

Development of a Solvent-Free Asphalt Emulsion for Prime Coats and Granular Sealing

Anton S. Kucharek, P.Eng., C.Chem.
Director Technical Services
McAsphalt Industries Limited
Scarborough, ON

J. Keith Davidson, P.Eng.
Director Technology and Product Development
McAsphalt Industries Limited
Scarborough, ON

Matt Kennedy
Sales and Marketing Representative
McAsphalt Industries Limited
Scarborough, ON

ABSTRACT

Prime coats and granular sealing refer to sprayed treatments intended to bind and stabilize the granular material on roads and on unpaved roadway shoulders. In addition to conferring cohesion and bond, these treatments also protect the underlying layers of granular material from moisture by creating a waterproofing layer at the surface.

This paper presents the development stages of a solvent-free asphalt emulsion designed to match the performance of a cutback primer. Starting with the basic principles such an emulsion has to meet, a number of formulations have been produced, tested and optimized at the laboratory level. Specialized tests such as the Modified Sand Penetration Test were used to assess duration and depth of penetration of the emulsions into granular materials having different mineralogy, different levels of compaction and variable moisture content.

A number of field trials of granular sealing on shoulders were done during 2006 and 2007, using emulsions optimized as described. Penetration during spraying was very good and performance to date of the treated areas is excellent.

RÉSUMÉ

Les couches d'imprégnation et le scellement granulaire réfèrent aux traitements épandus pour lier et stabiliser le matériau granulaire sur la route et sur les accotements non pavés. En plus de fournir la cohésion et le lien, ces traitements protègent aussi les couches sous-jacentes de matériau granulaire de l'eau en créant une couche imperméable à la surface.

Cet exposé présente les étapes de développement d'une émulsion de bitume sans solvant conçue pour égaler la performance d'un bitume liquide d'imprégnation. En partant des principes de base qu'une telle émulsion doit rencontrer, un nombre de formulations ont été produites, testées et optimisées au niveau du laboratoire. Des essais spécialisés tel que la pénétration modifiée du sable ont été employés pour évaluer la durée et la profondeur de pénétration des émulsions dans les matériaux granulaires de minéralogie différente, de niveaux différents de compaction et de teneur en eau variable.

Un nombre d'essais routiers de scellement granulaire sur les accotements ont été réalisés en 2006 et 2007 avec des émulsions optimisées tel que décrites. La pénétration durant l'épandage a été très bonne et la performance à ce jour des surfaces traitées est excellente.

1.0 INTRODUCTION

As part of today's general tendency of our society to review established processes and materials and eliminate all non-environmentally friendly aspects, the road industry is undergoing tremendous change as we speak. Engineers and scientists are spending significant effort to review and analyze current road construction practices and quantify the impact that our industry has on the environment. Suppliers and consultants are developing environmentally friendly materials and processes, while ensuring their suitability as good quality alternatives to the existing ones. Agencies are collaborating with the paving industry to develop new specifications for road construction that do not create a heavy environmental impact.

Any form of pollution or negative affect of the natural environment will come at a heavy cost in the near future. However, one key aspect of developing environmentally friendly materials and processes is doing so without compromising the quality and the performance of our roads. This in itself has indirect environmental implications, besides the main goal of delivering comfort and safety to the travelling public. A durable road will require less frequent intervention for maintenance or repair, translating into fewer pollutants associated with its life in use.

A major trend today in the road construction industry is the elimination of liquid asphalts (or cutbacks). Cutback asphalts utilize solvents as a carrier for the bituminous binder. They are expensive, toxic and dangerous. More so, with the scarcity and high cost of petroleum solvents it is uneconomical to use them as a carrier for the bitumen just to let them evaporate into the atmosphere once the product application is complete. In essence, we are currently spending a lot of money to create high Volatile Organic Compound (VOC) emissions.

Water can be used as an effective carrier for asphalt binders, in the form of asphalt emulsions. Asphalt emulsions have evolved considerably over the past years, well beyond their old and established uses as tack coats and high floats. New and high performance emulsifier chemistries are available, capable of delivering excellent products for virtually all road applications that involve bituminous binders. In addition, they are safer, cleaner, cheaper and better performing than cutback asphalts. In some jurisdictions in Europe and North America, cutbacks have been completely eliminated from use; being replaced entirely by emulsions. This trend will continue so that ultimately cutback asphalts will completely disappear from use in our industry.

2.0 GRANULAR SEALING AND PRIME COATS

2.1 Definitions and Scope

Granular sealing is a common technique for sealing granular materials and preventing washouts and erosion. It is suitable for application on traveled or un-travelled sections of a roadway. The definition of the granular sealing process partially overlaps with that of a prime coat, with only subtle differences, nuances and established terminology in the industry that can differentiate between the two. Prime coating refers to the application of a bituminous penetration treatment to an untreated aggregate base. Granular sealing includes other specific procedures, such as penetration treatments on roadway shoulders, graded slopes, etc.

Both terms are part of a larger process called a "penetration treatment". A penetration treatment consists of adding a bituminous binder to a pavement or to a granular aggregate surface by spraying the bituminous

material directly onto its surface. The primary scope of any penetration treatment is to stabilize the top layers of the substrate by delivering a binder film between the adjacent aggregate surfaces [1].

By applying a prime coat to an existing granular surface, the following benefits are achieved [2]:

- Temporarily waterproof the granular surface, sealing the base and protect it from water intrusion. This is a valid statement if the treatment is applied on a travelled section of a granular road or if it is applied to unpaved shoulders.
- Consolidate and bind the surface material and preserve the profile of the road. This can be done prior to applying subsequent layers of pavement or just for strengthening the surface of an existing unpaved road.
- Promote adhesion between the existing surface and subsequent pavement applications, such as surface treatments or thin Hot Mix Asphalt (HMA) lifts.
- Help with curing of a binder material that has been previously mixed with the granular material (ex. Portland cement, lime, etc.).
- Controls the generation of dust from the roadway surface

A number of different bituminous treatments or techniques can achieve similar benefits with those mentioned herein. However, applying a penetration treatment has the main advantage of being economical, fast and simple. The application of the priming material is done simply by spraying it onto the granular material, at the desired application rate. Occasionally, spraying the prime might be followed by a light sand application. The strength build-up in the granular layers happens quickly and the surface is ready to be returned to service almost immediately.

2.2 Materials and Process

2.2.1 Surface Preparation

Prior to the application of a penetration treatment, surface preparation is required. The type of surface preparation depends widely on the specifics of each project, but it is safe to say that grading, compaction and moisture addition will be the most likely operations employed.

