifier, changed the deformability pattern of HMA pavement.

Yuming Lin *et al.* (2019) said that existing procedures and techniques for disposal of waste polythene bags cause serious environmental issues. The addition of LDPE improved the resistance against rutting of an unmodified asphalt mix. LDPE additives as an asphalt binder modifier in HMA may reduce workability to some extent.

According to Naghawi *et al.* (2018), the objective of their research was the evaluation of the use of waste plastic as a low-cost bitumen modifier. According to their findings, this research would lead to producing a more durable and cost-effective pavement.

Abdullah *et al*. (2017) the concluded that 8% of plastic content revealed the highest value of tensile strength and resilient modulus of modified asphalt concrete, but stability was highest at 4% of plastic content.

Ahmad (2014) focused on the use of waste plastic bags in the construction of flexible pavements. Waste LDPE bags were shredded in 2-3mm sizes. LDPE was mixed with bitumen in different percentages by weight. The performance of the Marshall test on the HMA sample concluded that stability was significantly improved with the different percentages of plastic waste of the weight of asphalt binder. Flow decreased with the increase in plastic content.

Abo-Qudais and Al-Shweily (2007) indicated that conditioning of HMA specimens has a significant effect on the increase of creep deformation. The effect of antistripping additives on HMA creep behavior was evaluated using static creep. Antistripping additives showed a significant effect on reducing stripping and creep behavior.

Waste LDPE bags that do not decompose in landfills need to be utilized in a safe and efficient way to avoid its adverse effects on nature. Previous studies have determined higher OMC of LDPE in the asphalt mix mostly by directly incorporating it into the asphalt mix and performing Marshall and performance tests. The major problem with LDPE and other-waste plastic incorporation into the asphalt mix is that the effect on bitumen physical properties is neglected. LDPE was directly incorporated into the asphalt mix up to 8% or 10% and even up to 12% by the weight of bitumen, as in most of the studies. Therefore, its effect needs to be determined first. If it changes the bitumen properties above some specified content, then the critical modifier content (CMC) should be identified and the OMC for the performance evaluation should be computed below CMC so that the physical properties of bitumen remain the same, as bitumen grade for every region is specified according to its climatic conditions. The rutting test in previous research has been carried out with outdated equipment, such as a single-wheel tracker that uses a single sample and for an average of two samples one has to spend a lot of time and the result might contain errors. So, such performance tests need to be carried out using the latest equipment, like the Hamburg double-wheel tracker (HDWT) that gives more precise average results and the universal testing machine (UTM) should be used for an indirect tensile strength test.

Research Goals

The research objectives are as follows:

– Evaluating the utilization of waste LDPE bags as bitumen modifier.
– Evaluation of rut resistance of asphalt pavement by utilizing waste LDPE bags.
– Moisture-susceptibility evaluation of the asphalt mix with different LDPE contents.
– The cost comparison of unmodified and LDPE-modified asphalt binders.

MATERİALS AND METHODS

The entire planned methodology is shown in Figure 1. Asphalt binder was obtained from PAK-ARAB Refinaro Company, Limited (PARCO) and aggregates were borrowed from the area named Hattar near Taxila, Pakistan.

Aggregate Tests

Aggregate forms the main skeleton of HMA pavement and resists deformation in pavements, so it should be strong and durable to fulfill its required purpose on the pavement. Laboratory tests conducted on aggregates and their results are mentioned in Table 1.

