CONSTRUCTION AND PERFORMANCE

OF

ULTRA-THIN BONDED HMA WEARING COURSE

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ABSTRACT

In recent years the need for preserving our investment in the Nation's highway system has received increased emphasis. An effective pavement preservation program includes a number of maintenance strategies that are applied in a cost-effective and efficient manner. There have been a number of new technologies developed to address these problems. One of the more promising technologies is the use of an ultra-thin bonded HMA wearing course (UTBWC). It consists of a layer of hot mix asphalt (HMA) laid over a heavy asphalt emulsion layer or membrane. The thickness of the ultra-thin surface ranges from 9.5 mm (3/8 in) to 19 mm (3/4 in). The system is placed on a structurally sound rigid or flexible pavement, which may exhibit minor surface distresses. The process was developed in France in 1986 and has been in use in the United States since 1992. Both a review of published experimental project reports and inspections of recently completed projects in many locations indicate good performance of the UTBWC. The UTBWC provides a surface with excellent macro texture qualities, good aggregate retention, and excellent bonding of the very thin surfacing to the underlying pavement.

INTRODUCTION

In recent years the need for preserving our investment in the Nation's highway system has received increased emphasis. An effective pavement preservation program includes a number of maintenance strategies that are applied in a cost-effective and efficient manner.(1) There have been a number of new technologies developed to address these problems.(2) One of the more promising technologies is the use of an ultra-thin bonded HMA wearing course.(3)(4)(5)

OBJECTIVE AND SCOPE

The objective of this report is to document the materials needed and the construction procedures used for the ultra-thin bonded wearing course (UTBWC) and to evaluate the performance of the process. This report is based on a review of the literature and interviews with industry and DOT personnel on the use and performance of UTBWC.

GENERAL OVERVIEW OF THE CONSTRUCTION PROCESS

An ultra-thin--less than 25 mm (1 inch)—hot mix asphalt (HMA) bonded wearing course is a hot mix asphalt overlay that is used in a pavement preservation program and is generally placed on a structurally sound base. One type of ultra-thin bonded HMA wearing course was developed in Europe (France) in 1998 and introduced in the United States in the early 1990's with projects in Alabama and Texas in 1992.(6) It consists of a layer of hot mix asphalt (HMA) laid over a heavy asphalt emulsion layer or membrane. The thickness ranges from 9.5 mm (3/8 in) to 19 mm (3/4 in). The layer thickness is determined by the maximum aggregate size in the HMA. The asphalt emulsion is usually a polymer modified emulsion applied at 0.85 ± 0.3 liters/square meter (0.20 ± 0.07 gallons per square yard). The HMA is a gap-graded mix using a crushed aggregate bound together with a mastic made of sand, filler and asphalt binder. The maximum aggregate size ranges from 6.2 mm (1/4 in) to 12.5 mm (1/2 in). Generally a 9.5 mm (3/8 in) mix is used. The grade of the asphalt binder is chosen based on the climate and traffic conditions for the project. Both unmodified and modified binders have been used in the construction of an ultra-thin bonded HMA course. The binder content generally ranges from 5.0 to 6.0 percent depending on the traffic, climate and the condition of the existing pavement.

The ultra-thin bonded HMA is placed with a specially built machine that places the asphalt emulsion membrane and the HMA in a single pass. The heavy application of the membrane seals small cracks in the existing pavement and helps to ensure the adhesion of the HMA to the underlying pavement.

PROJECT DESIGN/SELECTION

The ultra-thin bonded HMA wearing course provides a thin HMA layer to be placed on a structurally sound pavement. It should not be used to bridge weak spots or to cover underlying pavement deficiencies. It should not be used as a rut filler or to level a rough pavement. The primary function is to provide a durable, friction resistant wearing course on an existing flexible or rigid pavement. It can be placed from 12.5 (1/2 inch) to 19.5 mm (3/4 inch) thick. Specifications generally require one of three different gradations, as given in Table 1. The gradation to be used is based on the traffic level and the surface condition of the roadway. The thickness is generally about 1 1/2 times the maximum aggregate size.

