한국도로학회 논문집
第8券3號 2006年 9月
pp. 39 ~ 48

코팅재료를 이용한 비쇄석골재의 성능향상

Improvement of Low-quality Local Aggregates Using Coating Materials

박 대 욱* 김 민 구**
Park, Dae Wook Kim, Min Gu

요 지

세립의 포리에틸렌, 카펫부산물, 시멘트와 라텍스로 코팅된 매끄럽고 둥근 규사질의 강자갈을 가지고 실험적인 조사가 이루어졌으며 아스팔트 혼합물 공시체를 만들었다. No. 4번체 이상에 남아 있는 골재만 코팅을 하였다. 개념은 매끄럽고 둥근 강자갈을 코팅함으로서 표면 거칠기를 증가시켜 공학적 특성이 우수한 혼합물을 만들어 내는 것이다. 표준 테스트와 비표준 테스트를 이용하여 아스팔트 혼합물 공시체를 평가하였다. 코팅과정과 제한된 혼합물 공시체 테스트 결과에 근거하여 다음과 같은 결과를 얻을 수 있었다. 세 가지 종류로 코팅된 골재를 사용한 혼합물들은 Hveem과 Marshall 안정도, 인장강도와 회복탄성계수가 증가되었으며 이는 코팅되지 않은 골재로 만든 혼합물과 비교하여 소성변형과 균열저항성이 향상된 것으로 판단할 수 있다.

핵심용어 : 아스팔트 혼합물, 골재코팅, 시멘트, 라텍스, 카펫부산물, 최저성능골재

Abstract

A laboratory investigation was conducted wherein smooth, rounded, siliceous river gravel aggregates were coated with fine-grained polyethylene, carpet co-product, or cement + styrene butadiene rubber latex and used to prepare hot mix asphalt concrete specimens. Only the coarse (+ No. 4) aggregates were coated. The concept was that the coatings would enhance surface roughness of the aggregates and, thus, produce asphalt mixtures with superior engineering properties. Hot mix asphalt specimens were prepared and evaluated using several standard and non-standard test procedures. Based on experiences during the coating processes and analyses of these limited test results, the following was concluded: All three aggregate coating materials increased Hveem and Marshall stability, tensile strength, and resilient modulus(stiffness). These findings are indicative of improved resistance to rutting and cracking in hot mix asphalt pavements prepared using coated gravel aggregates in comparison to similar uncoated gravel aggregates.

Keywords: asphalt mixtures, aggregate coatings, cement, latex, carpet co-product, marginal aggregate

* Member, Assistant Professor, School of Civil and Environmental Engineering, Kunsan National University, Kunsan, Korea
** Project Geotechnical Engineer, Williams Earth Sciences, Inc., Largo, Florida, USA.

1. INTRODUCTION

There are generally three basic types of coarse aggregates used in hot mix asphalt(HMA) pavement construction: naturally occurring uncrushed gravels, crushed or partially crushed gravels, and quarried or crushed stone. As a result of the production process, quarried stone particles have 100% crushed faces. This is a desirable trait from the standpoint of cohesive strength of paving mixtures, adhesive strength of cements(such as asphalt or cement), and shear strength of a stabilized compacted paving mixture. Naturally occurring gravels and sands, on the other hand, often have smooth, rounded surfaces(particularly those in the southeastern United States) and thus yield lower values of cohesive, adhesive, and shear strength in HMA.

Poor adhesion at the asphalt-aggregate interface may lead to premature failure of a pavement(rutting or disintegration) due to moisture susceptibility. Smooth, rounded aggregates also produce asphalt-paving mixtures with relatively low stability. Low stability mixtures are subject to premature rutting and/or shoving in the wheelpaths. These types of premature pavement distresses act to significantly reduce the service life and thus the cost effectiveness of paving materials. Generally, high quality, angular aggregates are most desirable and, therefore, are generally required in asphalt paving applications. In fact, pavement construction specifications are customarily written to limit or even disallow the use of the lower quality, rounded aggregates having smooth surface textures. Consequently, high quality aggregates suitable for paving purposes have been depleted or nearly depleted in many areas of the U.S. Only sands and gravels, which do not meet current state DOT specifications without crushing, are available at certain locations.

