Effects of high density polyethylene on the permanent deformation of asphalt concrete

Sinan Hinislioğlu*, Hatice Nur Aras, Osman Ünsal Bayrak
Department of Civil Engineering, Engineering Faculty, Ataturk University, 25240 Erzurum, Turkey

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This paper reports an investigation about the effect of high density polyethylene (HDPE) in powder form as a bitumen modifier on the permanent deformation of asphalt concrete using Marshall design parameters and creep behaviour. The parameters assessed are the compacted mix density, the percentage of air voids in the mixture, the percentage of voids filled with bitumen, Marshall stability and flow and also Marshall quotient (MQ), axial strain and stiffness modulus. It is also investigated the effect of HDPE on some physical properties such as penetration, softening point and ductility. Bitumen is mixed with the HDPE at 1-4% by weight of bitumen at 185°C for 60 min. duration using a high shear mixer. Marshall samples prepared with the HDPE modified binder provide the specification limits. The addition of 3% HDPE, results in an increase of 57% in Marshall quotient. In addition, it has been observed that the use of 2% HDPE decreased the permanent strain by 34% and increased the creep stiffness by 52%. The creep recovery values of the asphalt concrete with HDPE after 15 min have been found to be higher than control mixtures. It can be concluded that HDPE modified asphaltic binders provide better resistance against permanent deformation, because of their higher stability and stiffness, relatively lower flow. As a result, HDPE modified asphaltic binders are considered to be very useful in mitigating permanent deformation in hot climate regions.

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Asphalt concrete consists of a binder and graded aggregate. The binder may be normal penetration grade bitumen or modified bitumen. Polymer modification has been identified as a promising avenue to obtain high performance asphalt pavements. Recently, many studies have been attempted by adding different materials into the asphalt cement (AC) to improve the mechanical and physical properties of asphalt concrete. The Marshall design method is one of the most commonly used methods to evaluate the performance of both polymer modified and unmodified asphalt concrete and there are many studies about characterizing the Marshall stability and flow and creep behaviour of both polymer modified and unmodified creep behaviour of asphalt concrete specimens. Meegoda showed that asphalt concrete mixes made with petroleum-contaminated soils were strong enough to be used in low volume roads using Marshall design. Laboratory design of continuously graded asphaltic concrete containing recycled plastics and low-density polyethylene (LDPE) has been researched. LDPE partial aggregate replacement resulted in a 250% increase in the Marshall stability value and an improved Marshall quotient (resistance to deformation) value. They found that the values of creep stiffness of the plastiphalt mix are slightly lower than the control mix. However, the plastiphalt gives 14% recovery after one hour unloading time compared to 0.6% for to the control mix. Park et al. studied the effect of pyrolyzed carbon black (CBP) on asphalt pavements. They found increased Marshall stability and decreased permanent deformation. Fawcett et al. indicated that the morphology and rheological properties of modified binders were influenced by characteristics and content of the polymer and the nature of the bitumen. Polymer modified asphalts are prepared by incorporating recycled polyethylene (RPE) and a used-tyre-derived pyrolytic oil residue in asphalt. The asphalt mixtures containing 10% pyrolytic oil and 1% polymer were found to have the best low and high temperature performance. Gregg and Alcock showed that Marshall stabilities tended to increase for polymer-modified mixtures compared with the control mixture. Green and Toloneni reported that polymer modification has led to an increase of the rutting resistance as measured by wheel tracking.

*For correspondence (E-mail: shinis@atauni.edu.tr)
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experiments. The binder-rich mixture and the optimally designed polyethylene modified mixture were evaluated elsewhere\textsuperscript{17}. Binder-rich polyethylene modified asphalt concrete proved to be significantly less sensitive to permanent deformation than the control mixture. The other study of Little\textsuperscript{18} presents data which supports the premise that low density polyethylene (LDPE) modification reduces creep deformation in asphalt concrete mixtures. Hinislioglu and Agar\textsuperscript{19} investigated the influence of waste HDPE-modified binder obtained by various mixing time, mixing temperature and HDPE content on the mechanical properties. Four percent HDPE, 165°C of mixing temperature and 30 min of mixing time were determined as optimum conditions for mechanical properties. Qi et al.\textsuperscript{20} investigated the behaviour of permanent deformation of modified asphalt concrete mixtures with polyethylene as compared to that of unmodified asphalt concrete mixtures. Polyethylene modifiers produced higher creep modulus of modified mixtures than those of unmodified mixtures.

