Use of asphalt roofing shingle waste in HMA

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Abstract

Like other construction materials, shingles have their own service life based on raw materials, production method and environmental and climatic conditions. At the end of their service life, shingles need to be replaced. However, these old shingles together with manufacturing scrap and handling waste require large storage areas and pollute the environment in time. Hence, additional usage of shingle waste is desirable. In this study, shingle waste in amounts of 1%, 2%, 3%, 4% and 5% by weight was added as an additive to asphalt concrete mixes prepared with the optimum binder content which yielded the best stability value was 5%. After determination of the optimum percentage of shingle to be added, rutting tests were performed on the specimens. Taking into account, the binder content existing in the shingle, mixtures were prepared with the reduced binder content by 0.5% and 1.0%. Test results show that waste shingles can be used in HMA as an additive to improve the Marshall stability and rutting resistance of the mixtures.

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1. Introduction

The rise in the standard of living and the social and economic development over the last three decades has increased the demand for road usage, for safe and comfortable pavements in many countries. It is obvious that this demand can only be satisfied with pavement design procedures that result in pavements resistant to deformations, with longer service life and with satisfactory surface characteristics.

The commonly encountered distresses such as rutting, fatigue and low temperature cracking due to increase in axle loads, traffic volume, environmental conditions and construction and design errors decrease the expected performance and service life of pavements.

To cope with these types of failures techniques have been developed. One such technique is the modification of hot-mix asphalt (HMA) by the utilization of asphalt roofing shingle scrap. This technique can result in improved performance and service life of pavements.

Approximately 11 million tons of waste asphalt roofing shingles are generated in the US per year. Reroofing jobs account for 10 million tons, with another 1 million from manufacturing scrap. California is estimated to generate 1.2 million tons per year; of which 1.1 million are tear-offs from reroofing jobs [1]. Disposal of waste material is usually accomplished by transporting and depositing it in landfills. If a suitable means of reusing these materials can be found, then their environmental liability could be significantly reduced.

Since asphalt roofing shingles are composed of 30–35% relatively hard asphalt cement, 50–60% fine aggregate/mineral filler and 1–12% organic or inorganic fiber, an alternative to landfill deposition is to use the roofing
waste in a related bituminous material. Such applications could include its use in granular base stabilization, patching materials or in HMA concrete [2].

The objectives of this study were to review the literature to determine the effects of the use of roofing shingles on the engineering properties of HMA and to conduct experiments in order to evaluate the use of roofing shingle waste from the manufacturing process and from reconstruction in HMA concrete mixtures.

2. Literature review

Researchers at the University of Nevada-Reno investigated the economic and technical aspects of using waste roofing for reconstruction in HMA. They concluded that the use of shingle waste resulted in a lower cost of paving material [3]. Paulsen et al. [4] stated that the use of roofing waste tended to increase the stiffness of the mixtures. This could be reasonably expected due to use of higher viscosity asphalt in the shingles along with the reinforcing effect of the fiber.

Information provided from Brock and Shaw [5] showed that if a contractor provided a mixture with 5% organic shingles, the HMA cost could be reduced by 2.79% per ton.

Newcomb et al. [6] conducted some experiments so as to evaluate the use of roofing shingle waste from the manufacturing process and from reroofing construction as additives in both dense-graded and stone mastic asphalt mixtures. The study concentrated on low temperature and permanent deformation characteristics of HMA mixtures manufactured with roofing wastes. Their study showed that

1. Manufactured shingle waste can be incorporated into dense-graded asphalt concrete.
2. The use of shingle waste can result in a reduction of optimum binder content.
3. The utilization of fiberglass manufactured shingle waste in HMA would not offer an advantage at low temperatures.
4. The addition of shingle to dense-graded mixtures improves the rutting resistance of the mixture.

Gryzbowks[7] evaluated the use of recycled asphalt in dense-graded mixtures. The study concluded that the use of shingle waste would improve the rutting resistance of the mixture.

Ali et al. [8] studied the feasibility of using reclaimed roofing materials in HMA pavements. The results indicated that the use of shingles increased the stiffness of the mixtures. The addition of roofing shingles also resulted in a reduction in the additional asphalt cement (AC) required to produce an HMA mixture. Laboratory studies also indicated that incorporating shingle waste in asphalt mixes tends to improve high temperature susceptibility and rutting resistance properties as well as fatigue life of pavements.

