Comparison of Mix Design Methods for Asphalt-Rubber Concrete Mixtures

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INTRODUCTION

Over the past few decades, the optimum asphalt content of asphalt concrete paving mixtures has been selected from either the Marshall or Hveem procedure. Each procedure uses a series of laboratory tests to select the optimum asphalt content. This selection is based upon satisfying the following objectives:

1. Limiting permeability.
2. Providing room for additional traffic densification.
3. Insuring adequate strength for carrying traffic loads.
4. Resisting excessive permanent deformation.
5. Providing an adequate film thickness.

Test limits were selected subjectively for these objectives based upon the experience of engineers and historical observations of pavement performance prior to the 1960's. This experience and collection of historical observations reflect the performance of typical (i.e. unmodified) mixtures at lower tire pressures, and lighter truck payloads. When this basis for the design limits is considered, two important questions need to be asked:

1. "Can these conventional methods be used with modified mixtures to select the optimum asphalt content?
2. "Do the limits established for these mix design methods apply to modified mixtures?"

BACKGROUND

Previous research pertaining to mix designs for asphalt-rubber concrete have indicated potential changes in compaction temperature, flow limits (Marshall mix design), and air voids criteria are necessary. Suggested compaction temperatures reported in the literature are 275–300°F (Crafco, Texas A&M), 325–350°F (Vallerga), 375°F (Shuler).(1,2,3,4) Crafco, Inc. suggests increasing the flow limits to 24 for light traffic, 22 for medium traffic, and 20 for heavy traffic.(1) Mr. Vallerga suggests increasing the flow limit to 24.(3)

Criteria for acceptable air voids differs substantially. Crafco, Inc. suggests that the limits be tightened to 3 to 4 percent.(1) If these limits are not met, then adjustments for aggregate gradation or rubber size are recommended. A recent research program conducted by Texas A and M University reported using air voids of 7 percent as acceptable criteria.(2)

All of the information obtained from the literature was based upon the Marshall mix design. Conversations with personnel from Nevada Department of Transportation, and California Department of Transportation indicated that compaction temperatures for the Hveem method were elevated to around 300°F from the standard 230°F. However, Crafco, Inc. reported limited Hveem stability testing done with samples compacted at 230°F yielded satisfactory results.
RESEARCH PROGRAM

Purpose

The extended research program will include four phases of work and will evaluate:

Phase 1: The use of conventional mix design methods for determining the optimum asphalt content for rubber mixtures.

Phase 2: Permanent deformation characteristics between rubber and unmodified mixtures.

Phase 3: Fatigue characteristics for rubber and unmodified mixtures.

Phase 4: Low temperature cracking resistance of rubber mixtures.

This paper will present the outcome of the Phase 1 research. The incorporation of fundamental material properties (i.e. resilient modulus and tensile strength) will be added to the mix design procedures when possible. These tests were included in the anticipation of their providing help in recommending adjustments for current mix design parameters.

Scope

Mixture variables included in the Phase 1 research program were:

1. One aggregate.
3. Rubber AC-5 and AC-20 (16 and 17 percent by weight of asphalt cement, respectively).

The crushed granite aggregate and the AC-20 were selected from the list of materials in the Strategic Highway Research Program (SHRP) materials reference library. This selection will provide a future link between the data bases generated during this research program and the SHRP data base.
MATERIAL

Binders

Both the AC-5 and the AC-20 asphalt cement were obtained from Witco's Oildale, California refinery. The source of crumb rubber was selected by the sponsor and the asphalt-rubber binder was mixed by Crafco, Inc. at their Phoenix, Arizona laboratory.

The physical properties of the unmodified asphalt cement is presented in Table 1. The appropriate American Society for Testing and Materials (ASTM) specifications are also included in this table for comparison. The physical properties of the asphalt-rubber binder are presented in Tables 2 and 3.

Rubber

The rubber used in this research program was an ambient ground rubber with a rubber hydrocarbon content of approximately 45 percent, and a specific gravity between 1.100 and 1.200. The particle size, along with a gradation specification suggested by Crafco, are shown in Table 4.

Aggregate

The aggregate was obtained from Granite Rock Co., in Watsonville, California. This material is a 100 percent crushed aggregate with no history of stripping (i.e. debonding of asphalt from aggregate) problems. The physical properties are presented in Table 5.

The gradation used to prepare the laboratory samples is shown in Table 6 and Figure 1. This gradation was chosen to meet ASTM D3315 1/2-inch dense mixture, Nevada Type 2, and California 1/2-Inch medium specifications (also shown in Table 6).

