Finnish Cold-Mix Asphalt Pavement

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A Finnish-Minnesotan cooperative project to test paving materials for low-volume roads will embark in 1995. The subject of research is a Finnish cold-mix asphalt, oil gravel (*öljysora*). A test road selected by the Minnesota Department of Transportation will be surfaced with oil gravel to judge its suitability for conditions in Minnesota. The contents and mixing requirements of oil gravel and emulsion gravel pavement—aggregate, binder, mixing, and surfacing techniques—are identified on the basis of technical experience with this type of paving material in Finland.

Finnish experience with oil gravel has a long history. The Finnish National Road Administration (FinnRA) has a 77 000-km public road network. Of these 77 000 km some 47 000 km is paved roads—16 000 km with asphalt concrete and 31 000 km with oil gravel. The first modern cold-mix pavements were introduced at the beginning of the 1960s. The lifespan of an oil gravel pavement can be up to 20 years. Oil gravel and recently developed emulsion gravel are very similar products, the main difference being the binder.

Applications

Both oil gravel and emulsion gravel are used as surfacing for roads where average daily traffic (ADT) is at most 1,000 vehicles per day. Oil gravel is also used as patching or surface treatment mix for oil gravel roads.

The price of the oil gravel or emulsion gravel wearing course is about 65 percent of the price of an asphalt concrete wearing course. Annual statistics show that, for example, in 1993 the average price of asphalt concrete (100 kg/m^2) in Finland was 12.22 mk/m^2. In the same year, the average price of oil gravel (100 kg/m^2) was 7.70 mk/m^2.

Layers under the surface are also cheaper in emulsion gravel roads than in asphalt concrete roads: the latest calculations demonstrate that the unit cost of building an asphalt concrete road is 1.3 to 1.7 times higher compared with the cost of a similar emulsion gravel road.

Annual maintenance costs of emulsion or oil gravel roads are closer to those of gravel roads than asphalt concrete roads: according to the latest (1993) maintenance statistics, the average maintenance cost of asphalt concrete was 18 967 mk/km/year. For oil gravel the cost was 10 165 mk/km/year, and for gravel it was 8352 mk/km/year on average. These costs naturally depend on the standard of each road class and are not directly comparable.

The typical thickness of an emulsion gravel pavement layer is 70 to 100 kg/m^2. Emulsion gravel roads are usually designed to last 8×10^5 equivalent single-axle loads (ESALs) during 15 years (10-ton axle).

The number following the surfacing-type abbreviation is the average weight per square meter (kg/m^2) of the surfacing. For example, OS 20/100 means that the maximum grain size of the aggregate is 20 mm and the amount of oil gravel is 100 kg/m^2.

Recycled mixes are marked by adding the letter R (*R-rouhe-crush*) and a number, which shows the percentage of old mix in the total of the mix, to the end of the normal abbreviation, for example, AB 20/120 R 70.

Raw Materials

Aggregate

The aggregate is macadam or crushed gravel containing fine aggregate. The mixing properties and the grading of the mix can be improved by dividing the aggregate into grading classes. If grading, cleanliness or other properties are not in accordance with quality control, or if there are fears that the contents of the aggregate may essentially decrease the quality of the oil gravel, the success must be verified beforehand with laboratory tests.

The quality of crushed stone produced with the blasting and crushing methods used in the manufacture of surfacing aggregate must be as high as possible. The quality of aggregate used for surfacing must be tested in an approved laboratory.

All crushed stone used for paving must meet the quality requirements for the following upper and lower grading limits. The particle size fraction may not contain more than 5 percent by weight of material coarser than the upper grading limit. The whole particle size fraction must pass a sieve size 20 percent larger than the upper grading limit. The particle size fraction cut from both ends may not contain more than 10 percent by weight of material finer than the lower limit. At most 4 percent by weight may pass the sieve that is half smaller than the lower limit. If the particle size fraction has been determined with wet sieving, it may contain at most 2 percent by weight of material passing the 0.074-mm sieve. The latter does not concern such particle size fractions whose lower limit is zero.

Aggregate may not contain harmful quantities of contaminants like clay, peat, humus, topsoil, wood, ice, or salt. During stocking the aggregate sorts may not segregate nor mix together nor with the soil under them. The humus class of the aggregate can be determined by the NaOH test (TIE 221 method). For aggregate used for cold paving the maximum organic material (humus) class is II. If the humus class is III or worse, the qualifications of the aggregate must be determined separately by doing adhesion tests for test mixes, among others. Finnish TIE methods are in most cases comparable to corresponding ASTM and DIN methods. In the TIE 221 method, classes are from 0 (best) to IV (worse). Classes 0, I and II are proper without specific examinations. The cleanliness of fine aggregate is especially important in cold-mixing techniques.

