Minnesota’s Experience with Thin Bituminous Treatments for Low-Volume Roads

Greg Johnson

Three surface treatments placed on aggregate-surfaced roads (double-chip seal, Otta seal, and oil gravel) were investigated through field trials for performance. A double-chip seal used a single-size aggregate applied to a layer of hot asphalt binder. After 6 years of service, the performance of the road has required only routine preventive maintenance. The surface has a few thermal cracks and no rutting. An Otta seal, which uses a thick layer of soft asphalt to which a dense graded aggregate is added, has proven successful. The use of a chip spreader is recommended for precise aggregate application during construction. A large top-size aggregate, 1 in. (25 mm) minus, gave a rough texture to the surface, but the performance has not been adversely affected. Because of the fines included in an Otta seal, usually a locally available aggregate can be used. In design and construction, the oil gravel surface is similar to hot-mix asphalt. All the projects had some problems with segregation, but most can be corrected during construction with proper handling techniques. One benefit of this treatment is that additional material stockpiled during construction can be used in subsequent maintenance activities on the road. All three of the surface treatments require a strong base to work properly. The treatments add no structural component to the road. Therefore, the condition of the road needs to be carefully evaluated before construction. The roads that performed the best had the best base stability.

Minnesota has about 135,300 mi (217,744 km) of roads within the state, with aggregate roads making up 53% of the total network. Roadway officials are often looking for economical solutions for these roads. The “lightly surfaced” road treatment concept provides an alternative to hot-mix asphalt (HMA) or a means of stabilizing a road to minimize maintenance costs. This type of surface treatment is not new, and many agencies, both foreign and domestic, have used it successfully (1, 2). In the late 1920s the Minnesota Highway Department was an innovator in the use of road oils to get citizens out of the mud (3–5). Although the purpose and concept have not changed in 75 years, the technology has. With more precise application equipment and new emulsions, the surface treatment concept is being used again. The goal of providing a smooth all-weather driving surface to an existing aggregate road remains.

The standard practice in Minnesota when an all-weather surface is desired is to go from gravel to HMA. Three surface treatments were investigated through field trials as a less costly alternative. The treatments investigated were a double-chip seal, an Otta seal, and an oil gravel surface. This report summarizes the specifics of each type of treatment and the performance of 11 test sections in the field. All surface treatments require a strong stable base. The surfacing itself adds no significant structural benefit. Therefore, the condition of the road needs to be carefully evaluated before construction.

SURFACE TREATMENTS

Double-Chip Seal

A chip seal uses a uniform one-size aggregate combined with a rapid setting emulsion. Its main use is as a surface treatment to an existing HMA road. However, it can be used directly over an aggregate base.

Houston County is the southeastern-most county in Minnesota with a general topography of rolling bluffs and valleys. A 1-mi (1.6-km) section of limestone aggregate-surfaced road, which generally follows a constant contour around a series of hills overlooking a small valley, was the site of this project. This road has mainly agricultural traffic with an annual daily traffic (ADT) of 60. The road has a silty clay subgrade with occasional encounters with underlying limestone rock. The existing aggregate base consisted of 8 in. (203 mm) of 100% crushed limestone. The condition of the road before construction of the chip seal was stable, but with excess loose coarse aggregate on the surface. The loose coarse aggregate was blended with limestone screenings to replace the lost fines and recompacted before construction.

In August 1996, a chip seal surface was applied to the road. A modified asphalt (MAC-5) with 5% sprayer was sprayed at a rate of 0.45 gal/yd^2 (1.4 L/m^2) at 280°F (138°C) onto the aggregate base. Then limestone chips (45 lb/yd^2; 17.1 kg/m^2) were spread evenly over the surface with a chip spreader. The aggregate gradation met the specification for chip seal presented in Table 1. The aggregate was clean 0.5-in. (12.7 mm) minus 100% crushed limestone aggregate. The second lift consisted of asphalt (MAC-5) (0.40 gal/yd^2; 1.3 L/m^2) and the limestone chips (35 lb/yd^2; 13.3 kg/m^2). A pneumatic roller was used for compaction after each lift. Cost for all work in 1996 was $20,000 for the 1-mi segment ($12,500/km) with a surface width of 22 ft (6.7 m).