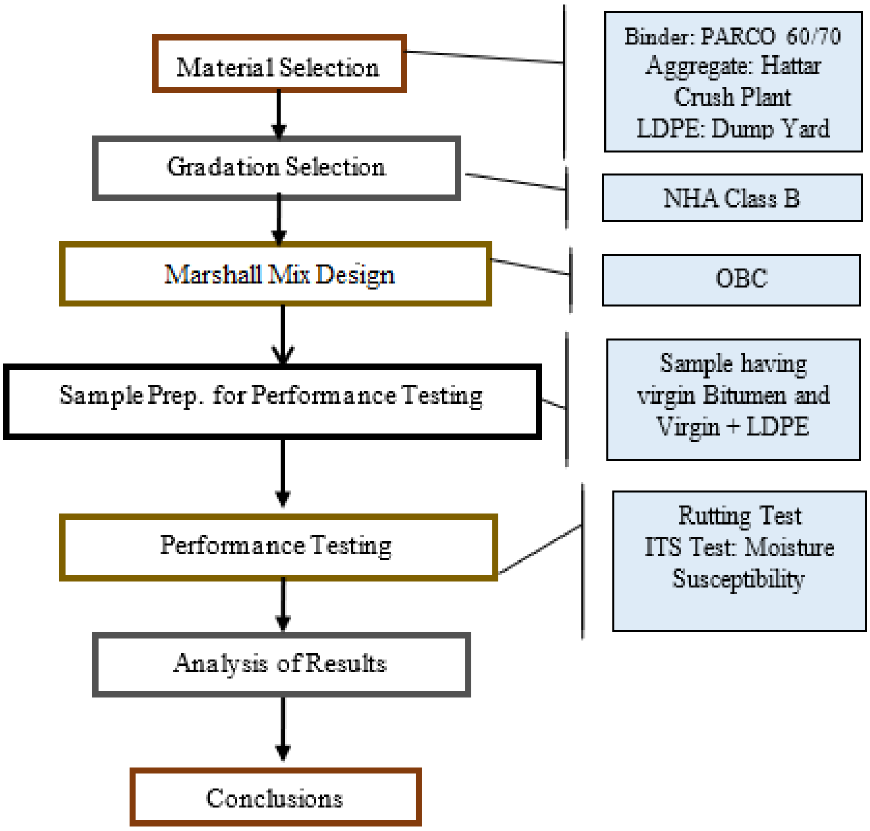


Figure (1): Flow chart of the entire planned methodology

Table 1. Aggregates' test results

Test	Specification		Result	Limits
Flakiness Index	ASTM D 4791		14.2%	≤15%
Elongation Index	ASTM D 4791		2.3%	≤15%
Aggregates Absorption	Fine	ASTM-C127	1.63%	≤3%
	Coarse		1%	≤3%
Impact Value	BS 812-112		18.6%	≤30%
Crushing Value	BS 812-110		21.96%	≤30%
Aggregates' Specific Gravity	Fine	ASTM-C128	2.56	-
	Coarse	ASTM-C127	2.625	-
LOS Angles Abrasion	ASTM-C131		20.6%	≤45%

Modified Binder Tests (Bitumen + LDPE)

The penetration test (AASHTO T 49-03), ductility test (AASHTO T 51) and softening temperature test (AASHTO-T-53) were conducted on an unmodified binder and an LDPE-modified binder. After performing the above-mentioned tests on the binder having grade 60/70, it was observed that the increase in LDPE content in the asphalt binder reduces the penetration value, making the binder harder, reduces the ductility value and increases the softening temperature. The results are shown in Figure 2 and Figure 3.