The following properties are determined from the aggregate:

- Point load index Is(50) (determined from a drill core),
- Ball mill value,
- Abrasion value (before ball mill value), and
- Shape index and flakiness.

The strength classification is shown in Table 1. The strength class is determined by the weakest value.

The shape classification of the aggregate is shown in Table 2. The shape class is determined by the shape index or the flakiness, depending on which one of them is worse. The shape class determinations are normally done using aggregate from the grading Class 8 to 12 mm. If the crushed stone product does not contain grain sizes 8 and 12 mm, the shape and quality class are determined using the grading Class 12 to 16 mm.

The aggregate of emulsion gravel is crushed stone similar to that of the oil gravel aggregate. The highest permissible humus content class is II. If the humus content class is higher than Class II, the suitability of the aggregate to the manufacture of emulsion gravel can be determined beforehand with laboratory tests.

Binder

In oil gravel the binder is BO-2T, road oil with adhesion-improving additive. The amount of adhesion additive must be high enough to ensure active adhesion. The adhesion-improving additive is a mix of mono- and diamines or just diamine. The recommended percentages for adhesion-improving additive are as follows:

Adhesion-Improving Additive	*Undrained Aggregate (%)*	*Drained or heated aggregate (%)*
Mono- and diamine mix	1.2	0.5
Diamine	0.8	0.5

TABLE 1 Strength Classes of Aggregate

Class	Point Load Index Is(50) TIE 241 MPa	Ball Mill Abrasion Value TIE 242 %
IA	≥ 13	≤ 7
IB	≥ 10	≤ 11
IC	≥ 8	≤ 14
ID	≥ 6	≤ 17
II	≥ 4	≤ 30

TABLE 2 Shape Classes of Crushed Stone and Their Limits

Shape class	Shape Value TIE 233				CEN-Draft prEN 933-6:1992 Flakiness %
	Elongation (c/a) Researched Fraction (mm)		Flakiness (b/a) Researched Fraction (mm)		
	8 - 12	12 - 16	8 - 12	12 - 16	
I	≤ 2.5	≤ 2.3	≤ 1.5	≤ 1.4	≤ 10
II	≤ 2.6	≤ 2.4	≤ 1.7	≤ 1.6	≤ 15
III	≤ 2.7	≤ 2.5	≤ 1.8	≤ 1.7	≤ 20
IV	≤ 2.9	≤ 2.7	≤ 1.9	≤ 1.8	≤ 25

If the additive is added to the binder in a refinery, the values are 0.1 percent higher than just given in the table. If adhesion between road oil and aggregate is not good, the additive content can, if necessary, be 0.1 to 0.3 percent greater.

The melting of the adhesion-improving additive is done on site in special melting kettles or by mixing it directly with the binder. The binder tanks must have efficient mixing equipment. After the additive is completely mixed with the binder, the mixing process must be continued until the mix has once more gone through the pump.

Gradually, mainly because of oxidation, the quantity and effect of the adhesion-improving additive mixed with the binder decrease. As the temperature increases the oxidation also increases. To reduce oxidation, the handling of the binder-adhesion mixture must be organized to make circulation in the tank possible only below the fluid level, to prevent oxidation increase caused by surging. Safety instructions for the handling of adhesion should be followed. Both the quality and the quantity of the adhesion and the operation time for the binder after reducing the adhesion are specified in the contract.

In emulsion gravel, the binder is of bitumen emulsion BE 1000 to 3000. The stiffness of the binder is chosen according to its use and desirable final strength of surfacing. Binder can be emulsified in the refinery or in the mixing plant. The emulsification of the binder in the mixing plant requires the emulsifying equipment to be connected with the mixing plant. Other specific requirements for bituminous-oil and bitumen-emulsion binders are given in Table 3.

