Development of Environmentally Friendly Cold Patching Compound

J. Valtonen & T. Pellinen
Department of Civil and Environmental Engineering, Aalto University, Espoo, Finland

T. Blomberg,
Nynas Oy, Vantaa, Finland

ABSTRACT: The aim was to develop a cold patching material that could be used in lieu of conventional oil gravel. The advantage of the oil gravel is that it can be scarified and re-compacted after laydown. Due to the softness of the oil gravel it is only used in the low volume roads in Finland. The new mixture was made of binder, which consisted of soft bitumen and bioflux. Bioflux is a bioproduct obtained from biodiesel production, which is based mainly on palm oil. Studies concentrated to the adhesion properties and hardening of mixtures during storage. Based on the adhesion tests, the binders had excellent adhesion to the aggregate. The conventional oil gravel mixture had up to 74% strength increase after four months of curing, while the indirect tensile strength gain in the oil gravel made of bio road oil was only 10 to 20%. The mixture's ability to stay soft may be both advantageous and disadvantageous; advantage is that mixture stays workable but disadvantage is that patches may not be able to resist displacement by traffic. However, road tests are suggesting that the biofluxed road oil could be used to replace the conventional road oil to produce soft paving mixture, which then could be used as regular surface mixture for the low volume roads.

KEY WORDS: Cold patching, soft asphalt, bioxlux, road oil, oil gravel

1 BACKGROUND

Finland is a relatively small country with large network of low volume roads. About 35 percent of these roads are still gravel roads but at 60's and 70's there was a big undertaking to pave low volume roads with oil gravel. Oil gravel is a continuously dense-graded cold paving mixture with cut-back bitumen (Valtonen, 1993). The cut-back bitumen or road oil is made of bitumen and mineral solvents such as diesel oil. The advantage of using cut-back bitumen was that due to the solvents the asphalt mixture stayed soft and could be scarified and re-compacted after placement to repair frost heave damages and other surface defects developing over time in service. Mixture was produced with a special mixing plant in which warm road oil and cold or warm (80°C) aggregates were mixed together.

At the beginning of 90's, however, there became the need to reduce VOC (volatile organic compounds) emissions, and the use of cut-back binders started to decline. Oil gravel was then replaced with similar warm asphalt mixture (PAB-V) made of very soft bitumen V1500 (Onikki and Eskola, 1996). The kinematic viscosity of the soft bitumen is 1500 mm^2/s at 60°C, while the typical road bitumen of PEN 70/100 has kinematic viscosity of $> 90 \cdot 10^6$

mm^2/s at 60°C. Although, the mixing temperature of this soft mixture can be as low as 40 – 45°C, hot mix asphalt plants can be used in the production.

In the wintertime, when mixing plants were closed, it was a common practice to manufacture oil gravel and stockpile it at the back of the mixing plant. This mixture was then used as a temporary cold patching compound for low volume roads and streets. Although, PAB-V mixtures could be used to replace the oil gravel as a paving material, it cannot be used as patching material because mixture looses its workability due to the excessive hardening during storage. This hardening occurs mainly due to the oxidization of bitumen. Therefore, original oil gravel has still been used today as a cold patching material. However, the need for an environmentally friendly cold patching material has led to the development of new road oil, which is made of bioflux and soft bitumen of V1500. Bioflux is a bioproduct obtained from biodiesel production, which is based mainly on palm oil.

The development work of the bioflux road oil has been done by Nynas Oy and the Aalto University has been involved with laboratory and field testing of mixtures made of this binder.

2 BIOFLUXED ROAD OIL

Biofluxed road oil is targeted to replace the conventional road oil, BL2K used in the oil gravel mixtures. In the new product, the mineral oil based solvents have been replaced with biobased, renewable flux, and also less flux is needed. The product has a better eco-balance and it gives less VOC emissions. The heavier flux brings along a better flash point. The flash point exceeds the critical temperature of 100 °C, being about 130 °C. This gives considerable safety factor when using hot mix plants in oil gravel production. It is expected that mixture retains good workability over longer period of time because of the heavier flux. The bio product should be used with antistripping agent similar to the conventional road oil. Table 1 gives some typical road oil properties according to PANK specification (PANK, 2007).

Table 1: Properties for road oils.

