Evaluating the Performance of Hot Mix Asphalt with Reclaimed Asphalt Pavement and Heavy Vacuum Slops as Rejuvenator

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Received: 05.03.2013 *Accepted: 05.05.2013*

Abstract:

Due to the high price of crude oil, and consequently asphalt binder, the application of Reclaimed Asphalt Pavement (RAP) in pavement technology is widely considered. The present paper is the result of a laboratory research which was carried out to investigate the effects of adding a rejuvenating agent to Hot Mix Asphalt (HMA) with RAP. To this end, test samples comprised of Aged Asphalt Binder (AAB) that were extracted from RAP, together with a rejuvenating agent were added in different ratios. The study made use of a variety of tests to determine the different percentage ratios of rejuvenator in terms of penetration, softening point and viscosity of the binder. The Marshall Method was then applied to investigate the impact of using a different recycling agent content on the performance of the prepared mixtures. Also, the Universal Testing Machine apparatus was used to determine the resilient modulus and dynamic creep of reclaimed asphalt. The results show that after adding 10% of Heavy Vacuum Slops (HVS) from the Tehran refinery as the rejuvenating agent to reclaim the aged asphalt, there is an improvement in the applicability of reclaimed asphalt cement. In addition, the test results suggest that adding 10% of the rejuvenator leads to RAP mixtures which meet the criteria of a virgin HMA.

Keywords: Reclaimed asphalt pavement, aged asphalt binder, rejuvenator, heavy vacuum slops, hot mix asphalt.

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1. Introduction

Chemically, asphalt binder is composed of two distinct components: asphaltenes and maltene (composed of resins and oils). During oxidation, the maltene fraction dissipates and causes a change in asphaltene - maltene ratio, which affects the stiffness properties of the asphalt [O'Sullivan, 2011]. This is called aging, which causes an increase in the viscosity and modulus of the asphalt cement and leads to an increase in stiffness and brittleness at intermediate and low temperatures, resulting in reduced resistance to fatigue and low temperature cracking [Solaimanian and Tahmoressi, 1996].

Asphalt rejuvenation is a process that restores aged asphalt's rheological properties to a point considered to be comparable to a virgin material, This process is done by the application of rejuvenating agents in RAP mixtures. Examples of rejuvenating agents are industrial process oil, "softer" Performance Grade binders (PG binders), asphalt flux oil, lube stock and slurry oil.

In general, increasing the Reclaimed Asphalt Pavement (RAP) content of a mixture increases its stiffness and reduces its shear strain, indicating the increased resistance to rutting. However, it is important to consider the RAP aggregate gradation and quality in the mix design, since a poor aggregate structure could reduce the mixture stiffness and ultimately its performance [McDaniel et al., 2002]. Applying rejuvenators can balance the asphaltene-maltene ratio of aged asphalt in RAP mixtures [Lin et al., 2012].

In this research, the effect of applying different proportions of Heavy Vacuum Slops (HVS), as the rejuvenating agent, in aged asphalt was evaluated, and the performance of RAP mixtures was compared to the virgin mixtures through a variety of tests. The Virgin mixtures were made of Asphalt Cement (AC 60/70) and with Iran's Highway Asphalt Paving Code gradation No.4. Finally, the ideal proportion of rejuvenator was determined so that the reclaimed mixtures meet the required properties of HMA.

2. Literature Review

The application of Reclaimed Asphalt Pavement (RAP) materials can have a significant impact on economics and environmental sustainability of pavement construction [O'Sullivan, 2011]. If designed properly, RAP mixtures have demonstrated a quality comparable to virgin mixtures in laboratory tests [Carvalho et al., 2010]. For instance, regarding the Superpave Method, a research project was sponsored by FHWA showed that if the RAP properties are properly accounted in the material selection and mix design process, Superpave mixtures with RAP can perform very well [McDaniel et al., 2002].