For flexible pavements, the ultra-thin bonded HMA should not be used when the longitudinal cracking exceeds the medium severity level as defined by the *Distress Identification Manual for the Long-Term Pavement Performance Program* (SHRP-P-338). Block cracking, edge cracking and reflection cracking at the joints should not exceed the moderate severity level. Any cracks greater that 6.3 mm (1/4 inch) should be cleaned, routed and sealed. Patches and potholes should not exceed moderate severity levels. All potholes and alligator cracked areas should be properly repaired. Rutting should not exceed 12.5 mm (1 1/2 inch). When rutting exceeds 12.5 mm (1 1/2 inch) the surface should be milled or the ruts filled with micro-surfacing or some other suitable material prior to placing the ultra-thin overlay.

For rigid pavements cracking should not exceed the moderate severity level. Any "D" cracking should not exceed the low severity level and any map cracking or scaling should not exceed 10 sq meters (10.9 sq yards) in any 100 sq meters (109 sq yards) area. If the rigid pavement has blowups or pumping and faulting problems, it should not be considered for an ultra-thin bonded HMA overlay.

MATERIALS

Aggregates

The aggregate mixture used in the ultra-thin bonded HMA is a gap-graded mix that includes a high proportion of "single-sized" crushed aggregate bound together with a mastic of fine aggregate, filler and asphalt binder. The coarse aggregate consists of 100% single face (85% two face) crushed material with a maximum Micro-Deval loss of less than 18% (or a maximum Los Angeles Abrasion of less than 35 % and maximum sodium sulfate soundness loss of 12% or magnesium sulfate soundness of less than 18%). The aggregate should be cubical with a maximum of 25% 3:1 flat and elongated particles. The fine aggregate should also be angular with a minimum uncompacted void content of 40%. There is a concern about moisture susceptibility of the mixture; therefore, a maximum of 10% methylene blue requirement along with a minimum 40% sand equivalent requirement is placed on the fine aggregate. During the mix design process the mixture is further checked for moisture sensitivity using AASHTO T-283.

Table 1 shows the gradation requirements for the three mixes commonly used. Figure 1 gives a comparison between a 12.5 mm coarse graded Superpave mix, a 12.5 mm Stone Matrix Asphalt (SMA) mix and a 12.5 mm ultra-thin bonded HMA mix.

Liquid Asphalts

Membrane

A membrane of a polymer modified asphalt emulsion is sprayed prior to application of the HMA layer to seal the existing surface and to bond the ultra-thin bonded HMA layer to the existing pavement. This membrane is placed at approximately 0.85 $\pm$ 0.3 liters/square meter (0.20 $\pm$ 0.07 gallons per square yard). The actual rate is dependent on the surface condition of the existing pavement. The objective is to fill the surface voids and to provide enough emulsion so that it rises to about one-third of the thickness of the ultra-thin bonded HMA course.

Binder for the ultra-thin bonded HMA

The grade of the asphalt binder is chosen based on the climate and traffic speed and loading conditions for the project. Both unmodified and modified binders have been used. Generally in addition to the PG specification requirements, the binder must also meet an elastic recovery requirement. In the Northern climates a PG 70-28 has generally been used and in the Southern climates a PG 76-22 has been used.

Mix Design

The goal of the mix design is to provide sufficient asphalt binder to insure adequate film thickness on the aggregate to provide for a durable HMA layer. The design is accomplished by compacting the HMA mixture with a Superpave gyratory compactor. The specimen is compacted using a 100 mm mold and 100 gyrations. After compaction the specimen is removed and the bulk specific gravity is determined. Due to the high voids in the specimen it is necessary to determine the bulk specific gravity using paraffin, parafilm or the core lock device. The desired air voids level in the mix is about 10% with a film thickness of about 10 microns. If the desired air voids cannot be obtained, the gradation blend is adjusted. After the design binder content has been determined, the mix is tested for moisture susceptibility using the procedures of AASHTO T-283. The specimens should be conditioned in accordance with standard agency procedures. The mix is also tested for draindown, with a desired draindown of less than 0.10%. A review of mix designs shows that the binder content ranges from 5.2% to 5.8%.