Granular shoulders are prepared in accordance with local or provincial specifications. For example, Ontario Provincial Standard Specification (OPSS) 305 [3] specifies that a minimum of two roller passes be followed by dampening of the granular material immediately prior to sealing.

For other applications of priming or sealing such as granular road bases, specific construction practices regarding the surface preparation are well defined and will not be described in detail for this paper.

2.2.2 Materials

The most important property that a bituminous material should fulfill for the purposes of priming is to have low viscosity. This is necessary for the primer to penetrate the compacted aggregate bed and effectively fill the capillary-sized voids in the granular surface.

For many years, the overwhelming majority of materials used for priming and granular sealing were cutbacks – rapid and medium curing. The most used grades of cutbacks are RC-30, RC-70, MC-30 and MC-70. If the granular material to be primed is open and penetration is not considered to be an issue, it is not uncommon to use higher viscosity cutbacks, such as MC-250 or even SC-250. Regardless of the grade, all these cutbacks are asphalt cements dissolved in different cuts of petroleum solvents (naphtha, mineral spirits, kerosene, etc.). They provide lower viscosities than the straight asphalt cements and have much reduced application temperatures. They are continuous fluids and have low surface tension, which makes them easily absorbed through capillary action and confers them good wetting capability for the fines in the granular material.

The role of the solvent is to act like a carrier for the asphalt cement, confer low viscosity, facilitate wetting and coating of the aggregate and then evaporate and leave the asphalt residue behind. In the process of evaporation, which can take several days, depending on the solvent grade, significant amounts of VOCs are released in the atmosphere. The definition of VOC can vary widely with the jurisdiction and usually is affected by the local or national policies. Essentially, it represents a group of organic substances that have high vapour pressures and therefore vaporize and enter the atmosphere. Numerous limits on VOC emissions are already in place across North America, from maximum VOC allowances to outright bans. These restrictions will only increase in number in the future.

Asphalt emulsions have also been used as priming agents for a number of years. Their rate of success has been generally good over the years. However, most emulsions used as primers have traditionally contained a sizable amount of petroleum based solvents as part of their formula. The main reason for the presence of the solvent is to improve wetting of the fine mineral aggregate and to facilitate capillary penetration. Overall, these emulsions have a number of advantages over cutbacks, such as a much reduced hazardous element (because of much higher flashpoints and no flammability), better economics and significantly lower VOC emissions. But organic emissions are still generated and these products will continue to fall under the scrutiny of the environmental regulators and be considered a pollutant.

In a number of instances, some emulsions have failed to perform as expected and this is mainly due to an insufficient focus of the existing specifications on addressing the truly important properties that a priming emulsion has to achieve. The current paper will attempt to shed more light in this direction. It is not uncommon that attempts are made to prime with the incorrect emulsions, with less than desired results. For example, it happens often that emulsions used for surface treatments such as chip seals or graded seals are used for priming the granular base prior to applying the seal. This is often done because of the convenience of having the chip sealing emulsion already on site. The results of such an attempt are almost never satisfactory. Rapid-setting emulsions used for chip sealing are too viscous and not sufficiently stable to perform well as a priming emulsion. On contact with the aggregate the emulsion breaks immediately and the film of asphalt that forms on the surface will actually hinder further penetration of the bitumen. The priming results are poor and the excess of binder that accumulates at the surface can even negatively affect the performance of the chip seal to be placed. An entire project's outcome can be jeopardised by trying to cut corners and save a few cents instead of using the right materials for their intended purpose.

Another material required on some sealing projects is sand [4]. Depending on the specifics of the project, an application of sand cover might be desired. The general requirements for the sand used as a cover for a prime coat is that it shall be clean, with 100 percent passing the 4.75 millimetre sieve and with a maximum fines content of 2 percent [2].

2.2.3 Process

Following the surface preparation, briefly discussed at the beginning of the current section, the priming materials shall be applied uniformly, using a pressure distributor [3]. The application rate and the application temperature will be determined by the engineer and they should be closely followed. If a sand cover is to be applied, it should be done after all the priming material has penetrated the existing granular surface. Should any other treatment be placed subsequently, the excess sand has to be swept off before proceeding.

Operational constraints during application can vary depending on the type of project and its specifics. Worth mentioning here are the following: the surface should be damp but free of standing water, precipitation should not be imminent, the weather should not be so windy as to break and drift the liquid spray, no frost should be on the ground, and finally, the temperature should be a minimum of 5 degrees Celsius and rising [3].

3.0 LABORATORY DEVELOPMENT

3.1 Overview

The goal of the current project was to develop an asphalt emulsion that does not contain any petroleum based solvents. Also, the emulsion should possess the required properties to work as a priming agent with performance that is comparable to that of a liquid cutback asphalt. In order to achieve this, a systematic approach was necessary for the development of such a product.

The first step was to identify and list the essential properties that such a product should fulfil. After careful consideration and review of existing work in the field, here are what we believe are some key essential parameters that a priming emulsion should satisfy:

- Viscosity of the emulsion should be low, in order to ensure adequate fluidity for penetration of the granular bed;
- Stability has to be very high, allowing the emulsion to undergo extensive contact with the fine aggregate before its destabilization and coalescence;
- Wetting of the aggregate by the prime should be very high (low contact angles), to allow excellent contact, good adhesion and moisture resistance;
- Emulsion particle size should be small, permitting the prime to have good penetration of the capillary-sized pores in the compacted granular bed.

Based on the above guidelines, a number of emulsions were formulated and tested at the McAsphalt Engineering Services laboratory. Without going into great detail about the formulation of these emulsions, the experimental stage in the laboratory will be outlined in the following paragraphs.

3.2 Materials

The laboratory stage of the experimental development consisted of the preparation of 6 samples of asphalt emulsion to be tested for granular sealing purposes. The samples were coded by the letters A-F for the

current study. One significant detail about the formulations of these samples is that none of the six contained any solvents of any kind and all six of them were prepared using the same grade and source of asphalt cement.

As part of the experiment, we selected an RC-30 cutback asphalt as Sample G. This is currently the main priming material utilized in the province of Ontario, as specified by OPSS 305 [3]. We decided to include RC-30 as a performance benchmark. This way, quantifying the performance of the emulsified primes would be done directly against that of the most commonly used priming cutback.

The seven samples of priming materials described here were prepared and their properties were tested. For the cutback, a full test as required by OPSS 1102 [5] was completed as shown in Table 1.