Manufacture of Mix

Figure 1 shows the general regulations for the composition of oil gravel mix and for the quantity of mix in the completed surfacing. Unless otherwise indicated, the mixture is made of undrained aggregate. Drainage and heating of the aggregate are usually necessary if

TABLE 3 Requirements for Bituminous Oil and Bitumen Emulsion

Aim of Testing	Requirement	Unit	Bituminous Oil BO-2	Bitumen Emulsion BE
Viscosity 25 oC	min.-max.	mm2/s		35-170
Viscosity 60 oC	min.-max.	mm2/s	350-650	
Fractional distillation				
- Distillate of the initial amount up to 225 oC	max.	vol %	0	
- Distillate of the initial amount up to 260 oC	max.	vol %	1.0	2.0
- Distillate of the initial amount up to 315 oC	max.	vol %	8.0	
- Distillate of the initial amount up to 360 oC	max.	vol %	12.0	
Distillation residue 260 oC	min.	weight %		60
Viscosity of distillation residue 60 oC	min.	mm2/s	2 000	900
Viscosity of distillation residue 60 oC	max.	mm2/s	4 000	4 500
Distillation residue, solubility to toluene	min.	weight %		99.5
Water	max.	weight %	0.5	
Flash point	min.	oC	56	
Sieving residue on 0.5 mm sieve	max.	weight %		0.2
Sedimentation, 5 days	max.	weight %		4
Breaking	max.	weight %		60

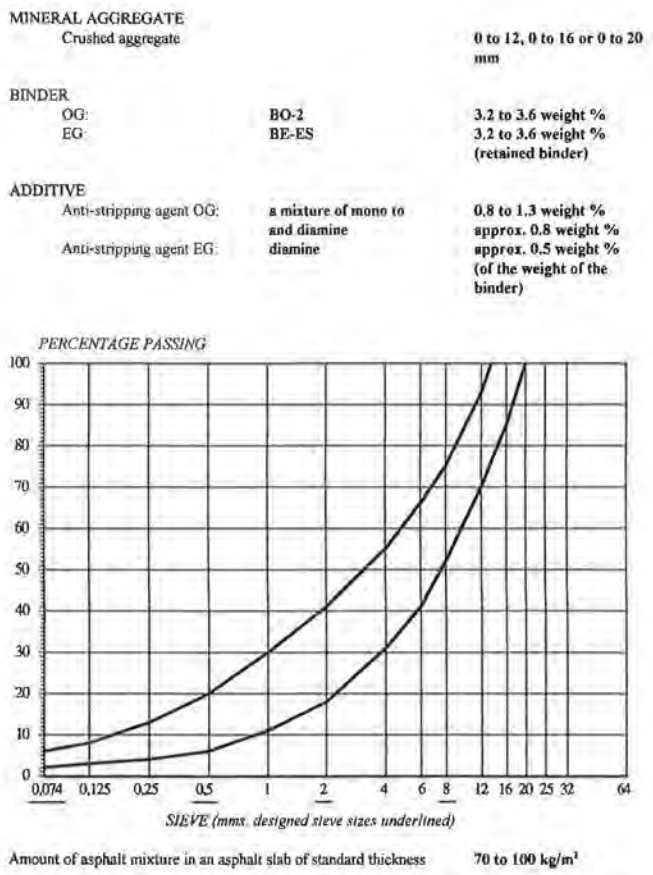

FIGURE 1 General regulations for the composition of oil gravel.

1. The percentage by mass passing a 0.074-mm sieve is more than 5 and the moisture content is over 3 percent,
2. The moisture content is more than 5 percent,
3. The air temperature during the laying mix is below +5°C and below 0°C if the mix is manufactured for stocking, and
4. The percentage by mass passing a 0.074-mm sieve is above 6.

The moisture content of drained and heated aggregate should usually be between 0.7 and 1.5 percent. The separation of aggregate and mixture should be prevented.

The spraying temperature of the road oil must be 100 ± 15°C before mixing with the aggregate. The mixing temperature is shown in Table 4.

In cold feeding process the feeding of aggregate and binder into the mixer should be done together and the feeding should last as long as possible; this way the mixing is effective. If the mixing time has been long enough, the mixture is homogenous and without clods. Oil gravel is not to be mixed on the road.

TABLE 4 Permissible Mixing Temperatures of Soft Mixture

Mixture	Equipment	Binder	Mixing Temperature °C
Soft asphalt concrete	Asphalt plant	B-800	110 - 130
Soft asphalt concrete	Oil gravel plant + drum or steam heating	B-800	60 - 90
Recycled soft asphalt concrete	Recycling plant	BÖ-4 B-800	70 - 100
Oil gravel	Oil gravel plant	BÖ-2	Cold mixing
Oil gravel (heated)	Oil gravel plant + drum or steam heating	BÖ-2	40 - 70
Oil gravel (dried)	Asphalt plant	BÖ-2	80 - 100
Recycled oil gravel	Recycling plant	BÖ-2	50 - 80

Before paving, the mix composition must be ascertained with weighing machines and checked with meters. The checking can also be done by taking a sample from the trial heat and testing it in the laboratory. Paving may start if the results show that the mix fulfills the requirements and if the composition (clods, segregations, etc.) and other properties (color, adhesion) are considered normal. The contract price can be reasonably reduced if the material laid on the road is not adequate. If failure makes the surfacing essentially worse, it must be totally removed. The mixing time and capacity are agreed upon separately for each site after it has been ascertained that the mix meets quality control standards.