CONSTRUCTION

Equipment

The ultra-thin bonded HMA process uses a specially built paving machine. Midland Machinery Co, Tonawanda, N.Y. and Joseph Vogele AG, Mannheim, Germany supply the machines in the U.S. The Midland truck, as shown in Figure 2, contains a receiving hopper, auger conveyors that transport the HMA to the screed, an insulated 11,300 liter (3000 gallon) storage tank for the emulsified asphalt and a combination vibratory bar screed for spreading and initial compaction of the HMA. The Vogele machine, as shown in Figure 3, has a 4000-liter (1057 gallon) emulsion tank. As the paving machine pushes the dump truck along, emulsion is sprayed at 50 to 80^{o}C (120 to 180^{o}F).

Immediately after the emulsion is sprayed the HMA is placed at 150 to 160°C (300°F to 315°F). The two materials bond to form a thin surface on the pavement. The paver operates at 18 to 36 meters (60 to 120 feet) per minute depending on the depth of the lift and the width of the pavement. The paver screed is hydraulically extendable, so the process can match varying widths of roadway as required (for example on a ramp off an Interstate or a street intersection).

Surface Preparation

The ultra-thin bonded HMA process does not add structural strength to the pavement. Therefore, for the process to provide a long lasting surface treatment, any structural problems (such as alligator cracking or potholes) must be repaired prior to the application of the ultra-thin bonded HMA wearing course. Generally, the ultra-thin bonded HMA wearing course should not be used for a leveling course or as a rut filler. It can, however, level small undulations and fill ruts less than 1/2 inch in depth. The pavement should be prepared as for a chip seal project. Pavement cracks or joints greater than 6.3 mm (1/4 inch) wide should be cleaned and filled. However, if they are sealed immediately prior to the application, the seal may bleed through. Concrete joints need to be routed and sealed with a high quality asphalt sealant, such as one that meets the requirements of ASTM D 3405. The entire pavement surface should be cleaned with pressurized water and/or a vacuum system to insure a clean surface. All manhole covers, grates, catch basins and other utility structures should be protected and covered with plastic or building felt prior to paving.

Application

An ultra-thin bonded HMA layer should not be placed on a wet pavement. It can be placed on a damp pavement provided there is no standing water. The pavement surface should be at least 10°C (50°F) at the time of placement.

Membrane

The polymer modified asphalt emulsion membrane should be sprayed at a temperature of 50 to 80°C (120 to 180°F) at a rate of 0.85 $\pm$ 0.3 liters/square meter. (0.20 $\pm$ 0.07 gallons per square yard.) The goal is to spray sufficient emulsion so that it will rise 1/3 of the way up through the mat. The spray rate may need to be adjusted based on the condition of the existing pavement surface and the traffic conditions. For example if the existing pavement has a very dry or oxidized surface, the tack rate should be increased. If it has a flushed surface, the rate should be decreased.

HMA

Plant production

The mix being produced is a gap-graded mix. Special attention should be paid to the calibration of the HMA plant prior to production due to the one-sized nature of the gap-graded mixes. Normal procedures used for a gap-graded mixes should be used, including increasing the mix cycle time in a batch plant, using slightly higher temperatures, and avoiding prolonged storage of the mix as it cools more quickly than dense graded mixes. Also, because it is a gap-graded mix, there may be a tendency for drain-down in the silo. The mix should be not be stored for more than 4 hours.