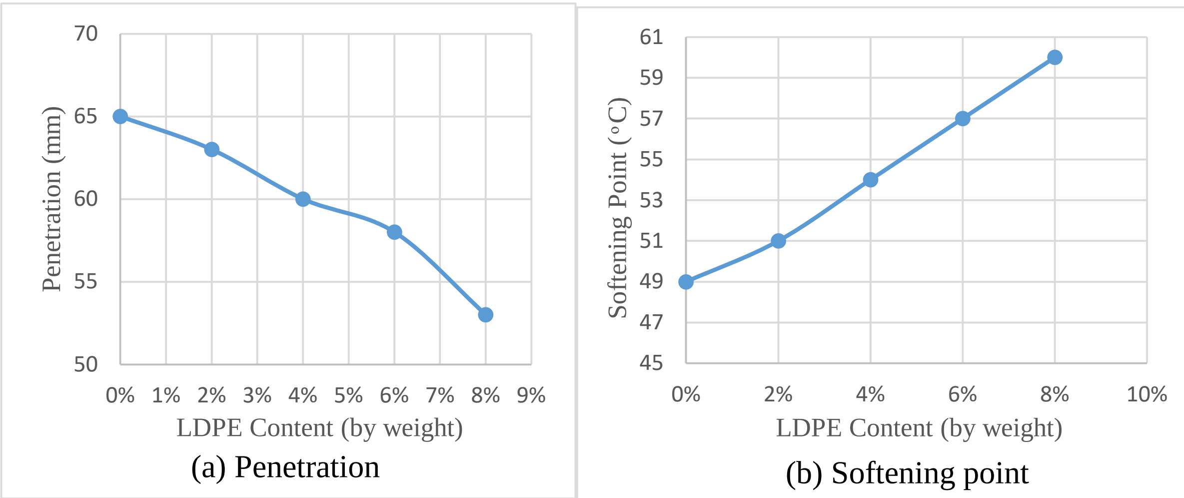


Figure (2): Penetration and softening-point test results for different LDPE contents. a) penetration and b) softening point

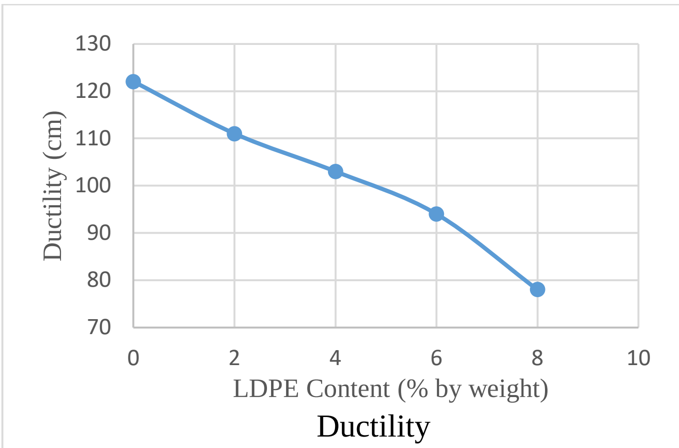


Figure (3): Ductility test results for different LDPE contents

From Figures 2 and 3, it was observed that, by adding LDPE with more than 4% by weight of bitumen, the bitumen properties and grade change, as penetration falls below 60, ductility falls below the specified limit of 100 cm and softening temperature goes above the specified limit of 54°C. So, the tests limit LDPE content to 4% of the weight of the unmodified bitumen, which can be termed as critical modifier content.

Gradation Selection

National Highway Authority Pakistan (NHA) gradation B was selected for HMA mix according to NHA standards and specifications (NHA general specifications, 305/1-6). Aggregates were sieved in the sieve shaker having sieves of openings mentioned in the specifications (NHA gradation B) and the amount obtained of each size was kept separately in a container. The upper limit and the lower limit as well as the corresponding selected gradation logarithmic curves are plotted in Figure 4, showing the NHA B gradation plot. This logarithmic chart presents sieve opening sizes on the x-axis and percent aggregates passing each sieve size on the y-axis.

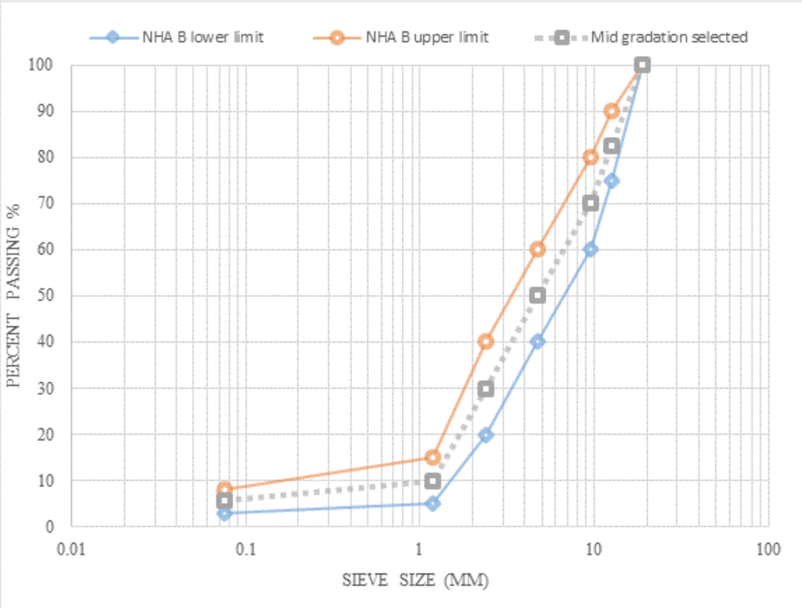
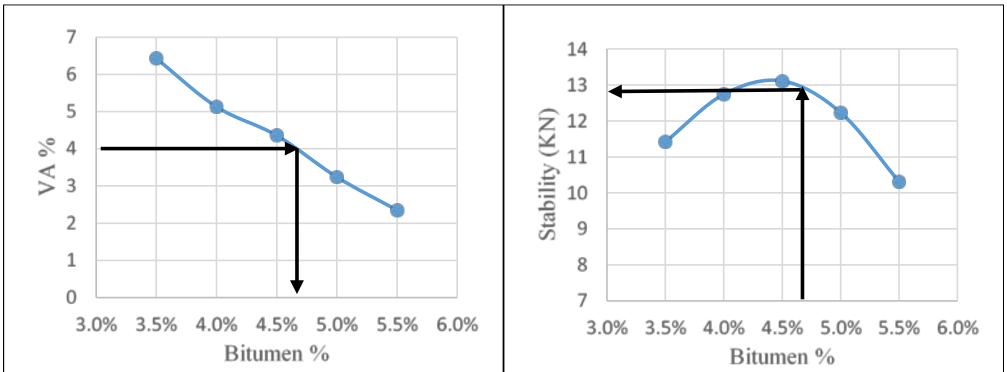