Property	Unit	Bio Road oil Typical values	Road oil Specification
Viscosity 60 °C	mm^2/s	750	350-650
Flash point, PM closed cup	°C	130	> 55
Density 15 °C	kg/m^3	970	965
Distillation			
- distillate at 225 °C	vol-%	0	0
- distillate at 260 °C	vol-%	0	< 1
- distillate at 315 °C	vol-%	0	< 8
- distillate at 360 °C	vol-%	2	< 12
Distillation residue viscosity 60 °C	mm^2/s	1500	2000-4000
Stabilized binder *) viscosity 60 °C	mm^2/s	1600	

*) 24 h at room temperature + 24 h at 50 °C + 24 h at 85 °C.

Figure 1 shows some typical viscosity curves for the road oils and V1500 bitumen. For the reference, the figure shows biofluxed road oil extracted from the field produced oil gravel mixture. The road oil has aged during production and laydown being approximately four times harder than the original “tank” oil.

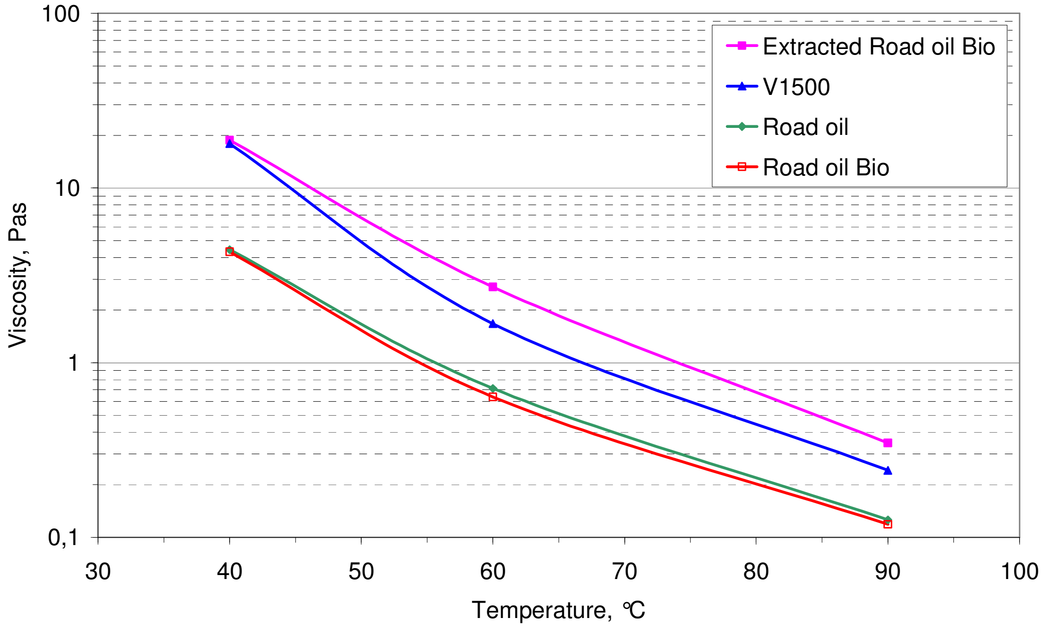

Figure 1: Viscosity curves of road oils and the base bitumen V1500 compared to the extracted bio road oil from oil gravel.

3 RESEARCH APPROACH

The requirement for a satisfactory patching material is that it stays workable while stored. At the same time, mixture must have good adhesion to the aggregate and it must produce durable patch. Stability, which allows the patch to resist displacement by traffic, requires that the compacted mixture gains some strength over time by curing. Below is a list of properties that bituminous patching mixture should have (Maher et al., 2001):

- *Stability*, to allow the patch to resist displacement by traffic.
- *Stickiness*, so the patch will adhere to the sides of the pothole.
- *Resistance to water action*, to keep the binder from stripping off the aggregate.
- *Durability*, so that the patch has satisfactory resistance to disintegration.
- *Skid resistance*, should be similar to the pavement in which the patch is placed.
- *Workability*, to enable the material to be easily shoveled and shaped.
- *Storageability*, so the mixture can be stockpiled without hardening excessively or having the binder drain off the aggregate.