Further, many of these materials are too small in diameter to crush and provide a usable product. Costs for hauling high-quality aggregates suitable for use in hot mix asphalt can exceed the cost of the aggregate itself when the haul distant is only 20 to 50 miles. Therefore, the benefits of a process that permits the use of otherwise unusable locally available aggregates could be tremendous. It should be feasible to treat the surface of aggregate particles to enhance surface texture and/or angularity and thus improve resulting pavement performance. A potentially beneficial treatment method is to permanently coat the aggregate particles with a hard, rough material that would improve adhesive strength of the asphalt-aggregate interface and cohesive strength or stability of a compacted asphalt paving mixture. The coating would need to be tough enough to resist being abraded off the particle surface during mixing in the asphalt plant and during subsequent handling associated with pavement construction.

The principal objectives of this research are to: review existing information on coating of marginal aggregates to improve the quality of asphalt paving mixtures, identify promising materials for coating marginal aggregates(particularly industrial by-products and consumer waste materials), and conduct a laboratory study to investigate the feasibility of using selected coating materials for improvement of aggregate and/or paving mixture quality.

2. LITERTURE REVIEW

Because of the rounded shape and smooth surface texture of most naturally occurring sand and gravel particles, these types of low-quality aggregates often yield poor performance in asphalt pavements from the standpoints of stability(resistance to rutting and shoving), flushing, moisture susceptibility, and skid resistance. The mechanism of adhesion between an aggregate surface and the bituminous binder and past experience of the authors and the industry indicates that a rough-textured aggregate develops improved mechanical interlock at the asphalt-aggregate interface that will promote adhesion and retard stripping. Furthermore, such roughness provides a significant increase in the internal friction of an asphalt paving mixture which, in turn, improves the shear strength and thus increases the load-bearing capacity of the HMA mixture.

Surface texture of aggregates, like particle shape, influences the workability and strength of hot mixed asphalt(Button et al., 1992). A rough, sandpaper-like surface texture, such as that found on most crushed stones, tends to increase shear and even tensile strength but requires additional asphalt cement to overcome the decrease in workability, as compared to the smooth surface such as that found on many naturally occurring river gravels and sands. Voids in a compacted mass of rough-textured aggregate are also usually higher which is important for providing adequate voids in the mineral aggregate(VMA).

Hunter et al.(1984) examined certain benefits in HMA from coating aggregates with a proprietary polymer called Accorex. Laboratory experiments indicated that a very small quantity of this material added to hot aggregate and subsequently used to prepare HMA specimens provided a coating that yielded significant improvements in resistance to cracking and rutting of pavements. Although not identified by the supplier, Accorex appeared similar to polyethylene or polypropylene. Coating of aggregates for use in HMA could prove to be a beneficial use of these common waste materials.

Button et al.(1992) investigated the effects of cement mortar coatings on round, smooth aggregate particles in HMA. A paste of portland cement and water was applied to coarse and intermediate sized aggregates, allowed to cure for at least seven days, and then used in HMA in the laboratory and in the field. Laboratory tests included Hveem and

Marshall stability, resilient modulus as a function of temperature, indirect tension, moisture susceptibility, creep, and permanent deformation. Laboratory test results indicated that asphalt mixtures made using cement-coated aggregate exhibited higher stability and lower creep-compliance than similar uncoated mixtures. This indicates that the cement coating process will decrease the rutting potential of asphalt mixtures made using marginal aggregates. Full-scale coating tests and subsequent production of HMA were successfully conducted in the field. The chief problem associated with the portland cement paste treatment was loss of the coating due to abrasion during mixing in the asphalt plant and subsequent handling associated with loading, hauling, placement, and compaction. Based on this work, a tougher, more abrasion-resistant coating was clearly desirable.

Williams et al.(1998) coated aggregates with SBR from latex to retard stripping in HMA. Stripping is defined as the loss of adhesion between the asphalt binder and the aggregate surface as a result of moisture infiltration into the asphalt concrete. Coating of aggregates with latex exhibited improved adhesion at the asphalt-aggregate interface as evidenced by improved resistance to moisture damage in the laboratory. One task of the Strategic Highway Research Program(SHRP), Project A-004, was to examine the utility of coating marginal aggregates for use in HMA(Brown et al., 1991). Most of this work was devoted to coating coarse aggregates with phenol. Phenol is a byproduct of the petroleum refining industry and is thus quite chemically compatible with asphalt. The primary objective was to improve resistance of HMA to moisture damage. The objective was achieved and, furthermore, phenol also produced significant improvements in stability of compacted HMA mixtures as measured in the laboratory. The phenol coating process was not attempted in the field, since, based on the laboratory experiments, the process did not appear to be cost effective.