There are a few thermal cracks and no rutting after 6 years of service. A preventive maintenance double-chip seal was applied in 2000 to the entire section. No other maintenance has been required.

Otta Seal

A graded gravel surface dressing was developed in Norway, with a field trial in the Otta valley in 1963 (6). It was originally meant as a temporary surface during construction projects but is now being used in many countries as a long-term surface treatment (7). Through a technology exchange program with Iceland, the Minnesota Department of...
Transportation (MnDOT) was reacquainted with this type of treatment. The process involves spraying a thick layer of soft oil on the surface (existing Otta seal or aggregate) and covering it with a locally available, graded aggregate. Specifically, the design that Minnesota used involved the emulsion’s being sprayed on the surface of the road with a distributor at a rate of 0.52 gal./yd² (1.7 L/m²) (8). Then a chip spreader laid aggregate over the emulsion at a rate of about 50 lb/yd² (19 kg/m²). The aggregate thickness was adjusted so that the emulsion was just starting to bleed through the surface in spots behind the chip spreader tires. If too little aggregate were applied, the aggregate would stick to the tires on the chip spreader and trucks delivering aggregate. The mixture was then compacted by two pneumatic rollers. A pneumatic roller was used because a steel roller would crush the aggregate and not provide the kneading action desired. This process was repeated for the second application. A double application is recommended, so the final thickness is about 1.25 in. (32 mm). Three projects have been done with this surface treatment to date in Minnesota.

**St. Louis County**

Minnesota’s initial trial with an Otta seal was on a county road in the northeastern part of the state in September 2000. The road has an ADT of 260, and the traffic is a mix of recreational and logging. The base was a graded sand and gravel with a thickness of 6 in. (152 mm) over a sandy gravel subgrade. A high float emulsion (HFMS-2s) was applied at a rate of 0.52 gal/yd² (1.7 L/m²). The aggregate was applied by spreading out of a truck box and then coming behind and applying more aggregate over the entire lane with a conventional paver. The aggregate was a screened aggregate that met the Otta seal gradation indicated in Table 1. The result was an inconsistent application of aggregate, usually too much. There is up to 2 in. (51 mm) of aggregate over the emulsion, and the emulsion was not able to permeate through all the aggregate to become a monolithic mat. As a result, the excess aggregate is still on the road, and the oil is buried in the base. Therefore, there are potholes and washboarding problems. Some of the wheelpaths have been worn down to the oil and provide a good running surface, but potholes are scattered throughout because of inconsistencies. What can be learned is that proper application of aggregate is important.

**Cass County**

In August 2001, five road segments (two county and three township) were surfaced with Otta seal with an improved construction technique (learning from previous experience). The main difference was the requirement of a chip spreader for aggregate application. This way the emulsion would not be driven on before the application of the aggregate, and a more precise control could be used for the application rate (thickness).

The two county roads have an ADT of 45 and 145 with a mix of residential and agricultural traffic. The road surface is 24 ft (7.3 m) wide, with 4 to 5 in. (102 to 127 mm) of graded aggregate that had been stabilized and treated with CaCl₂ over a sandy subgrade. The roads had good drainage, crown, and no surface distress.
The three township roads have an ADT ranging from 50 to 75, with a mix of residential and recreational traffic to lake home properties. The top width ranged from 20 to 24 ft (6.1 to 7.3 m) with a base thickness of 3 in. (76 mm) over a silty sand subgrade.

The aggregate was a crushed and screened graded sand and gravel aggregate that met the Otta seal gradation indicated in Table 1. The second lift was repeated over the top of the first on the same day. The construction was done with agency forces with a cost estimated at $22,000/mi ($13,671/km). After 9 months, no maintenance has been needed. The township roads are free of excess aggregate across the driving surface. There is about 1 in. (25 mm) of excess aggregate along both shoulders of the road. The township roads have about 0.5 in. (12.5 mm) of loose sandy aggregate on the surface. The roads have a brownish black appearance.

**Minnesota 74**

Also in August 2001, 2 mi (3.2 km) of MnDOT’s last remaining gravel road was surfaced. This road has an ADT of 395 of local and recreational traffic. The base–surfacing aggregate consists of 6 in. (152 mm) of a 100% crushed limestone aggregate over a loamy sand subgrade. The 100% crushed graded limestone aggregate used met MnDOT Class 5 gradation indicated in Table 1. The three differences between this project and that in Cass County were that there was a 3-week period between the first and second lifts, the aggregate was a 100% crushed limestone, and the aggregate had a top size of 2 in. (25 mm).

