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LABORATORY AND FIELD PERFORMANCE OF SILANE ANTI-STRIP AGENT

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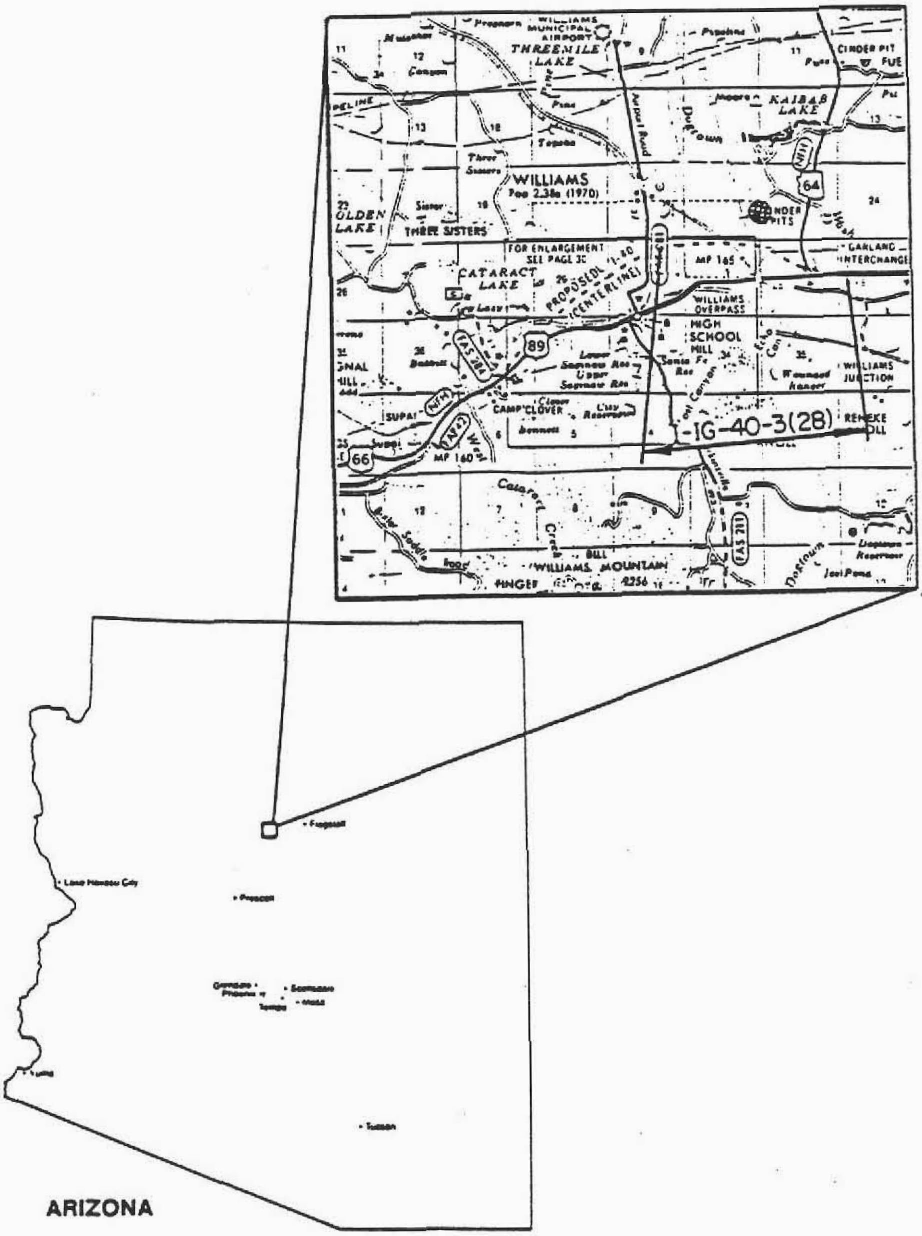

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16. ABSTRACT

A previous ADOT research project resulted in strong evidence that the use of organo-silane as an asphalt additive was very effective in preventing stripping in asphalt concrete pavements. A test section approximately 2800 ft long and 12 ft wide incorporating a silane agent, Dow Corning 990, was placed on the crossroad of the east Williams T.I. on SR 64 between MP 185.3 and 185.7 in October 1981 to verify that claim. Pave Bond Special (PBS) anti-strip agent was used on the remaining portion of the roadway. The PBS sections directly adjacent to the silane test section were designated as control sections.