The quality of cold mix can be improved by stocking. The usual amount of oil gravel stocked for maintenance is 30 tonnes per kilometer. Stored oil gravel usually contains 0.2 percent more binder than oil gravels used immediately after their manufacture. Oil gravel should not be stored in rainy weather if increasing moisture content decreases the quality of the mix. The disparition is to be avoided. The stockpiles should be made consistent to protect the mix from becoming dirty and getting damp.

Emulsion gravel mix is manufactured according to the instructions for oil gravel, to a certain extent. Emulsion gravel can be manufactured cold or heated. The best mixing results are achieved when the moisture content of mix is 2 to 3 percent.

Surfacing

The mix is usually laid with an asphalt paver so that no hand-laying is needed, except joint sealing. If so decided, the laying can be done with a drag or with other equipment suitable for this purpose. The amount of mix used and the area paved are noted after each work shift.

The average material consumption during each shift must be at least the same as the quantity ordered. The material must be laid evenly along the surface. The quantity of the mix measured in one place may at most be 15 percent smaller than ordered. The quantity of the material laid can be observed by comparing the weight of each truck with the corresponding area. Thin places must be corrected during the work.

The oil gravel is usually rolled soon after laying. Attention should be paid to the compaction of the edges of the road. Traffic on the new oil gravel road should be limited if the traffic loads seem to cause rutting, binder bleeding, or other serious damage.

The reasons for the weak adhesion between the aggregate and the binder, for the significant unsticking of large stones, for the binder bleeding, and for other similar failures of the new oil gravel surfacing must be determined and eliminated. If necessary, the paving work must be interrupted during the reconditioning.

If there are smooth or soft places or if the moisture content of the prepared surfacing is too high, the surface must be milled. After milling there should be a 2.5-cm-high prepared layer on the pavement. The surfacing is rolled after milling.

Emulsion gravel is laid with an asphalt paver and compacted efficiently in the same way as oil gravel. Warm mix is more easily workable than cold mix. Because the strength development of emulsion gravel is rapid, the mix must be compacted immediately after laying and the surfacing needs more compaction than oil gravel.

Milling and Increase of Mix

Old oil gravel surfacing is generally repaired by milling the underlay, increasing the mix, and compacting. Old oil gravel is milled by a ripping/milling device joined to a motor grader or by a separate miller.

Milling can be done only in dry weather. To avoid clods the surfacing can be warmed. Milling must not be done in such a way that the crushed stone below it is mixed with oil gravel. After milling the underlay is leveled. New mix is added to the leveled underlay and the surfacing is compacted.

The design grading curve must be chosen by the use. After the design grading curve has been chosen, the binder content used for minor works can be determined by interpolating the binder contents of the design grading curves.

If the specific gravity of the aggregate differs from the value 2.70 kg/dm^3 the binder content has to be changed as follows: if the specific gravity of aggregate changes +0.08 kg/dm^3, it is correspondent with the binder content change −0.1 percent by weight.

Recycled Oil Gravel and Soft asphalt Mix

Applications

Recycled oil gravel containing at most 70 percent oil-gravel crush is used as the normal oil gravel. The recycled oil gravel in which the oil gravel percentage is over 70 is used for low-traffic roads (with AADT less than 300 vehicles per day).

The applications for the recycled soft asphalt are the same as for the normal soft asphalt concrete. The manufacture and the laying are done following the instructions for the recycled oil gravel.

Oil-Gravel Crush

The old oil gravel surfacing is milled with an asphalt miller or a scarifier with a motor of its own. These machines have adjustable milling depth and the crush is loaded directly onto the vehicle.

The oil gravel surfacing suitable for milling should be even, so that milled crush will not contain too many big stones and crushed aggregate from the base. The surfacing should be solid and coherent enough to bear milling without splitting into clods. It is better not to mill the edges of the surfacing or the wide and puddled failures; if these are milled, the crush must be stored separately. Oversized grains must be separated from the crush with sieving.

The serviceability of the milled part of the road can be improved by leaving a sufficient unmilled layer on top of the underlay. The milling should preferably be done just before the improvement is started, since holes appear easily in the milled base.

The oil gravel crush is stored in loose stacks. The machines may not move on top of the stacks. If the crush is stored over the winter, the stacks should be covered.