The road was reviewed in April 2002. It had a slightly coarse appearance but has performed well. One location had distress cracks due to a weak subgrade, but no thermal cracks were observed. The road is a deep brown color. It has the aesthetics of a gravel road with the performance of an HMA road. There is no loose float, rutting, washboarding, or dust. The mat thickness is 1.375 in. (35 mm), black, and flexible. A slight fragrance of cutters could still be smelled from the surface 9 months after construction. Overall performance is very good. No maintenance has been required.

**Oil Gravel**

The oil gravel surface treatment is a mixture of asphalt and aggregate blended at ambient (or slightly elevated) temperatures (cold mix asphalt) and placed with a conventional paver. Minnesota began by using a cutback asphalt (MC-3000) and has now moved to a high float emulsion (HFE-300). The design uses a softer, lower viscosity, and higher penetration asphalt than HMA. The softer binder is designed to minimize transverse cracking and prolong the aging process. A pugmill can be used to mix the aggregate and emulsion. A conventional drum-type plant was used on many projects because of availability. Oil gravel uses a high-quality durable crushed aggregate with the gradation limits indicated in Table 1. The mixed product can be placed immediately or stockpiled for future use in construction or maintenance activities.

Originally developed in Sweden in the 1950s, it is now one of the main pavements constructed in Finland. Finland partnered with Minnesota to demonstrate the technology at the 1995 International Low-Volume Road Conference. That project, along with six others, has been done in the state and is described here.

Oil gravel is placed with the same construction technique that would be used for HMA. The difference is that the material remains pliable, so areas that need to be repaired can be scarified and replaced with material that was stockpiled during the original construction.

**City of Ostego (Jalger Avenue) Test Section**

The product was produced in a specialized oil gravel plant that was shipped from Finland to Minnesota as a demonstration project for this technique at the 6th International Low-Volume Road Conference. The traffic volume is low but rising steadily because of nearby commercial and residential development. Road preparation included increasing the bearing capacity by adding 6 in. (152 mm) of graded sand and gravel aggregate. The oil gravel mix design involved 3.3% asphalt blended with a 100% crushed granite aggregate (Table 1). The design mat thickness was 1.75 in. (44.5 mm) thick.

One year after construction (1996) some distressed areas developed. This was due to the inadequate base strength in isolated areas. The base and subgrade in these areas were replaced with a large, 1.5-in. (38-mm) minus open-graded 100% crushed granite aggregate. The areas were then repaved with material that had been stockpiled from the preceding year.

Since 1996, no maintenance has been needed on the road. As of 2002, there were two thermal cracks and no rutting.

**St. Louis County Test Sections**

Three roads were surfaced in St. Louis County, located in northeastern Minnesota, with this process during the fall of 1995. The Finnish oil gravel plant was shipped to a project in Russia in late summer of 1995. The technique was modified to use locally available construction equipment. The composite aggregate was 100% crushed dense 0.75-in. (19-mm) minus graded aggregate from three sources. The aggregate and high float emulsion (HFE-300) were mixed warm (150°F; 65°C) in a conventional drum hot-mix plant with an asphalt content of 3.4%.

**St. Louis County Road 6B**

This was a 3-mi (4.8-km) construction project; the first mile (1.6 km) was HMA, and the remaining 2 mi (3.2 km) was oil gravel that was constructed in September 1995. The base is a mixture of 3 to 6 in. (76 to 152 mm) of reclaimed bituminous to which 6 in. of graded aggregate was added at the time of construction. The underlying subgrade is 3 ft (0.91 m) of fill over 4 to 6 ft (1.2 to 1.8 m) of peat. In sections, there are rows of logs laid crossways (curduroy) on top of the subgrade to help float the road over the peat subgrade. The road has an ADT of 150 local and logging truck traffic. A 2-in. (52-mm) mat thickness was constructed with a 2% crown. Segregation was a minor problem during construction because the mix was gap graded. Improved construction techniques minimized the problems.