In January 1984, visual observations of the silane test section indicated that the pavement surface experienced slight raveling throughout the section and moderate to severe raveling at several localized areas. The PBS control section was in excellent condition. The experimental test section was overlayed by 1" ASCS in October 1984 which prevented further field evaluation.

Laboratory tests were conducted on asphalt concrete samples obtained at the time of construction and on cores taken from the silane and PBS sections 5 months and 3 years after construction. The results showed that the PBS treated material have superior properties. However, several factors made the results questionable: difference in bulk densities between PBS and silane cores, clay material was observed in both mixtures and therefore increasing the moisture susceptibility, and long delays between the time the cores were drilled and the time they were tested.

Because of the limited field evaluation and the limitations on the validity of the laboratory results, no major conclusions can be drawn regarding the effectiveness of the silane in preventing stripping.

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INTRODUCTION

An asphalt concrete pavement is inherently dependent upon the cohesive and adhesive characteristics of the binder to hold it together. As a result, the bond between the asphalt binder and the mineral aggregate is of special importance. It is critical that good bond is developed during construction and maintained for the life of the pavement. Any degree of loss of the asphalt-aggregate bond will result in a corresponding loss of pavement performance in one manner or another. The strength of an asphalt concrete mixture is a result of the cohesive resistance of the binder, the adhesive bond between the binder and the aggregate, aggregate interlock and frictional resistance between aggregate particles.

Under certain circumstances, an asphalt binder will separate from the aggregate, a complex phenomenon known as debonding (commonly referred to as stripping). Debonding is a function of the environmental conditions, traffic loading, binder and aggregate characteristics, mixture properties and more. Even though a proper bonding of the asphalt to the aggregate may take place during construction, debonding is still possible. Water intrusion is the mechanism that will facilitate debonding by replacing the asphalt coating on mineral aggregates. Since water will always be present in one form or another, stripping is always a possibility. A brief review of the mechanisms of stripping is presented in a subsequent section of this report.

Failure caused by stripping occurs in two stages: the first stage is the breaking of the adhesive bond between the aggregate surface and the asphalt cement. The second stage is failure of the pavement under traffic (1). If stripping within the pavement becomes excessive, loss of strength may result in excessive deformations caused by repeated loading. Failure caused by stripping can also result in cracking and surface raveling of the pavement.

Several methods have been used to limit the possibility of stripping. Some of the more common methods are:

1. The addition of dry lime or portland cement in small percentages to the mix or lime slurry treatment of mineral aggregate,
2. Precoating aggregates with bitumen prior to asphalt concrete production,
3. The addition of selected natural mineral fillers,
4. Disallowance of known hydrophilic aggregates,
5. Washing, wasting or blending of aggregates, and
6. The addition of chemical anti-stripping agents.

All of these methods, for one reason or another, are not always acceptable or economical in every situation.

OBJECTIVE

A previous ADOT research project (HPR-PL-1(19) Item 178) entitled "An Evaluation of Chemical Coupling Agents to Control Debonding of Asphalt from Aggregates" resulted in strong evidence that the use of organo-silanes were very effective in preventing stripping of asphalt by action of moisture (2). To complement the laboratory investigation, a construction experimental project was approved to establish a test section of asphalt concrete utilizing an Amino functional organo-silane as a stripping preventative.

The purpose of the test section was to compare the performance of an organo-silane known as Dow Corning 990 against Pave Bond Special, an asphalt additive commonly utilized by ADOT.

MECHANISMS OF STRIPPING

Taylor and Khosla (1) indicated in their report that as many as five different mechanisms have been blamed for the loss of bond between the aggregates and the asphalt binder. A brief summary of those mechanisms is given below.

Detachement:

Detachement is the separation of an asphalt film from an aggregate surface by a thin layer of water, with no obvious break in the asphalt film. The asphalt film can be peeled cleanly from the aggregate indicating a complete loss of adhesion.

Displacement:

In this mechanism, water penetrates to the aggregate through a break in the asphalt film. This break can be caused by incomplete coating of the aggregate initially, by film rupture, or by pinholes in the asphalt film which can form after coating dusty aggregates.

Spontaneous Emulsification:

Water and asphalt combine to form an inverted emulsion where asphalt represents the continuous phase and water represents the discontinuous phase. The presence of emulsifiers such as mineral clays and some asphalt additives can aggravate further the stripping problem.