Foo et al. [9] prepared mixture designs of HMA mixtures with and without shingles. Their study showed that

1. The asphalt from the shingles causes a significant increase in the stiffness of the recycled asphalt binder, and in order to increase the performance grade (PG) of the recycled asphalt binder by one grade, 5% additional shingle is sufficient.
2. The use of shingles in HMA mixture improves the rutting resistance of the mix. However, the mix may have a lower fatigue resistance and also a lower low temperature cracking resistance. The use of appropriate softer neat asphalt improves the fatigue and low temperature performance of the mix.

3. Processing and engineering properties of roofing shingles

3.1. Processing

Asphalt roofing shingles undergo some processing before being used in HMA. These processes are shredding, screening, blending and watering.

Roofing shingle scrap used in HMA is typically shredded into pieces approximately 13 mm (1/2 in.) in size and smaller using a shingle shredding machine that consists of a rotary shredder or a high speed hammer mill. After this operation, shredded shingles are screened to the desired gradation and stockpiled. Experience indicates that the size of processed pieces should be no larger than approximately 13 mm to ensure complete digestion of the roofing shingle scrap and uniform incorporation into the HMA [10]. Scrap shingle greater than 13 mm in size does not readily disperse, functioning much like aggregate.

Processed roofing shingle material can harden during stockpiling, necessitating reprocessing and rescreening prior to introduction to the hot-mix plant. In order to mitigate this problem, processed roofing scrap may be blended with a carrier material such as sand or recycled asphalt to prevent the particles from sticking together.

A watering process is used to keep the roofing shingle material from agglomerating during processing. However, the application of water is not very desirable because the processed material becomes quite wet and must be dried prior to introduction into the HMA.

3.2. Engineering properties

Some of the properties of roofing shingles tabs are of particular interest when roofing shingles are used
in asphalt paving including asphalt cement content (ACC), asphalt hardness, aggregate content and gradation [10].

The composition of roofing shingle waste materials is complex, varying between product types and forms. They are generally composed of 30-40% air-blown asphalts; 50-60% inorganic mineral filler/granules which supplement the fine aggregate fraction of HMA; and 1-12% inorganic and/or organic fiber (fiberglass, cellulose, etc.) [7,10].

Accurate determination of the shingle scrap asphalt content and penetration is not possible using conventional recovery techniques because asphalt in shingle waste is much harder than that normally used in asphalt concrete paving mixtures. It also contains fibers which tend to stiffen asphalt concrete mixtures. Extended soaking periods are required to extract and determine the available asphalt.

4. Experimental

4.1. Materials

HMA mixtures were prepared with limestone aggregate from Torbali/Izmir quarry. Gradation chosen for this project is the wearing course Type 2 gradation of Turkish specifications. Table 1 summarizes the properties of the aggregate.

<table>
<thead>
<tr>
<th>Test</th>
<th>Specification used</th>
<th>Actual value</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gradation</td>
<td>ASTM C 136</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/4 in.</td>
<td></td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1/2 in.</td>
<td></td>
<td>92</td>
<td>83-100</td>
</tr>
<tr>
<td>3/8 in.</td>
<td></td>
<td>80</td>
<td>70-90</td>
</tr>
<tr>
<td>No. 4</td>
<td></td>
<td>48</td>
<td>40-55</td>
</tr>
<tr>
<td>No. 10</td>
<td></td>
<td>32</td>
<td>25-38</td>
</tr>
<tr>
<td>No. 40</td>
<td></td>
<td>15</td>
<td>10-20</td>
</tr>
<tr>
<td>No. 80</td>
<td></td>
<td>10</td>
<td>6-15</td>
</tr>
<tr>
<td>No. 200</td>
<td></td>
<td>7.5</td>
<td>4-10</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>ASTM C 127</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(coarse aggregate)</td>
<td>Bulk</td>
<td>2.663</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SSD</td>
<td>2.678</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Apparent</td>
<td>2.705</td>
<td></td>
</tr>
<tr>
<td>Specific gravity</td>
<td>ASTM C 128</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(fine aggregate)</td>
<td>Bulk</td>
<td>2.650</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SSD</td>
<td>2.670</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Apparent</td>
<td>2.703</td>
<td></td>
</tr>
<tr>
<td>Specific gravity</td>
<td>ASTM C 131</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(filler)</td>
<td>LA Abrasion (%)</td>
<td>21.5</td>
<td>Max. 35-45%</td>
</tr>
<tr>
<td>Flat and elongated</td>
<td>ASTM D 4791</td>
<td>7.5</td>
<td>Max. 10%</td>
</tr>
<tr>
<td>particles (%)</td>
<td></td>
<td>42</td>
<td>Min. 40% for medium traffic level</td>
</tr>
<tr>
<td>Fine aggregate</td>
<td>ASTM C 1252</td>
<td>36</td>
<td>Min. 35% for medium traffic level</td>
</tr>
<tr>
<td>angularity</td>
<td>AFNOR P 18-564 (French specification)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soundness</td>
<td>AASHTO T 104</td>
<td>1.2</td>
<td>Max. (10-20%)</td>
</tr>
</tbody>
</table>