In October 1995, a flood caused water to cover the road for days and washed out certain sections. No adverse effects were evident upon inspection. The washed out sections were repaired with additional aggregate base, and the surface was patched with the stockpiled oil gravel mix left over from construction. The road experienced heaving and thermal cracking during February 1996 when the minimum air temperature dropped to −59°F (−51°C). Some of the thermal cracks were as wide as 3 to 4 in. (76 to 102 mm). Inspection in spring of 1998 indicated that up to 2-ft (610-mm) frost heaves were present, but after spring thaw the road returned to an acceptable driving surface. Performance in 2002 indicated that the surface had rutted 1 to 1.5 in. (25
to 37 mm) in the outer wheelpaths, with alligator cracking throughout. There are major thermal cracks every 6 ft (1.8 m), which are sealed; minor cracks (not crack sealed) every 3 ft (0.9 m); and longitudinal cracking. The rutted areas were filled by tight blading in HMA. The major surface cracks were sealed in 2001. The section is showing the effects of a weak base. The base instability is causing fatigue and differential settling. This project is an indicator that the surface performance depends on the total pavement structure.

**St. Louis County Road 405**  A segment 2.1 mi (3.4 km) long was constructed in the summer of 1998. The road is in a light farming to residential area with an ADT of 135 of mostly local traffic. The existing aggregate road had a base thickness of 6 in. (150 mm) of granular aggregate. At the time of construction an additional 4 in. (100 mm) of base aggregate was added to the surface. A crown of 2% was graded into all layers. The oil gravel used was an HFE-300 emulsion and blended with a 0.75-in. (19-mm) minus composite aggregate. The residual asphalt content was 4.5%. The treatment was placed 2.5 in. (60 mm) thick and 12.8 ft (3.9 m) wide with a conventional paver and compacted with a pneumatic-tired roller. The cost of the oil gravel was $44,723/mi ($27,623/km).

In the 4 years since construction, there has been no need for maintenance. There are small tight thermal cracks at a random spacing between 70 and 150 ft (21 to 46 m) and less than 0.125 in. (3 mm) of rutting in the wheelpaths. It is scheduled to be crack sealed in 2003.

**St. Louis County Road 636**  This project is 1.0 mi (1.68 km) long. The road has an ADT of 30. The existing road had a bituminous surface, which was reclaimed along with the existing aggregate base to a depth of 6 in. (150 mm). The oil gravel used an HFE-300 emulsion and was blended with a 0.75-in. (19-mm) minus composite aggregate. The design asphalt content was 5.0%. The treatment was placed 2.5 in. (60 mm) thick and 10.8 ft (3.3 m) wide with a conventional paver and compacted with a pneumatic-tired roller. The cost of the oil gravel was $35,325/mi ($21,950/km). The entire section was crack sealed in 2001. In 2002, there were thermal cracks every 60 to 100 ft (18 to 31 m), longitudinal cracks between the wheelpaths, and up to 0.125-in. (3-mm) rutting in the wheelpaths.

### Blue Earth County Test Section

Two 1.5-mi (2.4-km) sections were constructed in Blue Earth County in south central Minnesota in 1996. High float emulsion (HFE-300) was blended with 100% crushed quartzite aggregate for one section and a 50:50 blend of graded sand and gravel aggregate and the 100% crushed quartzite aggregate for the other. The base thickness was increased from 4 to 9 in. (102 to 229 mm) with the addition of a graded sand and gravel aggregate. A continuous drum asphalt plant was used to mix and heat the aggregate and emulsion to 150°F (66°C). Then the 2.5 in. (64 mm) of oil gravel was laid down with a conventional paver. Three rollers (one steel vibratory, one pneumatic intermediate, and a final steel roller) were used to compact the mix. The mix remained soft for hours, so construction traffic ruts and closing construction joints could be completed in a leisurely manner. There were segregation problems during construction due to the coarse mix. Therefore, a seal coat was applied to the road 1 year later (1997) to cover the segregation problems that occurred during construction (9). This treatment cost $34,277/mi ($21,228/km) for the 50:50 aggregate blend and $38,421/mi ($23,874/km) for the 100% quartzite. A review of the road in 2002 showed that over the 5-year period some minor snowplow damage was evident; low-severity thermal cracks were spaced between 70 and 200 ft (21 to 61 m), with 0.125 in. (3 mm) of rutting in the wheelpaths.