Pore Pressure:

Pore pressure has been suggested as a mechanism of stripping in high void mixes where water may circulate freely through interconnected voids. Densification due to traffic may entrap some water in the voids. Further traffic can cause high water pressure which could lead to the loss of adhesion between the aggregates and the binder.

Hydraulic Scouring:

This mechanism is only applicable to surface courses. Stripping results from the action of traffic tires on a saturated pavement surface. This causes water to be pressed down in front of the tire and immediately sucked away from the pavement behind the tire.

It has been indicated that stripping begins at the bottom of the asphalt bound layer and progresses upward to the top of the layer. This is true because the lower portion of the layer is under tension. This could lead to the rupture of the asphalt film causing water intrusion and therefore increasing the possibility of stripping.

PRODUCT DESCRIPTION

Pave Bond Special:

Pave Bond Special (PBS) is a registered trade name of a Carstab Corporation product. It is marketed as an asphalt additive to prevent debonding. This product was extensively used by ADOT prior to the modification of the asphalt concrete mix design procedures in 1982. Currently this product is an approved anti-strip agent for asphalt concrete friction courses.

Dow Corning 990:

Silane coupling agents were first introduced to improve the water resistance of reinforced plastics. It was soon observed that they also imparted significant improvement to initial properties of laminates (3). Hydrophilic mineral surfaces were used in preparing composites with organic polymers and silane was used to improve the bond. The similarity between the polymer-glass systems and the pavement materials was noted and it was felt that silanes may have the potential to increase the bond between asphalt and mineral aggregate surfaces.

The original product used in the initial laboratory study under HPR-PL-1(19) Item 178 was known as Dow Z-6020. It was a registered trade name of Dow Corning. It was primarily used as a coupling agent for the resin and plastic industry (3). It is a low viscosity liquid of the type: aminoalkyl functional silane with the molecular formula (CH3O)3SiCH2NHCH2CH2NH2. It is only one member of one subclass of the much larger group of functional organo-silane coupling agents.

Dow Z-6020 was not initially marketed for the highway industry. However, the same product was later renamed to Dow Corning 990 and identified as an asphalt additive. According to the manufacturer's information, Dow Corning 990 additive is effective as an anti-stripping agent at low concentrations (0.5 - 1.0 lb per 1000 lb bitumen). The exact quantity added depends on the nature of the particular asphalt mix. A uniform blend is important and can be accomplished by metering the additive directly into the mixing system of an asphalt plant or by adding it to filled tank trucks and recirculating through a bypass system for at least 20 minutes for each of the 1000 gallons of asphalt. A third option available to the contractor is the pretreatment of the aggregate with the additive.

CONSTRUCTION REPORT

The experimental test section is located on the crossroad of the East Williams T.I. on SR 64 between mile posts 185.3 and 185.7. The test section was established by a change order (C.O. # 28) on project I-IG-40-3 (28). This construction experimental feature consisted of adding two-tenths of one percent silane by weight of the asphalt and placing the treated asphalt concrete in a section of pavement that is approximately 2800 feet in length. Two test areas were constructed:

1. Section A is located on the northbound lanes between station 3027+40 and station 592+72 (3046+36.62=593+55.63). The 1980 feet long by 12 feet wide section was placed in the inside travel lane near the centerline of the highway.

2. Section B is located on the southbound shoulder and a part of the outside travel lane between station 3013+73.62 and Station 3021+70. The width of the section varied between 8 and 14 feet (8 ft between sta 3013+73.62 and sta 3016+50, 8 to 14 ft taper section between sta 3016+50 and 3018+00, and 14 ft between 3018+00 and 3021+70).

The location of the test section was selected in the Williams area because of the past history of stripping problems along I-40 in the Williams, Flagstaff and surrounding areas. Stripping has been reported in pavement shortly after the completion of construction activities even when anti-strip agents were used.

The project location and geomerty are shown in Fig. 1 and 2. The size of the section was adequate for field testing and evaluation. The remainder of the project was constructed using PBS, the anti-strip agent originally specified in the construction project. The sections containing PBS and which are directly adjacent to the silane test sections were designated as control sections.

A total of 872.85 tons of asphalt concrete containing the silane was used for this experiment. The silane treated material was placed in the top 2 inch lift of the surface course. The pavement structural components are also shown in Fig. 2. The application rate of the silane was approximately 0.20 % silane by weight of the asphalt cement. The test sections were placed on October 14, 1981. There were no problems associated with placing and compacting the pavement.

