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Enhancement of the Rutting Resistance of Asphalt Mixtures at Different High Temperatures Using Waste Polyethylene Polymer

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HIGHLIGHTS

- Using low-density polyethylene in asphalt paving enhances the road construction systems and the environment's protection against pollution.
- A remarkable improvement in the performance of asphalt paving was achieved using different percentages of low-density polyethylene.
- The optimum percentage of LDPE additive was verified as 4% by weight of asphalt through all laboratory results (Marshall tests).

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ABSTRACT

The temperature and stress caused by the load can be cited as two main parameters leading to breakage in asphalt pavement, especially rutting (permanent deformation). So, to reduce the problems of rutting of roads, several actions have been taken, including improving pavement quality and the structure design methods. The increase in the attention of respective engineers in the last few years to modify and improve the asphalt performance through providing different types of additives and replacing the raw materials of asphalt mixture with recycled materials to improve the environment and reduce the cost of modified pavement mixture. This study discussed the use of low-density waste polyethylene as an asphalt modifier in percentages of (2, 4, and 6) % by the weight of asphalt and their impact on the performance of asphalt mixtures at high temperatures. This study showed that using plastic waste (low-density polyethylene) as a bitumen modifier improved the performance of asphalt mixtures at different high temperatures. This was achieved by reducing the rut depth by (80.5) % and (82.3) % at temperatures of 50 C and 60 C, respectively, using low-density polyethylene waste at an optimum value of about 4% by weight of asphalt in addition to enhancing the Marshall stability by using this percentage of polymer.

1. Introduction

The performance and efficiency of asphalt concrete mix depend on several factors, including aggregate gradation, aggregates' types, loading conditions, physical properties of binder, and mixture volumetric properties[1, 2]. Among these factors, the binder is considered a viscoelastic behavior material that acts Extremely important key in many aspects of the performance of the mixtures [3]. In the last years, various factors, for instance, growth permissible vehicle pressure and increased traffic load, have increased the tension stresses in the layer of asphalt pavement. As a result, the service life of asphalt concrete pavements will be reduced [4]. Furthermore, alligator cracks (fatigue) and permanent deformation (Rutting) are the most common important problems of the asphalt concrete pavement, which have a significant impact on the asphalt pavement performance [5, 6]. To address early asphalt failure, one of the successful solutions is the use of modifiers in the paving industry [7].

The road pavement construction agencies have worked performance improvements in asphalt binders, primarily by modifying pure bitumen with elastomers and plastomers polymer additives to enhance the road pavement's characteristics at high and low temperatures. Therefore, Thermoplastic plastomers and elastomers have been widely studied as either virgin products or recycled wastes [8]. Plastomers are a class of polymers used in asphalt binders that, when stretched, will yield and remain in their stretched position when the load is released. Polyethylene (PE) polymers are classified within the category of plastomeric polymers that soften to flow when heated and solidify and become stiff when cooled. Polyethylene is found in various types, such as low-density polyethylene (LDPE) and high-density polyethylene (HDPE), which are commonly used to modify asphalt binders [9]. According to recent studies, the melting point ranges between (110 and 120)◦C for LDPE [10-12]and between (130

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and 149)◦C for HDPE [13, 14]. These temperatures are lower than the range typically used in the production of hot asphalt mixtures.

Consequently, these materials can be easily mixed into bitumen, and the lower the melting point compared to the mixture temperature, the slower the mixing speed required. For this reason, it is preferred to use plastic polymers to modify asphalt binders such as low-density polyethylene (LDPE). In addition to its high ability to improve the properties of asphalt binder and the performance of asphalt mixtures [15].

2. Problem Statement

The temperature and stress caused by the load can be cited as two main parameters leading to breakage in asphalt pavement, especially rutting (permanent deformation). When the traffic load increases and temperatures are high, rutting failure is more likely to occur. Therefore, research is needed in the areas of hot mix asphalt (HMA) constituent improvement, mixed design, analytical methods, and pavement design. This extends the useful life of the pavement and, as a result, prevents the costs that are set to be spent repairing pavement failures. Consequently, researchers and engineers are continuously trying to improve asphalt pavement performance.