Placement

The mix is generally applied at a temperature of 143 to 165°C (290 to 330°F) and is <u>spread immediately</u> after the application of the membrane. The exact temperature used will depend upon the grade of the asphalt binder. The asphalt binder supplier should be consulted with regard to the proper temperature. Because the mix is placed very thin, it cools rapidly. If the screed is not preheated, the startup process can be a nightmare. Because of the rapid cooling, there have been problems with “bumps” and smoothness when the paver stops and restarts. Stopping the paver can also slow the process. Logistics are, therefore, very important. Sufficient nurse trucks for the emulsion should be available, and the plant production and laydown process should be balanced so that the mix can be placed without requiring the laydown machine to stop for lack of materials.

Handwork

The material cools very quickly, it has a harsh aggregate gradation, and it can be made with a modified asphalt binder. Therefore handwork is difficult, and care is needed to achieve a smooth finish.

Compaction

Compaction of the HMA should consist of a minimum of two passes with a steel double drum roller weighing at least 9 metric tons (10 tons) operating in the static mode. The compaction process is not designed to compact the HMA, but, rather, to seat the aggregate. The joint should be rolled first. If low spots occur, a pneumatic tired roller can be used to roll locations bridged by the steel roller. The compaction process should begin immediately after the application of the ultra-thin bonded HMA. The timing of compaction of the mix is critical due to the thin layer of the HMA. Compaction should be completed prior to the temperature of the mix dropping below 85°C (185°F).

Traffic Control

Due to the thin layer of HMA being placed, the mix cools quickly and the roadway can generally be opened to traffic in about 15 minutes. Typically the mix temperature will drop about 38°C (100°F) in the first five minutes after placement. The reason for this rapid drop is the thin lift, moisture release from the emulsion, and the open-graded nature of the mix. The road can be opened to traffic when the mix temperature drops below 85°C (185°F).

Quality Control/Quality Assurance

The quality control process for the ultra-thin bonded HMA mixtures should generally follow the guidelines of the specifying agency. It should include at least the following:

1. Periodic checks on the spread rate for the asphalt emulsion membrane.
2. Periodic checks on the spread rate for the HMA.
3. Periodic checks throughout out the day on the asphalt content and gradation of the HMA. The frequency of this should be established based on the specifying agency's standard guidelines for HMA paving projects.

PERFORMANCE

The ultra-thin bonded HMA process was developed in France in 1986 by Screg Routes et Travaux Publics and is marketed in Europe by them. In was introduced into the United States in 1992. It is thought that this process will provide the following performance characteristics:

4. Excellent skid properties
5. Good surface macrotexture
6. Excellent aggregate retention
7. Strong adhesion to the underlying surface (reduced delamination)
8. A seal for the small cracks in the underlying surface.

To evaluate the performance of the process, a review of reports that have been prepared by various agencies was conducted, and the author visited a number of projects.

Review of published reports.

In 1992 and 1993 projects were built in Pennsylvania, Texas and Alabama. In each case reports were prepared by the Departments of Transportation on the construction of the projects. The results of a performance review of the projects is summarized below.

Pennsylvania

The Pennsylvania Department of Transportation (PennDOT) constructed three projects in September 1993 and one project in May 1996. A report by PennDOT gives the construction details .(7) The four projects were monitored at regular intervals over a five-year period. The evaluation included visual performance for raveling, weathering, and delamination in addition to skid resistance testing, surface macrotexture depth testing, surface roughness (IRI) and transportation related noise measurements. Their conclusions were that:

"Overall performance results of NovaChip were excellent. Based on this study, NovaChip can be considered an alternate maintenance option for preventative maintenance and surface rehabilitation, especially on roads which have high average daily traffic." (8)

Project Site A - SR 0309, Bucks County.

The existing pavement was HMA over a jointed concrete pavement. The pavement had minor rutting and the transverse cracks had reflected through. An existing center turning lane of HMA was used as control section. The International Roughness Index at time of construction was an average of 173 which is in the poor to fair category. After placement of the UTBWC, the IRI fell to 120 and after five years it was 138 (which is in the fair category). The average skid number when the evaluation period was completed was 58. The macro texture of the ultra-thin bonded HMA wearing course ranged from a low of 0.042 inches to a high of 0.078 inches (measured using the Sand Patch Test). The macro texture of the control section ranged from a low of 0.022 inches to a high of 0.027 inches. Reflection cracking was evident but did not produce any problems.