Figure (4): NHA B gradation plot

Determination of OBC from Marshall Mix Design Samples

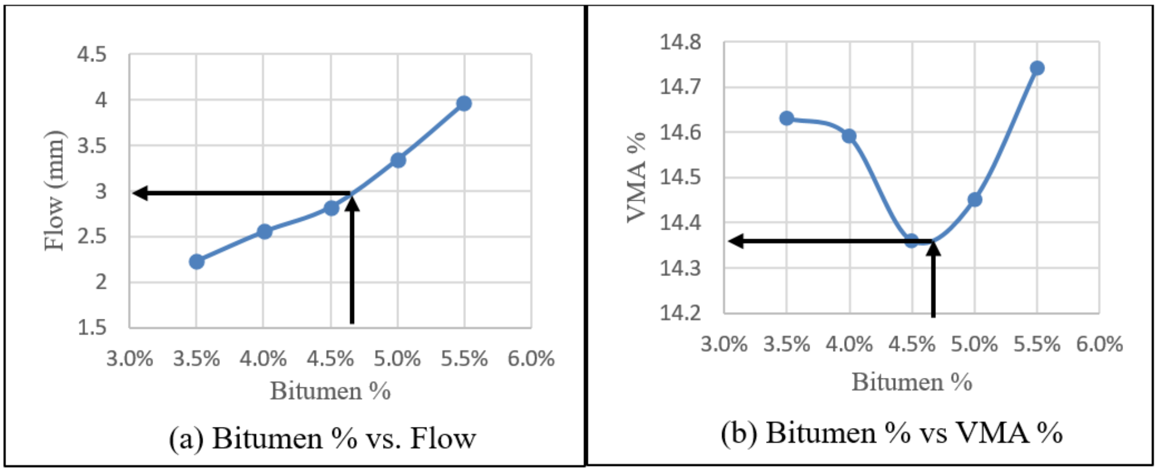
Three samples for each percentage; i.e., 3.5%, 4%, 4.5%, 5% and 5.5% of bitumen were prepared and tested in a machine having a capacity of 5 tons and a loading rate of 50 mm/min. During the sample-preparation process, bitumen was heated to a temperature of 160°C and was mixed with aggregates and filler weighing 1200gm at a temperature of 160°C. The prepared asphalt mix was compacted on each face with 75 blows at 140°C in a compactor and allowed to cool at room temperature for about 24 hours. Height, weight and diameter of each specimen were noted for any correction if required and samples were kept in a water bath for an hour. Marshall stability test according to (MS-2, 7th edition) was performed to find stability, flow, air voids (VA), voids in mineral aggregate (VMA) and voids filled with asphalt (VFA), as shown in Figure 5 which illustrates air voids and stability test results for different bitumen contents. Figure 6 shows the flow and VMA test results for different bitumen contents. Figure 7 shows bitumen % *versus* VFA %.