3. The Aim and Objectives

3.1 The Aim

This study aims to assess the performance of Asphalt mixtures modified with waste low-density polyethylene to prepare an asphalt mixture that can withstand heavy traffic loads and provide a long-lasting pavement under adverse weather conditions economically.

3.2 Objectives

The objective of this study is to investigate the influence of using solid recycling waste such as plastic wastes (low-density polyethylene) on the performance of asphalt mixtures at different high temperatures.

4. Literature Review

The asphalt binder is defined as a viscous-elastic material with temperature and time-dependent properties [16]. Because of increased traffic loads and unfavorable environmental conditions, the pavement materials of roads have been subjected to several failures in recent years [17]. The primary one is its susceptibility to high temperatures. Due to the high paraffin content can flow at high temperatures and remain crisp at low temperatures [15]. Therefore, the unmodified asphalt cannot satisfy the current requirements, and nowadays, more researchers are trying to modify the ordinary asphalt oil [18, 19].

Low-density polyethylene polymer is one of the successful options to use in modifying asphalt. In addition, it can be found in several objects, such as reusable bags, trays, and containers. In contrast, High-density polyethylene is found in toys, milk and shampoo bottles, pipes, and various items of houseware [20, 21].

Plastic bags are manufactured using polyolefin polymers such as low-density polyethylene (LDPE) and high-density polyethylene (HDPE). These additives have demonstrated their beneficial effects on bitumen efficiency, particularly in terms of stiffness and resistance to rutting at high temperatures [22, 23]. This is confirmed by many researchers, including Al-Jumaili and Al-Jameel, (2020) [24]. They used high-density polyethylene in addition to styrene-butadiene-styrene (SBS) to reduce the depth of rutting by using these polymers as bitumen modifiers. Their results showed a noticeable improvement by decreasing the rut depth by 72% and 65% using high-density polyethylene with an optimum value of 8% and SBS with an optimum value of 6%, respectively, through trials blended with various percentages of HDPE & SBS (4, 6, 8 and 10) % by weight of asphalt.

Other researchers also investigated the use of HDPE as a modifier for bitumen. They found that the HDPE modified binders provide better rutting resistance at 3% and 5% by weight of asphalt than the SBS modified binders [25].

Furthermore, field investigations established the ability of LDPE plastics to improve asphalt paving materials [26, 27].

It has been reported that recycling LDPE and modifying asphalt increases bitumen's high-temperature performance and decreases its temperature susceptibility. Additionally, LDPE is highly resistant to corrosion and offers good waterproofing [28]. The following are the fundamental properties of LDPE, according to [11, 12].

1) Melting temperature: (110 to 120° C)
2) Density: 0.918–0.934 (g/cm3)

5. Materials

5.1 Asphalt Cement

The asphalt cement with penetration grade (40-50) has been utilized in this work as a virgin asphalt binder, provided from the Al-Dura refinery located in the south of Baghdad. The implemented tests on asphalt cement prove that its properties met the specification of SCRB [29]. Table 1 illustrates the physical properties of asphalt cement.

Table 1: Asphalt binder characteristics

Property	ASTM Designation	Test result	SCRB specification
Penetration at 25 °C,100 gm,5 sec.	D-5	46	(40-50)
Ductility at 25 °C, 5 cm/min. (cm)	D-113	140	>100
Flash point, (°C)	D-92	323	Min. 232
Softening point, (°C)	D-36	52	-----------
Viscosity @ 135 °C, C.s	D-4402	612	Min. 400
Viscosity @ 165 °C, C.s	D-4402	155	------------
Specific gravity at 25 °C	D-70	1.04	----------

5.2 Aggregates

The aggregate used is a crushed aggregate that has been produced from the Al-Nibaie quarry. The used aggregates satisfy the specifications of fine and coarse to meet Type IIIA of surface course gradation as required by State Corporation of Roads and Bridges (SCRB) specifications [29]. Therefore, the standard tests have been done in the aggregate to assess its characteristics. Figure 1 and Table 2 Show gradient curves of aggregate and characteristics of coarse and fine aggregates, respectively being used in this study. The results indicate that the selected aggregate fulfilled the SCRB specifications.

