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Effects of high-density polyethylene and crumb rubber powder as modifiers on properties of hot mix asphalt

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HIGHLIGHTS

- Modifiers used are high-density polyethylene (HDPE) and crumb rubber powder (CRP).
- Using HDPE and CRP as modifiers improves the physical properties of asphalt.
- Marshall stability, flow and MQ values of modified mixtures are higher than the control mixture.
- Resistance to moisture damage increases significantly after addition of HDPE and CRP.
- Resistance to permanent deformation (i.e., rutting resistance) increases with an increase in the HDPE and CRP contents.

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ABSTRACT

The effects of high-density polyethylene (HDPE) and crumb rubber powder (CRP) on the properties of hot mix asphalt were investigated. The physical properties, penetration, softening points, and ductility of unmodified and modified asphalt were measured for various HDPE and CRP contents. Marshall stability and flow, Marshall quotient, moisture sensitivity, and wheel tracking (rutting) tests were also conducted. The results showed that using HDPE and CRP as modifiers improves the physical properties of asphalt and Marshall properties of HMA mixtures. The resistance to moisture damage increased significantly after the addition of HDPE and CRP, as did the resistance to permanent deformation.

1. Introduction

Asphalt modifiers can improve the properties of asphalt and asphalt mixes. Asphalt containing such modifiers is called modified asphalt. Rubber-modified asphalt and polymer-modified asphalt are usually used under conditions involving extreme climatic variations. Some of the properties of modified asphalt are as follows:

- Lower susceptibility to temperature variations.
- Significant resistance to deformation at high temperatures.
- Better long-term resistance properties.
- Higher fatigue life.
- Better adhesion between asphalt and aggregates.
- Prevention of rutting and cracking.

In recent years, polymeric materials have usually been used as asphalt modifiers in road construction [1,2]; this has been one of the main reasons for decrease in the number of asphalt-pavement-related disasters in recent years [3–6]. The characteristics of blends of asphalt and polymer depend on the type and concentration of the polymer used. Usually, the polymer is used in concentrations of approximately 4–6% of the asphalt weight [7]. Polyethylene is a very popular plastic used widely all over the world. When used for modifying asphalt, polyethylene can improve the rigidity of asphalt pavements, thus decreasing their deformation under heavy traffic loads at high temperatures [8]. Rubber has also been used as an asphalt modifier in road pavements since the middle of the last century. McDonald used crumb rubber (CR)-modified asphalt to improve the performance of asphalt mixtures [9–11]. In previous years, CR has been employed widely as an additive for the asphalt mixtures used for road pavements [12]. The moisture damage of hot mix asphalt (HMA) mixtures is one of the commonest forms of damage that occur in asphalt pavements. Moisture damage is defined as the loss of the mechanical properties of materials owing to the presence of water

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in the HMA mixture [13,14]. Rutting is one of the major issues related to the HMA mixtures used for road pavements and is usually manifested under heavy traffic loads [15,16]. In the laboratory, a rutting device can be used to simulate a wheeled vehicle to assess the permanent deformation resistance of test specimens based on the rut depth. The rut depth is considered an appropriate index for comparing the sensitivity of asphalt mixtures to permanent deformation.

Al-Hadidy and Tan [17] reported that adding low-density polyethylene to asphalt improves its resistance to deformation at high and moderate temperatures. In addition, its shear resistance is also improved. Moatasim et al. [18] found that adding high-density polyethylene (HDPE) to asphalt improves its resistance to deformation under high and moderate temperatures as well as its shear resistance. Further, it also improves the Marshall quotient (MQ) and indirect tensile strength (ITS) of asphalt mixtures. Sinan and Emine [19] investigated the suitability of different types of plastic waste containing HDPE as modifiers for asphalt concrete. Their results indicated that HDPE-modified asphalt concrete exhibits increased Marshall strength (stability) and a higher MQ value.