(a) Bitumen % *vs.* VA %

(b) Bitumen % *vs.* Stability(kN)

Figure (5): Air voids and stability test results for different bitumen contents.
(a) bitumen % *versus* VA % and (b) bitumen % *versus* stability



(a) Bitumen % vs. Flow

(b) Bitumen % vs VMA %

Figure (6): Flow and VMA test results for different bitumen contents. (a) bitumen % *versus* flow and (b) bitumen % *versus* VMA %

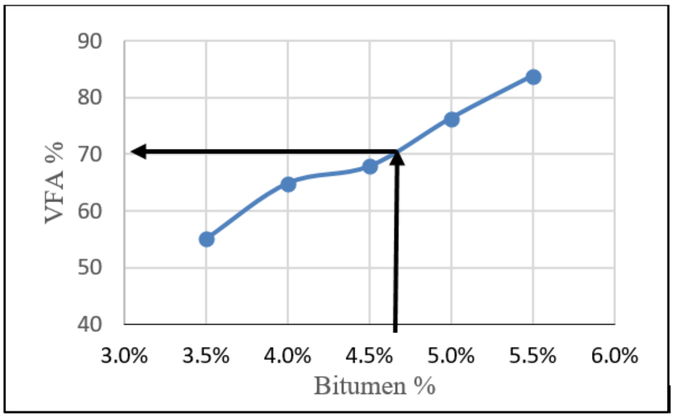


Figure (7): Bitumen % *versus* VFA %

The asphalt content at 4% air voids corresponds to OBC. The mix has an OBC of 4.66%. Other volumetric properties are checked at the determined OBC. According to MS-2 criteria, the VMA value should be greater than 13%, while it is 14.37%. VFA should be ranging between 65% and 75%, while the calculated value is 70.5%. Stability should be at a minimum of 8.006 kN, while the determined value is 12.83 kN. Flow is 2.98 mm lying within the range of 2-3.5mm.

Moisture Susceptibility Test Method

Preparation of samples for moisture-susceptibility testing was carried out in accordance with (ALDOT 361), which defines conditioned and unconditioned Marshall samples having 2.5” height and 4” diameter. The procedure for sample preparation is the same as explained in the previous sub-section. Only conditioning in a water bath is added for conditioned samples.

LDPE was mixed with bitumen at a temperature of 160°C in a mixer. Oven-dried aggregates were mixed with bitumen containing LDPE at 160°C. Compaction was achieved at 135°C.

According to (ASTM D6931-07), samples were placed in the universal testing machine (UTM) and loaded at the rate of 50mm/minute across its vertical diametral plane. The maximum load upon failure was checked and noted and tensile-strength calculation was carried out according to the formula given in (Equation 1).

$$St = \frac{2000\,P}{\pi D t} \qquad (1)$$

where:

St = Tensile strength of the sample, kPA.

P = Maximum load, N.

t = Sample height before tensile test, mm.

D = Sample diameter, mm.

TSR indicates the possibility of damage caused by moisture to the pavement. TSR is the ratio of tensile strength of a conditioned sample to that of an unconditioned sample. TSR for each sub-set of specimens is determined by (Equation 2).

$$TSR = [\frac{S2}{S1}] \qquad (2)$$

where:
S1 = Mean tensile strength of an unconditioned sample.
S2 = Mean tensile strength of a conditioned sample.