Project Site "B" - SR 0422, Montgomery County.

The existing pavement was a four-lane jointed concrete pavement. It was highly polished and had ruts caused by studded tires. A control section was constructed using a cold-layed asphalt emulsion pavement. The International Roughness Index at time of construction was an average of 150. After placement of the UTBWC, the IRI fell to 77 and after five years it was 96. Prior to construction the concrete pavement had skid number of 27. The average skid number of the ultra-thin bonded HMA wearing course section after five years was 60. The macro texture of the UTBWC ranged from a low of 0.038 inches to a high of 0.078 inches (measured using the Sand Patch Test). The macro texture of the control section ranged from a low of 0.019 inches to a high of 0.039 inches. The report concluded that the average texture depth of the control section was 2.3 times higher than the control section. There are normally concerns that thin HMA sections will not bond to the existing surface (especially a concrete surface). The report indicates that the UTBWC has an excellent bond with no signs of delamination after five years. Reflection cracking was evident but did not produce any problems.

Texas

The Texas Department of Transportation (TxDOT) constructed two projects in the San Antonio District in October 1992.(9) A section of a nearby highway served as the control section. The control section was a double chip seal that was in relatively good condition. The two projects were monitored at regular intervals over a three-year period.(10) The monitoring consisted of semi-annual evaluations of the performance, plus friction data was collected semi-annually and ride quality was measured annually. Their conclusions were that:

"Field performance . . . was excellent throughout the study. Three years following the rehabilitation project, the surface was essentially in the same condition as it was immediately after construction, showing no signs of significant distress."

US 281 was in good condition at the time the UTBWC was placed. The wearing course consisted of a double chip seal with moderate flushing and slight raveling. A six-kilometer (3.7 mile) section was surfaced with UTBWC and three kilometers (1.8 miles) received no treatment and served as a control section. Skid measurements showed a skid value of 30 before application and leveled off at 45 after application of the UTBWC. The ride prior to application of the UTBWC was good and remained so during the evaluation period.

SH 46 was in good condition at the time the UTBWC was placed. The surface was a dense graded HMA with sealed longitudinal cracks and some raveling. Skid measurements showed a skid value of 31 before application of the UTBWC and leveled off at 46 after application of the UTBWC. The ride prior to application of the UTBWC was good and remained so during the evaluation period

Alabama

The Alabama Department of Transportation constructed two projects in North Central Alabama in the Fall of 1992. The construction and evaluation details are given in a 1996 report.(11) The two projects were monitored annually with the last inspection in July 1995. In addition friction testing was conducted in 1994 and 1995. Their conclusions were:

"The surface texture . . . is very similar to that of a typical open-graded friction course. No significant raveling was observed on the two projects after about 3 3/4 years of service, which indicates very good bond . . . [with] the underlying surface. The . . . surface has significantly higher pavement surface friction numbers compared to dense-graded HMA wearing course. It appears to be a potential alternate for chip seals, micro-surfacing and open-graded friction course."

Both of the ultra-thin bonded wearing course projects were placed on a dense graded HMA. Each project had a control section. On the US 280 project, the ultra-thin bonded HMA wearing course section at the end of the evaluation period had a skid number of 45 versus 42 for the control mix (a dense graded granite mix). On the SH 21 project, the UTBWC section at the end of the evaluation period had a skid number of 49 versus 41 for the control mix. The report comments that there was no raveling after 3 ¾ years and thus there was a very good bond between the UTBWC and the underlying surface.

Inspection of other projects

In addition to the review of documented literature discussed above, a visual inspection was conducted in the summer of 2000 on a number of recent projects built using the ultra-thin bonded wearing course technology. Projects were inspected in Alabama, Missouri, Minnesota, Iowa and Colorado. The following presents a brief discussion of those projects and their performance.