The properties of the AC are shown in Table 2. As seen from the Table, the AC used in this study is 60/70 penetration grade asphalt (ASTM D 946).

The roofing shingle waste was provided by BTM A.S., a local company in Izmir/Turkey. The properties of the shingle waste are given in Table 3.

4.2. Experimental programme

The plan of this study included the following steps:

1. Determine aggregate physical properties: This section includes sieve analysis (ASTM C 136); specific gravity of coarse aggregate (ASTM C 127), fine aggregate (ASTM C 128) and filler (ASTM D854); Los Angeles abrasion resistant test (ASTM C 131), flat and elongated
Table 3  
Properties of the shingle\textsuperscript{a}  
\begin{tabular}{|l|c|}  
\hline  
Type of material & Value (\%) \tabularnewline  
\hline  
Asphalt (10/20) & 32.5 \tabularnewline  
Fiberglass (glass felt) & 2.5 \tabularnewline  
Filler (CaCO\textsubscript{3}) & 30 \tabularnewline  
Aggregate (Basalt) & 35 \tabularnewline  
\hline  
\end{tabular}  
\textsuperscript{a} Provided by BTM A.S./Izmir, Turkey.

The test is repeated for other specimens of each ACC and an average value for each ACC is taken. As the specific gravity of aggregates and asphalt, bulk density, stability and flow value of the specimen are known, the following graphical curves can then be plotted:

(a) Corrected Marshall stability versus asphalt content.
(b) Marshall flow versus asphalt content.
(c) Percentage of void (Vh) in the total mix versus asphalt content.
(d) Unit weight or bulk specific gravity (Dp) versus asphalt content.
(e) Percentage of void filled with asphalt (VFA) versus asphalt content.
(f) Percentage of void in mineral aggregate (VMA) versus asphalt content.

To determine the optimum asphalt content for the mix design, one takes the average value of the following three asphalt contents found from the graphs obtained in the previous steps.

(i) Asphalt content corresponding to maximum stability.
(ii) Asphalt content corresponding to maximum bulk specific gravity (Dp).
(iii) Asphalt content corresponding to the median of designed limits of percent air voids (Vh) in the total mix (i.e., 4%).

By referring to the curves, stability value, flow value and VFA at the optimum asphalt content are determined and each of these values is checked with Marshall mix design specification values.

Mixes with very high stability value and low flow value are not desirable as the pavements constructed with such mixes are likely to develop cracks due to heavy moving loads.

4. Prepare HMA mixtures with a maximum of 1–5\% roofing shingle as well as control mixtures.

5. Determine the engineering properties of HMA mixtures with and without shingles by conducting Marshall stability test.

6. Draw conclusions based on the results.

7. Conduct rutting tests on the mixtures that contains the optimum single content addition which gives the best value in terms of Marshall stability.

The purpose of the tests performed with the LCPC (Laboratoire Central des Pont et Chaussées) Pavement Rutting Tester (French type traffic simulation equipment) is to characterize the resistance to rutting of the asphaltic materials in conditions which are similar to prevailing conditions on roads.

8. Make overall conclusions and provide recommendations on the use of shingles and on further research.
4.3. Test results and discussion

4.3.1. Marshall mix design

After determining the properties of the materials used in this project, the Marshall stability test was conducted on the specimens that contain different asphalt content in order to determine the optimum asphalt content. The result of Marshall mix design is presented in Table 4 and Fig. 1.

The optimum asphalt content that corresponds to 4% air voids was found as 5%. The calculated and measured mixture properties and their comparison according to design criteria are given in Table 5.