Rutting Test Method

The preparation of samples for the rut-resistance test was carried out according to (AASHTO T 312), which defines the gyratory sample having 2.4” height and 5.9” diameter for a rut-resistance test. Batching of aggregates of about 6kg in accordance with NHA B gradation is done for the mix design and aggregates were then oven-dried at 110°C for 2 hours. Asphalt binder was heated to about 160°C and optimum content of that asphalt binder was mixed with aggregates at 160°C in a mechanical mixer. After mixing of aggregates and asphalt, the mix sample was transferred to gyratory compaction mold and plates along with filter paper were placed on the upside and downside of the sample and the mold was placed in a machine and compaction was carried out with 125 gyrations at a temperature of about 135°C. When compaction was achieved, the mold containing compacted sample was taken out and the sample was ejected through a mechanical ejector. Sample obtained was about 6” in diameter and 6” in height which after letting the sample cool for about 24 hours at room temperature was cut with the help of saw cutter to the height of 2.4” and the diameter of 5.9”. Two types of samples were prepared; one having unmodified bitumen only and the other having various LDPE contents as a replacement of OBC in the asphalt mix. LDPE was mixed in these samples with the same wet mixing method in which waste LDPE was added in the bitumen at high temperature and mechanical mixing was done to achieve a homogeneous LDPE-modified bitumen. Hamburg double-wheel tracker was used for determination of rut depth. The mechanism of Hamburg double-wheel tracker is explained by Chaturabong and Hussain (2017).

RESULTS

Moisture-induced Damage

Tensile-strength ratio (TSR) was determined for moisture-sensitivity evaluation as described in the standard (EN 12697-12) for which indirect tensile strength test (ITS) was first performed according to (ASTM D6931-07) and ITS values were determined. For HMA containing unmodified asphalt binder only, two samples were prepared for the test of unconditioned indirect tensile strength and two samples were prepared for the test of conditioned indirect tensile strength. The same number of samples of two conditioned and two unconditioned samples were prepared for each 2%, 4% and 6% LDPE in the HMA mix. So, as each set consisted of two samples, the results of each percentage of LDPE-modified samples (conditioned and unconditioned) is the average of the results of samples. ITS and TSR results and their comparison are shown in Figure 8 which illustrates indirect tensile strength comparison of LDPE-modified mix and unmodified mix, while Figure 9 shows tensile strength ratio comparison at different LDPE contents.

It was observed that indirect tensile strength of HMA mix increases with increasing LDPE content. ITS recordered for unmodified mix was 831.7 kPa, while for mix modified with 4% LDPE, ITS recorded was 862 kPa. Although TSR values were more than 80%, as suggested in (ALDOT 361), it decreased as the percentage of LDPE increased.

Rutting Test

The samples that were prepared for rutting-resistance testing were divided into two categories; one category having 2 samples of unmodified asphalt binder and the other category having 6 samples in which the percentage of OBC is replaced with different LDPE contents; i.e., 2%, 4% and 6% with two samples for each percentage, so that the total is 8 samples. Hamburg double-wheel tracker (HDWT) was used for determining the dry rut depth in mm of the asphalt-mix sample due to repeated cyclic loading of 157 pounds per wheel on the sample under a fixed temperature inside the HDWT chamber with the simulation of roadway condition (AASHTO T 324, 2011). The failure criterion was set at 12.5 mm rut depth. Samples were subjected to wheel passes of 10000 (5000 cycles) and speed was maintained at 25 cycles/minute. The test was set to stop if 5000 cycles are completed or 12.5-millimeter rut depth is achieved, whichever occurs first. Each result is the average result of two samples. Detailed results and comparison between the results are shown in Figure 10 which illustrates the rut-resistance comparison of an unmodified mix and an LDPE-modified mix.

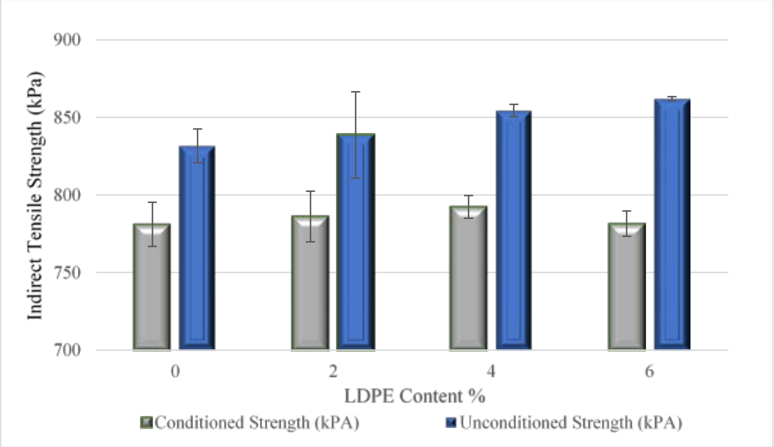


Figure (8): Indirect tensile strength comparison of LDPE-modified and unmodified mixes