The aim of the overall study is to develop more environmentally friendly cold patching material. This paper presents the preliminary study findings concentrating mainly on laboratory testing of laboratory and plant fabricated mixtures. Due to the exploratory nature of the work, only some of the properties listed above were studied. The study was conducted in three stages:

- Laboratory study comparing oil gravels made of conventional road oil and bio road oil
- Construction of two test roads
- Testing of stockpiled oil gravel

Laboratory study investigated the adhesion properties and hardening of mixtures due to curing. The target for the test roads was to compare bio road oil gravel to the soft asphalt PAB-V made of soft bitumen V1500. The aim for testing stockpiled oil gravel was to investigate hardening of mixture during long term storage.

4 LABORATORY STUDY

4.1 Sample Preparation

Experimental plan consisted of using two types of aggregates, vulcanite and granodiorite, and two binders, the new biofluxed binder (bio road oil) and as a reference the cut-back bitumen (BL2K road oil) used in the conventional oil gravel (PANK, 2007). The experimental plan is shown in Table 2.

Table 2: Studied materials.

Mix type	Binder type	Aggregate type	Notes
Oil gravel	BL2K road oil	Koskenkylä vulcanite	Non susceptible for stripping
Oil gravel	Bio road oil		
Oil gravel	BL2K road oil	Teisko granodiorite	Susceptible for stripping
Oil gravel	Bio road oil		

Koskenkylä vulcanite is a typical hard aggregate used in high volume roads in Finland, while Teisko granodiorite is a typical low volume road aggregate with less resistance to wear caused by studded tires. Based on previous studies Teisko aggregate is also more susceptible for moisture damage.

Table 3 shows the binders used in the study. Both binders were blended at Porvoo refinery and 0.4% of antistripping agent (by weight of binder) was added in the laboratory just before mixing. If antistripping agent is added at the refinery, usually 0.5% is used to compensate degradation during transport.

Table 3: Binder Properties

Binder Type	Base binder	Solvent	Fatty acids (%)	Viscosity (mm^2/s) at 60°C	EVT (°C)
BL2K road oil	V2000-4000	Mineral oils	0.4	712	84
Bio road oil	V1500	Bioflux	0.4	636	82

A recipe approach was used to design the mixtures. Due to the fact that Finnish aggregates are very dense, binder absorption is neglected in the design. Fabricated mixtures had a typical dense-graded soft asphalt PAB-V16 aggregate gradation according to Finnish specification (PANK 2007); the passing % of 0,063 mm sieve was 5%, 2 mm sieve was 35% and 11.2 mm sieve was 65%. Aggregate blend did not have mineral filler or hydrated lime. Specification requirement for the binder content is 3.9% by weight of the mixture, when bitumen V1500 is used, but binder content was reduced to 3.4% due to lower viscosity of the road oil used (see Figure 1).

A total of 15 specimens were fabricated per mixture having five replicates for each curing time experiment. Aggregates were at room temperature and before mixing 2% water (weight of the aggregate) was added to the cold aggregate blend followed by the binder heated to the equiviscous temperatures (EVT), shown in Table 3. Mixing time was one minute. Samples were compacted with the Finnish ICT-gyratory compactor using 100 mm molds. Approximately 60 mm high samples were compacted applying 100 gyrations at 20 –25 °C temperature. The gyratory compaction angle was 17.5 mrad (1°) and pressure was 600 kPa.

4.2 Test Results

Adhesion ability of mixtures was measured using MYR test (SFS-EN 12697-12, method C) in which loose mixture is placed to a glass beaker with water, which is then flipped around 20 times. Water from the beaker is poured to a filtering paper and it is dried in the oven at 110°C to a constant mass. The amount of fines in grams extracted from the mixture is then used as water sensitivity indicator for the mixture. It also tells the ability of the binder to coat the aggregate. Mixtures were tested after mixing and then again after four weeks of curing in the loose stage. Testing was conducted using two replicates. All tests gave between zero to 0.1 grams of loose fines. As the specification criteria for good adhesion is < 2.0 g, it can be concluded that all mixtures had good adhesion properties.

Mixture hardening was studied with the help of Indirect Tensile strength test (SFS-EN 12697-23) conducted at +10°C using loading rate of 50 mm/minute. A total of five replicates were tested. Compacted samples were allowed to cure one, four and eighteen weeks (four months) before testing. The specimens were stored at room temperature. The IDT strength test results are shown in Figure 2. Figure also shows the error bars (2·standard deviation) for average test results. The coefficient of variation (CV) ranged between 2.6% and 12.2% being 6.9% in average.