As seen from Table 5, all of the properties of mixture are within specification limits for wearing course.

After determining the design asphalt content (5%), in order to evaluate the effect of shingle waste addition on the properties of conventional (unmodified-neat) HMA, the Marshall stability test was conducted on the mixtures that contain no shingle (control mixes) and on the mixtures that contains 1–5% of roofing shingle waste.

The reason for using 5% as the maximum value of shingle waste addition is that above 5% shingle waste addition, the HMA mixture will exceed the binder tolerance which is ±0.3%. Information on materials used to procedure HMA mixtures is given in Table 6.

The Marshall stability test results of the mixtures that contain shingle waste and control samples; and the change of Marshall stability values based on different shingle waste addition are given in Table 7 and Fig. 2, respectively.

From Fig. 2, it can be seen that Marshall stability values increase up to 1% shingle waste addition. However, as the shingle waste addition increases, the stability values decrease. Therefore, it can be concluded that stability values increases of up to 1% shingle waste addition give the best results in terms of stability. It should be noted that the level of air voids decreases with shingle waste addition (Table 7). Based on the past research [6], it was found out that mixtures containing shingle waste were easier to compact than conventional (unmodified) mixtures. Therefore, it can be concluded that a very low air void level in mixtures may be due to the shingle waste addition.

Researchers indicated that the use of roofing shingle waste can result in a reduction of optimum asphalt content [12,13]. Based on past studies, in order to evaluate the utilization of shingle waste on the reduction of optimum asphalt content, 5% asphalt content was decreased by 0.5% and 1%. The Marshall stability test was conducted on the specimens that were prepared with these two asphalt contents (4.5% and 4%) and 1% roofing shingle waste. Results are presented in Table 8.
Results showed that for both of the specimens compacted with 4.5% and 4% binder content together with 1% shingle waste, the Marshall stability values increased when compared to the control samples (compacted with optimum binder content of 5%). Among these, the sample prepared with 4.5% binder content gave the best value in terms of stability. Therefore, it can be concluded that the utilization of roofing shingle waste in HMA results in a reduction in the optimum asphalt content. The 0.5% reduction in the optimum binder content can result in significant reduction in the cost of HMA.

It is interesting to note that the level of air voids is higher when compared to the control samples. It may be due to the reduction of asphalt cement content. However, the level of air void that corresponds with the mixture that contains 4.5% asphalt stays within the specification limits (3–5%).

4.3.2. Rutting test

When taking 1% roofing shingle waste addition into account, rutting tests were performed on both of the specimens compacted without shingle and 1% shingle waste addition by LCPC pavement rutting tester.
Table 5
Properties of the mix at 3% asphalt content and design criteria for wearing course

<table>
<thead>
<tr>
<th>Type of material</th>
<th>Value</th>
<th>Design criteria for surface course (heavy traffic condition)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>Marshall stability</td>
<td>1036</td>
<td>900</td>
</tr>
<tr>
<td>Bulk specific gravity (Gsb)</td>
<td>2.658</td>
<td>2.658</td>
</tr>
<tr>
<td>Flow (mm)</td>
<td>2.70</td>
<td>2</td>
</tr>
<tr>
<td>Voids in total mix</td>
<td>4.136</td>
<td>5</td>
</tr>
<tr>
<td>Aggregate voids filled with asphalt (VFA)</td>
<td>71.041</td>
<td>65</td>
</tr>
<tr>
<td>Voids in mineral aggregate (VMA)</td>
<td>14.282</td>
<td>14</td>
</tr>
<tr>
<td>Blows</td>
<td>75</td>
<td>75</td>
</tr>
</tbody>
</table>

* Based on normal maximum aggregate size.