The combined gradation of both the aggregate and the rubber particles are also shown in Figure 1.

SAMPLE PREPARATION AND TESTING SEQUENCE

Marshall Mix Design

Sample preparation and testing was completed according to ASTM D1559. Two exceptions were made in the ASTM D1559 procedure. First, the material was placed in a 275°F oven for 1-hour after mixing and before compacting to insure that the mixture was at the appropriate compaction temperature. Secondly, the compacted modified samples were allowed to remain in the molds overnight, placed in 230°F for 5 minutes, then extruded. This delay in extrusion was to ensure that there was no volumetric increase in sample size due to the rebound properties of the rubber.

The testing sequence was:

1. Mixing, compaction (50 blows per side, by hand), and extrusion of samples.
2. Cooled to 77°F and heights, resilient modulus (ASTM D4125) and bulk specific gravity (ASTM D2726) determined.

3. Samples were then placed in a 140°F water bath for a half hour. Marshall stability and flow were determined (ASTM D1559).

4. Theoretical maximum specific gravity (ASTM D2041) was determined on extra material retained during mixing.

The resulting data was evaluated according to the criteria for stability, flow, unit weight, air voids, and VMA described in the Asphalt Institute's Manual Series No. 2.

The resilient modulus was determined with a Retsina Mark IV device that dynamically loads a diametrically positioned sample for 0.1 seconds every 3 seconds.

**Hveem Mix Design**

ASTM D1560 and D1561: Samples were originally prepared in accordance with ASTM D1561 and tested according to ASTM D1560.(5) The only exception to either test method was that the samples were extruded after the leveling load and cooled to 77°F for resilient modulus testing. The following sequence for sample preparation and testing was used:

1. Mixing, compaction (20 blow at 250 psi, 150 at 500 psi), leveling load (12,600 pounds) and extrusion of samples.

2. Samples were then cooled to 77°F and the sample height, resilient modulus (ASTM D4125) and bulk specific gravity (ASTM D2726) determined.

3. Samples were placed in a 140°F oven for 2 hours, then the Hveem stability was determined.

4. Samples were cooled to 77°F, then the tensile strength was determined.

5. Theoretical maximum specific gravity was then determined.

Evaluation of test results from this procedure yielded unacceptable test results. Based upon this information, a decision to increase the compaction temperature from the traditional 230°F to 300°F was made. This temperature is consistent with previous field compaction temperatures reported by Crafco, Inc.

Samples were extruded immediately after the leveling load was applied; samples were not cooled down prior to extrusion.

Modification to Compaction Procedure: Samples were mixed, and placed in a 300°F oven for three hours. Samples were then compacted, extruded, and tested as outlined above.

**ANALYSIS OF TEST RESULTS**

The analysis will be presented in five sections:

1. Marshall mix design.
2. Hveem mix design.

3. Comparison between mix design methods.

4. Testing concerns.

5. Additional testing (i.e. resilient modulus and tensile strength).

Table 7 presents the design criteria as presented in the Asphalt Institute's Manual Series No. 2, 1984 for both the Marshall and Hveem mix designs for medium traffic conditions. (6)

**Marshall Mix Design**

Table 8 and Figures 2 and 3 present the test results for both the unmodified and modified mixtures. It can be seen that the addition of rubber tends to reduce the stability and unit weight, while increasing the voids in mineral aggregate (VMA) and flow. Similar levels of air voids can be obtained. These trends are consistent with other research findings and are expected.

It is interesting to note that a mixture with originally unacceptable VMA (Figure 2) can be remedied by the addition of rubber. This is most likely a result of greater film thickness due to the increased viscosity and less absorption of the binder by the aggregate.

The increased flow values while greater than the mix design limits, should be expected. Asphalt-rubber materials should be expected to exhibit greater ability to deform prior to failure.

Based on these limited test results, it appears that only the flow criteria for the Marshall mix design needs to be increased with rubber materials. Rubber mixtures can be formulated to meet all of the other design criteria.

**Hveem Mix Design**

Tables 9 and 10, and Figures 4 through 7 present the test results for this testing. Mix design samples were originally prepared according to the conventional mix design procedure prescribing a 230°F compaction temperature. This data is presented in Table 9 and it can be seen that the majority of the test results are unacceptable.