3. LABORATORY TESTS AND RESULTS

3.1 Experimental Design

Low-quality aggregates typical of those found in southern and southeastern Texas as well as the southeastern United States were used to perform a comparative evaluation of the changes in engineering properties of asphalt concrete mixtures using uncoated and coated aggregates. The experiment design consisted of one type of aggregate(uncoated and coated), one type of asphalt binder, and three different types of coating materials. The coating materials included:

- fine-grained polyethylene,
- a by-product or co-product from the nylon carpet recycling process, and
- portland cement paste plus styrene butadiene rubber latex.

Asphalt mixture designs by TxDOT method were performed; then a total of 48 hot mix asphalt mixture specimens were prepared and tested to accomplish the objectives of this study. Several common laboratory test protocols were employed to evaluate any benefits of the aggregate coatings on HMA properties. Triplicate tests were performed to ensure statistical validity of the findings.

Asphalt cement with a grade of PG 64-22 was selected for use in the asphalt aggregate mixtures tested in this research. Uncrushed siliceous river gravel and sand(field sand and concrete sand) were obtained from local sources that mine the Brazos River flood plain, Brazos County, Texas. These materials ranged in size from 19 mm to minus No. 200(0.075mm). Additionally, siltsize material from iron ore gravel obtained from East Texas was used to supplement the fine material in the HMA mixture design. All aggregates were separated using preselected sieves then recombined to accurately produce the desired gradation. Specific gravity of the coarse and fine aggregates was measured in accordance with the ASTM C 127(AASHTO T 85) and C 128(AASHTO T 84), respectively. These values represent the averaged results from standard laboratory tests conducted on the three different aggregate samples that were blended to produce design gradation.

Gradation of the aggregates used to prepare the asphalt specimens was achieved in accordance with TxDOT Type C hot mix asphalt mixture design. Coincidentally, this gradation also meets the Superpave gradation requirements for a 12.5-mm nominal size hot mix asphalt. An aggregate gradation is provided in Table 1.

Table 1. Aggregate gradation (12.5mm nominal maximum size)

Sieve size (mm)	Total percent passing (%)
19.0	100
12.5	95.0
9.5	83.0
4.75	60.0
2.36	37.0
1.18	22.0
0.6	14.0
0.3	10.0
0.15	5.5
0.075	3.5

Hot mix asphalt mixture design was performed in accordance to TxDOT Method, Tex-204-F(TxDOT, 2005). The Texas gyratory shear compactor was used to fabricate all asphalt-aggregate mixture specimens in this research.

A best-fit line was constructed through the plotted points. An air void content of 4% was used to establish the optimum asphalt content. The optimum asphalt content was determined to be 4.3% by weight of total mix.

3.2 Description of Coating Materials

Three different types of materials were used to coat the coarse aggregates prior to their use in fabrication the hot mix asphalt specimens. Each coating material was applied to the surfaces of the aggregates retained on the No. 4 sieve. A description of each coating material and the methodology employed during application of the coatings are presented below.

Polyethylene

Millions of tons of polyethylene are recycled each year. Many more millions of tons are deposited in landfills. Virgin or recycled polyethylene is relatively easily obtained at many locations across the United States. Due to convenience and availability, virgin polyethylene was used in this study; however, the primary concept was to use recycled polyethylene. Low density granulated polyethylene was used herein to coat the coarse aggregate. Polyethylene particle sizes ranged from 1mm to 2mm. A description of the coating process follows.

Coarse aggregates were placed in a 188℃ oven for 24 hrs. Temperature and duration in the oven were chosen from many trial and error laboratory experiments. An oven temperature at 188℃ was selected for this particular polyethylene because it was just hot enough to melt the polyethylene such that it would stick to the aggregate surfaces and leave a textured polyethylene surface with minimal adhesion between the coated aggregates. A higher temperature would completely melt the polyethylene such that it would form a smooth surface on the aggregate and would glue the aggregate particles firmly together upon cooling.