Table 1. Test Results for RC-30 Cutback (Sample G)

Test	Result
Kinematic Viscosity, 60°C, mm ² /s	33.7
Distillate to 190°C, % vol. to total dist.	79.5
Distillate to 220°C, % vol. to total dist.	88.7
Distillate to 260°C, % vol. to total dist.	94.5
Distillate to 316°C, % vol. to total dist.	98.0
Distillation Residue, 360°C, %	59.5
Penetration of Residue, 25°C, dmm	90
Ductility of Residue, 25°C, cm	100+

For the six emulsions, testing the samples against the emulsified prime specification currently in OPSS 1103 [6] was not an option, as the current specification requires a minimum of 10 percent oil portion in the distillate. This requirement can not be met with our current formulations, which have no solvents or oils as part of the formula. In addition to the typical emulsion tests, we have also performed particle size analysis, as this is an important property for the prime. A Horiba laser scattering particle size analyser was used for this purpose. A summary of the test results for the priming emulsions A-F are shown in Table 2.

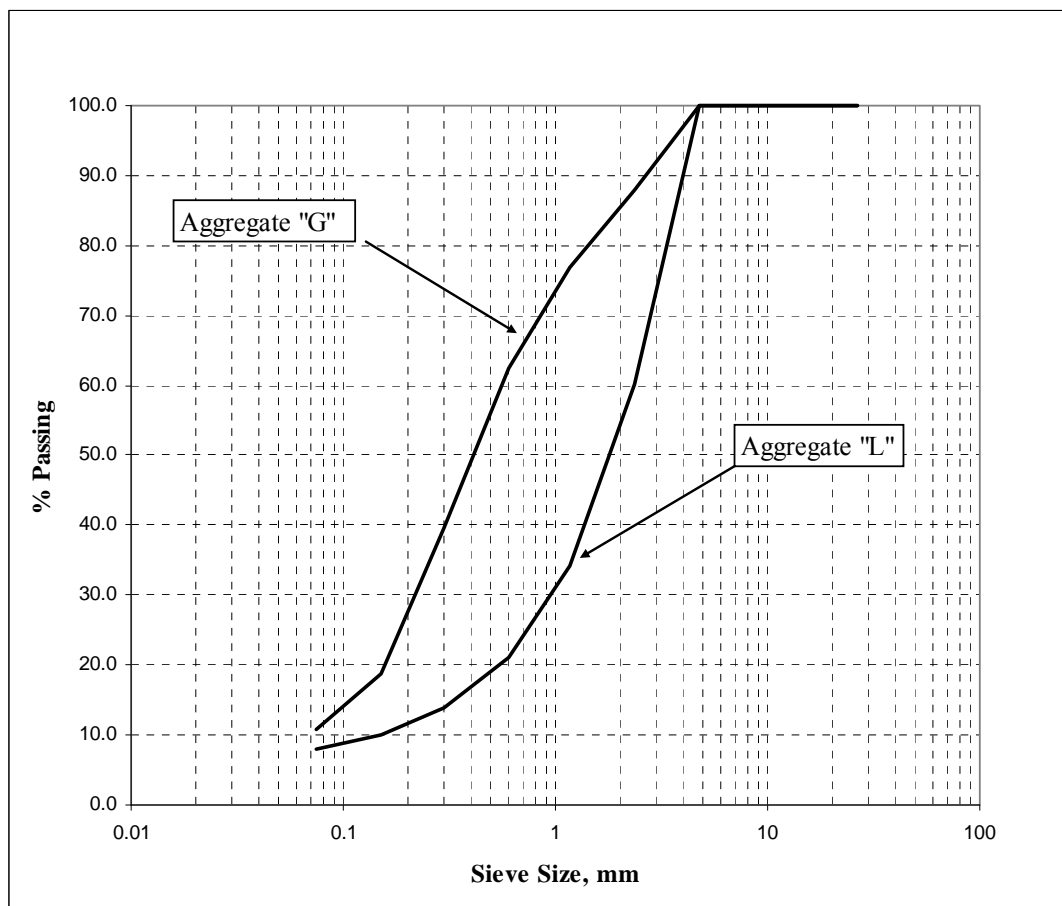
Table 2. Summary test results for the priming emulsion samples

Emulsion	Viscosity, 25°C, SFS	Dist. Residue % mass	Res. Penetration, 25°C, dmm	Median Particle Size, μ
A	9.5	40.1	76	4.357
B	10	40.2	75	4.414
C	11	40.1	78	4.398
D	10	40.4	76	4.302
E	13	40.2	79	11.391
F	11	40.1	77	6.898

For the full characterization of the penetration properties of the priming materials, two aggregates were selected. The two aggregate are coded “L” and “G”, the letters standing for the source type of each of the two – namely “Limestone” and “Gravel”. The gradation bands of these aggregate were selected to conform to a typical granular material, but all of the aggregate coarser than the 4.75 millimetre sieve was removed. The gradations of the two aggregates are shown in Table 3 and in Figure 1.

Table 3. Gradations for Aggregate “L” and “G”

Sieve Size, mm	Aggregate “L”, % passing	Aggregate “G”, % passing
9.5	100	100
4.75	100	100
2.36	60.1	87.9
1.18	34.2	76.8
0.600	21.0	62.4
0.300	14.0	39.5
0.150	10.1	18.8
0.075	7.9	10.8

**Figure 1. Gradations for Aggregate “L” and “G”**

3.3 Experimental Work

For assessing the suitability of the emulsions A-F as priming materials, the capability of the six samples to penetrate compacted granular materials had to be quantified. For doing this, we have selected the use of the Modified Sand Penetration Test.

The asphalt emulsions used as primes by different jurisdictions are almost never directly tested for their capability to penetrate, wet and bind compacted granular materials. For doing this, our laboratory has started from a sand penetration test developed originally by the Pennsylvania Department of Transportation (PennDOT) for dust suppressants. In this test, a sample of a reference silica sand #20326 is dried, then moisture is added to a level of 1.5 percent by mass. A small sample of this sand is placed in an 8 oz. ointment can and it is compacted to 100 psi by a flat-side plunger. Subsequently, a sample of 5 grams of the dust palliative solution is poured in the centre of the container and allowed to flow by itself. The time is measured, in seconds, for the liquid to completely penetrate into the compacted sand. After penetration is complete, the sand bed is cut in half with a spatula and the average penetration depth of the liquid is measured and recorded.

For our purpose of assessing priming materials, we have modified the existing test as follows. The reference silica sand has been replaced with the aggregate described in Section 3.1. Initial laboratory trials utilizing a reference silica sand have shown that this material is easily penetrated by standard slow-setting emulsions with reduced viscosities. We decided to replicate a more difficult scenario, utilizing aggregate with higher fines contents and less uniform gradation, leading to better interlocking and higher densities.