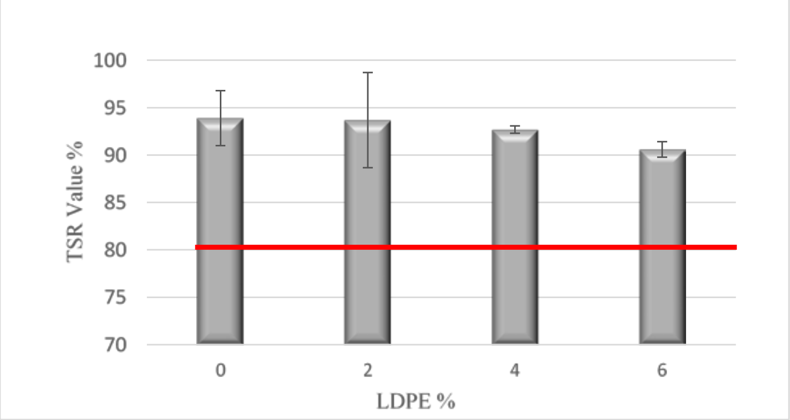


Figure (9): Tensile strength ratio comparison at different LDPE contents

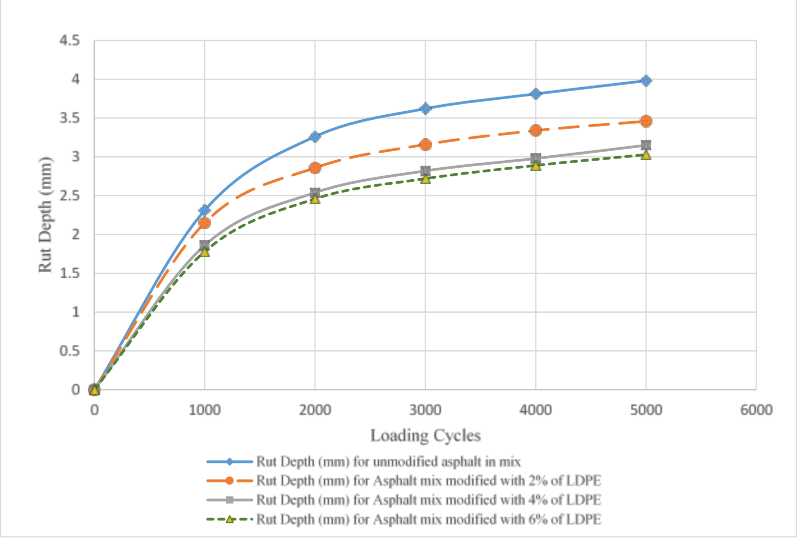


Figure (10): Rut resistance comparison of an unmodified mix and an LDPE-modified mix

For unmodified binder used in the mix, the deformation value of 3.98mm was observed after 5000 cycles and for 4% LDPE-modified mix, the deformation value of 3.15mm was observed after 5000 cycles of loading, which shows a significant improvement of about 20.86% in rut resistance. A negligible increase in rut resistance is observed after adding LDPE as a replacement of asphalt binder above 4% as shown by the rutting value for 6%. Previous studies suggested 6% to 8% of optimum plastic modifier content in the mix without performing bitumen physical tests for the same content of additives and without considering the change in the physical properties of bitumen.

Cost Comparison between Unmodified Binder and LDPE-modified Binder

In this research, a comparison of the cost (in Pakistani currency) of unmodified asphalt binder and LDPE-modified asphalt binder is carried out. Comparison is carried out for a one-kilometer pavement patch that has one lane having a width of 3.6 meters with a thickness of 2 inches (50 mm). The amount of bitumen based on OBC for the section was found to be 19.71 tons. In Pakistan, the current bitumen price is Rs 81000/ton.

The calculated amount of bitumen according to OBC that is to be used in the section was replaced with 4% LDPE and the bitumen amount was reduced to 18.92 tons, thus saving cost as the waste LDPE bags which are available free of cost. Graphical values are shown in Figure 11 which depicts a cost comparison of unmodified and modified binders.