Table 2: Characteristics of Course and fine aggregate

Property	ASTM Designation	coarse aggregate	Fine aggregate	Specification
Bulk Specific Gravity	C127, C128	2.612	2.567	------------
Apparent Specific Gravity	C127, C128	2.656	2.629	------------
Percent Water Absorption	C127, C128	0.94	0.91	-----------
Angularity	D 5821	97%	------	Min. 90%
Toughness, by (Los Angeles Abrasion	C535	20.8%	------	Max. 30%
Soundness	C88	4.1 %	------	Max 12 %

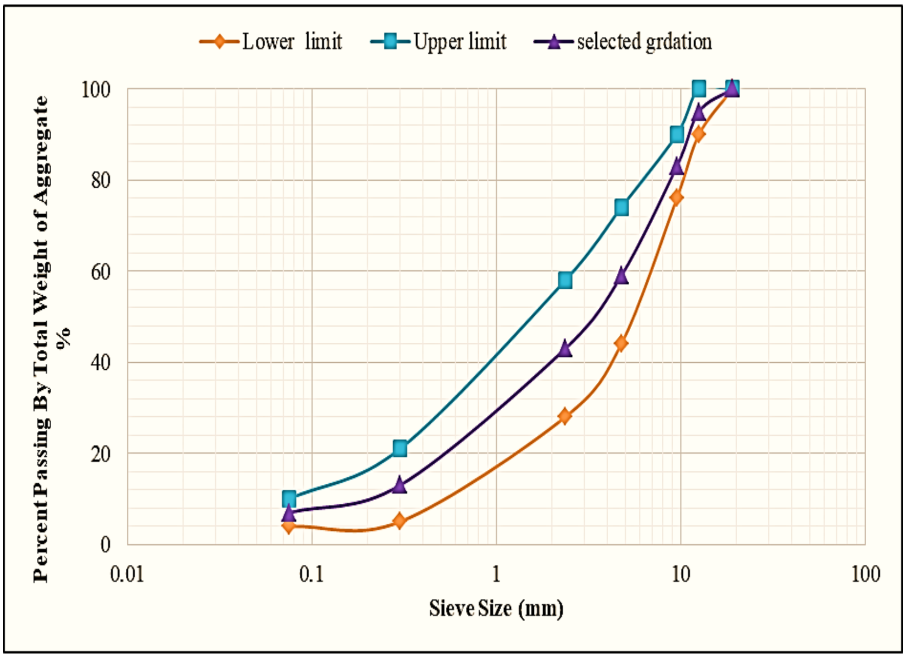

Figure 1: Gradation curves of an aggregate for wearing coarse

5.3 Mineral Filler

Portland cement, which is made locally, was used as a filler in this work. Table (3) shows the physical properties of Portland cement that passed through sieve No. 200 (0.075 mm).

Table 3: Physical Properties of Portland cement filler

Property	Result
Bulk specific gravity	3.20
Passing Sieve No.200 (0.075 mm)	97%

5.4 Additive

5.4.1 Waste low-density polyethylene (WLDPE)

Low-density polyethylene (LDPE) from wastewater containers and Plastic bags is the type of plastic waste implemented in this work. This plastic waste was derived from recycling factories for plastic waste north of Baghdad. This waste is powdered and sieved on a #100 sieve. Plate (1) and Table (4) show the plastics used in this work and their properties.