Table 6
Material information for Marshall design

<table>
<thead>
<tr>
<th>Aggregate (gr)</th>
<th>No Shingle</th>
<th>1% Shingle</th>
<th>2% Shingle</th>
<th>3% Shingle</th>
<th>4% Shingle</th>
<th>5% Shingle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binder (gr) (5% of mixture weight)</td>
<td>1184</td>
<td>1137.925</td>
<td>1228.85</td>
<td>1113.775</td>
<td>1101.7</td>
<td>1089.625</td>
</tr>
<tr>
<td>Shingle (g)</td>
<td>1282</td>
<td>1282</td>
<td>1282</td>
<td>1282</td>
<td>1282</td>
<td>1282</td>
</tr>
<tr>
<td>Mixture (gr)</td>
<td>1207.5</td>
<td>1207.5</td>
<td>1207.5</td>
<td>1207.5</td>
<td>1207.5</td>
<td>1207.5</td>
</tr>
<tr>
<td>Binder tolerance (±3%)</td>
<td>0.05%</td>
<td>0.09%</td>
<td>0.16%</td>
<td>0.22%</td>
<td>0.26%</td>
<td>0.26%</td>
</tr>
</tbody>
</table>

The test was performed on asphalt concrete slabs (500 x 180 x 100 mm) at 60 °C. The compaction was performed by “LCPC Plate Compactor” for all the mix specimens. The specimens were set at room temperature for 12 h before being tested. The applied load on each pneumatic wheel (400 mm diameter by 90 mm

Table 7
Marshall stability test results based on shingle waste addition

<table>
<thead>
<tr>
<th>Number of blow : 75</th>
<th>Marshall design based on shingle waste addition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Specific gravity of bitumen</td>
</tr>
<tr>
<td></td>
<td>Bulk specific gravity of mix</td>
</tr>
<tr>
<td></td>
<td>Effective specific gravity of mix</td>
</tr>
</tbody>
</table>

Specific gravity of bitumen (Gbm) 1.029
Specific gravity of coarse agg. (Gck) 2.663
Specific gravity of fine agg. (Gf) 2.650
Specific gravity of filler (Gfil) 2.686
Aggregate (gr) 1150

Specific gravity of bitumen (Gbm) 1.029
Specific gravity of coarse agg. (Gck) 2.663
Specific gravity of fine agg. (Gf) 2.650
Specific gravity of filler (Gfil) 2.686
Aggregate (gr) 1150
wide) was 5000 N during the test that provides 600 kPa flexible wheel pressures.

A pre-test loading condition was applied prior to determination measurement; specimens were subjected to 1000 cycles without preheating (1 cycle = 1 travel and return of the tyre). Deterioration measures were then carried out after 100, 300, 1000, 3000, 10,000, 30,000, 50,000 cycles. The test was stopped when the average recorded rut depth after a series of measures was higher than 10% and that the previous results anticipated a rut depth of more than 15% at the following step.

The rut depth was obtained by calculating the average of the 15 measurements located under the wheel movement between the origin and the considered cycles. It is expressed in percentage of the thickness of the original specimen.

\[ \text{Pi(\%)} = 100 \left( \sum \left( \frac{m_{ij} - m_{ij}}{15 \times E} \right) \right) \]  

(1)
Table 8
Marshall stability test results based on optimum binder content reduction

<table>
<thead>
<tr>
<th>Shingle</th>
<th>Bitumen %</th>
<th>Weight in air (gr.)</th>
<th>Weight in saturated surface dry (1%)</th>
<th>Saturated surface dry (1%)</th>
<th>Volume</th>
<th>Bulk specific gravity</th>
<th>Max. theoretical specific gravity</th>
<th>Voids %</th>
<th>VMA %</th>
<th>VPA %</th>
<th>Specimen height (mm)</th>
<th>Stability (kg)</th>
<th>Correlation factors</th>
<th>Flow (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>5.0</td>
<td>1205</td>
<td>702</td>
<td>1206</td>
<td>504</td>
<td>2.391</td>
<td>2.392</td>
<td>14.282</td>
<td>71.041</td>
<td></td>
<td>1114</td>
<td>1000</td>
<td>1023</td>
<td>1036</td>
</tr>
<tr>
<td>1%</td>
<td>4.5</td>
<td>1180</td>
<td>692</td>
<td>1181</td>
<td>489</td>
<td>2.412</td>
<td>2.403</td>
<td>13.846</td>
<td>65.013</td>
<td></td>
<td>1241</td>
<td>1227</td>
<td>1161</td>
<td>1254</td>
</tr>
<tr>
<td>1%</td>
<td>4.0</td>
<td>1195</td>
<td>693</td>
<td>1197</td>
<td>504</td>
<td>2.370</td>
<td>2.530</td>
<td>59.543</td>
<td>57.255</td>
<td></td>
<td>1102</td>
<td>1109</td>
<td>1149</td>
<td>1150</td>
</tr>
</tbody>
</table>

Specific gravity of bitumen (Gb) 1.029
Coarse aggregate % (K%) 46.0
Penetration 60/70
Fine aggregate % (1%) 4.9
Filler % (F%) 4.9
Effective sp. grav. of mix (Gsb) 2.687
Bulk specific gravity of mix (Gsb) 2.687

where \( J \) is the number of measured points; \( m_{10} \) the measure of a certain cycle (average of 15 points); \( m_{100} \) the measure of after 1000 cold cycles (average of 15 points); and \( E \) is the depth of the sample.