Next, we have replaced the flat faced plunger with one that has an indentation with a diameter of 35 millimetres and a depth of 5 millimetres. This will allow a more precise delivery of an exact quantity of priming material to a known area. A picture of the compaction plunger and of a compacted granular material is shown in Figure 2.



Figure 2. Compaction Plunger and Compacted Granular Specimen

To summarize the testing protocol, each of the six emulsions, plus the RC-30 cutback was tested for penetration on a compacted granular bed consisting of limestone and gravel. The testing matrix includes tests at three moisture levels (0, 1.5 and 3.0 percent water) and two compaction levels (50 psi and 70 psi). The compaction of the granular material is performed using a pneumatic compaction device normally used to prepare the Schultz, Breuer and Ruck [7] test specimens for the ISSA A143 micro surfacing design protocol [8]. A picture of the compaction apparatus is shown in Figure 3.

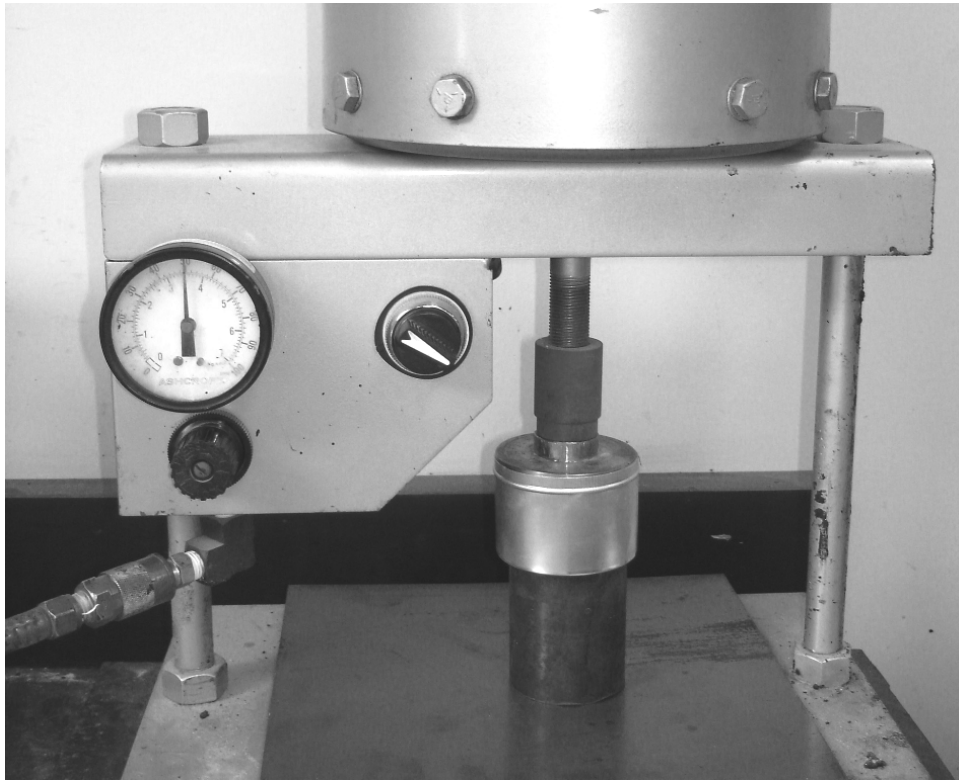


Figure 3. Compaction of the Granular Material Using the SB&R Device

For each test point, 5 grams of emulsion was applied to the sunken area, measuring 9.6 square centimetres. Compared to a typical field application rate, the rate used in this test is somewhat higher, translating into 5.2 kg/m^2 . For the RC-30, Sample G, the sample size was adjusted from 5 to 3.3 grams, as the residual asphalt of the RC-30 is approximately 60 percent, compared to 40 percent of the emulsion samples. This way, similar amounts of residual asphalt are delivered to the aggregate. This application rate translates into 3.44 kg/m^2 .

The priming material was timed from the moment of its application to the point where no remaining liquid was visible at the surface. In case the penetration was not complete, the timer was stopped at 720 seconds, after which time the remaining emulsion at the surface has lost sufficient fluidity to assume no further penetration will occur. The samples were left to cure for 24 hours, and then they were cut open using a scraper. The average depth of the penetration was measured and the whole condition of the bonded layer was evaluated.

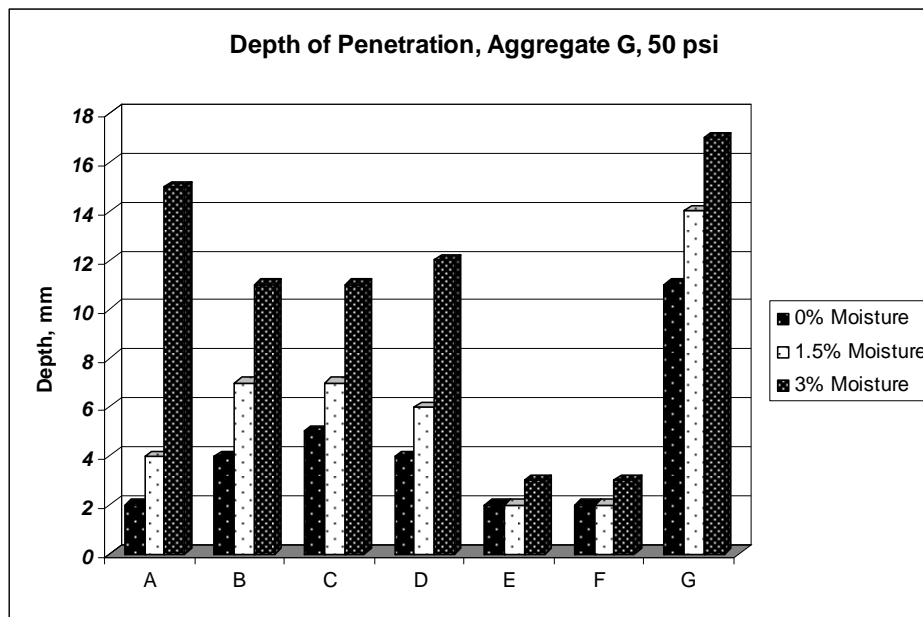
3.4 Modified Penetration Test Results

The results obtained by running the Modified Penetration Test as described above have provided good information about the different emulsion formulations and about the parameters that are impacting the performance of the priming materials.

