The Effects of Aggregate Gradation on Permanent Deformation of Asphalt Concrete

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ABSTRACT

The purpose of this research was to evaluate the rutting resistance of different asphalt concrete mixtures. Different aggregate gradations used in this research included dense gradation, stone mastic asphalt, and hot rolled asphalt. Three kinds of asphalts, i.e. penetration with 85/100 and 60/70, and modified asphalt, were used to fabricate the specimens. Marshall and gyratory testing machine (GTM) mix design method were utilized to design the mixtures. Resilient modulus tests, indirect tensile tests, wheel tracking tests, and gyratory tests were performed to evaluate the rutting resistance of the mixture.

The consequence of this research concluded that SMA had a outstanding performance on resistance of permanent deformation. An advancing evaluating of aging, fatigue, and stripping for SMA were highly recommended. Moreover, constructing an test road to evaluate the performance of SMA in field would be also recommended.

INTRODUCTION

In recent years, the permanent deformation, i.e. rutting, has been experienced in the field of flexible pavement. This is attributed by the tremendous increase of volume of traffic and the raises of axle load and truck tire pressure.

It is known that the rutting resistance of hot mix asphalt is primary related to the aggregate gradation. In order to eliminate the rutting problem, the highway agencies in North America are trying to utilize the stone mastic asphalt (SMA) mixtures in the flexible pavement. The basic concept of these mixes is changing the aggregate gradation to improve the rutting resistance of the mixes.

The purpose of this study is to evaluate the rutting resistance of different asphalt concrete mixtures, and trying to find a solution for the rutting problems in Taiwan. The objectives of this study are:

1. Study the relationship between rutting resistance and aggregate gradation.
2. Evaluate the effects of different grade asphalts on rutting resistance.
3. Establish test data for GTM in Taiwan.
4. Realize the SMA and HRA mixtures that have been suggested as possible solutions to the problem of rutting in Europe, and to study the feasibility in Taiwan.
REVIEW OF LITERATURE

The Cause of Rutting

Rutting of asphalt concrete pavements is the permanent deformation as a result of repetitive traffic loads. Deformation can be caused by consolidation or plastic flow in the pavement layers [1,2]. One of the contributors to rutting in hot mix asphalt (HMA) pavements is excessive asphalt content. Too much asphalt will lead to the loss of interlock between aggregate so that traffic loads will be bore by asphalt not aggregate. Increasing the design asphalt content will decrease the shear resistance of mixtures to induce later movement of materials. An increase in the viscosity of the asphalt cement at the same pavement temperature can improve rutting resistance. For aggregate with larger nominal maximum size, more fractured faces, and more rough surface texture will have obvious effects on mixture to restrain plastic flow [3,4,5].

The rutting associated with the HMA layer, especially on routes with heavy loads and high tire pressures, can be attributed to improper mix design. Some of the most common mistakes when designing heavy duty HMA mixtures are: asphalt content is too high, use of excessive filler material (minus 200 material), and use of too many rounded particles in aggregates [2].

Gyratory Testing Machine (GTM)

The GTM developed by J. L. McRae in 1960’s has been tested to be an effective tool in the evaluation of HMA mixture quality [6,7]. The GTM has the capacity to compact HMA mixtures, and is also a testing machine. This kneading action of GTM can simulate the compaction exerted by rollers during construction and by traffic after construction [2,8].

The GTM has the flexibility on changing vertical pressure, gyration angle, number of gyrations, and type of upper roller (fixed-roller, oil-roller, and air-roller) to simulate field compaction equipments and subsequent traffic. Typically, the vertical pressure applied is 100 or 120 psi, which is approximately equal to truck tire inflation pressures. The settings for the gyration angle and the number of revolutions vary between laboratories.

During compaction of a specimen in the GTM, several parameters which include Gyratory Stability Index (GSI), Gyratory Compatibility Index (GCI), Gyratory Shear (Gs), and Gyratory Shear Factor (GSF) will be determined [2,9]. These parameters are used to evaluate properties of mixtures.

