SOLVENT-FREE BITUMEN EMULSION FOR PRIME COATS AND GRANULAR SEALING

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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.

Medium and rapid-curing cutback asphalts still take an important share in North America as materials used for prime coats and granular sealing. A number of asphalt emulsions have been developed in the past for this purpose but most of these still contained significant solvent fractions and their performance was spotty, especially regarding their capability for penetrating compacted granular layers. In light of today's increased environmental awareness, it is of high importance to develop water-based products with little or no emissions but with equal or better performance.

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, based on the fundamental theory of flow of emulsions through porous media, a number of formulations have been produced, tested and optimized at 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 2006-2009, using emulsions optimized as described. Granular penetration during spraying was very good and performance to date of the treated areas is excellent.

1.0 INTRODUCTION

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, 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, by producing cutbacks 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. 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 then 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

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 bitumen film between the adjacent aggregate surfaces [1].

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

- Waterproof the granular surface, sealing the base and protect it from water intrusion
- Consolidate and bind the surface material and preserve the profile of the road
- Promote adhesion between the existing surface and subsequent pavement applications
- Help with curing of a binder material previously mixed with the granular material
- Controls the generation of dust from the roadway 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. Regardless of the grade, all these cutbacks are asphalt cements dissolved in different cuts of petroleum solvents (naphtha, mineral spirits, kerosene, etc.). 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.

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. 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.

3.0 LABORATORY DEVELOPMENT

The goal of the current project was to develop an asphalt emulsion that does not contain any petroleum based solvents and to 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, 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.

Flow of emulsions through porous media is described by a relationship developed from Darcy's law, but which also takes into account the pressure differential required for the dispersed phase droplets to be penetrating the voids or capillaries [10]. This pressure differential is dependent on the interfacial tension and on the radius of the droplets. Hence, the need for priming emulsions to consistently have small particle size.

Based on the above guidelines, a number of emulsions were formulated and tested at the McAsphalt Engineering Services laboratory.

3.1 Materials

The laboratory stage of the experimental development consisted of the preparation of 6 samples of asphalt emulsion, coded A-F, to be tested for granular sealing purposes. 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, as a performance benchmark. This is currently the main priming material utilized in the province of Ontario. 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 and cutback G are shown in Table 1.

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.

Table 1. Summary test results for the laboratory samples

Sample	Visc, SFS, 25°C	Dist. Res, %	Res. Pen, 25°C, dmm	Median Part 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
G	33.7 (cSt, 60°C)	59.5	90	-

3.2 Experimental Work - 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-sided 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. 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 1.

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 Schultze, 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 2.

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 equals 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.

Fig 1. Plunger and Compacted Specimen

Fig 2. Compaction Using the SB&R Device

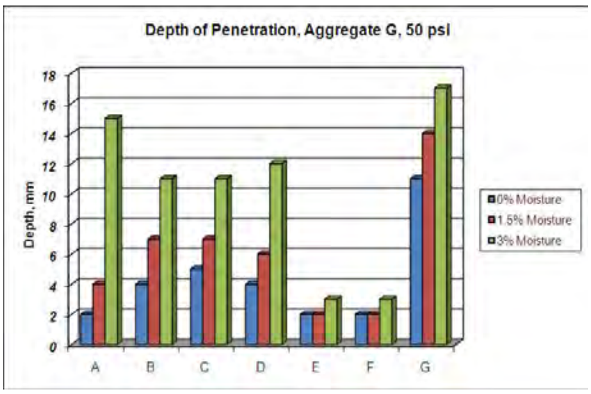
4.0 EXPERIMENTAL RESULTS

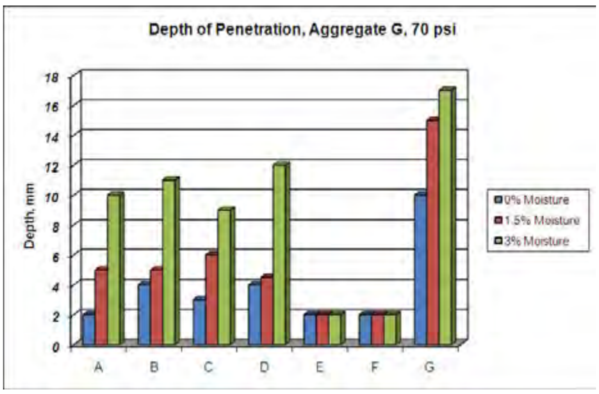
Table 4 and Fig. 3-6 show a summary of the data that describes the depth of penetration and the time for complete penetration for all the moisture and compaction levels for the aggregate "G". Although the laboratory data matches well with the intuitive trends, there are some results that are more difficult to explain.