Alabama

A project was built on I-65 north or Birmingham in 1998. It consisted of a type B mix (Table 1) placed on a Portland cement concrete pavement. During construction the concrete joints were sealed on the north bound lanes and not on the south bound lanes. The only distress noted in the ultra-thin bonded HMA wearing course was reflection cracking from the underlying PCC pavement. The reflection cracks were more severe in the south bond lanes. The overlay did not show any signs of debonding or raveling. The performance of this project indicates the need to properly seal concrete joints before placement of the ultra-thin bonded HMA wearing course.

Missouri

The Missouri DOT built two ultra-thin bonded HMA overlays on ramps off of I-29 north of Kansas City in 1998 and 1999. They were placed on highly polished concrete pavements. The goal was to improve skid resistance and thereby reduce wet weather accidents. When inspected in the summer of 2000, they were both performing very well with no evidence of raveling and only a few spots of debonding on the 1998 project. Reports from the state police have indicated a major reduction in wet weather accidents on the ramps.

Minnesota

The Minnesota DOT constructed two projects in the Minneapolis-St. Paul area in 1999. One project was built on US 169 and the other on I-35. In both cases the ultra-thin bonded HMA course was placed on an asphalt pavement. The existing pavements were in good condition with some thermal cracking. The thermal cracks were reflecting through the mix. On the I-35 project, there was some minor raveling. On the US 169 project, there was significant raveling along the centerline joint. It was reported that there were some problems with the application of the membrane along that joint, and that the joint may not have received a proper application of the membrane. This indicates a need to insure that the membrane is properly placed.

Iowa

As a part of a 1998 study conducted by Iowa State University on thin maintenance procedures, the Iowa DOT built a ultra-thin bonded HMA wearing course section on an asphalt pavement south of Ames on US 69. There were no observed problems with the project. The layer was bonded and no raveling was noted. Because of the success of this test section, the Iowa DOT built another ultra-thin bonded HMA wearing course on I-35 starting at the Minnesota/Iowa state line.

Colorado

Five Colorado ultra-thin bonded HMA wearing course projects were inspected. Two were built in the Colorado Springs area and three were built in and near Denver. Three were built in 1998, one in 1999 and one shortly before the inspection in the summer of 2000. All of the projects had good surface texture and a good bond. A couple of the projects were on high volume roads that receive heavy snow plowing in the winter. (Colorado has a clean pavement policy with regard to snow removal.) The scrape marks from the plows could be seen in spots on the top aggregate, but no raveling was observed. Minor flushing was seen on one of the 1998 projects. This project used an unmodified AC-10 as the binder, and it is thought that this may be contributing to the flushing.

CONCLUSIONS

Based on a review of the literature, conversations with DOT and industry personnel, and personal inspection of a number of ultra-thin bonded HMA overlays, the following conclusions are drawn:

1. The system provides excellent aggregate retention.
2. The system has excellent bond to the underlying surface. Delamination of the system from the surface is generally not a problem.
3. The ultra-thin bonded HMA wearing course surface has excellent macro texture qualities. Thus, the system will provide a surface with a high level of skid resistance. And, because of its high macro texture surface, it should also provide a surface that will reduce hydroplaning problems ..
4. Cracks in the existing pavement will reflect through the surface. But, it appears that cracks sealed prior to placement of the UTBWC present no performance problems.

TABLES AND FIGURES

TABLE 1. MIXTURE REQUIREMENTS

SIEVES		Composition by Weight Percentages					
		6.2 mm (1/4 in) - Type A		9.5 mm (3/8 in) - Type B		12.5 mm (½ inch) Type C	
Metric (mm)	ASTM	Design - General Limits % Passing	Production Tolerance (%) (±)	Design - General Limits % Passing	Production Tolerance (%) (±)	Design - General Limits % Passing	Production Tolerance (%) (±)
19	¾ inch					100	
12.5	½ inch			100		85-100	5
9.5	3/8 inch	100		85 - 100	5	60 - 80	4
4.75	# 4	40 - 55	4	28 - 38	4	28 - 38	4
2.36	# 8	22 - 32	4	25 - 32	4	25 - 32	4
1.18	# 16	15 - 25	3	15 - 23	3	15 - 23	3
0.60	# 30	10 - 18	3	10 - 18	3	10 - 18	3
0.30	# 50	8 - 13	3	8 - 13	3	8 - 13	3
0.15	# 100	6 - 10	2	6 - 10	2	6 - 10	2
0.075	# 200	4 - 7	2	4 - 7	2	4 - 7	2