Stone Mastic Asphalt (SMA)

SMA has been developed in Germany since 1970. SMA is such a material: technologically it can be seen as a porous asphalt in which the voids are filled with mastic asphalt. The porous asphalt part forms a very strong aggregate skeleton, which delivers the mix stability. The mastic asphalt, which itself is a mixture of filler and sand that is overfilled with bitumen, forms the durable stuffing [10,11,12].

The concept of the mix can be explained through Figure 1. Figure 1 shows the development of the voids when mixing two aggregates at several mixing ratios. When starting with sand and adding
stone to that sand, the voids content decreases until a minimum value. When adding more stone, the voids content is increasing again.

HMA mixture has a typical stone content in the mix of about 55 percent; so the voids of the mineral aggregate indeed is at a very low level and almost all mineral aggregate takes part in the mix structure. The voids in this structure are stuffed with filler and binder. When overfilling the voids in the structure, the structure looses its cohesion and the stuffing material has to deliver the stability. When the optimum equilibrium between stability and durability for this mix cannot be reached, a solution can be found by changing the design concept: do not look for the highest aggregate density to reduce the binder need, but create more space in the aggregate structure to be able to add more binder, in such a way, the stability of the structure is kept.

Figure 1 shows that can be reached in two ways: either by increasing the sand content or by increasing the stone (coarse aggregate) content. In practice, both ways have been developed: the first way leads to HRA, the second way to SMA.

The theory behind SMA is to maximize the interaction and contact among the coarse aggregate fraction in an asphalt hot mix. This coarse aggregate or stone fraction provides stability and shear...
resistance. The asphalt cement and finer aggregate portions provide the mastic that holds the stone in close proximity. The main mixture features of a SMA are: large proportion of high quality coarse aggregate, high content of relatively high viscosity asphalt cement, relatively high portion of aggregate filler and utilization of stabilizing additive [13].

TEST PLAN

Materials

Two kinds of asphalts (penetration with 85/100 and 60/70), and modified asphalt (penetration with 50/60) were used to fabricate the specimens. The aggregate was from the middle of Taiwan as the Freeway Agency used. Lime was used as a filler. Six aggregate gradations selected corresponds to the specifications of medium gradation, as shown in Table 1 and Figure 2. These aggregate gradations included two dense gradations (DG), three SMA gradations with different nominal maximum size which were suggested by Stuare [14], and one HRA gradation.

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Test Procedures

A flow chart of this study is shown in Figure 3. SMA mixtures were tested to determine if drainage would be a problem and to determine the addition of fibers [14]. The mix design methods were 75 blows per side with the Marshall hammer and 300 revolutions, 100 psi ram pressure, 9 psi upper air-roller pressure, and 3 degree angle with the GTM. The samples were then tested for unit weight, voids in mineral aggregate (VMA), air voids, Marshall stability and flow. The gyratory shear (Gs) was also recorded for each GTM compacted sample in accordance with ASTM D3387 [9].
The optimum asphalt content were used to fabricate the specimens and then tested for resilient modulus, indirect tensile strength, and deformation from wheel tracking test.

**TEST RESULTS AND ANALYSIS**

**Marshall Mix Design**

The drainage-loss in SMA1 mixtures were greater than 0.3 percent for all three asphalts used in this study. There was a tendency that the binder would run off when aggregate with larger nominal maximum size. It was possible that the asphalt cement drains from the coarse aggregate in SMA1 mixtures during the mixing, hauling, and placing operations. Fibers were added into the SMA1 mixtures to stabilize the mastic and significantly reduce the degree of asphalt cement drainage.
The optimum asphalt content was determined by the Marshall mix design method, and the properties of mixtures were obtained as shown in Table 2. Number of findings were concluded from these results as follow:

1. For all three kinds of asphalts, the optimum asphalt content in DGAC1 was lower than in DGAC2.
2. For all three different asphalts, the optimum asphalt contents in SMA mixtures were in order as SMA1<SMA2<SMA3. SMA mixtures with larger nominal maximum size had lower optimum asphalt contents.
3. Although HRA has a lower air void, the stability met the specification requirement.
4. Types of asphalts had no significant effects on unit weight, air void, VMA, Marshall stability and flow.