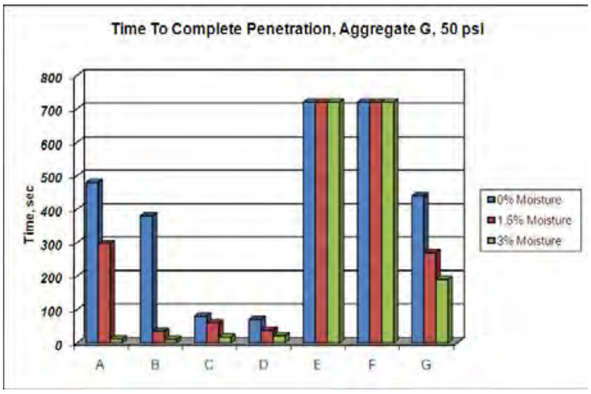
Table 2. Summary of Modified Penetration Test Results for Aggregate "G"

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

Fig 3-6. Depth and time of penetration for aggregate "G"







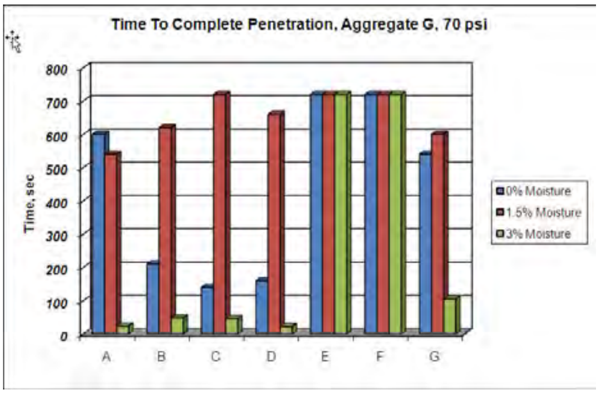
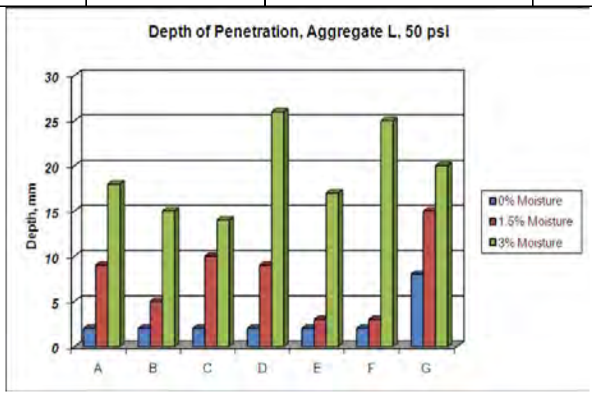
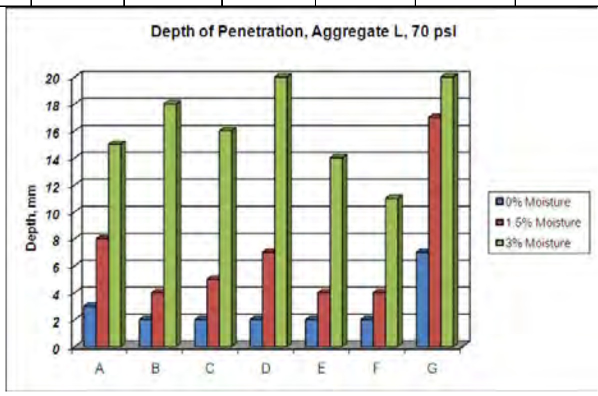
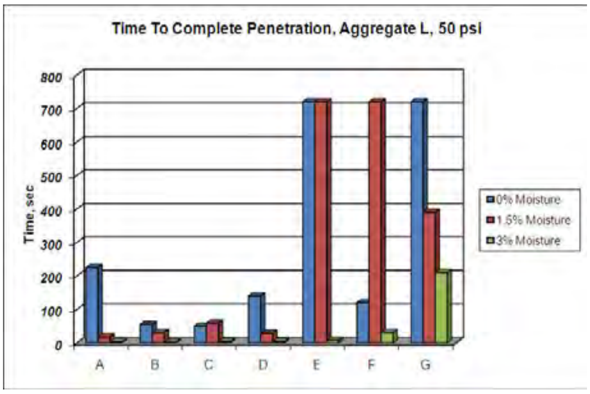


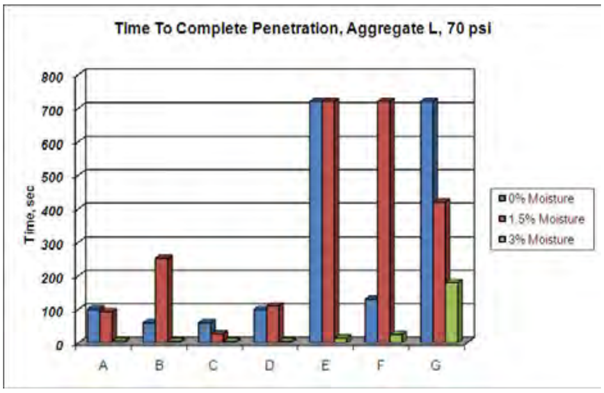
Table 3 & Fig. 6-10. Summary of Modified Penetration Test Results for Aggregate "L"

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









5.0 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.

Some of the emulsion formulations studied, noticeably Emulsions E and F, have consistently shown poor performance in our experiments. 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.

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. 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.

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. 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. Field trials using C and D were successfully completed and the two have become commercially available products since.

6.0 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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