FIGURE 1. GRADATION COMPARISON

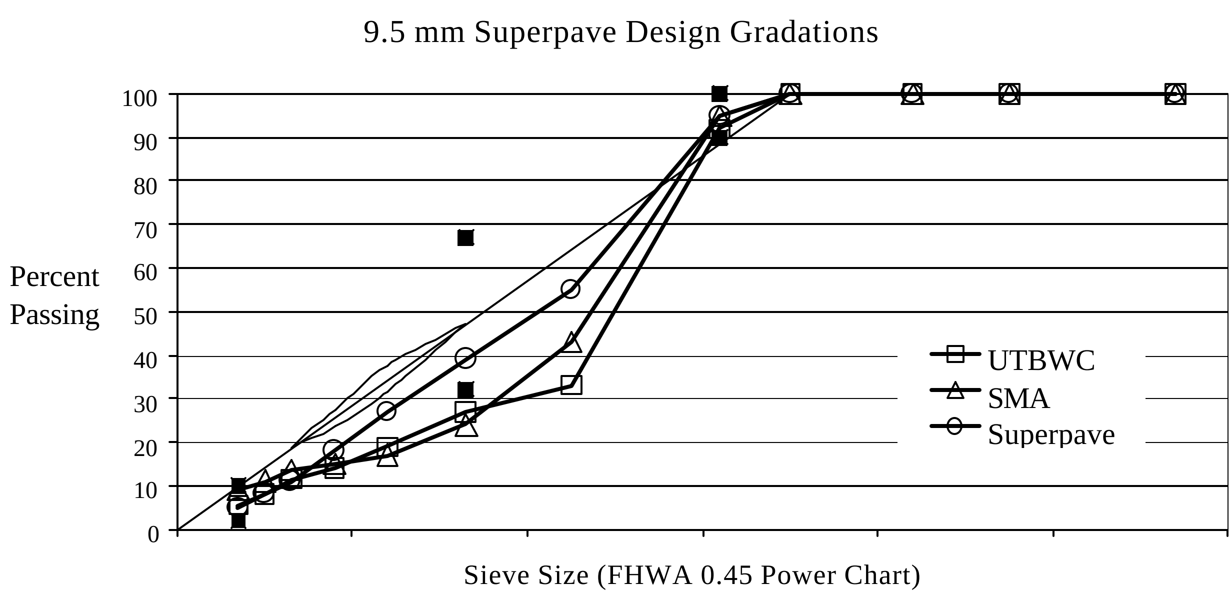


FIGURE 2. UTBWC MACHINE (MIDLAND)