Table 4 shows a summary of the data that describes the depth of penetration and the time for complete penetration for all the moisture and compaction levels for the aggregate “G”. Although the laboratory data matches well with the intuitive trends, there are some results that are more difficult to explain.

Table 4. Summary of Modified Penetration Test Results for Aggregate “G”

Water, %	Compaction, psi	Test Type	A	B	C	D	E	F	G
0	50	Depth of Pen, mm	2	4	5	4	2	2	11
		Time to Full Pen, sec	480	380	80	70	720+	720+	440
	70	Depth of Pen, mm	2	4	3	4	2	2	10
		Time to Full Pen, sec	600	210	140	160	720+	720+	540
1.5	50	Depth of Pen, mm	4	7	7	6	2	2	14
		Time to Full Pen, sec	296	34	60	38	720+	720+	270
	70	Depth of Pen, mm	5	5	6	4.5	2	2	15
		Time to Full Pen, sec	540	620	720+	660	720+	720+	600
3.0	50	Depth of Pen, mm	15	11	11	12	3	3	17
		Time to Full Pen, sec	12	11	18	22	720+	720+	190
	70	Depth of Pen, mm	10	11	9	12	2	2	17
		Time to Full Pen, sec	24	48	46	23	720+	720+	105

**Figure 4. Depth of Penetration for Aggregate “G”, 50 psi**

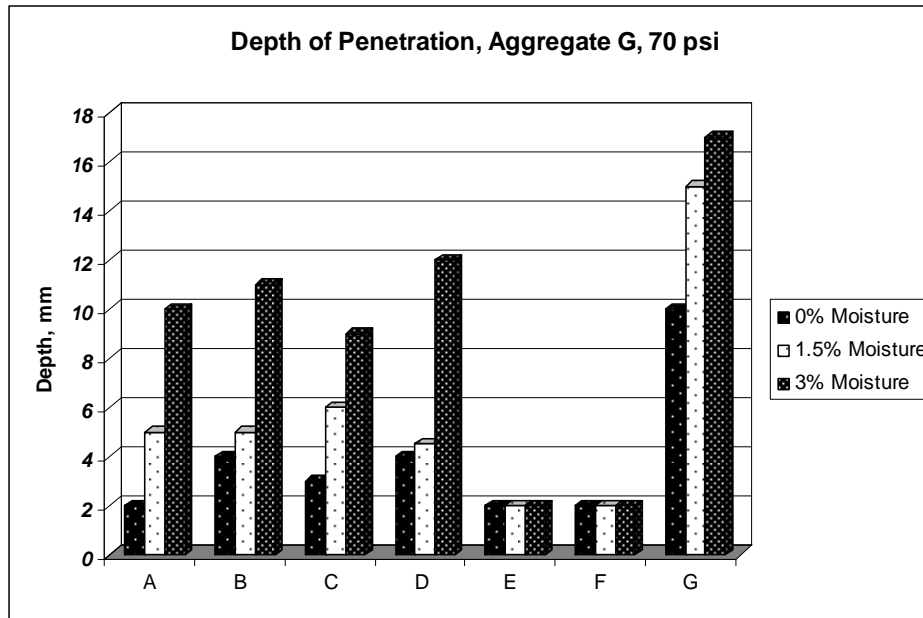


Figure 5. Depth of Penetration for Aggregate “G”, 70 psi

For a better visualisation of the results, the tabled data was grouped by test type and by level of compaction and is displayed in Figures 4, 5, 6 and 7.

Experimental data for the aggregate “L” is shown in Table 5 and the trends for each emulsion are displayed in Figures 8 to 11.