The results of the rutting tests are given in Fig. 3.

It should be noted that at the end of 10000 wheel load cycles, the rut depth for the mixture prepared with 1% shingle waste was about 4 mm, while the rut depth for the mixture prepared without shingle was about 16 mm. In addition, the rut depth value after the 30000 cycles (7.5 mm) of the mixture containing shingle is under the specification limit (10 mm).

This result shows that the addition of roofing shingle waste improves the rutting resistance of the mixture considerably.

5. Conclusions and recommendations

The objectives of this study were to firstly evaluate the utilization of shingle waste addition on the performance of HMA in terms of stability and resistance to permanent deformation and secondly to determine the addition on the reduction of optimum asphalt content.

The literature review showed that shingle waste addition increases the stiffness of asphalt concrete paving mixtures. In cold climate conditions, this situation can lead to problems with thermal cracking. However, this project was performed in the hot climatic conditions in Turkey. Therefore, rutting properties of asphalt concrete that contains shingle waste are the main focus of this experimental investigation rather than cold temperature properties of asphalt pavement.
Based on the data presented in this paper, the following conclusions can be drawn:

1. Manufactured roofing waste shingles can be incorporated into the dense graded mixtures and the addition of these waste shingles can produce properties comparable to conventional (unmodified) HMA mixtures.

2. The effect of shingle waste addition on the properties of HMA (containing 1–5% shingle waste) was evaluated by Marshall mix design (Table 7). From Fig. 2, it is concluded that Marshall stability values increase up to 1% shingle waste addition. However, as the shingle waste addition increases, the stability values decrease. Therefore, it can be concluded that 1% shingle waste addition gives the best results in terms of stability and this content is recorded as optimum shingle content addition.

3. The stability values of the mixtures that contain 3% and 4% shingle waste are somewhat lower than the control samples. However, the stability values of these mixtures are still higher than the minimum value of the specification criteria which is 900 kg. The addition of shingle waste above 5% may cause some problems; the binder tolerance of ±0.3% will be exceeded and also some problem may arise during application in batch plants if feeding is done manually.

4. Although shingle waste addition of more than 2% decreases the stability values compared to control samples, flow values do not significantly change and all flow values stay within the specifications (Table 5).

5. The air void level of mixtures containing shingles waste decreases because mixtures containing shingle waste were easier to compact than conventional mixtures. This is also due to the composition of the shingle, which contains 30% filler.

6. In order to evaluate the utilization of shingle waste on the reduction of the optimum asphalt content, the Marshall test was conducted on the specimens that were prepared by 4.5% and 4% asphalt content together with 1% shingle waste.

The results showed that the reduction of the optimum bitumen binder content by 0.5% in the HMA that contains 1% roofing shingle waste significantly increases the stability values of the mixture that contains the same percentage of shingle waste (Table 8). This is another benefit of using a roofing shingle waste in HMA from the performance and economic point of view.

7. The rutting test was performed on the specimens that contain 1% shingle waste by LPCP pavement rutting tester. Test results (Fig. 3) show that the addition of shingle waste improves the rut resistance of the mixture significantly.

8. The literature review indicated that fiberglass shingle waste does not affect the low temperature properties of the mixture. However, it may improve the resistance to fatigue cracking of the asphalt concrete pavement. This study could be improved by conducting further research in order to evaluate the fatigue cracking properties of HMA.

Based on the above results, the advantages of the utilization of shingle waste in HMA are listed below:

1. A reduction in the cost of shingle waste disposed.
2. An environmental benefit resulting from the conservation of landfill space.
3. A reduced cost in the production of HMA concrete resulting from reduction in the use of new material.
4. An improved resistance to pavement cracking due to reinforcement provided by the fibers in shingle.
5. An improvement to pavement rutting due to a combination of the fibers and harder asphalt (10/20 penetration at 25 °C) used in the shingle.

References