By experimentation, the appropriate amount of polyethylene was determined to be 2.5% by weight of coarse aggregate, which equates to 1.0% by weight of total aggregate. This amount did not completely coat all individual aggregate particles but did provide a rougher surface texture. It is also believed that this amount is near the maximum that is economically attractive.

A bowl of aggregates was removed from the oven and, immediately, the granulated polyethylene was slowly sprinkled onto the hot aggregate while during mixing to coat the aggregate particles as uniformly as possible. Mixing was continued until the aggregate had cooled sufficiently to avoid sticking of the aggregates. Typically, aggregates should be heated to a temperature 5.5 to 11℃ above the desired temperature to ensure adequate time to accomplish the mixing/coating process before excessive cooling.

Recycled Carpet Co-Product

A co-product from the Allied Signal nylon carpet recycling process was used to coat coarse gravel aggregate. The composition of the co-product consists of approximately 45% $CaCO3$, 11% styrene-butadiene rubber(SBR from latex), 35% polypropylene, and 9% other(including dirt, etc.). The raw co-product consists of "flakes" up to 25mm in diameter and about 6mm thick. After grinding, the material has the appearance of brown dust with a grain size of approximately 2.4mm to 0.15 mm. In this experiment, the finer carpet co-product was used to enhance uniform distribution onto the aggregate surfaces and to facilitate rapid melting when the material contacted the hot aggregate. The smaller particles assisted adhesion to the aggregates. The coarser(unground) co-product would likely induce nonuniform coatings on the aggregates and agglomerations among the aggregate particles upon cooling.

Coating the carpet co-product onto surfaces of aggregates involves essentially the same process as that of coating with polyethylene. The appropriate amount of co-product for coating was visually determined to be 2.5% by weight of coarse aggregate. The oven temperature used was 188℃, but, for future work, the authors suggest that a higher temperature may improve the process and the resulting coating quality.

Cement & Latex

Button et al.(1992) coated aggregate with portland cement paste(no latex) and allowed the paste to completely cure prior to fabricating asphalt-aggregate mixtures in the laboratory and in the field. They found that a major portion(> 90%) of the cement coating was abraded off the aggregate surfaces during subsequent handling of the aggregates(i.e., transporting, mixing with asphalt, and compacting). Therefore, they concluded that the cement paste was not effective for coating aggregates to permanently improve roughness of aggregate surface texture and angularity nor other properties of asphalt-aggregate mixtures.

A small amount of styrene butadiene rubber(SBR) latex was incorporated into the wet cement paste in an attempt to improve the toughness and thus abrasion resistance of the subsequent coating on the coarse aggregate. The basic remise of the cement + latex coating is to create a rough-textured surface on the coarse aggregate particles in order to enhance inter-particle friction and promote adhesion between the asphalt binder and aggregate surface.

The concept was to coat aggregate particles with a hydrated cement film, which is thick enough to permanently shield the aggregate particle surface, but not so thick as to cause the particles to stick together and form cemented aggregate agglomerations. To formulate optimum cement coating quantities, the following three parameters were previously determined by Bayomy et al.(1984):

- Percent of cement added for each type and size of aggregate,
- Water content needed for cement hydration and bringing the aggregate to the saturated-surface-dry condition, and
- Minimum hydration time needed to achieve permanent bond of the cement coating film to the particle surfaces.

The portland cement content calculated and used for this research was a 4.3% by weight of the coarse aggregates. After coating the aggregates with cement and allowing it to hydrate, latex was applied onto the coated aggregates. The ideal amount of latex for coating the cement-treated aggregates was determined by trial and error. The idea was to apply as much latex as possible without causing the aggregates to stick together. Latex content was selected as 0.5% by weight of aggregate for subsequent HMA sample fabrication. An excessive quantity of latex caused agglomerations between the cement coated aggregates.

The aggregates coarser than the No.4 sieve were coated using an appropriate amount of cement paste and allowed to cure. Then, the calculated amount of latex was added onto the coated aggregates in an attempt to increase adhesion between asphalt cement and surfaces of aggregates. After cement and latex coating of the aggregates is completed, the coated aggregates were cured in a humidity and temperature controlled environment for at least two days. The latex content selected was 0.5% by weight of coarse aggregates.