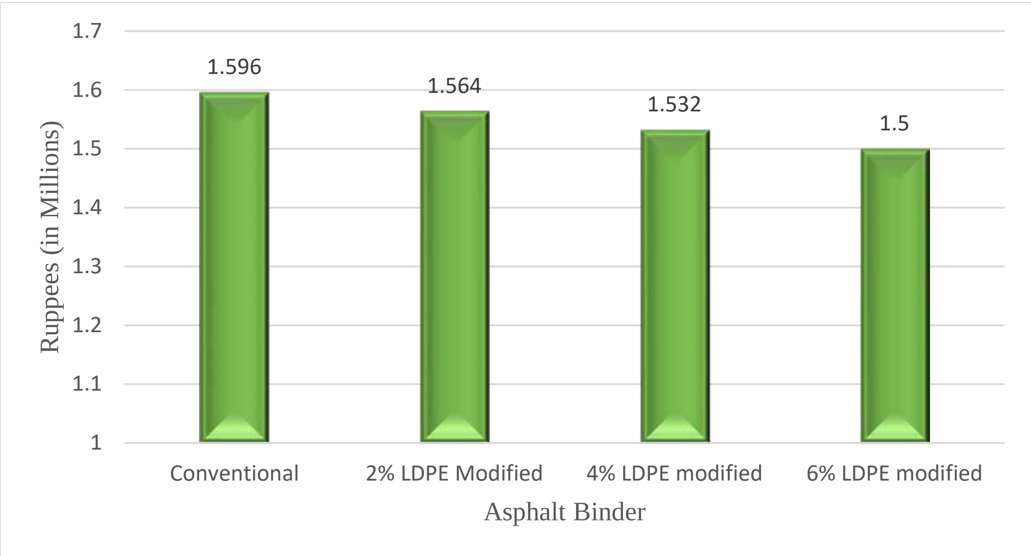


Figure (11): Cost comparison of unmodified and modified binders

CONCLUSİONS

Effective utilization of waste LDPE in pavements is gaining more attention in today's world. Different researchers have worked on safe disposal of plastic waste and its utilization in a beneficial way in pavements by different methods. This research is carried out for performance improvement of asphalt pavements along with effective utilization of waste LDPE bags collected from dump yards. The conclusions drawn from the analysis of the performance tests are as follows:

- Increasing the LDPE content in bitumen decreases penetration and ductility values making bitumen harder and increases softening point temperature.
- Asphalt-mix samples prepared with modified bitumen containing 4% LDPE showed better resistance to rutting than the samples prepared with unmodified bitumen and a small, almost negligible increase in rut resistance is observed after adding LDPE content greater than 4% in bitumen.
- Indirect tensile strength of asphalt mix increases with the increase of LDPE content in the bitumen. A slight

decrease in moisture-susceptibility value is observed, but the TSR-value criterion that is above the specified limit of 80% was fulfilled.

- The cost of an asphalt mix that contains LDPE content as a replacement of OBC shows that 4% of LDPE content of the weight of OBC in the asphalt mix can save up to 4% of the bitumen cost.

Recommendations

Based on the results and conclusions drawn from this research, the following recommendations are made:

In this research, rutting-susceptibility test and moisture-susceptibility test were performed for testing performance. Other tests, like fatigue cracking, creep, workability, dynamic modulus, flow number and flow time tests, were not performed. It is recommended to perform different tests on different contents of LDPE in HMAs to categorize LDPE behavior more in HMAs.

- It is also recommended to determine the chemical behavior of LDPE with asphalt binder, to see whether any rejuvenating agent can improve the properties of LDPE and can be used in addition to LDPE in HMAs. In this way, more amount of LDPE might be utilized, reducing the unmodified bitumen content.

Strength

Based on the performance evaluation, the strength of this study can be categorized as:

- An increase in deformation resistance against cycling loading.
- An increase in indirect tensile strength of the asphalt-mix samples.
- A reduction in the cost of the asphalt binder, as a portion of the asphalt binder was replaced with LDPE.

Limitations

Based on the mixing techniques used, the limitations of this study can be stated as follows:

Extra effort and energy are required for shredding and mixing of LDPE thoroughly with the asphalt binder before mixing with aggregates, as the wet mixing method was adopted.

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