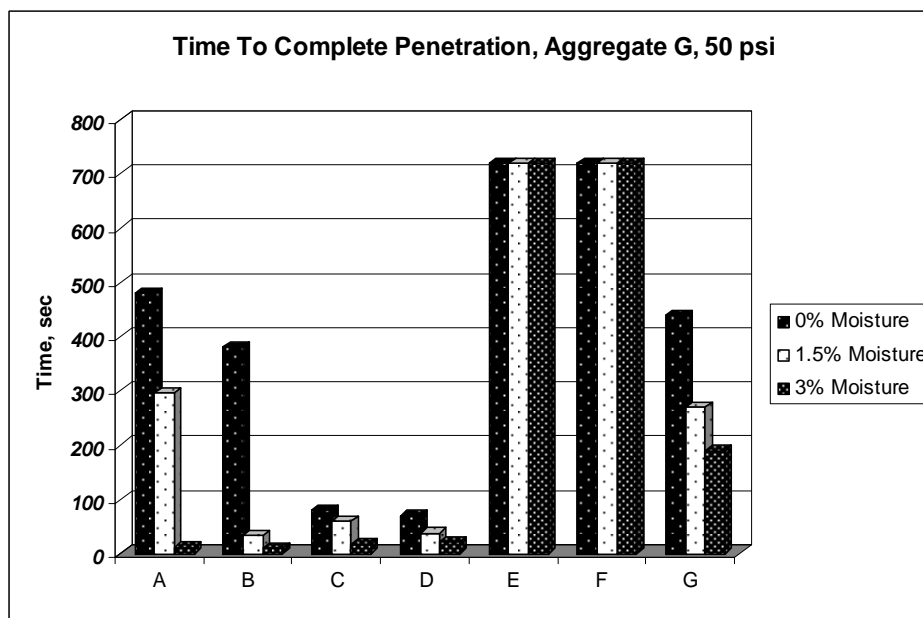


Figure 6. Time to Maximum Penetration for Aggregate “G”, 50 psi

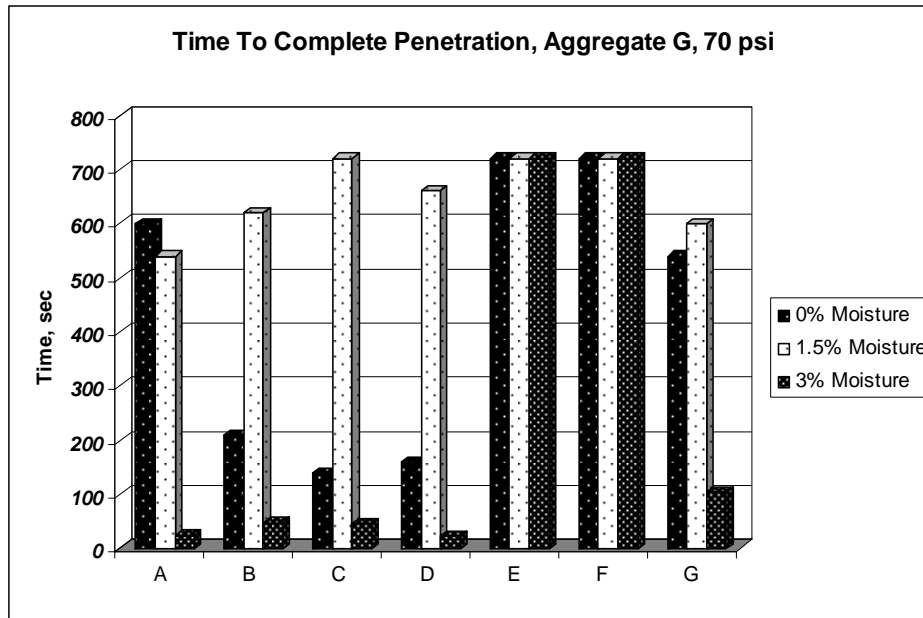


Figure 7. Time to Maximum Penetration for Aggregate “G”, 70 psi

Table 5. Summary of Modified Penetration Test Results for Aggregate “L”

Water, %	Compaction, psi	Test Type	A	B	C	D	E	F	G
0	50	Depth of Pen, mm	2	2	2	2	2	2	8
		Time to Full Pen, sec	225	55	50	140	720+	120	720+
	70	Depth of Pen, mm	3	2	2	2	2	2	7
		Time to Full Pen, sec	101	60	60	100	720+	130	720+
1.5	50	Depth of Pen, mm	9	5	10	9	3	3	15
		Time to Full Pen, sec	18	31	59	29	720+	720+	390
	70	Depth of Pen, mm	8	4	5	7	4	4	17
		Time to Full Pen, sec	93	252	27	110	720+	720+	420
3.0	50	Depth of Pen, mm	18	15	14	26	17	25	20
		Time to Full Pen, sec	3	2	4	4	8	31	210
	70	Depth of Pen, mm	15	18	16	20	14	11	20
		Time to Full Pen, sec	6	5	5	5	14	25	180

Figure 12 shows a comparison of three specimens with different penetrations, low, medium and high, and also shows the samples in section, after the specimens were cut for measuring the penetration depth.

3.5 Discussion of the Results

By analysing the data presented, it is safe to conclude that an increase in moisture content of the compacted granular material increases the penetration depth of the emulsified prime and shortens the penetration time. Moisture is needed in the granular bed to facilitate wetting by the asphalt emulsion.