In this study, the influence of HDPE in powder form on the Marshall design parameters and creep behaviours has been investigated. Some physical properties of HDPE modified asphalt, such as penetration, softening point and ductility have also been studied.

**Materials and Methods**

The materials and experimental design procedure used to evaluate the effect of mix variables (Bitumen-HDPE mix) on the properties of HDPE modified asphalt concrete are as follows. The bitumen used in this study was AC-10 asphalt cement. The asphalt was subjected to standard laboratory tests to determine its physical properties. In order to see the effect of the HDPE on the binder properties, penetration, softening point and ductility tests were performed for all HDPE contents. The flash point of the asphalt cement was found to be 215°C in accordance with ASTM D92\textsuperscript{16}. The results of both unmodified and HDPE modified binder tests are given in Table 1. In this investigation, the modifier used is HDPE in powder form. All the HDPE particles passed No. 10 (2 mm) sieve and retained on No.40 (0.42 mm) sieve. The specific gravity of HDPE was measured as 0.935 g/cm\textsuperscript{3}. Crushed limestone was used as the aggregate. A typical heavy traffic gradation for hot-mix asphalt (HMA), designated as Type II in the Turkish State Highway Specifications, was selected. The selected gradation and the specification limits are shown in Table 2. Some physical properties of the crushed limestone and specific gravities of aggregates are given in Tables 3 and 4, respectively. A Siverson high shear mixer was used to mix the HDPE and bitumen. Temperature control during mixing was achieved by using a thermostat. The mixing speed was 3000 rpm. Bitumen and HDPE was blended at 185°C for 60 min.

The Marshall test method was used to determine the resistance to plastic flow of asphalt concrete specimens with HDPE modified binder. The Marshall
specimens (10.4 cm in diameter by 6.35 cm in height) were fabricated in accordance with ASTM D 1559. Seventy-five blows were applied on each side of the specimen using a mechanically operated Marshall Compactor. The optimum amount of bitumen was found to be 5% (by weight of aggregate) for unmodified asphalt concrete. Each sample was prepared by using 1150 g aggregate and 57.5 g binder. HDPE concentrations selected were 1, 2, 3, and 4% (by weight of optimum bitumen content). All specimens were evaluated according to the Turkish State Highway Specifications. The specification limits for Marshall design are given in Table 5. The compaction temperature for Marshall specimens was adjusted so as to give the same void ratio. Each test was repeated three times and the average value was used in the calculations. Marshall tests were performed at 60°C.

Generally, creep test is utilized for characterizing the permanent strain behaviour of the paving mixtures at relatively high temperatures where the flexible pavements are more susceptible to rutting distress. This test is carried out either in the static or repeated mode of loading. In this investigation, repeated load uniaxial creep test was performed at the temperature of 40°C, preloading for 2 min at 10 kPa, as a conditioning stress; constant repeated load (100 kPa) with constant loading time (loading time of one second and rest period of two second). Test was terminated after 3600 pulses giving an accumulated loading time of one hour. After each test, deformation recovery is measured for 15 min. During the test, axial deformation was measured as a function of time so that the stiffness modulus, $S_{\text{mix}}$, at any loading time can be determined. The creep stiffness was calculated from the ratio of applied stress to cumulative compressive strain at a defined temperature and time of loading.