Depending on the type of the rejuvenating agent, the aged binder and traffic level, different agencies recommend different portions of rejuvenator to be applied in RAP. In Minnesota, for instance, the Department of Transportation Specification 2360, allows up to 40% to be added based on the traffic level and binder grade [Li et al., 2008]. The Superpave method also effectively limits RAP content in HMA to 40%. A study conducted at the Worcester Polytechnic Institute (WPI), Massachusetts, in conjunction with RAP Technologies in Linwood, NJ in 2009 concluded that 100% recycled mixes with good performance can be produced with existing quality control procedures in a suitable plant [O'Sullivan, 2011].

In application of mixtures with RAP, asphalt rejuvenation approach has proved to be effective. In a research program, the rejuvenation approach was applied to upgrade the self-healing capability during service life. Results of this research showed that the rejuvenation approach can be very cost-effective for asphalt concrete containing highly aged reclaimed asphalt [Zhang et al., 2012]. Results of another research showed that rejuvenator significantly affected the performance-based properties of both the rejuvenated aged binders and the mixtures containing the rejuvenated aged binders. The properties of the asphalt paving mixtures with the rejuvenated binders were even improved or in the same level as the properties of the virgin mixtures [Shen et al., 2007].

Rejuvenators can also be used for the maintenance of the existing pavements. In a laboratory research, asphalt cement was firstly aged by Rolling Thin-Film Oven Test (RTFOT) and Ultra-Violet light and then treated by two kinds of rejuvenators. Results indicated that both rejuvenators significantly decreased the viscosity and complex modulus of aged asphalt and could be softened efficiently by rejuvenator materials [Lin et al., 2012].

Relevant research works show that when the proper rejuvenator contents are applied, mixtures with 100%

of RAP and no virgin material can perform on a par with virgin mixtures. In an experimental research, totally recycled HMAs were produced with the best previously observed combinations, and their performance was assessed based on water sensitivity, rutting resistance, stiffness, fatigue resistance and binder aging. It was revealed that totally recycled HMAs can be good alternatives for road paving, especially if rejuvenator agents are used to reduce their production temperature and to improve their performance [Silva et al., 2012].

3. Objective and Scope

The objective of this research is to evaluate the performance of the HMA with and without the addition of RAP. Five asphalt cement types were applied to prepare five mixture types. Types of asphalt cement and their corresponding asphalt mixtures are presented in Table 1.

In order to evaluate the quality of the asphalt cement types, the penetration, softening point and Saybolt viscosity tests were implemented based on ASTM D5, ASTM D36, and ASTM D88, respectively.

The Marshall Method (ASTM D1559) was implemented for determination of the optimum asphalt content (OAC). Using the determined OAC, five mixture types were then prepared based on the type of the asphalt cement and the portion of HVS (Table 1).

In order to evaluate and compare the performance of the mixtures, the prepared specimens were tested by Marshall Stability and the Indirect Tensile Test (IDT) for determination of resilient modulus. For dynamic creep test. Universal Testing Machine (UTM) was applied as Accelerated Pavement Testing (APT) equipment.

4. Laboratory Procedure

4.1 Materials

Materials used in this research included aggregates, AC 60/70 as the asphalt cement and HVS as the rejuvenator, which are described in the following paragraphs:

Aggregates: Aggregate compounds were prepared using the control sieves with IHAPC No.4 gradation (Figure 1). This gradation, with a maximum aggregate size of 19 mm, is suitable for both the binder course and surface course of roads.

Table 1. Mixture types, asphalt cement types and their description.

Asphalt Cement Type	Description	Corresponding Mixture Type
AC 1	Control asphalt cement, i.e., virgin AC 60/70	AM 1
AC 2	Aged asphalt cement extracted from the RAP, with no HVS added	AM 2
AC 3	Reclaimed asphalt cement containing 5% HVS	AM 3
AC 4	Reclaimed asphalt cement containing 10% HVS	AM 4
AC 5	Reclaimed asphalt cement containing 15% HVS	AM 5