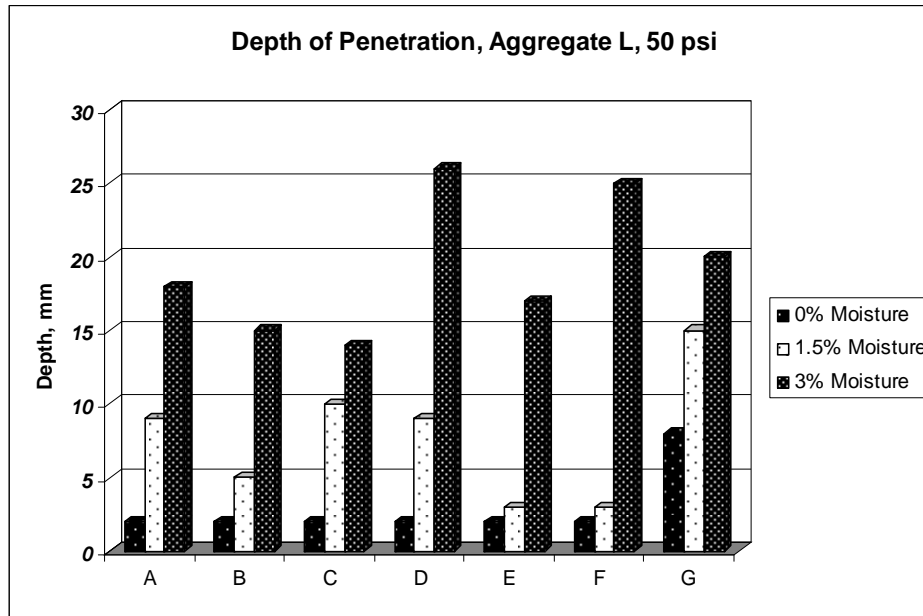


Figure 8. Depth of Penetration for Aggregate “L”, 50 psi

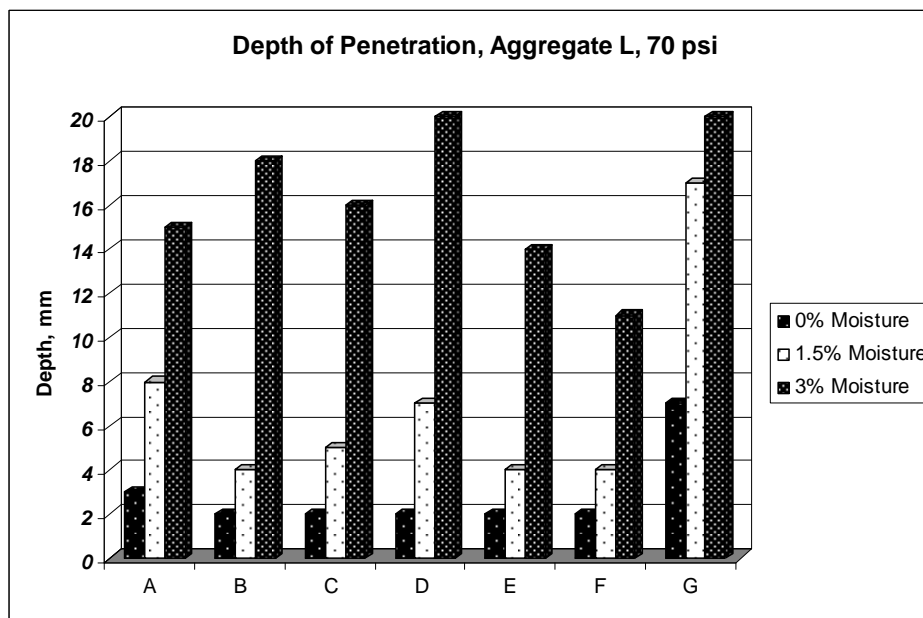


Figure 9. Depth of Penetration for Aggregate “L”, 70 psi

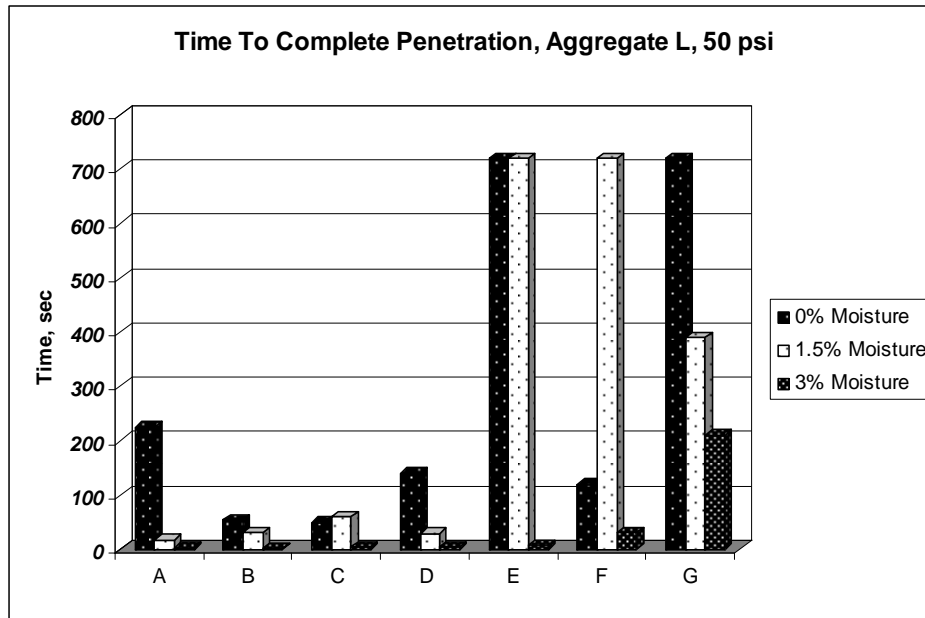


Figure 10. Time to Maximum Penetration for Aggregate “L”, 50 psi

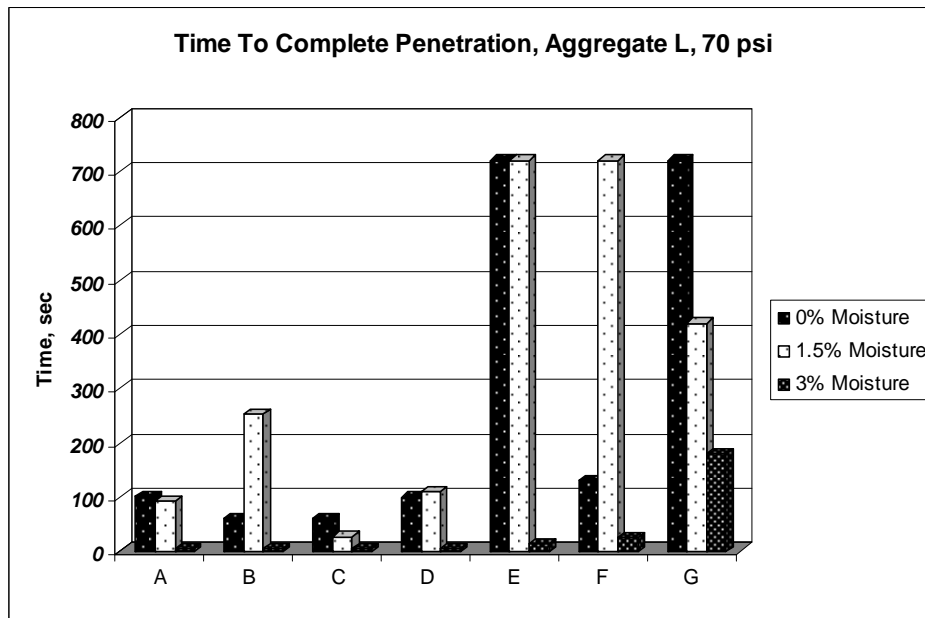


Figure 11. Time to Maximum Penetration for Aggregate “L”, 70 psi

However, too much water can harm. Our current study has not completed any experiments where the water content in the aggregate was higher than 3 percent. However, past field observations made during attempts to prime very wet granular materials using emulsions have concluded that too much water can act as a diluting agent for the super-stabilized priming emulsion. This leads in general to a sizable portion of the emulsion being washed away by the excess water, instead of penetrating the granular material. There

is also the danger that the emulsion can be carried into water bodies by the excess moisture (rivers, ponds, ground water) and end up as a contaminant for the natural environment.



Figure 12a. Surface Comparison



Figure 12b. Penetration Depth Comparison

Figure 12. Comparison of Specimens with Low, Medium and High Penetration

Some of the emulsion formulations studied, noticeably Emulsions E and F have consistently shown poor performance in our experiments. Specifically, they have constantly shown very high penetration times and very low depths. By analyzing the data, it is obvious that Emulsions E and F have noticeably higher particle size than Emulsions A-D, as shown earlier in Table 2. Moreover, by analyzing the particle size distribution in more detail, it was noticed that none of the particles in Emulsion E had a diameter below 4 microns. By comparison, Emulsion F had 11.5 percent of the particles below 4 microns in diameter and Emulsion A had 43 percent of the particles below 4 microns in diameter. Existing publications [9] suggest that the fraction of the particles of an emulsion smaller than 4 microns is mainly responsible for the capillary penetration into the deeper layers of the compacted granular material, while the particle fraction over 4 microns tends to penetrate superficially or deposit at the surface. Certainly there are other factors affecting the penetration depth, such as surface tension of the emulsion and voids size in the aggregate, among others, but the particle size and the particle size distribution of the emulsions seems to correlate well with the depth of diffusion of our emulsion samples into the aggregate.

If we look at comparing the performance of the emulsions with the RC-30 cutback (Sample G), one of the first observations is that the depth of penetration of Sample G is on average the highest. The residual asphalt in the cutback is delivered to the granular by means of a carrier with very low surface tension – a naphtha grade solvent. The difference between the cutback and the emulsions is especially obvious with the dry aggregate, where the wetting power of the solvent is much higher. With the increase in moisture content in the granular, the difference in penetration depth is decreasing between the cutback and some of the emulsions. This behaviour is no surprise as the presence of water in the aggregate helps reduce the surface tension of the emulsion and facilitates wetting. More so, at 3 percent moisture the performance of Emulsions A-D become similar to, or even better than, the RC-30 cutback.

Looking at the times needed for penetrating the granular surface, the cutback's penetration speed is no match for the emulsion formulations that have shown good performance. The emulsions (especially Emulsions A-D) have shown consistently shorter penetration times. Curing times are also longer for the cutback; this observation was made in the laboratory by watching the specimens after application of the priming materials.