4. MIXTURE PROPERTIES AND TEST RESULTS

4.1 Sample Preparation

Uncoated aggregates were separated using appropriate sieves and then recombined in accordance with the mixture design to ensure an accurate and consistent gradation in all HMA specimens. Asphalt concrete specimens(100mm diameter by 50mm height) were prepared using the Texas gyratory compactor in accordance with TxDOT standard Tex-206-F(TxDOT, 2005). Mechanical properties of the asphalt mixture specimens containing uncoated and coated aggregates with the three different coating materials were compared based on Hveem stability, Marshall stability, resilient modulus, and indirect tension.

4.2 Hveem Stability

Hveem stability tests were conducted in accordance with ASTM D 1560. Hveem stability is an empirical measure of the interparticle friction of the aggregates comprising an HMA mixture. Hveem stability of the coated samples was consistently higher than that of the uncoated samples.

This result indicates that all three coating materials improved the surface texture of the aggregates thereby improving the internal friction and thus enhancing the Hveem stability of mixture. This is indicative that the HMA mixtures containing coated aggregates will exhibit improved resistance to rutting in a pavement. Figure 1 shows a bar chart to facilitate comparing Hveem stability of the different sample types. Each value represents an average from three independent tests. Polyethylene coated aggregates appear to provide the largest improvement Hveem stability.

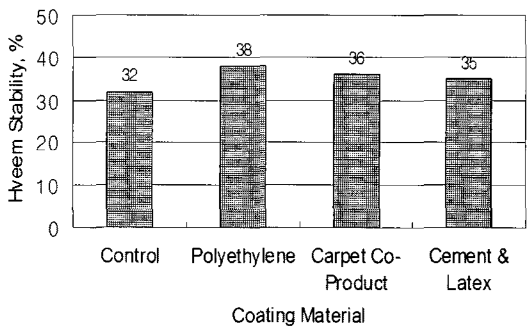

Figure 1. Hveem Stability for Tested Mixtures

4.3 Marshall Stability

Marshall and Hveem tests have been used for more than 50 years to design and evaluate HMA paving materials. Marshall stability was performed in accordance with ASTM D 1559. Marshall stability and flow values of asphalt concrete materials are recognized as measures of the material's ability to resist plastic flow. Typically, aggregates with higher angularity and surface texture will produce HMA with higher Marshall stabilities and lower Marshall flow.

Marshall stabilities of the mixtures containing the three different types of coating materials and the uncoated mixture are compared in Figure 2. Generally, the asphalt samples containing coated aggregates exhibited approximately 30% higher stability values.

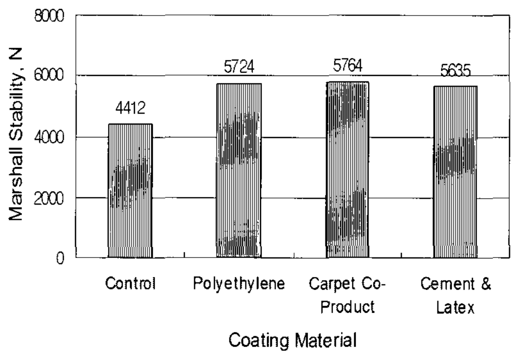

Figure 2. Marshall Stability for Tested Mixtures

4.4 Resilient Modulus(M_R)

Repeated load indirect tension resilient modulus tests(ASTM D 4123) were performed on compacted HMA specimens containing coated and uncoated aggregates at temperatures of 1℃, 20℃, 25℃, and 40℃, respectively. The resilient modulus test, developed by

Schmidt(1972) was designed to measure the stiffness or load bearing capacity of asphalt stabilized aggregate mixtures. This method is simple, fast, and economical and can be performed on standard size(100mm diameter and 50mm height) cylindrical asphalt specimens. During the course of test, a dynamic load was applied and total deformation was recorded. In the computation of M_R, Poisson's ratio was assumed to be 0.35.

M_R of the four different types of specimens were plotted as a function of temperature(Figure 3). The asphalt samples containing coated materials consistently exhibited higher M_R values than uncoated(control) samples. These findings indicate the coated aggregates produce HMA mixtures with greater stiffness and thus higher load bearing capacity.