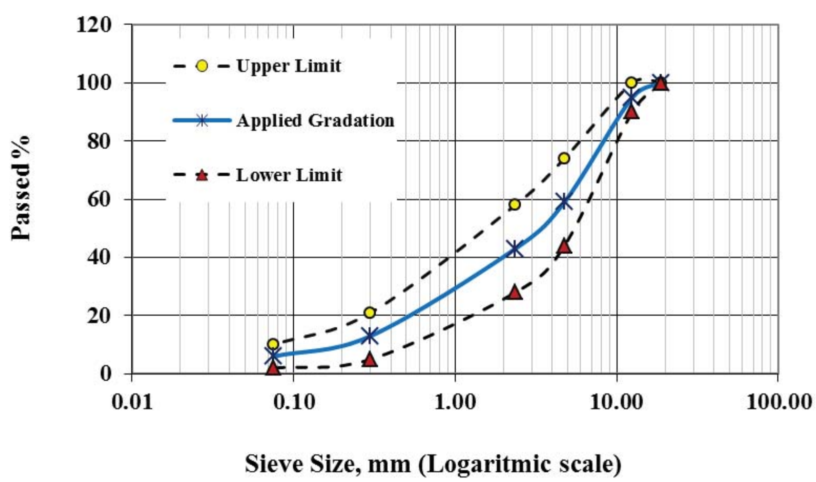

Figure 1. The applied gradation curve, together with IHAPC No.4 upper and lower limit.

Asphalt cement: AC 60/70 (the number refers to the penetration grade in 0.1 mm) was used to prepare the mixtures. AC 60/70 is the most widely used asphalt cement in Iran. Properties of AC 60/70are presented in Table 2.
Rejuvenator: Heavy Vacuum Slops (HVS), a product of the Tehran oil refinery, was used as the rejuvenating agent to reclaim the aged asphalt cement. The components of the applied rejuvenator are presented in Table 3. This product of the Tehran Oil Refinery Company is inexpensive and is available in large quantities, due to its large-scale application in a variety of industrial fields,

4.2 Asphalt Cement Extraction

In this research, the extraction of the aged asphalt from the used HMA was done based on the ASTM D2172 procedure, using the centrifuge extractor and trichloroethylene as the solvent. The used HMA was provided from a rehabilitation project in the intersection of Sahahid Chamran and Niayesh highways in Tehran, Iran. The used HMA contained AC 60/70 as the asphalt cement.

4.3 Tests on Asphalt Cements and Asphalt Mixtures

After adding the rejuvenator, the following tests were implemented on the reclaimed asphalt, in order to evaluate and compare the properties of virgin and reclaimed asphalt cement.

Penetration Test:

The penetration test in this research was based on the ASTM D5 procedure. This test was done to compare the stiffness of the asphalt cements with different percentage of HVS. Harder asphalt cement will have a lower penetration, contrary to the softer one with higher penetration [Tam, 2006].

The Softening Point Test:

The softening point test in this research was carried out according to ASTM D36. This test determines the temperature at which asphalt cement changes from a semi-solid to a fluid. This was important, since an asphalt binder should never reach its softening point under traffic [Brennan and O'Flaherty, 2002].

Viscosity Test:

The viscosity test in this research was implemented according to ASTM D88, as the standard test method for Saybolt viscosity. Viscosity is an important property of asphalt cement, especially at high temperatures, due to which the asphalt cement needs to be pumped, mixed with aggregates and compacted at site [Brennan and O'Flaherty, 2002].

Marshall Tests:

In order to evaluate the performance of the mixtures with RAP, virgin HMA produced from AC 60/70 was used as the control mixture to which other mixtures were compared. In the first step, the Marshall Method (ASTM D1559) was applied in order to determine the optimum asphalt content (OAC). The final specimens were then prepared with the determined OAC using

Table 2. Properties of AC 60/70 asphalt cement.

Type of test	Test Result	Standard
Specific gravity @ 25/25 C	1.03	ASTM-D70
Penetration @ 25 C	66	ASTM-D5
Softening point C	٤٩	ASTM-D36
Ductility @ 25 C	101	ASTM-D113
Saybolt Viscosity (SFS)	273	ASTM D88

Table 3. Components of the applied rejuvenator (HVS).

Component	Portion (%)
Asphaltene	Approximately 0
Saturated Hydrocarbon	53.64
Polar Aromatic Compounds	13.01
Naphthene Aromatic Compound	32.26

AC1 to AC5 in Table 1 and brought to the Marshall Method tests. These tests included Marshall strength, flow, percentage of air voids and determination of unit weight.