**GTM Mix Design**

The design asphalt content was chosen as that when produced a sample having a gyratory shear of 3.8 kg/cm² after densification for 200 revolutions [6]. From the comparison between Table 2 and Table 3, the optimum asphalt contents determined by GTM mix design were lower than by Marshall mix design, and the optimum asphalt contents in SMA mixtures were higher than in DGAC.
The gyratory shear of 3.8 kg/cm² was the lower limit required for acceptable rutting resistance of mixtures [6]. For the same aggregate gradation, mixtures with 85/100 asphalt had lower gyratory shear values than mixtures with 60/70 asphalt and modified asphalt, as shown in Figure 4. In Figure 5, SMA mixtures had the highest gyratory shear values then followed by DGAC and HRA mixtures. In addition, the gyratory shear for HRA mixtures with 85/100 asphalt were under 3.8 kg/cm². However, the change on gyratory shear for both SMA and HRA mixtures were more energetic than for DGAC. Also, the amount of air voids in the SMA was affected significantly by the asphalt content and compaction level.

Resilient Modulus Test and Indirect Tensile Test

Resilient modulus and indirect tensile tests were performed at temperature of 4°C and 40°C on the GTM mixtures with 85/100 asphalt. Figures 6 and 7 show SMA specimens have higher Mr and indirect tensile strength than others at high temperature but lower Mr and indirect tensile strength at low temperature. This results indicated SMA mixtures had preferred structural strength to resist...
rutting caused by traffic loads at high temperature. Besides, lower Mr and indirect tensile strength at low temperature implied, SMA had less probability in having thermal crack and split problems to damage pavement.

Wheel Tracking Test

Figure 8 shows the results of wheel tracking test for mixtures with 85/100 asphalt at 60°C. The optimal asphalt contents in the mixtures were determined by the GTM mix design method. SMA specimens had stronger rutting resistance than DGAC and HRA. After 2100 rolling procedures finished, the rutting depth of DGAC was approximately 50% more than SMA mixtures. Moreover, the rutting depth of HRA mixture accumulated to 2.5 cm after 400 rolling procedures.

Specifications of the Marshall mix design method were developed by field experiences. From the test, the Marshall mix design method can determine a similarly optimal asphalt content with the GTM method. But the Marshall stability and flow can not evaluate rutting resistance for different aggregate gradations as in Table 2. However, the gyratory shear in GTM method can be used to evaluate rutting resistance of mixtures. Therefore, the gyratory shear in GTM is a better indicator on estimating of rutting resistance for asphalt concrete.
CONCLUSIONS AND RECOMMENDATIONS

Based on observations and test results, the following conclusions and recommendations could be made:

1. One of potential problems with SMA mixtures with larger nominal maximum size was drainage or separation of the binder and mineral filler during storage, hauling, and placement.
2. The SMA was better than the dense grade mixture to resist rutting. During the compacting procedure by GTM, the SMA specimens were proved having greater Gs. Besides, SMA specimens had stronger rutting resistance than DGAC and HRA for wheel tracking test.
3. The SMA specimens have higher Mr and indirect tensile strength than others at high temperature but lower Mr and indirect tensile strength at low temperature.
4. The amount of air voids in the SMA was affected significantly by the asphalt content and compaction level.
5. The gyratory shear would be various for mixtures with different grade of asphalts. The 60/70 asphalt and modified asphalt could improve the rutting resistance of asphalt concrete.
6. The HRA specimens had worse rutting resistance than DGAC specimens, but this result was unlike many previous experiences in England. The difference could be caused by different environments, various asphalt materials, and diverse asphalt mixtures.
7. The Marshall mix design method could determine a similarly optimal asphalt with the GTM method. Yet the Marshall stability and flow could not evaluate rutting resistance for different aggregate gradations. Therefore, the GTM provided a more effective approach to evaluate the rutting resistance of asphalt concrete mixtures.
8. The consequence of this research concluded that SMA had a outstanding performance on resistance of permanent deformation. An advancing evaluating of aging, fatigue, and stripping for SMA were highly recommended. Moreover, constructing an test road to evaluate the performance of SMA in field would be also recommended.
REFERENCES