Resilient modulus was calculated using the following equation:

$$M_R = P\frac{(\upsilon + 0.273)}{t\delta} \quad (1)$$

where, P = vertical load(kg),
υ = Poisson's ratio,
t = specimen thickness(cm),
δ = horizontal deformation(cm), and
M_R = resilient modulus(kg/cm²).

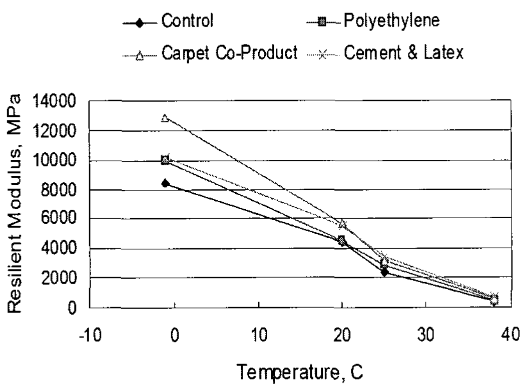

Figure 3. Resilient Modulus for Tested Mixtures

4.5 Tensile Properties

Tensile properties of asphalt mixtures with and without coating were measured using the indirect tension test method(Tex-226-F). A 50mm tall and 100mm diameter cylindrical specimens were loaded diametrally at a constant rate of deformation until complete failure occurred. All tests were conducted at a temperature of 25℃ and a deformation rate of two inches per minute. Based on these test results, tensile strength of this asphalt mixture was consistently and significantly increased by the three coating materials(Figure 4).

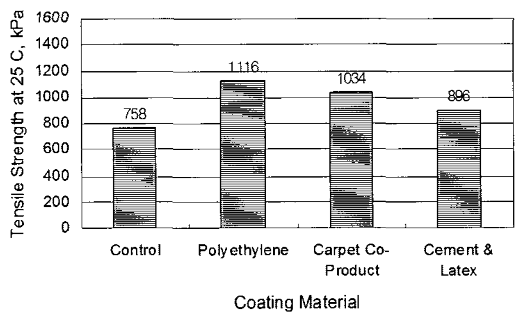

Figure 4. Tensile Strength for Tested Mixtures

4.6 Inspection of Coated Aggregate Surfaces

A common magnifying glass was used to carefully inspect surfaces of uncoated aggregates and compare them with those of the coated aggregates. It was clearly evident that the coated aggregate particles possessed significantly greater surface texture or roughness than the uncoated aggregates. Photographs with a 3X magnification(Figures 5 through 7) show the surfaces of uncoated and coated aggregates.

4.7 Inspection of Coated Aggregates After Mixing and Molding

In earlier work at TTI on coating of marginal

Figure 5. Typical Uncoated(Control) Aggregates (Magnified 3 Times)

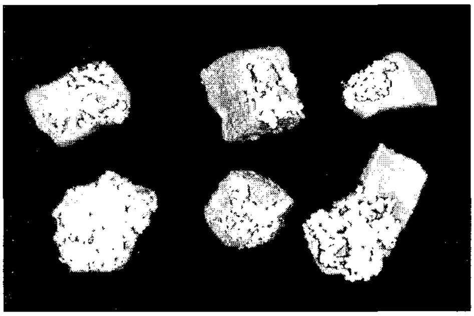

Figure 6. Typical Aggregates Coated with Fine-Grained Polyethylene(Magnified 3 Times)

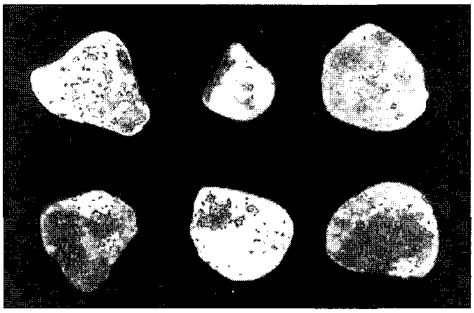

Figure 7. Typical Aggregates Coated with Carpet Co-Product(Magnified 3 Times)