Dynamic Tests on HMA:

Dynamic tests on HMA were carried out during this study in order to obtain a more realistic prediction of the performance of RAP mixtures. In this research, the Indirect Tensile Test (IDT) for determination of the resilient modulus and the dynamic creep test are performed to investigate the effect of the specified rejuvenator on performance properties of the mixtures, using a Universal Testing Machine (UTM).

Resilient modulus is one of the characteristics of HMA that is used for the evaluation of material quality and as an input for pavement design, evaluation and analysis (ASTM D 7369-09, 2010). Using the determined OAC, the main specimens were prepared and tested under the Indirect Tensile Test. For each mixture type, 3 specimens were prepared for the test and each specimen was mounted in the machine and tested for two perpendicular rotations. Using a UTM-5, the IDT was performed for determination of resilient modulus based on Australian Standard AS 2891.13.1-1995. Plate 1 shows the UTM and a specimen mounted in the machine (for Dynamic Creep Test).

In this study, the Dynamic Creep Test was performed based on Australian Standard AS 2891.12.1-1995. An approach to determine the permanent deformation characteristics of paving materials is to employ a repeated dynamic load test for several repetitions and record the accumulated permanent deformation as a function of the number of cycles over the testing period [Witczak, 2005].

Universal Testing Machine (UTM) is an apparatus that provides repeated dynamic loading for a Dynamic Creep Test. In this test, a repeated pulsed uniaxial load is applied to an asphalt specimen and the accumulated deformation of the specimen under the repeated load is measured. While performing the test, the UTM software reports the test results in the form of an S-shaped curve. A sample of the dynamic creep report provided by the UTM software is illustrated in Figure 2. This report also includes setting parameters.

The cumulative permanent strain curve is generally defined by primary, secondary and tertiary zones (Figure 2). The starting point, or cycle number, at which tertiary flow occurs, is referred to as the flow number [Witczak, 2005]. The operator cannot measure the rutting depth using the flow number, but this value is a criterion required to compare the creep behavior of different HMA specimens and their resistance to permanent deformation.

Using the determined OAC, the specimens were prepared and tested by Dynamic Creep Test. For each mixture type, three specimens were prepared for the test.

Plate. 1. UTM (right) and specimen mounted in the machine for dynamic creep test (left)
(Asphalt and Bitumen Research Center, Iran University of Science and Technology)

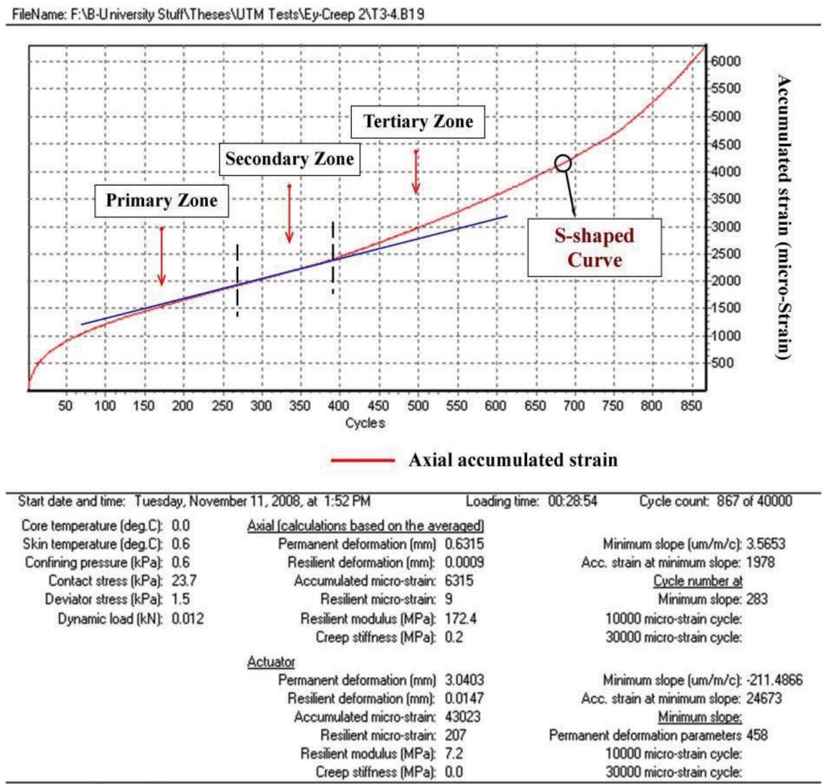

Figure 2. Primary, secondary and tertiary zones on a printable Dynamic Creep Report provided by the UTM software.