A second set of mix design samples was prepared using a compaction temperature of 300°F. The results of this testing are shown in Table 10. A comparison of test results for the different compaction temperatures is shown in Figures 4 and 5. In general, the higher compaction temperature can reduce stability and air void values. The impact of compaction temperature on VMA and unit weight varies between AC 5 and AC 20 modified mixtures.

Based upon this comparison, the 300°F compaction temperature for modified mixtures was chosen for the selecting the optimum asphalt content and any further comparisons of data.

Modified mixtures tend to exhibit a reduction in stability, similar to the trend observed in the Marshall mix design. However, the impact of rubber on the unit weight, VMA, and air voids varies with the base asphalt. While the trends varied between base binders, acceptable ranges of air voids were obtained with both modified mixtures. Neither modified mixture met the Hveem stability limits.
This failure of modified mixtures to meet the traditional Hveem stability limits while being able to meet Marshall stability requirements should be expected and can be explained by the differences in the tests. Marshall stability is a measure of ultimate material strength while Hveem stability is a measure of the material's ability to deform laterally for a given vertical load. Given the deformable nature of rubber, it should be expected that rubber mixtures will deform more for a given load, thereby reducing the Hveem stability values. On this basis, it is suggested that lower Hveem stability limits than those traditionally used could still produce acceptable mixtures.

**Comparison Between Marshall and Hveem Mix Designs**

Figure 8 shows a comparison of the optimum asphalt contents selected for each mix design. It can be seen that adding rubber to the mixtures increases the optimum asphalt content, regardless of mix design method. In general, there appears to be a variation of ± 0.5 percent optimum asphalt content between the mix design methods, regardless of type or modification of binder.

**Testing Concerns**

One of the concerns expressed during this research program was the potential volumetric expansion of the sample after extrusion due to the ability of the rubber to rebound. A limited investigation of this phenomena was investigated.

Both one-dimensional expansion of the sample in the mold and three-dimensional expansion of extruded samples were examined. A soil consolidation gauge was used to measure the expansion of a sample in a mold both immediately after compaction and after storage at 77°F for 24 hours. The average expansion of the modified AC 5 was 30/10,000 of an inch. It is felt that this was an insignificant volume change.

Hveem compacted modified AC 5 samples were extruded immediately after the leveling load was applied. Table 11 shows the results for two of these samples. Heights were measured four times around the sample and the diameter was measured twice for each of the top and bottom. Again, it can be seen that the volume change appears to be insignificant.

**Fundamental Material Properties**

Figures 9 and 10 present the results of both the resilient modulus and tensile strength testing for samples compacted at the optimum asphalt cement content. Figure 9 shows that modified mixtures significantly decrease material stiffness at the colder temperatures. The material stiffness is either unaffected or significantly increased at the warmer temperatures.

These trends indicate that modified mixtures can be beneficial in reducing thermal cracking by reducing material stiffness at cold temperatures. It also indicates that rutting (i.e. permanent deformation) can be decreased by increasing material stiffness at the warmer temperatures. Further research in the areas of fatigue testing and permanent deformation will be necessary to ascertain the magnitude of the benefits obtained from these rubber materials.
Figure 10 shows the tensile strengths of both unmodified and modified mixtures. It can be seen that the addition of rubber results in a slight decrease in tensile strengths.

CONCLUSIONS

This research program supports the following conclusions:

1. Marshall mix design. Asphalt-rubber mixtures can be expected to exhibit lower stability and unit weights, and higher VMA and flow than unmodified mixtures; four percent air voids can be obtained with rubber mixtures. It is recommended that the flow limits be increased; previous suggestions of 22 to 24 for flow appear to be reasonable.

2. Hveem mix design. An increase in compaction temperature from 230 to 300°F produces mixtures that can meet the majority of the traditional Hveem mix design criteria. The Hveem stability limits should be lowered because of the increased lateral deformation per given load that is obtained with the presence of rubber.

3. Comparison of mix design methods. Rubber appears to increase the optimum asphalt cement content, regardless of mix design method. Variations of + 0.5 percent asphalt were noticed between the two methods, regardless of binders or modifiers.

4. Testing concerns. It appears that the volumetric increase in the sample size is insignificant when the samples are extruded immediately after compaction. However, this conclusion is based on limited results and should be explored more extensively.

5. Fundamental material properties. A significant reduction in material stiffness at cold temperatures is obtained when rubber is added to the mixture. Material stiffness can possibly be increased at warmer temperatures with the addition of rubber. The addition of rubber tends to result in a slight reduction in tensile strengths.

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