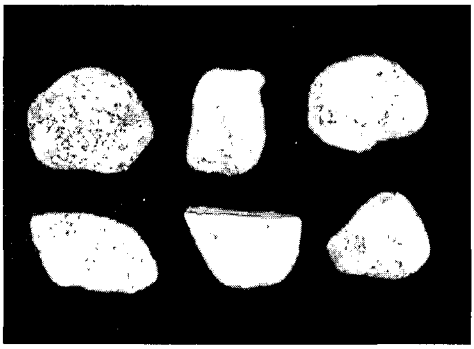

Figure 8. Typical Aggregates Coated with Cement & Latex (Magnified 3 Times)

aggregates with cement mortar(Button et al., 1992), it was found that, during mixing with asphalt and molding of specimens, much of the coating was abraded off the aggregate particles. This loss of coating was a particular problem during the field phase of that earlier work. Therefore, loss of the coatings was a concern during this study.

Compacted asphalt-aggregate specimens containing aggregates coated with the three materials were subjected to a solvent to extract the asphalt. Individual aggregates were then visually inspected to estimate the quality of the coating remaining. The results, particularly for the carpet co-product and the cement/latex, were disappointing. It was observed that about 30% of the carpet co-product and about 20% of the cement/latex remained on the surfaces of aggregates. However, more than 60% of the polyethylene remained. The polyethylene coating adhered well to the aggregate surfaces and resisted wear during handling and compacting. Based on this finding, fine-grained polyethylene appears to be most promising of the three coating materials tested.

5. CONCLUSIONS

A laboratory investigation was conducted wherein smooth, rounded, siliceous gravel aggregates were coated with fine-grained polyethylene, carpet co-product, or cement + SBR latex and used to prepare asphalt concrete specimens. Only the coarse(+No. 4) aggregates were coated. The concept was that the coatings would enhance surface roughness of the aggregates and, thus, produce asphalt mixtures with superior engineering properties. Hot mix asphalt specimens were subsequently evaluated using several standard and non-standard test procedures. Based on experiences during the coating processes and analyses of these limited test results, the following conclusions are tendered:

1. Hveem stability of the asphalt mixture was slightly increased by all three aggregate coatings.
2. Marshall stability of the asphalt mixture was substantially increased by all three aggregate coatings.
3. Tensile strength of the asphalt mixture was consistently increased by all three aggregate coatings.
4. Resilient modulus(stiffness) of the asphalt mixture was consistently increased by all three aggregate coatings.
5. Conclusions 1 through 4 are indicative of improved resistance to rutting and cracking in hot mix asphalt pavements fabricated using coated rounded gravel aggregates in comparison to pavements made using similar uncoated aggregates.
6. Although the cement + SBR latex and carpet co-product coated aggregates demonstrated improved mechanical properties of the asphalt mixtures, extraction of the asphalt and examination of the coarse aggregates indicated that about 80% of the coating was abraded away during mixing with asphalt and compaction of the specimens.

REFERENCES

1. Bayomy, F.M.S. and Guirguis, H.R.(1984). "An upgrading Technique for AC Pavement Materials," *Roads* and *Developments*, Vol. 2, Roads and Development Center, Kuwait.
2. Brown, S.F., Rowlett, R.D., Boucher, J.L.(1990). "Asphalt Modification," *Proceedings, Conference of the U.S. Strategic Highway Research Program,* London, UK.
3. Button, J.W., and Jagadam, V.(1992). *"Cement Coating Marginal Aggregates for Use in Asphalt Pavements,"* Research Report 1253-1F, Texas Transportation Institute, College Station, Texas, USA.
4. Hunter, D.D., and Button, J.W.(1984). *"Evaluation of Accorex - an Asphalt Mixture Additive,"* Report 4974, Texas Transportation Institute, College Station, Texas, USA.
5. Schmidt, R. J.(1972). "A Practical Method for Measuring the Resilient Modulus of Asphalt Treated Mixes", *Highway Research Record 404,* Highway Research Board, pp.22-29.
6. Texas Department of Transportation(TxDOT)(2005). *"200-F, Bituminous Test Procedures"*, Austin, Texas, USA. pp. 521
7. Williams, T. M., Miknios, F. P., and Schulz, G. O.(1998) *"Aggregate Coating Reduces Asphalt Repair,"* Better Roads, Des Plaines, Illinois, USA, pp. 19.

접 수 일 : 2006. 4. 25
심 사 일 : 2006. 8. 31
심사완료일 : 2006. 9. 11