5. Results and Discussion

5.1 Penetration Test

Table 4 presents the penetration test results for AC1 to AC5. The presented results are the average value from five test results for each AC type. Results show that by increasing the proportion of rejuvenator in the specimen, there is a higher penetration. Results also show that adding 10% of HVS to the aged asphalt results in reclaimed asphalt cement with similar penetration grade to the virgin asphalt, i.e., AC 60/70. Further, adding 5 and 10% of HVS to the aged asphalt results in reclaimed asphalt cement with similar penetration grade to AC 40/50 and AC 85/100, respectively; hence, AC3 and AC5 are not appropriate for using in the same road with the same weather conditions.

5.2 Saybolt Viscosity

Viscosity of five types of asphalt cement is determined and presented in Table 4. It is concluded that increasing the proportion of HVS results in a lower Saybolt viscosity. This occurs due to an increase in proportion of maltene, with a a lower viscosity than asphalt cement. Results also show that the viscosity of specimen AC4 is the most similar to that of the control asphalt cement type, i.e., AC1.

Table 4. Asphalt cement test results.

Asphalt Cement Type	Penetration (0.1 mm) ASTM D5	Saybolt Viscosity (SFS) ASTM D88	Softening Point (° C) ASTM D36
AC 1	66	273	49
AC 2	28	397	72
AC 3	45	304	61
AC 4	63	246	52
AC 5	105	122	38

5.3 Softening Point

Based on the softening point test results (Table 4), adding HVS to the aged asphalt leads to a lower softening point. This occurs because HVS compensates the dissipated maltene portion of the aged asphalt cement. Generally, maltene portion of the asphalt cement has lower melting point compared to its asphaltene portion; hence, an increase in the amount of HVS results in a lower softening point. Similar to the previous test results, the softening point of AC4 is approximately equal to the softening point of AC1, i.e., AC 60/70.

5.4 Marshall Properties

The selected asphalt cement contents to determine the OAC were: 4.5, 5, 5.5, 6 and 6.5 percent, with 3 specimens prepared for each asphalt content (i.e., fifteen Marshall specimens in total). The OAC is determined to be 5% based on the Marshall mix-design procedure and application of AC 60/70.

Using the determined OAC, three specimens were prepared for each mixture type and tested in the Marshall Stability Test. Marshall Stability, Marshall Flow, air void fractions and unit weights of the five mixture types are presented in Figure 3.

According to the graph, unit weights of the five mixture types have similar values. This occurs due to the insignificance of the weight or proportion of asphalt cement in an asphalt mixture compared to the weight or proportion of the aggregates.

Conversely, the Marshall Stability differs for the 5 types. The virgin mixture has the greatest Marshall Stability among other mixtures, followed by the AM 4 mixture, with the stability just 7.4% lower than that of the virgin mixture. However, according to this value, AM 4 still meets the IHAPC lower limit for Marshall Stability, which is 8 kN (800 kg). This was expected, since the results of the tests on asphalt cement types showed that the properties of AC4 are similar to that of