Comparing penetration depths and times between the two aggregate types, it can be seen that for the Aggregate L the measured penetration depths are higher and penetration times are shorter than for Aggregate G, the gravel source. We attribute this to the finer gradation of the Aggregate G and its higher dust content. It can be visually observed in the laboratory that Aggregate G packs more tightly in compaction and has less voids than material “L”. We believe the difference relates exclusively to the density of the compacted granular and not to the chemical type of the aggregate. However, this is only an assumption based on visual observation. To fully elucidate if surface tension plays a role, measurements of the contact angle between the aggregate and the prime samples are needed. This could well be a future stage of this study.

It is also worth mentioning that the penetration times for the Aggregate G at 70 psi compaction and 1.5 percent moisture seem to be abnormally high for all the samples and do not fit the general trend observed for the rest of the experimental stages. We are unsure at this point if these results are related to some error in preparing the specimens or there is another reason for these results. Unfortunately, there was no time for repeating this experimental stage before the preparation of the current report. We tend to treat this data with suspicion at this point in time, and intend to repeat and re-scrutinize this particular stage of the experiment.

Overall, Emulsions E and F seem to perform poorly as priming materials. Emulsions A-D have shown much better results, with Emulsions C and D being considered the best-suited formulations of the materials studied here for performing as solvent-free emulsified priming materials.

4.0 FIELD TRIALS

In parallel with the ongoing laboratory work, a number of projects in the field were scheduled. This allowed continuation of the development work by choosing emulsion formulations that were performing well in laboratory trials and evaluating their performance in real life. The Modified Sand Penetration Test is a good tool for assessing a limited number of parameters related to an emulsion, but it will not provide any information about field-specific constraints.

A total number of three field trials were completed during the last two years in Ontario. Here is an outline of the specifics for each of the three projects.

4.1 City of Vaughan, Huntington Road., November 2006

This project was a reconstruction of Huntington Road by Graham Brothers Construction. The granular shoulders were prepared as per the Ontario construction specifications and the contract was calling for sealing the shoulders using RC-30 cutback. After obtaining permission from the City for replacing the cutback with an experimental solventless prime, the project was completed by sealing the granular shoulders with an asphalt emulsion using Emulsion C from the laboratory study presented.

The day of the spraying, the weather was cold but dry. The shoulder was dry and no pre-wetting or dampening of the granular was done prior to the application. The application rate for the emulsion was 3.2 kg/m² and spraying was done with a computer-controlled distributor. The average time for the material to penetrate the granular shoulder was 20-30 seconds and no runoff occurred. The average penetration depth into the granular was measured at 4-5 millimetres.

The job has been inspected in 2007 and in early 2008 and is performing excellent to date.

4.2 King City, King-Vaughan Line, September 2007

Another reconstruction project, the work was done on King-Vaughan Line between Bathurst and Dufferin Street during September of 2007. Density of the shoulder material was not very high and overall, the shoulder looked a bit soft. Prior to application of the solventless prime, the granular material was sprayed with a water truck for dampening.

Application rate for the asphalt emulsion was 3.0 l/m^2 . Penetration times were on average 10 seconds and penetration depths were 8-10 mm. Spring inspection during 2008 shows good performance after the first winter. A photo of the road after application of the solventless prime is shown in Figure 13.

4.3 MTO Contract #2003-2010, Queen Elizabeth Way (QEW) St. Catharines, November 2007

Prior to the trial with the Ministry of Transportation of Ontario (MTO), the City of Vaughan project was visited together with engineers from the MTO. Performance of the shoulder sealing after one year was found to be satisfactory, so the MTO agreed on replacing half of the RC-30 cutback for the QEW project in St. Catharines with a solventless emulsified prime. The project was a widening of QEW between Glendale Avenue and Mountain Road in St. Catharines. The selected formula for the emulsion was equivalent to Emulsion D of the laboratory project. The concept was to spray the shoulder on one side of the highway with RC-30 (northbound lane) and the other side (southbound lane) with the solventless prime. Performance and durability can be compared directly in this way.

No pre-wetting was done prior to spraying the products, but the shoulder was damp because of rain the previous day. Application rates were varied on purpose between several sections and they range between 2.8 and 3.5 l/m^2 . The application rate of 3.5 l/m^2 produced the best results. The granular material on the shoulders had a high degree of compaction. It was very hard and very difficult to penetrate. Figure 14 shows a close-up of the sprayed shoulder with the emulsified prime.

The average penetration time for the emulsion was 20-30 seconds and the average diffusion depth is about 5 mm. These numbers were better than our initial expectations, given the density of the shoulder. Despite a minor inconvenient involving some foaming of the product during the application, the project was completed as scheduled and no delays or other problems were noticed. A field inspection this spring showed excellent performance to date.



Figure 13. King-Vaughan Line after Shoulder Priming with Enviroprem Emulsion



Figure 14. Granular Shoulder Sprayed with Solvent-Free Emulsion Prime

5.0 CONCLUSIONS AND SUMMARY

Priming and granular sealing are simple treatments. However, they require materials that are precisely engineered to balance a number of properties and deliver good and quick penetration of the granular material, fast setting and long-lasting performance. In addition, the impact these materials have on the surrounding environment should be minimal.

Liquid asphalts, or cutbacks, have long performed excellent as priming agents, but have a number of shortcomings that will see them completely eliminated from use in the near future. They are polluting our air, they are dangerous, and they are expensive. Much friendlier solutions are available today, capable to achieving similar results.

In developing an asphalt emulsion aimed at being a good prime, the first cornerstone was that no solvents should be incorporated as part of the formula. Besides this, the main properties targeted were excellent stability, good wetting power, low viscosity and low particle size. As part of the lab development work, the PennDOT Sand Penetration Test used for dust suppressants was modified and adapted to capture the behaviour that was desired from a priming material.

As part of the development project, a number of asphalt emulsions were characterized and tested for their penetrating properties of granular materials, using the Modified Sand Penetration Test. The tests were done on two different aggregates (a limestone and a gravel), at two different compaction levels (50 and 70 psi) and at three different moisture contents (0, 1.5 and 3 percent).

The best performing emulsion formulations, or variations thereof, were produced at plant level and field trials were conducted. Three field trials were done so far, two with municipal agencies and one with the MTO. All three projects are performing excellent to this date.

Field data were collected, and continue to be collected, and this data is utilized for continuous improvement and refining of the existing formulation of the solvent-free asphalt emulsion prime.

The development of the Enviroprem solvent-free priming emulsion is just another small stage in the large endeavour that is re-defining our products and processes and make them friendly to the environment.

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