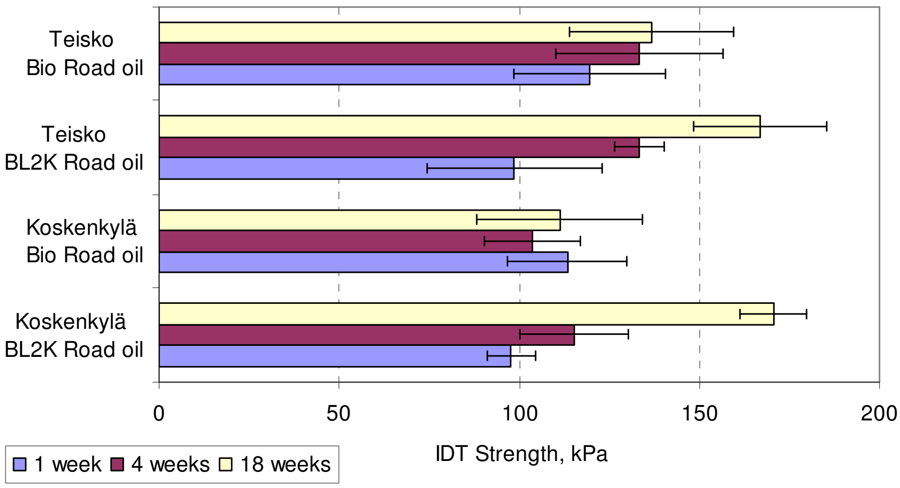

Figure 2: IDT strength gain due to curing of specimens.

The conventional oil gravel mixture with BLK2Kref binder was hardening as function of curing time, as would be expected. This curing phenomenon did not seem to depend on aggregate type; 18 weeks cured specimens had 74% and 69% higher IDT strength than that of the one-week-old specimens. However, the oil gravel with bio road oil was not hardening at all when Koskenkylä aggregate was used. There was some slight hardening with Teisko aggregate, but results were not statistically significant as the error bars indicate.

5. TEST ROADS

Although the original goal was to develop cold patching material, the laboratory study results were encouraging enough to warrant construction of two full-scale test roads. Due to the good adhesion properties, the hypothesis was that oil gravel made of bio road oil could be used in lieu of the soft asphalts as the paving material for the low volume roads. Punkalaidun test road was constructed during August 2008 and then Elimäki test road during September 2008. For Elimäki test road, mixing plant was located in Iitti, which is about 45 km away.

5.1 Mixture Production

In Punkalaidun and Iitti two different mixtures were produced, a soft asphalt PAB-V and the oil gravel, see Table 4. The maximum aggregate size of the Punkalaidun mixes was 16 mm and it was a typical local aggregate used in the low volume roads (PANK, 2007) while the Iitti mixtures had 11 mm top size and gradation was specially proportioned for the job. Quality control tests showed that for both plants the produced mixture gradation matched the target gradation. The stockpiled aggregate had 2.6% moisture content in Punkalaidun mixing plant and 3.8% in Iitti.

Table 4: Materials used on Test Roads.

Mixing plant	Mix type	Binder type	Viscosity mm^2/s at 60°C	Binder content (%)	Aggregate moisture content (%)
Punkalaidun	Soft asphalt	Bitumen V1500	1260	3.5	2.6
	Oil gravel	Bio road oil	529		
Iitti	Soft asphalt	Bitumen V1500	1490	3.6	3.8
	Oil gravel	Bio road oil	557		

For bio road oil, the soft base bitumen V1500 and bioflux was mixed in the tank, while delivering the blend from the refinery. There was no need for high-shear mixing because fluids were able to flow easily and mix together. All mixtures were produced by turbo mixing plant that uses steam to warm up the aggregate. The mixing temperature for the oil gravel ranged from 50 to 55 ºC.

5.2 Laydown and Compaction

Mixtures were placed using paver and compacted with steel wheel rollers. Compaction temperature was slightly higher or at the ambient temperature. Based on visual inspection after few weeks of laydown, the oil gravel test sections looked similar to the soft asphalt sections. The only difference was that the soft asphalts seemed to be a little bit more open compared to the oil gravel surfaces. Both test roads were in very good condition, and no damages were visible.