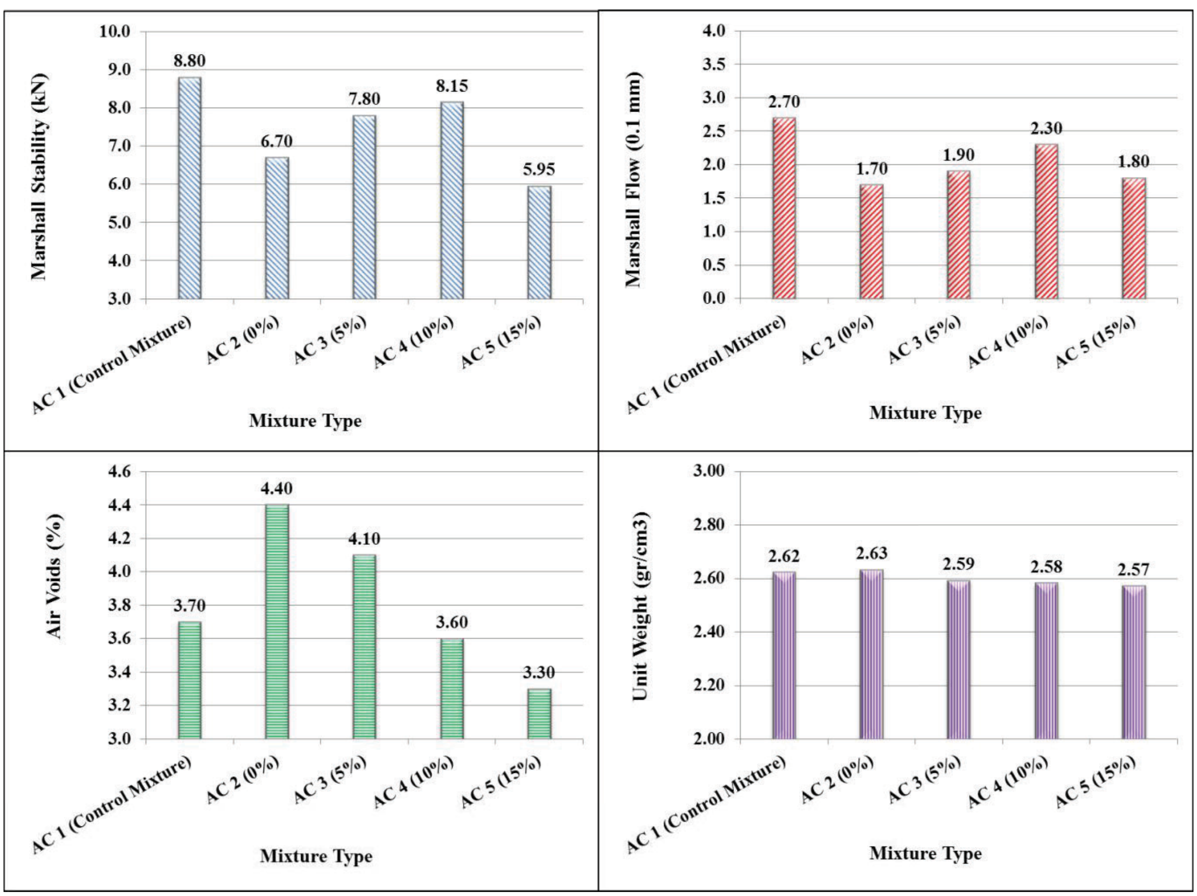

Figure 3. Results of Marshall method test on the mixture types: Marshall Stability (top left), Marshall Flow (top right), air voids (bottom left), and unit weight (bottom right)

the virgin asphalt cement.

Similarly, the virgin mixture has the highest Marshall Flow. Among the other four types, AM4 is the only mixture that meets the IHAPC Marshall Flow limitations, that are 2 and 3.5 mm.

According to the results, the air void fraction of the mixtures decreases by increasing the proportion of HVS in the reclaimed asphalt cement. Asphalt cement with a lower viscosity results in more compact mixtures, and any increase in the proportion of HVS reduces the viscosity of asphalt cement. Consequently, AM 2 with no HVS has the highest air voids, whereas AM 5 with 15% HVS has the lowest air voids. Air voids of the AM 4 mixture are almost equal to those of the virgin mixture.

In general, based on the results of the Marshall Method test, as one of the most common methods for quality control of HMA in practice, AM4 showed comparable properties to the virgin mixtures. In addition, AM4 meets IHAPC requirements for HMA. As a result, this mixture can be a suitable alternative for the virgin mixtures.