Al-Hadidy and Tan [20] studied the effects of CR as a modifier on the properties of stone matrix asphalt (SMA) mixtures. They found that the addition of CR to SMA mixtures results in a significant increase in the Marshall stability as well as the MQ and ITS values. Alireza et al. [21] investigated the effects of using reclaimed asphalt pavement (RAP) on the rutting performance of rubberized asphalt mixtures. The test results indicated that the use of CR and RAP in HMA mixtures can effectively improve the engineering characteristics of these mixtures. Punith and Veeraragavan [22] investigated the use of reclaimed PE in asphalt concrete mixtures as an additive. They found that PE-modified asphalt mixtures showed improved rutting resistance and lower temperature susceptibility compared to unmodified mixtures.

The main objective of this study was to investigate the effect of HDPE and CRP as modifiers on the properties of HMA (Marshall design parameters, moisture sensitivity, and rutting resistance). The physical properties of HDPE and CRP-modified asphalt, such as the softening point, penetration, and ductility, were also evaluated.

2. Materials and methods

2.1. Asphalt used

The asphalt used in this study was of 60/70 penetration grade. Several physical tests such as the penetration test, softening point test, ductility test, and specific gravity test were performed to characterize the properties of the asphalt. The engineering properties of the asphalt are listed in Table 1.

2.2. Aggregates used

The crushed coarse and fine aggregates used in this study were obtained from Harbin City in northeast China. The properties of the aggregates are listed in Table 2; they had a maximal normal size of 19 mm. Fig. 1 shows the gradation limits of the aggregates used in this study as determined based on the ASTM D3513 standard [23] for HMA mixtures; the selected gradation lay in the middle of the limits. The filler used was passed through a #200 sieve and had a specific gravity of 2.78.

Table 1
Physical and mechanical properties of asphalt binder used in this study.

Test	Standard	Result
Penetration (100 g, 5 s, 25 °C), 0.1 mm	ASTM D5	64
Ductility (25 °C, 5 cm/min), cm	ASTM D113	150 +
Softening point (°C)	ASTM D36	55
Specific gravity at 25 °C (g/cm^3)	ASTM D70	1.03
Flash point (°C)	ASTM D92	321
Penetration index (PI)		0.601

Table 2
Properties of aggregates used in this study.

Aggregate property	Value
Crushing value (coarse aggregate)	12.9
Los Angeles abrasion value (%)	16.8
Apparent specific gravity (g/cm^3)	2.84
Water absorption (%)	0.426
Apparent specific gravity (fine aggregate)	2.84
Sand equivalent (%)	73.8

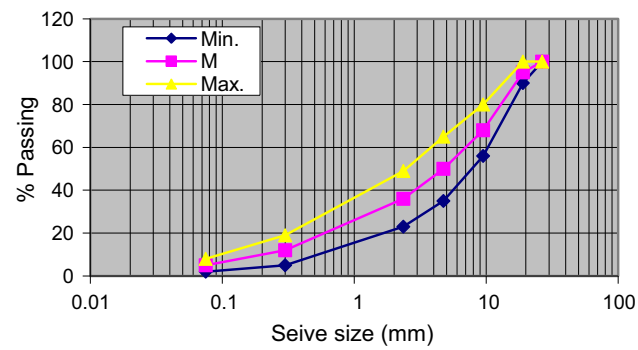

Fig. 1. Gradation of aggregates used in this study.

Fig. 2. High-density polyethylene.

Table 3
Physical and mechanical properties of HDPE used in this study.

Property	Value
Density (g/cm^3)	0.955
Tensile strength (MPa)	27
Flexural modulus (MPa)	1372
Elongation at break (%)	560

2.3. Additives used

Polyethylene is the most commonly used plastic in the world. Hence, HDPE (see Fig. 2) was used as the asphalt modifier in this study. The physical and mechanical properties of the HDPE sample used are listed in Table 3. A CRP sample that had been passed through an ASTM #40 mesh was also used as an asphalt modifier in this study (see Fig. 3). Its gradation is listed in Table 4.

2.4. Experimental setup

Fig. 4 shows the experimental setup used in this study. The flowchart shows the methods and materials used to prepare the asphalt mixtures and the various tests performed to evaluate the physical properties tests of the asphalt and engineering properties tests of the asphalt mixtures.