Plate 1: Photograph of waste low-density polyethylene (LDPE)

Table 4: Properties of LDPE

Property	Results
Melting temperature (°C)	(110-120)
Specific Gravity	0.94

6. Experimental Works

6.1 Preparation of Asphalt Binder Modified With Waste Plastics (LDPE)

To prepare asphalt binder modified with low-density polyethylene. First, the pure asphalt binder is heated to about (160 °C) before being mixed with three percentages (2, 4, and 6% by weight of asphalt) of LDPE (as a substitution of asphalt weight). These percentages of WLDPE were chosen according to several studies that specified the percentage of waste polyethylene in the binder. They range between 1% and 10% by weight of the asphalt, with the most common value being between 3% and 5% [20, 30]. Then, the mixing process was performed w Plate (2) shows the mixing process and asphalt binder modified with (LDPE) after the mixing process.

Plate 2: Preparation of asphalt binder modified with (LDPE)

6.2 Preparation of Asphalt Mixtures Samples

The Marshall mix design method was followed during the current study for both the conventional and waste low-density polyethylene modified asphalt mixtures. The Marshall mix design method is commonly used in Iraq to design asphalt mixtures. The current study involved several laboratory examination stages; the first stage involved the selection of the aggregates (coarse and fine), comprising determining their physical properties and composite grades that will meet the requirements for asphalt mixtures. This stage followed the specification provided by the General Standards of the SCRB [29]. The second stage is divided into two phases. First, conventional asphalt mixtures (without polyethylene) were prepared by adding five proportions of preheated asphalt (4, 4.5, 5, 5.5, 6) % of the total mixture weight to the aggregate. The purpose is to determine the percentage of optimum asphalt content that gives a good balance among the tested properties (flow value, Marshall stability, bulk density, and total air voids), and the optimum binder content was found (4.9) % by weight of the total mix. Second, the effect of LDPE on the resulting mixture was examined by heating the optimum content of asphalt cement with various proportions of LDPE.

At this stage, three samples were prepared for each mixture. First, the WLDPE was added to the asphalt mixtures using a wet process. Next, the WLDPE were added at various proportions of (0, 2, 4, and 6%) by weight of asphalt. Next, the asphalt was heated to about 160 °C before adding the polyethylene. The blending temperature (asphalt cement + polyethylene) was maintained at (150 ± 10)°C for 45 min. Then, the hot blending of asphalt cement and polyethylene was added to the heated aggregate, and the mixture was manually mixed until homogeneity was achieved. Having been homogenized, the blending of asphalt modified with LDPE was added to the heated aggregate at the desired amount and thoroughly mixed manually for about 2 minutes until the aggregates were fully coated with asphalt. Finally, assessment of the performance of asphalt mixtures in terms of the Marshall test and permanent deformation through the wheel track test. Marshall and wheel track tests were performed for both conventional and modified asphalt mixtures to assess unmodified and modified mixtures at different high temperatures. Plate (3) shows part of prepared modified asphalt mixtures specimens.

Plat 3: Preparation and Marshall test of asphalt mixtures specimens

6.3 Wheel Track Test

To assess the dynamic stability of the bituminous mixtures, the wheel tracking test has been described as a test machine to measure the rutting behavior in the laboratory for unmodified and LDPE modified asphalt mixtures with an optimum value of polyethylene (4) % by weight of the binder. Hamburg Wheel Tracking (HWT) is a widely used measure of loaded wheels. It is a device used to simulate paving conditions to test the fragmentation sensitivity of asphalt mixtures. The evaluation is performed according to (AASHTO: T324, 2013) and (BS EN 12697 - 22, 2003). A steel wheel (standard specification) rolls over the surface of the asphalt mixture sample with an additional load of 705 N (158 lb) at a standard inspection temperature of 50 C and 60 C [9, 31, 32]. The test runs for 10,000 cycles (20,000 passes) or before 20 millimeters of deformation is achieved. Four compacted slab specimens (unmodified asphalt mixture and LDPE modified asphalt mixtures) were prepared for this test. The compacted asphalt slab specimens with a length of 40 cm, a width of 30 cm, and a thickness of 5 cm were cooled at room temperature for 24 hours in compliance with the standard specification [32]. Plate (4) shows Hamburg Wheel Tracking Test.