5.5 Determination of Resilient Modulus

Figure 4 shows the resilient moduli of the mixtures (left), together with the penetration grades of their corresponding asphalt cement for comparison (right). The resilient moduli presented in Figure 4 are the average grades obtained from three Indirect Tensile Tests for each mixture type.

The graph shows that increasing the proportion of HVS causes a reduction in the value of the resilient modulus as well as an increase in the penetration grades. It also reveals that the aged mixture has the greatest resilient modulus among the five mixture types. This is because the asphalt cement in the aged mixture is the stiffest among others, resulting in the stiffest mixtures. A stiffer mixture has a stiffer resilient modulus; however, a higher resilient modulus is not always desirable, since it causes an increase in brittleness and stiffness, and accordingly a reduction in resistance to fatigue as well as low temperature cracking.

Results also show that with regards to resilient modulus, AM4 is the most similar mixture to the virgin one. In fact, its resilient modulus is merely 5.5% lower than that of AM1. Considering this negligible difference and the results of Marshal Stability test (section 5.5), AM 4 is expected to perform properly as virgin HMA.

5.6 Dynamic Creep Test Results

The flow numbers that are presented in Figure 5 (Left) are the average values obtained from three Dynamic Creep Tests for each mixture type. Figure 5 also shows the percentage that the flow number of other mixtures is lower compared to AM1.

The flow numbers demonstrated in Figure 5 show that the mixtures prepared by the application of the reclaimed asphalt cement are less resistant to permanent deformation compared to the virgin mixture. The rutting depth cannot be measured with the flow number; however, this value is a criterion to compare the creep behavior of different HMA specimens or their resistance to permanent deformation.

Generally, aged asphalt pavement shows more resistance to permanent deformation. In this case, however, results show that increased proportion of HVS initially causes a rise in the flow number, but that adding more than 10% of the rejuvenator causes a fall in its value.

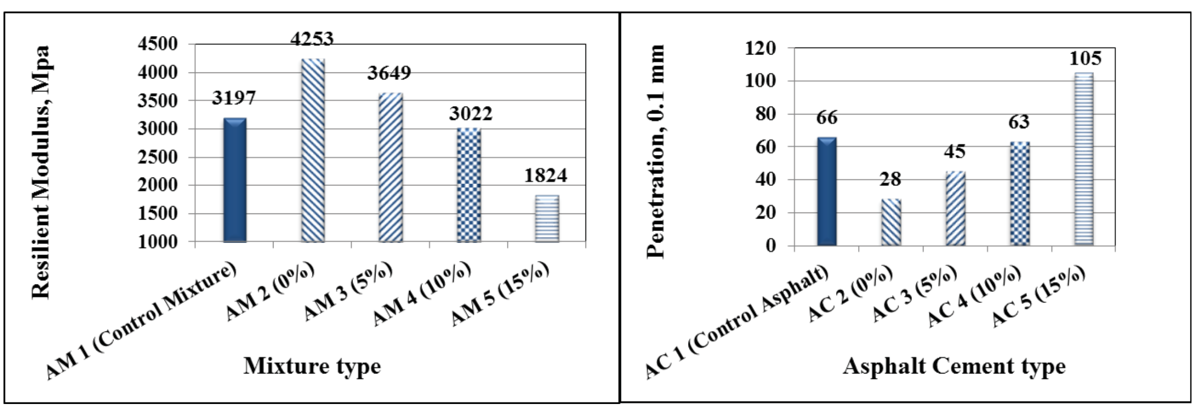

Figure 4. Resilient Modulus of the five mixture types (left) and the penetration grades of their corresponding asphalt cement (right).