**Results and Discussion**

All the Marshall test results and Marshall quotient values are given in Table 6. The bulk specific gravities of asphalt concrete with HDPE were lower than that of the control specimen due to lower specific gravity of HDPE. HDPE affected the theoretical specific gravity in the same manner. Approximately the same void ratio (3.88—4.21%) was obtained for all specimens. The voids in mineral aggregate and the ratio of the voids filled with binder were not significantly affected by the HDPE content. Flow values of the specimens with HDPE were lower than that of the control mixture. This may imply that HDPE affects the internal friction of the mixture in a negative manner. Binder tests demonstrated that penetration and ductility decreased with increasing HDPE whilst softening point increases (Table 1). Penetration decreases with increasing HDPE content, meaning that viscosity increased with increasing HDPE content. Since cohesion increases as the viscosity of the HDPE modified binder increases. Stability showed the increase in the range of 3—21% whilst flow decreased in the range of 17—25%. Therefore, high stability may be attributable to higher cohesion of the binder and internal friction. MQ values were calculated to evaluate the resistance to permanent deformation of specimens. It was seen that all the specimens with HDPE have higher MQ values than that of the control mixture due to both lower flow and higher stability. MQ increased 40—56% compared with control specimen.

By the evaluation of the results, the creep stiffness increased 52% with 2% HDPE (Fig. 1). At the same time, the axial strain results of specimens with HDPE at 40°C from the repeated loading creep test showed improved performance. It was observed that the use of...
2% HDPE decreased the permanent strain by 34% (Fig. 2). Thus, it can be inferred that this mixture with HDPE will result in less rutting. In addition, as seen in Table 7 the creep recovery values of the asphalt concrete with HDPE after 15 min were found to be higher than control mix because of higher viscoelastic behaviour.

The price of the HDPE is about 20 times higher than the normal bitumen. Since the cost of energy for mixing HDPE-bitumen is very low, cost of mixing can be made negligible. It is possible to increase the stiffness modulus of the asphalt concrete by 52% with the 38% increase in the cost of HDPE modified asphalt by using 2% HDPE (0.98 × 1 + 0.02 × 20 = 1.38).

For the optimum dose of the HDPE, it is difficult to decide what percentage of the HDPE is optimum for the resistance to the plastic deformation. 2% HDPE is optimum for the stiffness modulus as 3% HDPE is optimum for MQ. However, it can be concluded that 2% HDPE is optimum since the stiffness modulus is more scientific criterion than MQ for simulating the repeated traffic loads.

Conclusions
The following conclusions can be drawn from this study: (i) Stability showed the increase in the range of 3-21% whilst flow decreased in the range of 17-25%, (ii) HDPE additive decreased the flow values and increased the stability of HMA, (iii) MQ is increased 40 to 56%, (iv) It can be concluded that HDPE modified bituminous binders provide better resistance against permanent deformation, because of their high stability and relatively lower flow and lower softening.

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<tr>
<th>HDPE (%)</th>
<th>Percentage recovery (%)</th>
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<tbody>
<tr>
<td>0</td>
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<tr>
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Fig. 1—Variation of stiffness modulus with HDPE

Fig. 2—Axial strain versus pulse count from the repeated loading creep test at 40°C
point for the HDPE modified bitumen, (v) The use of 2% HDPE decreased the permanent strain by 34%, (vi) In terms of creep stiffness, mixes with HDPE were found to have higher values than the control mix, (vii) The creep recovery values of the asphalt concrete with HDPE after 15 min were found to be higher than control mixtures, (viii) As a result, asphalt concretes with HDPE modified bituminous binders can perform successfully in certain specialized applications with acceptable resistance to permanent deformation, potentially superior resistance to fracture (reflection cracking and thermal cracking), and they are considered to be very useful in mitigating permanent deformations in hot climate regions17-20, (ix) It can also be concluded that 2% HDPE is optimum since the stiffness modulus is more scientific criterion than MQ for simulating the repeated traffic loads, and (x) It is possible to increase the stiffness modulus of the asphalt concrete by 52% with the 38% increase in the total cost of HDPE modified asphalt by using 2% HDPE.

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