### CONCLUSIONS

This report summarizes the construction and performance of three types of surface treatments that can be used to upgrade an existing aggregate road to a paved surface. The general characteristics of each treatment are presented in Table 2. The double-chip seal used a single-size aggregate applied to a layer of hot asphalt. The high application rate was closer to a double Otta seal than a traditional chip seal project. However, after 6 years of service the performance has included no need for anything but a routine maintenance chip seal.

An Otta seal is similar to a double-chip seal in the application rate of the asphalt, but the dense-graded aggregate includes the fines. A high float emulsion was used as the binder. The first project indicated that uniform application of the aggregate is important. If aggregate application is too much or nonuniform, the mat will not become monolithic and will have pothole problems. Later Otta seal projects indicated the second treatment could be applied right after the initial treatment with no effects on performance. A large top-size aggregate, 1 in. (25 mm) minus, gives the surface a rough texture, but performance is not adversely affected. Because of the fines included in an Otta seal, a locally available aggregate usually can be used.

<table>
<thead>
<tr>
<th>Surface Treatment</th>
<th>Surface Thickness inches (mm)</th>
<th>Cost $/mile ($/km)</th>
<th>Quality of Aggregate</th>
<th>Design Complexity</th>
<th>Construction</th>
<th>Typical Traffic Volumes (ADT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chip Seal</td>
<td>⅛ (16)</td>
<td>$25,000¹ ($15,535¹)</td>
<td>Medium to High</td>
<td>Moderate</td>
<td>Agency or Contractor</td>
<td>50–200</td>
</tr>
<tr>
<td>Otta Seal</td>
<td>1 ⅛ (35)</td>
<td>$34,000² ($21,126²)</td>
<td>Low to Medium</td>
<td>Low</td>
<td>Agency or Contractor</td>
<td>40–400</td>
</tr>
<tr>
<td>Oil Gravel</td>
<td>2 (50)</td>
<td>$45,000² ($27,961²)</td>
<td>High</td>
<td>High</td>
<td>Contractor</td>
<td>150–500</td>
</tr>
</tbody>
</table>

¹ Contractor and public agency cooperative project.  
² Contractor bid costs.
The oil gravel surface is similar to HMA in design and construction. All the projects had problems with segregation during construction. This problem can be minimized by proper handling and construction techniques. One benefit of this treatment is that material stockpiled at the time of construction can be used in subsequent maintenance activities. The surface just needs to be scarified and fixed and the stockpiled oil gravel replaced. Therefore, road repairs are similar to a procedure that would be expected for an aggregate-surfaced road. Small thermal cracks that develop during the winter will heal themselves during the summer because of the use of the soft high float emulsion asphalt, which remains flexible. These projects showed the greatest differential in performance. Those that were constructed in areas of weak subgrade showed problems with rutting, fatigue, and thermal cracks. Those constructed on a strong stable base had <0.125-in. (<3-mm) rutting and 60 to 150 ft (18 to 46 m) between thermal cracks.

All three surface treatments require a strong stable base to work properly. The treatments add no structural component to the road. Therefore, this needs to be understood so that problem soft areas along shoulders and over culverts or other areas are corrected before application of a surface treatment. Proper project evaluation and selection is very important.

Minnesota is currently beginning a research project to determine the economics of upgrading an aggregate road. The surface treatments mentioned here will be included in this project and evaluated for performance and cost. Recommendations can be given about when each treatment would be chosen.

ACKNOWLEDGMENTS

The author gratefully acknowledges the Minnesota Local Road Research Board for its financial support in conducting this research. The author also thanks the following individuals for providing information and assistance with this paper: Kevin Adolfs and the St. Louis County staff; Gary Bruggeman, Allen Henke, and the Houston County staff; Dave Redig and the MnDOT District 6 maintenance staff; Dave Enblom and the Cass County staff; Blue Earth County engineer Allen Forsberg; Haraldur Sigursteinsson and Einar Thorvardarson of the Iceland Road Administration; and colleagues in the MnDOT Research Office for their assistance during construction of the test sections and assembly of information for this paper.

REFERENCES


The contents of this report reflect the views of the author, who is responsible for the facts and accuracy of the data presented here. The contents do not necessarily reflect the views or policies of the Minnesota Department of Transportation. This report does not constitute a standard, specification, or regulation.