Plate 4: Hamburg Wheel Tracking Test

7. Results and Discussions

7.1 Marshall Test Results

Figures (2, 3) reveal the Marshall stability and flow values for unmodified and modified specimens (WLDPE). Through Figure (2), it can be noted the increase in Marshall's stability and resistance to plastic deformation of the modified mixtures with (WLDPE), as the Marshall stability values increased by (23.8) % using 2% of (WLDPE), (34.5) % using 4% of (WLDPE) and (48) % using 6% of (WLDPE), respectively. All mixtures modified with different proportions of polyethylene (WLDPE) showed a significant increase in Marshall Stability compared to the conventional mixture, as shown in the Figure. This increase in the Marshall Stability values results from the increase in the viscosity of the asphalt and its hardness after adding polyethylene waste. On the other side, the flow values of the asphalt mixtures modified with WLDPE showed a gradual decrease with the increase in the percentage of WLDPE in the mixture, as shown in Figure (3). This is a logical explanation for the higher the Marshall values increased, the lower the flow values. These Figures also noticed that the highest value of Marshall's Stability was achieved with a percentage of 6% (WLDPE), which is considered a positive and good indicator.

In contrast, the flow value of the modified mixtures decreased by 27%, from 2.53 to 1.85, using (6%) of (WLDPE). This is undesirable as the flow value has become outside the Iraqi standard (SCRB)[29]. Consequently, through the Marshall Stability results and the flow values of modified mixes, the optimum percentage of the (WLDPE) additive can be obtained to be 4% by the weight of asphalt. It gave a high result for Marshall stability with degree (34.5%) compared to the conventional mixture. Also, the mixture's flow value at this percentage of (4%) was within the Iraqi standard, as shown in the figures.

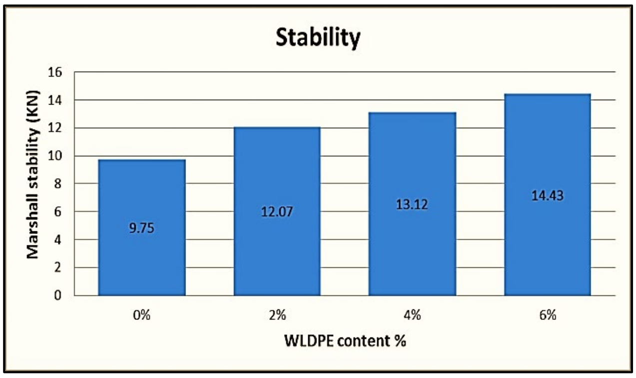

Figure 2: Marshall stability values for mixtures modified with (WLDPE)

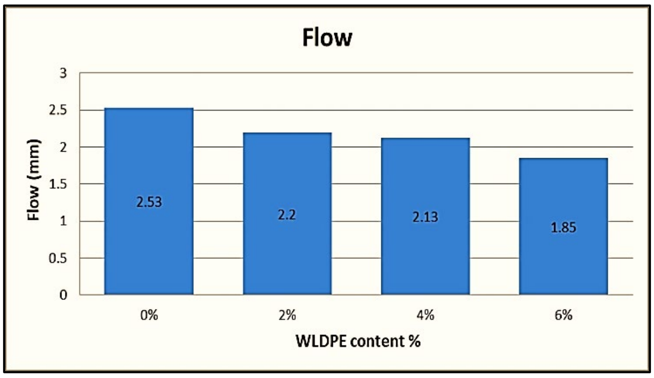

Figure 3: Flow values for mixtures modified with (WLDPE)

7.2 Wheel Track Test Results

The rut depth data for HMA mixtures obtained using the wheel track test are manifested in Figures (4 and 5), respectively. The figures' apparent results show the tremendous positive effect of adding plastic wastes (WLDPE) on reducing the sensitivity of mixtures to high temperatures by decreasing the rutting depth compared to the traditional mixture.