Although it was suggested by research personnel that three ranges of silane concentrations be tested (0.05 %, 0.15%, and 0.25 % by the weight of asphalt), only one could be estimated (0.20%) due to problems with metering the low concentration of the silane additive.

PRODUCT EVALUATION PLAN

The research workplan submitted by the Arizona Transportation Research Center (ATRC) to the Federal Highway Administration (FHWA) indicated that the evaluation of the experimental section will consist of conducting laboratory testing on the treated asphalt concrete in both the experimental and control section. A copy of the workplan is enclosed in appendix D.

The tests were to be conducted during construction (i.e. sampled material prior to placement and compaction) and at several stages during the life of the pavement. In addition, the evaluation included visual determination of stripping (if any).

LABORATORY EVALUATION

The laboratory testing program consisted of the evaluation of properties that would reflect the moisture susceptibility of the asphalt concrete mixture. These properties included the strength retention ratios as estimated from the immersion-compression and dynamic stripping tests, conventional mix design properties (i.e. Marshall and Hveem parameters), and the determination of the asphalt binder viscosity to study the effect of the additives on the aging of the binder. The laboratory evaluation consisted of a series of tests that were conducted at three stages within the service life of the pavement. Tests were performed on the treated mixture sampled during construction and on cores obtained from the field 5 months later and 3 years later.

Material Sampled During Construction:

The tests listed below were conducted on both the PBS and silane field mixtures obtained prior to compaction:

A) Immersion-compression, Marshall stability and flow, Hveem stability and cohesion , and viscosity of extraction binder.

B) Resilient modulus on Hveem compacted specimens when dry and after conditioning with the hydraulic device. The test is continued until failure.

Part A of this program was completed on January 22, 1982. Part B was delayed until July 9, 1982 due to equipment malfunctions. The results of both parts are shown in Tables 1 to 3.

Cores Obtained After Five Months:

Field samples were obtained on March 10, 1982 from the experimental and control sections. Twenty cores were taken at random in each section. The location of the cores are included in Table 4. The tests conducted on these samples included the immersion-compression, resilient modulus tests on original and conditioned cores, and visual determination of stripping. The results of these tests are presented in Tables 5 and 6.

Cores Obtained After Three Years:

Field samples were taken again after the pavement had been in service for three years. A total of eighty four cores were drilled. Some of the cores were drilled next to the 1982 locations and the remaining were selected at random in both the control and experimental sections. The location of the cores are included in Table 7. The coring operation began in January 9-10, 1985 and was completed in February 12-14, 1985.

A comprehensive testing program was performed on the cores selected from both the control and the experimental section. The tests included the resilient modulus evaluation, Hveem and Marshall tests on both the original and remolded cores and binder extraction on both PBS and silane mixtures. The test program was completed in April 24, 1986. The results are listed in Tables 8 and 9.

Discussion of Laboratory Results:

The results of tests performed on the samples obtained from the field during construction showed a slight difference between the properties of both the silane and PBS treated mixtures. The silane mixture showed slightly higher stability values which might be attributed to the difference in the average bulk density. Although the silane mixture exhibited a higher wet strength, the strength retention ratio obtained from the immersion-compression test was a little higher for the PBS samples.

Higher resilient modulus values were obtained for the dry specimens containing the silane treatment. The specimens containing both the PBS and silane treated material cracked after conditioning. Note that the resilient modulus tests were delayed for approximately six months after the completion of the first part of the testing program. In addition, a substantial amount of clay was observed throughout the mix. Therefore the results should be reviewed with caution.

The results of the tests conducted on the cores obtained in March of 1982 are listed in Tables 5 and 6. Visual observation during testing revealed obvious weakening of cores after exposure to moisture. The weakening was observed as cracking and small eruptions in the cores. Closer examination of the cores showed clay balls to be the cause of the distress. The presence of clay was also noted in the production samples which were tested earlier. The influence of the clay on the results of the tests conducted on the cores limits the validity of any conclusions drawn on the performance of the two additives.

The results indicated that the PBS cores showed superior properties to the silane cores. Strength retention values from both the immersion compression and dynamic stripping were higher for the PBS specimens.