The mixes of Punkalaidun asphalt plant were placed on a local road, which had traffic volume of 177 vehicles per day, see Figure 3-a. The length of both test sections was 780 m and they are located side-by-side on the opposite traffic lanes. The mixes of Iitti asphalt plant were also placed on a local road at Elimäki, but the road was more heavily trafficked; the traffic volume was 533 vehicles per day, see Figure 3-b. The length of the oil gravel test section was 346 m. The soft asphalt section is located on the opposite traffic lane as a reference.

Figure 3: Test roads: a) Punkalaidun: oil gravel is on the right side, b) Elimäki test road.

5.3 Laboratory Testing and Test Results

All produced mixtures passed the MYR test; all test results gave zero grams of loose fines. This suggests that mixtures should not have any moisture problems.

During the following day, after production in Punkalaidun, 15 specimens were compacted with the ICT-gyratory compactor. The specimens were stored at room temperature. Five specimens of both mixes were tested after one week of curing time at +10 °C, following five specimens after four weeks and the last five after four months. One week after production in Iitti, five specimens of both mixes were compacted with the gyratory compactor. The IDT strengths of those specimens were tested after one-week of curing time. Test results are shown in Figure 4.

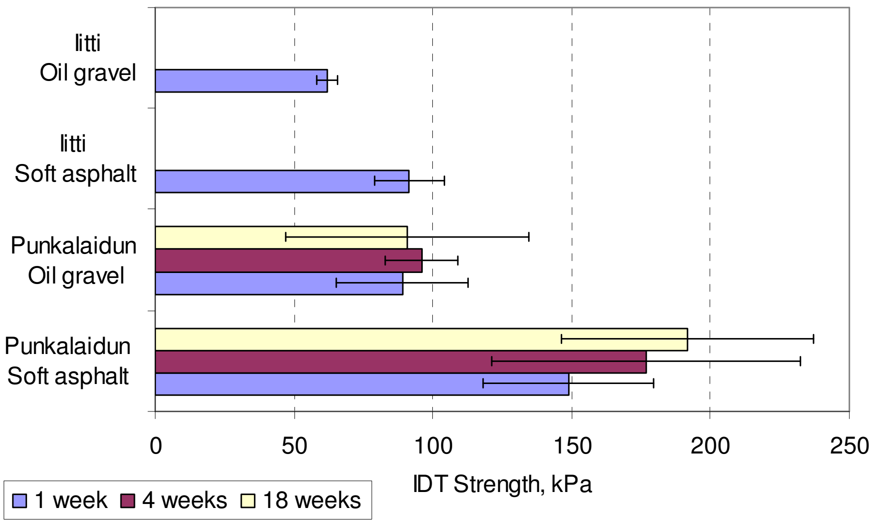

Figure 4: Test roads: IDT strength results.

Similar to the laboratory test results, the oil gravel mixtures had no hardening, while 30% strength increase took place at Punkalaidun soft asphalt mixtures during 18 months of curing. Opposite to laboratory results, the aggregate type seemed to have an effect on the strength values. The soft asphalt with 16 mm top aggregate size had 66% higher strength than the mixture with 11 mm top size. The difference for the oil gravel mixture was less being 44%. The CV ranged from 3% to 24.2% average being 11.5%, which is twice the amount encountered in the laboratory. It is obvious that the plant produced mixture was more variable that the laboratory produced mixture. One contributor may the moisture variation in the stockpiled aggregate.

As the oil gravel mixtures showed no hardening in compacted stage, it was decided to continue the research by stockpiling mixtures and storing them for a longer period of time and then retest the IDT strength to see if more strength would develop.

6. STRENGTH INCREASE DURING STOCKPILING

Oil gravel mixture produced at Iitti mixing plant was stockpiled for patching purposes for three separate locations: Iitti, Lappeenranta, and Kouvola. The binder content of the stored mixture was 0.2% higher than that of the mixture placed on the road.

The three stockpiles were sampled in April 2009 for strength testing. In Iitti the stockpile was covered with snow and the oil gravel was very hard. It was very difficult to dig the pile with spade to obtain enough material for testing and iron bar had to be used to loosen the mixture. In Kouvola the stockpile had been covered with a tarpaulin, but it had been removed before the sampling took place, see Figure 5. The mixture was not as hard as in Iitti, but just by using a spade it was not possible to get enough loose mix and again iron bar had to be used. In Lappeenranta small portion of the mixture had been brought to a warm warehouse to soften it up. Therefore, it was very easy to sample the mixture with a spade.