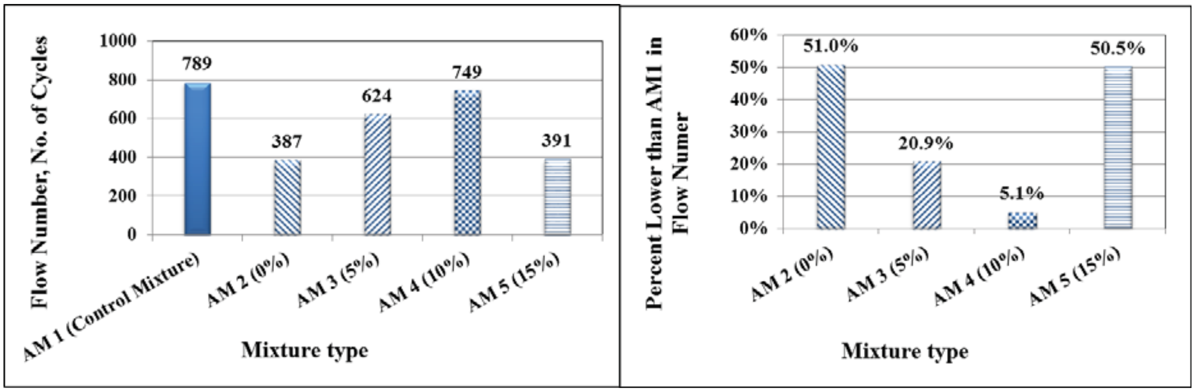

Figure 5. Dynamic creep test results for the five mixture types (left) and the percentage that the flow number of other mixtures is lower compared to the virgin mixture (right).

This may be due to the procedure by which mixtures are prepared. Aged asphalt pavement in the field may show more resistance to permanent deformation, but AM2 is prepared by mixing aggregates with the asphalt cement that is extracted from aged asphalt pavements. In fact, extracted aged asphalt cement contains less maltene, which causes low adherence and consequently lower resistance to permanent deformation. As a result, AM2 (with 0% HVS) has the lowest flow number among the five types. In addition to that, AM5 (with 15% HVS) contains asphalt cement with a low viscosity, resulting a smoother mixture with a low resistance to permanent deformation. Results also show that AM 4 has the greatest resistance to permanent deformation, among the reclaimed mixture types. In fact, the flow number for the AM 4 mixture is only 5.1% lower than that of the control mixture, which is a negligible difference. As a result, AM 4 can perform properly as virgin mixtures in terms of resistance to permanent deformation.

6. Conclusions

In this research, heavy vacuum slops, a product of the Tehran refinery, was used as a rejuvenating agent to reclaim aged asphalt cement by compensating for its lost maltene. In order to evaluate its performance, the reclaimed asphalt cement and the reclaimed asphalt mixtures were tested in a variety of tests. Virgin mixtures, made of AC 60/70 according to Iran's Highway Asphalt Paving Code No.4, were taken as the control mixture. The following conclusions have been drawn:

- Among the asphalt cement types that were reclaimed by using heavy vacuum slops, the reclaimed asphalt with 10% of heavy vacuum slops can be used instead of AC 60/70 under similar conditions.
- None of the reclaimed asphalt mixtures present greater Marshal Stability than the virgin mixture; however, the mixture with 10% of heavy vacuum slops meets the requirements of Iran's Highway Asphalt Paving Code such as for Marshall Stability, Marshall Flow and air voids for HMA. The Marshall Stability of the mentioned mixture is merely 7.4% lower than the stability of the virgin mixture.
- Results of the Indirect Tensile Test show that the virgin mixture and the reclaimed mixture with 10% of heavy vacuum slops present almost equal resilient moduli. The resilient modulus of the latter is merely 5.5% lower than that of the virgin mixture.
- The Dynamic Creep Test results show that the virgin mixture has the greatest resistance to permanent deformation. Among the reclaimed mixtures, the mixture with 10% of heavy vacuum slops presents the highest flow number, which is merely 5.1% lower than that of the virgin mixture.
- Results of the aforementioned tests show that adding 10% of heavy vacuum slops to the aged asphalt results in a mixture that can perform properly as an alternative to virgin HMA.

The heavy vacuum slops produced in the Tehran Oil Refinery Co. are inexpensive and available in large quantities. HMA, on the other hand, is a costly construction material. As a result, using this substance for reclaiming the used HMA, instead of producing virgin HMA, is a cost-effective measure.

Finally, applying 10% of the heavy vacuum slops in order to reclaim the aged asphalt cement is recommended due to economic reasons and the fact that the reclaimed pavement meets the required properties of the virgin HMA.

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