Similar visual observations were made on the cores obtained in 1985. Clay material was observed throughout the mix. Another factor limiting the validity of using these test results to compare the performance of the two additives is the long delay experienced between obtaining the cores and the completion of the testing program (approx. 15 months). To complicate the matter further, the cores showed consistently higher densities in the PBS section. The results of the tests indicated that the PBS have superior properties. It is not known to what extent the difference in the densities had on these results. Voids calculations showed higher air voids in the silane section. Air voids in both the silane and PBS cores were higher than the expected design air voids as obtained by the Marshall and Hveem methods. Note that the higher air voids in the mixture, the higher chance for water intrusion and therefore the higher moisture susceptibility of the mixture. This could explain some of the difference between the properties of both PBS and silane mixtures.

Absolute viscosity tests conducted on extraction binders from cores obtained in January 1985 indicated the silane agent increases the viscosity of the asphalt binder. This increase in viscosity may result in a decrease in the flexibility of the pavement and therefore a decrease in the pavement serviceability due to possible fatigue cracking.

In conclusion, although the PBS cores indicated higher stripping resistance as shown by the higher strength retention ratios for tests conducted on the original mixtures as well as the cores, it is hard to rank one product over another. The difficulty arises from different factors which include the presence of clay material in both mixtures, the difference in densities between the PBS and silane cores, and the delay in testing the cores after obtaining them.

FIELD EVALUATION

The project suffered a delay in inspection reporting until January, 1984 when the test section was visually inspected and photographed (Fig. 3-7). The control sections were in excellent condition (Fig. 8) with no apparent visual distresses.

Fine particle erosion was observed in the silane test areas. Slight raveling was visible throughout test area A. The fine particles were eroded leaving the coarse aggregates exposed (Fig. 6 & 7). On the other hand, test area B showed more localized raveling of higher severity than that observed in section A (Fig. 3 & 4). The distressed areas in test area B were located near the construction joint between the silane and the PBS test sections.

The original pavement design required an 8 1/2 in. thick asphalt concrete surface course and 1/2 in. thick asphalt concrete friction course (ACFC) be placed on top of the 10 in. aggregate base. The friction course was to be placed the following fall. However, the friction course was later deleted and the thickness of the surface course was reduced by 1/2 in. (C.O. # 24 project I-IG-40-3(28)). This action was taken by the Materials section because of problems experienced with the open-graded friction courses in a freeze-thaw environment (4). These problems were more visible in areas that were not exposed to sunlight because of ice accumulation. This condition is typical of that existing in the premises of the experimental project.

The reduced thickness was replaced by a 1 in. thick asphalt concrete dense mix overlay with a 1/2 " maximum aggregate size. The overlay was placed under project I-IG-40-3(58) which was completed in October of 1984. Portland cement was used in the 1 inch overlay to prevent stripping.

The presence of the overlay prevented ATRC's personnel from visually comparing the stripping potential of the control and experimental sections. A visual field inspection was performed in August of 1985 to evaluate the condition of the pavement after the overlay had been placed (Figure 9-11). No signs of distress were observed other than two transverse cracks extending across the full width of the pavement at the beginning and end of the test section.

No major conclusions could be drawn for the purpose of comparison between the experimental and control section based on the available field inspection reports.

CONCLUSIONS AND RECOMMENDATIONS

The results of laboratory tests conducted at different stages during the three year evaluation period suggest that PBS has superior properties. However, the reliability of these results is questionable due to several factors: a difference in the bulk densities of the cores obtained from the test sections was experienced with PBS cores consistently exhibiting higher densities, clay material was observed in all mixtures increasing the moisture susceptibility, and long delays were experienced between the time the cores were obtained and the time they were tested.

The field evaluation indicated a slight to moderate raveling of the fine particles in the silane test sections. The long term performance of the additives could not be obtained since both sections were overlayed.

In conclusion, the comparison of the PBS and silane anti-strip additives are inconclusive and would not affect current ADOT specifications. At the present time, ADOT uses liquid anti-strip agents on ACFC mixes. Several products are included on the Material's approved products list. Portland cement and lime are currently used to control stripping in dense mixtures. Usually, 1 to 2 % by weight of the mineral aggregates are added to original mixes and 1 % by weight of virgin and salvaged material are added to recycled asphalt concrete.

Further laboratory and field testing will be required before recommendations could be made as to whether or not this product should be included in the anti-strip agents' approved list.

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