Water content of stored mixtures was determined in the laboratory and six specimens were compacted with the ICT-gyratory compactor for testing. The IDT strengths of the specimens were tested at +10 ºC after one-week curing time. Also densities of compacted samples were calculated using compaction information from the gyratory compactor. IDT strength test results are presented in Table 5.

Table 5: Oil gravel test results.

Stockpile	Water content (%)	Bulk density (kg/m^3)	IDT Strength (kPa)		
			Avg.	St.dev.	CV%
Iitti, Fresh (1 week)			69.6	4.8	7.0
Iitti, Stockpiled	3.4	2252	83.5	5.7	6.8
Kouvola, stockpiled	3.3	2259	84.6	4.7	5.5
Lappeenranta, stockpiled	2.0	2241	76.4	5.2	6.8

The IDT strength increased 10 to 20 percent during the 6 to 7 months of storage through the wintertime. In Lappeenranta the increase was smallest being 10%. The warm warehouse storage had dried the mixture in Lappeenranta, compared to the other locations. Because water provides lubrication during compaction, it can be speculated that this caused the specimens to be less dense compared to the other specimens. This may have also decreased the strength of the mixture compared to the other stored mixtures.

It is a clever idea to store oil gravel into the warm warehouse before patching to increase workability of the mixture. However, the decrease of water content during a long storage time may make the mixture hard to compact when patching.

Figure 5: Stockpiled oil gravel made of bio road oil in Kouvola.

7. DISCUSSION

As a summary, Figure 6 compares aggregate-binder combinations used in the study. As would be expected, the highest strength values were obtained for the mixtures with bitumen V1500 (see Figure 1). As discussed above, the maximum aggregate size seemed to have effect on mixture's strength values. In addition to aggregate size, the binder absorption to the aggregate may also play a role in the strength gain. Although bitumen absorption to the aggregate can be neglected during mix design, it may be possible that due to the road oil's low viscosity it can actually penetrate to the aggregate. There is this porous layer of aggregate, where bitumen cannot penetrate, but which is accessible for water. The apparent specific gravity of aggregate is computed taking this pore space account, while the effective specific gravity calculation takes account the pore space accessible for both water and the bitumen. It may be possible that the road oils can absorb to the aggregate. How this affects the performance of mixture is not yet known.

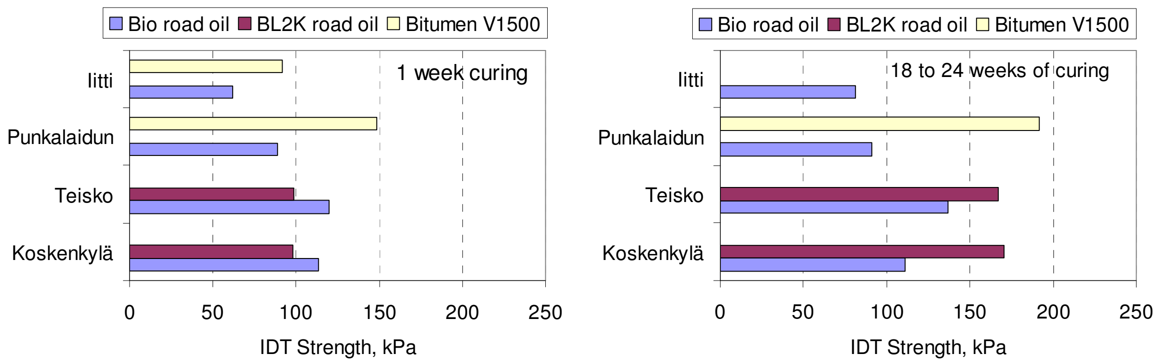

Figure 6: Comparison of binders with different aggregates used in the study.

8. CONCLUDING REMARKS

Preliminary laboratory and field trials have been quite promising. Although the original idea was to develop more environmentally friendly cold mixture for patching purposes, it looks like the oil gravel with bio road oil could be used as a surface mix for the low volume roads. The only worry is that the strength of the oil gravel with bio road oil seems to increase extremely slow compared to conventional oil gravel mixtures. That of course helps the patching work because the mixture stays workable, but patches may not be able to resist displacement by traffic. In a separate trial, oil gravel made of bio road oil was used as the patching material in a low volume road paved with soft asphalt. This trial included other patching materials for reference. After one winter, all oil gravel patches were in good condition. Due to these encouraging results, this research will continue with further laboratory studies and field trials.

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