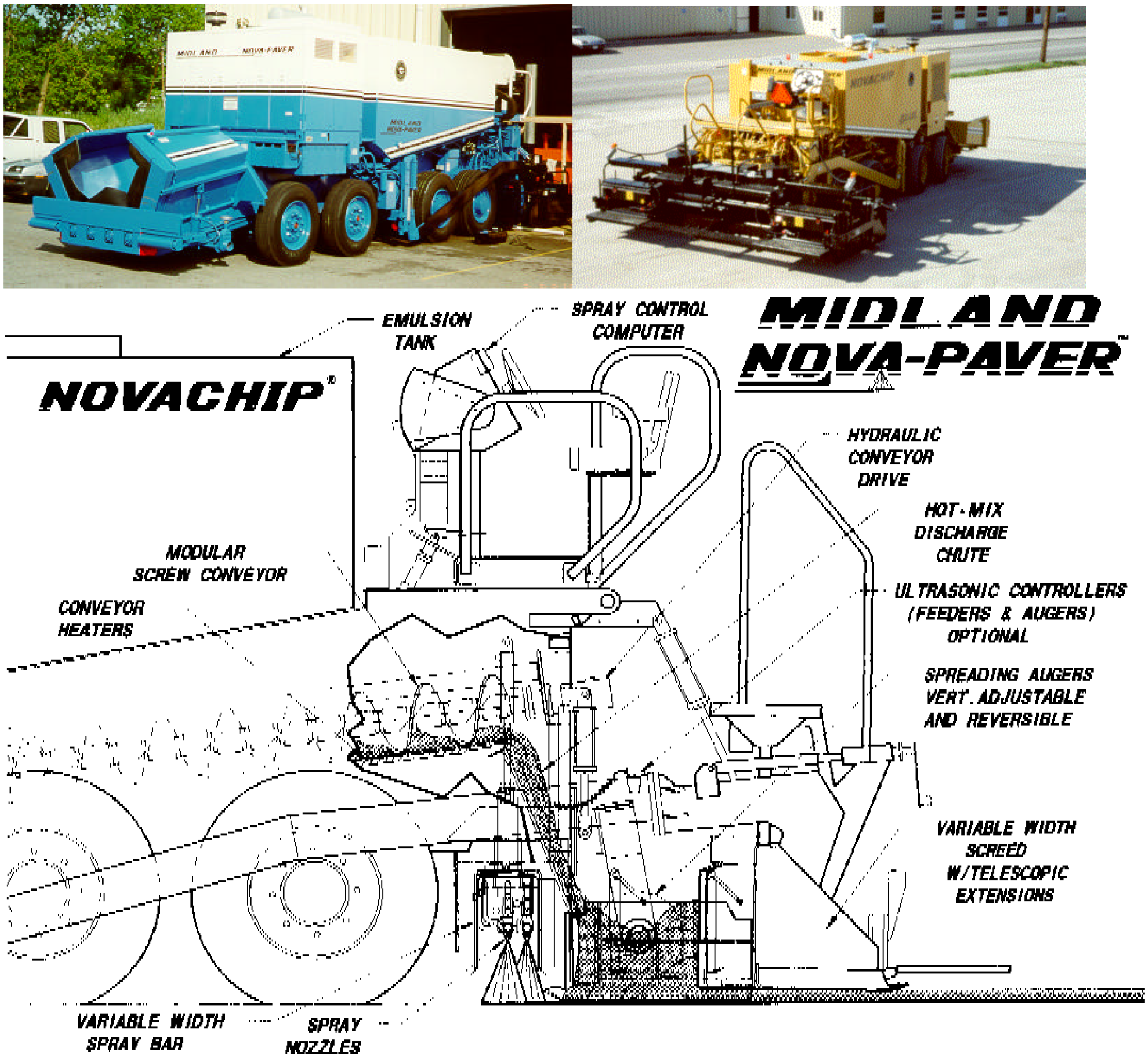
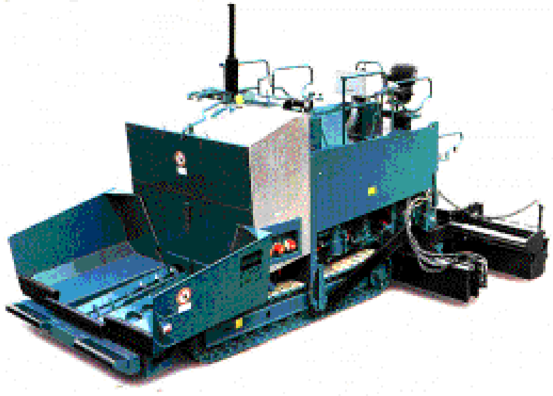


FIGURE 3. UTBWC MACHINE (JOSEPH VOGELE)



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LIST OF TABLES AND FIGURES