The maximum grain size for the oil gravel crush is typically 90 percent of the original maximum grain size. The quantity of the fine aggregate (percentage by mass passing the 0.074-mm sieve) is 7 to 9 percent. The binder content varies between 2 and 3 percent.

Proportioning

The grading of the recycled oil gravel can be improved with the crushed stone containing little fine aggregate, for example, grading Class 8 to 18 mm. In general the aggregate increase is over 30 percent.

The additional aggregate is often used on busy roads, where it increases the quantity of active binder in the mix and decreases the tendency for segregation.

The crush stimulated with nothing but additional binder can be used on low-traffic roads, although such a mixture tends to be dry and to segregate.

The quantity of additional binder is calculated with the following formula:

$$P_{add} = P_{aim} - 0.85 \ldots 0.95 * R/100 * P_{crush}$$

where

P_{aim} = binder content determined by the proportioning,
P_{crush} = binder content of the oil gravel crush, and
R = oil gravel percentage in recycled mixture (0 to 100 percent).

The coefficient is 0.85 if the crush contains old and hard binder, and the mix contains a lot of crush (≥70 percent). The coefficient is 0.95 if the crush is moist, and the crush content of the mix is small (≤50 percent).

The binder used is made of road oil BO-2 cured with adhesion-improving additive. When oil gravel is used in the manufacture of soft asphalt concrete, the binder used is made of road oil BO-4 or bitumen B-800.

Manufacture and Laying of Mix

The manufacture and laying of mix are done according to the regulations for normal oil gravel. The cold-mixing can be done either in the batch-mixing or continuous-mixing oil gravel plants. In the continuous mixing process the functioning of the cold feed unit must be controlled all the time since the feeder tends to be clogged rather easily.

The heat mixing can be done either in a batch-mixing plant supplied with a heating drum and a batch mixer or in an asphalt plant with a continuous drum mixer. In the continuous mixing plant the cold feeder unit must have an automatic belt weighing machine for aggregate weighing. The final moisture content of the mix has to be 0.4 to 0.8 percent.

Quality Control

Good working methods and building materials as well as skilled foremen and workers should be used. One sample per 500 tons of mix is taken randomly from the oil gravel crush and the reclaimed asphalt mix during the crushing and storing of crushed material. The binder content, the grading, and the water ratio are determined from the samples. In order to find out the binder qualities of the crush, one crush sample (about 4 kg) for each beginning 5,000 tons is sent to the central laboratory of the Finnish National Road Administration.

One mix sample is generally taken for each beginning 500 tons of mix. Depending on the maximum grain size, the quantity of the sample to be investigated is as follows:

Maximum Grain Size (mm)	*Sample (g)*
12–20	1,700
>20	1,900

The samples are investigated to determine their binder content and grading and also the water ratio of oil gravel mixes. The test results must be ready by the time about 500 additional tons of mix have been manufactured (since the samples were taken). The sampling systems for projects that need a small increase of mix (remixing, ART, etc.) are agreed on separately.

The average composition of the mix is determined from the average samples. The quantity of one hot-mix sample is about 8 kg and the quantity of one cold-mix sample is about 7 kg.

The adhesion of oil gravel is always investigated after the increase of adhesion-improving additive and randomly at an interval of 500 tons of mix (the bucket test). If the adhesion is poor, it must be tested. Cold-mixed oil gravel has to be checked at an interval of 5,000 tons of mix. At least one adhesion control test is taken from every mixing plant.

For aggregate and mixture weighing the continuous oil gravel mixers must have weighing machines equipped with belt scales with an accuracy of ±2.0 percent. For oil quantity measuring there must be flow meters with an accuracy of +1.0 percent. The binder content measured with such a meter may not differ more than +0.2 percent units from the design value.

Oil gravel or soft asphalt concrete joints are not heated or coated. Recycled oil gravel or soft asphalt concrete must meet the quality control standards for normal oil gravel or soft asphalt concrete. The quality control standards for emulsion gravel is the same as those for oil gravel.

Conclusions

Finnish oil gravel will soon be tested in the United States by the Minnesota Department of Transportation (MnDOT). In Finland and other Nordic countries, especially Sweden, oil gravel pavement has taken its place as a surface type for low-volume roads. The price-quality ratio is best for this pavement type when the traffic volumes are less than 1,000 vehicles per day. The adaptability of this pavement type to Minnesotan climate and traffic conditions will be apparent after one year of traffic load on the pavement. So far, the cooperation between MnDOT and FinnRA has been a success story in many areas of road and traffic engineering, including winter

maintenance, an engineer exchange program, and the MnROAD project. The joint project on oil gravel pavement should also be among the successful cooperation projects between these two road administrations.

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