The results showed that the use of LDPE by 4% by weight of asphalt, which is the optimal percentage obtained from the previous test results (Marshall tests), reduced the rutting depth by (80.5%) from 15.11 to 2.95 mm at a temperature of 50°C. In addition, the rutting depth was also reduced from 20.35 to 3.6 mm (i.e., 82.3%) at a temperature of 60°C. This is due to increasing the viscosity values of the asphalt binder through the addition of waste polyethylene (LDPE). Polyethylene (LDPE) reduces the sensitivity of the asphalt to high temperatures. This, in turn, reflects positively on the performance of the asphalt and the mixture in hot climates and reduces the chances of permanent deformation occurring at higher temperatures.

In conclusion, the reported results showed that the modified mixtures with WLDPE as a percentage of asphalt weight are less affected by high temperatures than conventional mixtures due to reducing the sensitivity of the asphalt to high temperatures by increasing its viscosity and hardness.

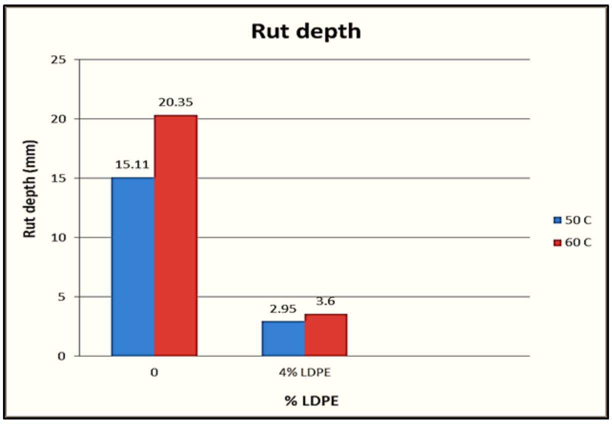

Figure 4: Influence of the waste polyethylene (LDPE) upon the rut depth

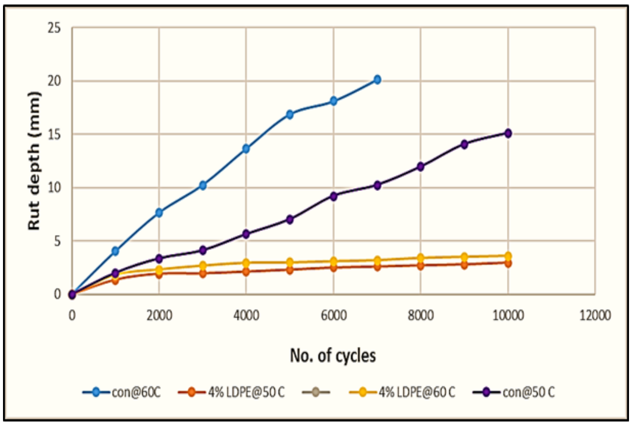

Figure 5: Relationship between number of cycles and rut depth for control and mixtures modified with Low waste Density

8. Conclusions

According to the results achieved in this study, the following conclusions can be drawn:

1) The use of waste materials such as waste plastics (low-density polyethylene) in the construction of asphalt paving has positive effects on both road construction systems and the protection of the environment from the risk of pollution from the accumulation of these wastes on the environment.
2) All percentages of low-density polyethylene waste used in this study showed good results and a remarkable and high improvement in performance through the results obtained from the laboratory tests conducted in this study.
3) The optimum percentage of LDPE additive was verified as 4% by weight of asphalt through all laboratory results (Marshall tests) obtained in this study.
4) As a result of the accumulation of waste materials in sanitary landfill sites and cities and the pollution and environmental problems they cause, using these waste materials in pavement construction would reduce its harmful effects on the environment and reduce the costs of transporting, storing, and recycling of these wastes.

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Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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